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# Pumping tests and flow logging

## Boreholes HFM20, HFM21 and HFM22

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Januari 2005

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# Abstract

The boreholes HFM20 and HFM21 are drilled in the residential area in the north parts of the investigation area, close to the nuclear plant in Forsmark. The borehole HFM22 is drilled northeast of the residential area. HFM20 is drilled with the purpose of investigating the hydraulic characteristics and the hydrogeochemisty of the surrounding bedrock. HFM21 and HFM22 are drilled for the purpose of serving as flush water wells for the core drilling of KFM07A at drilling site DS7 and KFM08A at drilling site DS8.

The main objectives of the hydraulic tests in the percussion boreholes HFM20–22 were to investigate the hydraulic (e.g. occurrence of sub-horizontal zones) characteristics and the water chemistry of the boreholes.

Pumping tests were performed in all three boreholes in conjunction with flow logging. In order to confirm the results from the flow logging, a short injection test between two packers was performed in the upper part of HFM21 (i.e. above the highest position for flow logging). In HFM20, a short injection test below a single packer was performed below the lowest inflow zone. In HFM22, flow logging was conducted up to the casing and no additional test was required.

Water sampling was performed to investigate the hydrochemistry of the borehole water in all boreholes in conjunction with the pumping tests. No other borehole tests had been carried out in the actual boreholes before this campaign.

The total borehole transmissivity of HFM20 was estimated to $6.9 \cdot 10^{-5}$ $m^2/s$. The flow logging indicated three conductive sections at c 22.5–28 m with a transmissivity of $5.7 \cdot 10^{-5}$ $m^2/s$, at c 77–78 m with a transmissivity of $1.8 \cdot 10^{-6}$ $m^2/s$ and at c 118–118.5 m with a transmissivity of $1.0 \cdot 10^{-5}$ $m^2/s$. The injection test below 121 m resulted in a transmissivity of the section 121–301 m of $6.4 \cdot 10^{-7}$ $m^2/s$.

The total transmissivity of borehole HFM21 was estimated to $6.8 \cdot 10^{-4}$ $m^2/s$. Three conductive parts were found during the flow logging; at c 26–27 m with a transmissivity of $1.4 \cdot 10^{-4}$ $m^2/s$, at c 97.5–99.5 m with a transmissivity of $3.3 \cdot 10^{-4}$ $m^2/s$ and at c 157–163 m with a transmissivity of $2.1 \cdot 10^{-4}$ $m^2/s$. The injection test in the upper part of the borehole (14–20 m) resulted in a transmissivity of $3.9 \cdot 10^{-7}$ $m^2/s$.

The total transmissivity of HFM22 was estimated to $1.6 \cdot 10^{-4}$ $m^2/s$. Two conductive sections were detected during the flow logging; at c 28–29 m with a transmissivity of $1.9 \cdot 10^{-5}$ $m^2/s$ and at 60.5–64 m with a transmissivity of $1.5 \cdot 10^{-4}$ $m^2/s$.

# Sammanfattning

HFM20 och HFM21 har borrats i bostadsområdet i de norra delarna av undersökningsområdet. HFM22 har borrats nordöst om bostadsområdet. HFM20 är borrad för att undersöka det omgivande bergets hydauliska och hydrogeokemiska egenskaper. HFM21 och HFM22 är borrade med syfte att tjäna som spolvattenbrunnar inför borrningarna av KFM07A på borrplats DS7 respektive KFM08A på borrplats DS8.

Huvudsakliga syftet med denna mätinsats i hammarborrhålen HFM20–22 var att undersöka hydrauliska egenskaperna (t.ex. förekomsten av sub-horisontella zoner) och vattenkemin hos borrhålen.

Pumptester i kombination med flödesloggning utfördes i alla tre borrhålen. För att bekräfta resultatet från flödesloggningen utfördes ett kortare injektionstest mellan två manschetter i de övre delarna av borrhål HFM21 (dvs ovan den högsta flödesloggade punkten). I HFM20 utfördes ett injektionstest under en enkel manschett under det lägsta inflödet. I HFM22 kunde flödesloggning utföras ändå upp till casingkant och inga ytterligare tester behövdes.

Vattenprover för undersökning av borrhålsvattnets hydrokemi togs i samband med pumptesterna i borrhålen. Före denna mätinsats hade inga andra hydrauliska tester genomförts i dessa borrhål.

Totala transmissiviteten för HFM20 uppskattades till $6{,}9\cdot10^{-5}$ m$^2$/s. Flödesloggningen indikerade tre konduktiva avsnitt; på ca 22,5–28 m djup med en uppmätt transmissivitet på $5{,}7\cdot10^{-5}$ m$^2$/s, vid ca 77–78 m med uppmätt transmissivitet på $1{,}8\cdot10^{-6}$ m$^2$/s och vid ca 118–118,5 m med en transmissivitet på $1{,}0\cdot10^{-5}$ m$^2$/s. Injektionstestet mellan 121–301 m resulterade i en transmissivitet för sektionen på $6{,}4\cdot10^{-7}$ m$^2$/s.

Den totala transmissiviteten för HFM21 uppskattades till $6{,}8\cdot10^{-4}$ m$^2$/s. Tre konduktiva sektioner påträffades under flödesloggningen; dels vid 26–27 m med en transmissivitet på $1{,}4\cdot10^{-4}$ m$^2$/s, dels vid 97,5–99,5 m med en transmissivitet på $3{,}3\cdot10^{-4}$ m$^2$/s och på 157–163 m med transmissivitet på $2{,}1\cdot10^{-4}$ m$^2$/s. Injektionstestet i den övre delen av borrhålet resulterade i en transmissivitet på $3{,}9\cdot10^{-7}$ m$^2$/s.

Transmissiviteten för HFM22 uppskattades till $1{,}6\cdot10^{-4}$ m$^2$/s. Två konduktiva avsnitt detekterades under flödesloggningen på 28–29 m med en transmissivitet på $1{,}9\cdot10^{-5}$ m$^2$/s och på 60,5–64 m med en transmissivitet på $1{,}5\cdot10^{-4}$ m$^2$/s.

# Contents

# 1 Introduction

Pumping tests and flow logging were performed in percussion boreholes HFM20, HFM21 and HFM22. Water sampling was undertaken in all three boreholes in conjunction with the tests. In addition, short injection tests were performed below the first detected flow anomaly in HFM20 and in the upper part of HFM21. No other borehole hydraulic tests had been carried out in the actual boreholes before this campaign.

Borehole HFM21 is situated close to drilling site DS7, HFM20 c 250 m west of drilling site DS7 and HFM22 c 50 m south of KFM08A see Figure 1-1. A detailed map of the boreholes is shown in Figure 1-2.

This document reports the results of the hydraulic testing of boreholes HFM20, HFM21 and HFM22 in the Forsmark site investigation. The work was carried out in accordance to SKB internal controlling documents; see Table 1-1. Data and results were delivered to the SKB site characterization database SICADA.

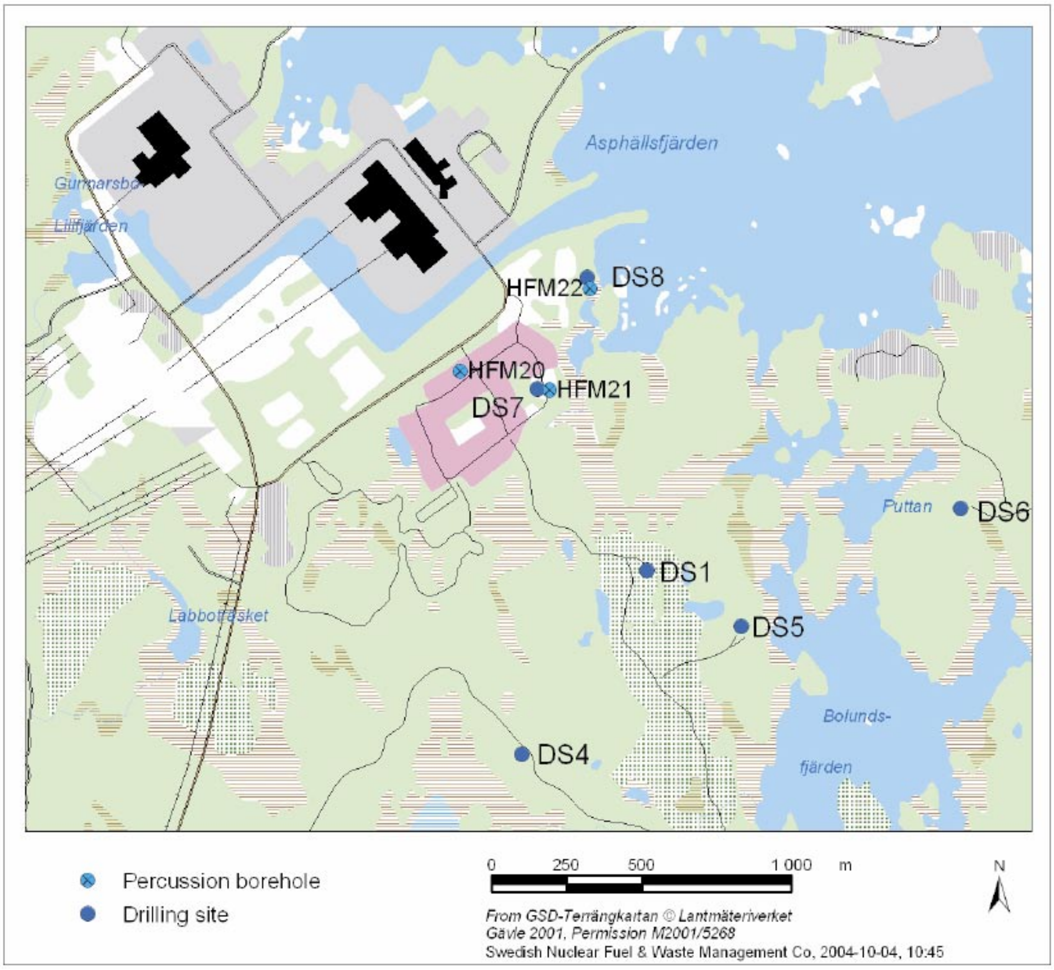



***Figure 1-1.*** *Map showing the location of boreholes HFM20, HFM21 and HFM22.*


***Figure 1-2.*** *Map showing the location of HFM20, HFM21 and HFM22 in the residential area close to the nuclear power plant in Forsmark.*

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

| **Activity Plan** | **Number** | **Version** |
|---|---|---|
| Hydrotester och vattenprovtagning i hammarborrhålen HFM20 och HFM21 | AP PF 400-04-75 | 1.0 |
| Hydrotester och vattenprovtagning i hammarborrhålet HFM22 | AP PF 400-04-91 | 1.0 |
| **Method descriptions** | **Number** | **Version** |
| Metodbeskrivning för hydrauliska enhålspumptester | SKB MD 321.003 | 1.0 |
| Metodbeskrivning för flödesloggning | SKB MD 322.009 | 1.0 |
| Instruktion för analys av injektions- och enhålspumptester | SKB MD 320.004 | 1.0 |
| Mätsystembeskrivning för HydroTestutrustning för Hammarborrhål. HTHB | SKB MD 326.001 | 3.0 |

# 2 Objectives

The main objectives of the pumping tests and flow logging in boreholes HFM20–22 were to investigate the hydraulic properties of the rock in the boreholes (e.g. occurrence of sub-horizontal zones) and furthermore, to investigate the hydrochemistry of the borehole water. The position and size of the main inflow zones to the boreholes should be identified.

# 3 Scope

## 3.1 Boreholes tested

Technical data of the boreholes tested are displayed in Table 3-1. The reference point in the boreholes is always top of casing (ToC). The Swedish National coordinate system (RT90 2.5 gon W) is used in the x-y-plane together with RHB70 in the z-direction. Northing and Easting refer to the top of the boreholes at top of casing. The borehole diameter in Table 3-1 measured as the diameter of the drill bit refers to the final diameter of the boreholes after drilling to full depth. The borehole diameter may decrease along the borehole due to wearing of the drill bit.

During the open-hole pumping tests, water samples were collected and submitted for analysis, see Section 6.2. Manual observations of the groundwater level in the pumped boreholes were also made during the tests. The boreholes were measured in the following order: HFM21, HFM20 and HFM22.

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

| Borehole ID | Elevation of top of casing (ToC) (m a s l) | Borehole length from ToC (m) | Bh-diam. (below casing) (m) | Inclin. -top of bh (from horizontal plane) (°) | Dip-Direction -top of bh (°) | Northing (m) | Easting (m) | Casing Length (m) | Casing Inner diam. (m) | Drilling finished Date (YYYY-MM-DD) |
|---|---|---|---|---|---|---|---|---|---|---|
| HFM20 | 2.97 | 301.00 | 0.139 | –85.45 | 354.41 | 6700188 | 1630777 | 12.03 | 0.160 | 2004-06-01 |
| HFM21 | 3.98 | 202.00 | 0.139 | –58.48 | 88.81 | 6700126 | 1631074 | 12.03 | 0.160 | 2004-06-07 |
| HFM22 | 1.54 | 221.00 | 0.139 | –58.854 | 90.081 | 6700456 | 1631217 | 12.03 | 0.160 | 2004-09-10 |

## 3.2 Tests performed

**Table 3-2. Borehole tests performed.**

| 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) |
|---|---|---|---|---|---|
| HFM20 | 12.0–301.0 | 1B | Open hole | 2004-08-16 22:01 | 2004-08-18 08:45 |
| HFM20 | 12.5–295.0 | 6, L-EC [2] | Open hole | 2004-08-17 13:22 | 2004-08-17 18:48 |
| HFM20 | 121.0–301.0 | 3 | Below packer | 2004-08-18 14:36 | 2004-08-18 15:53 |
| HFM21 | 12.0–202.0 | 1B | Open hole | 2004-08-10 09:45 | 2004-08-11 09:31 |
| HFM21 | 20.0–195.0 | 6, L-Te, L-EC | Open hole | 2004-08-10 15:00 | 2004-08-10 20:56 |
| HFM21 | 14.0–20.0 | 3 | Between packers | 2004-08-11 13:20 | 2004-08-11 15:25 |
| HFM22 | 12.0–221.0 | 1B | Open hole | 2004-09-22 09:05 | 2004-09-23 10:38 |
| HFM22 | 12.08–211.2 | 6, L-EC, L-Te | Open hole | 2004-09-22 15.23 | 2004-09-22 18:45 |

[1] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller. L-EC: EC-logging, L-Te: temperature logging.

[2] Temperature sensor out of function during measurements in HFM20.

## 3.3 Equipment check

An equipment check was performed at the site prior to the tests 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 P1 and P2 (cf Figures 4-1 and 4-2), the pressure in air was recorded and found to be as expected. Submerged in water while lowering, P1 coincided well with the total head of water ($p/\rho g$). During the injection test in the upper part of borehole HFM21, pressure sensor P2 was used. The sensor P2 showed expected values in air but submerged in water at position for the injection test, P2 differed from expected values. However, the injection test indicated a transmissivity below the measurement limit. Pressure sensor P2 was calibrated before the measurements in HFM20 and showed no deviations from expected values during calibrations. The temperature sensor showed expected values in both air and water but stopped functioning during the measurements in HFM20. Later, a fracture on one of the cables from the sensor was found. Hence no temperature data from HFM20 are available. During the measurements in HFM22 the temperature sensor was functioning again.

The sensor for electric conductivity displayed a zero value in air. The impeller used in the flow logging equipment worked well as indicated by the rotation on the data logger while lowering. The measuring wheel (used to check the position of the flow logging probe) and the sensor attached to it indicated a length that corresponded well to the pre-measured cable length.

# 4 Description of equipment

## 4.1 Overview

The equipment used in these tests is referred to as HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes) and described in the user manual of the measurement system.

The HTHB unit is designed for percussion boreholes to perform pumping- and injection tests in open boreholes (or above a single packer), see Figure 4-1 and in isolated sections of the boreholes (Figure 4-2) down to a total depth of 200 m. With the HTHB unit, it is also possible to perform a flow logging survey along the borehole during an open-hole pumping test (Figure 4-1). The pumping tests can be performed with either constant hydraulic head or, alternatively, with constant flow rate. For injection tests, however, the upper packer can not be located deeper than c 80 m due to limitations in the number of pipes available.

Since borehole HFM20 is 301 m deep, the standard flow logging equipment was insufficient in length and alternative equipment with adequate length was used. The equipment used from Geosigma is: logging cable, measuring wheel, data logger and a conductivity sensor.

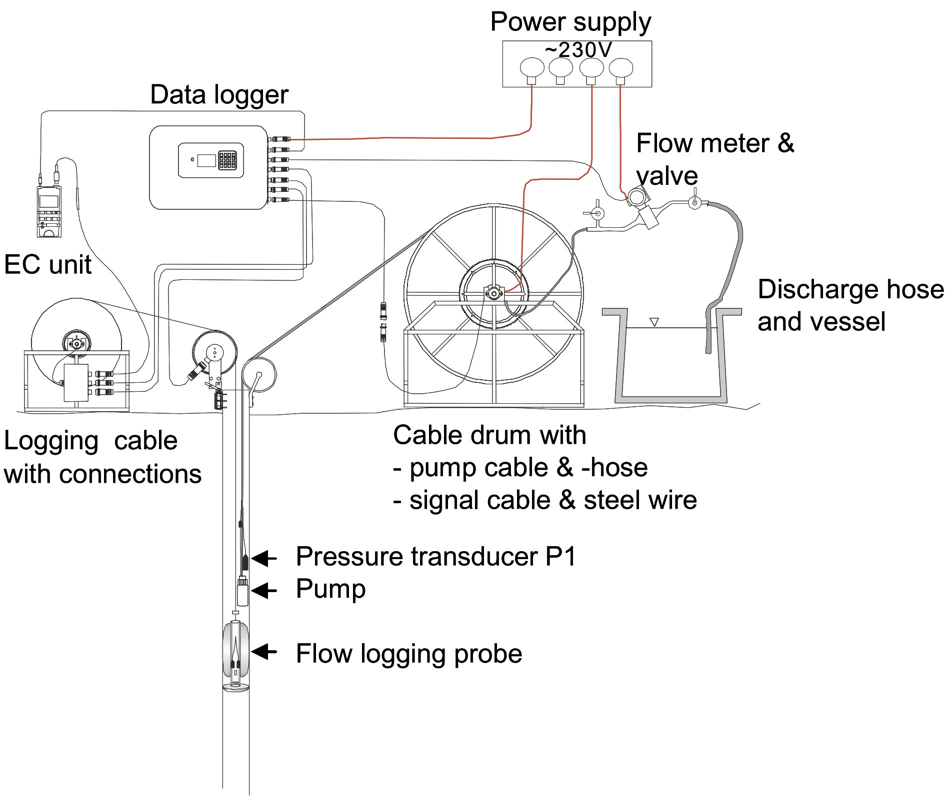



***Figure 4-1.*** *Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (From SKB MD 326.001, SKB internal document).*

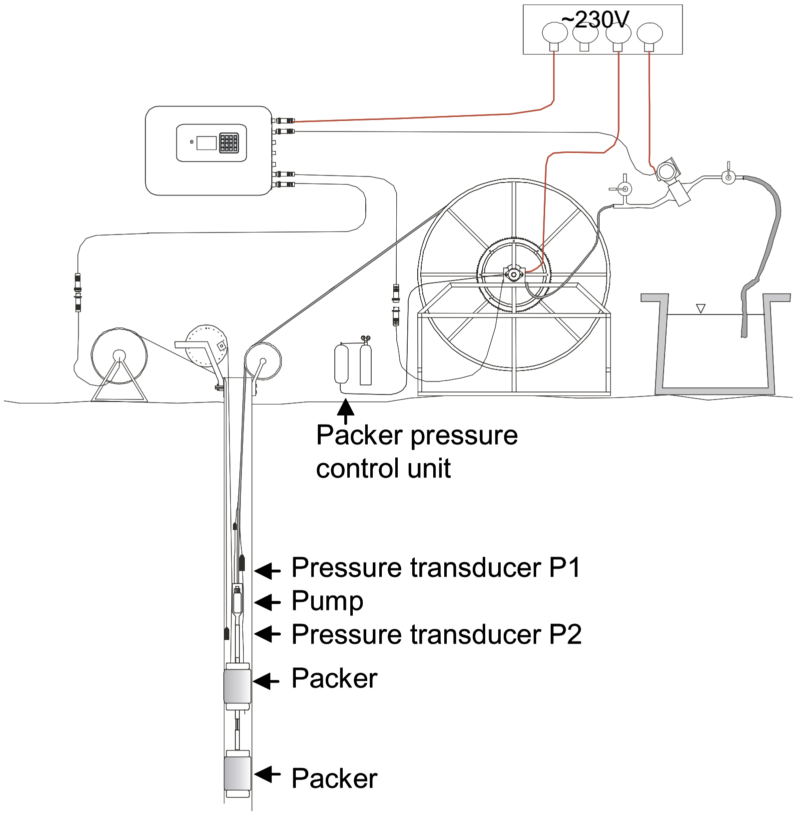



***Figure 4-2.*** *Schematic test set-up for a pumping test in an isolated borehole section with HTHB. (From SKB MD 326.001, SKB internal document).*

In HFM20, it was desired to perform an injection test below the lowest flow anomaly. Because of the great depth (more than 80 m) and expected low flow below this anomaly the standard HTHB equipment for injection tests was considered insufficient and alternative equipment also had to be used. The equipment used in HFM20 consists of a pressurized water tank connected via a Tecalan hose to a packer down the hole. The pressurized water tank is graded which makes it possible to make readings of the water level versus time during injection.

All equipment that belongs to the HTHB system is, when not in use, stored on a trailer and can easily be transported by a standard car. The borehole equipment includes a submersible borehole pump with housing, expandable packers, pressure sensors and a pipe string and/or hose. During flow logging, the sensors measuring temperature and electric conductivity as well as down-hole flow rate are also employed. At the top of the borehole, the total flow/injection rate is manually adjusted by a control valve and monitored by an electromagnetic flow meter. A data logger samples data at a frequency determined by the operator.

The packers are normally expanded by water (nitrogen gas is used to pressurize the water) unless the depth to the groundwater level is large or the risk of freezing makes the use of water unsuitable. In such cases, the packers are expanded by nitrogen gas. A folding pool is used to collect and store the discharged water from the borehole for subsequent use in injection tests.

## 4.2 Measurement sensors

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

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

| Technical specification<br>Parameter | | Unit | Sensor | HTHB system | Comments |
|---|---|---|---|---|---|
| Absolute pressure | Output signal | mA | 4–20 | | |
| | Meas. range | kPa | 0–1,500 | 0–1,500 | |
| | Resolution | kPa | 0.05 | | |
| | Accuracy | kPa | ±1.5 * | ±10 | Depending on uncertainties of the sensor position. |
| Temperature | Output signal | mA | 4–20 | | |
| | Meas. range | °C | 0–50 | 0–50 | |
| | Resolution | °C | 0.1 | | |
| | Accuracy | °C | ± 0.6 | ±0.6 | |
| Electric Conductivity | Output signal | V | 0–2 | | |
| | Meas. range | mS/m | 0–50,000 | 0–50,000 | With conductivity meter. |
| | Resolution | % o.r.** | | 1 | |
| | Accuracy | % o.r.** | | ± 10 | |
| Electric Conductivity | Output signal | V | 0–10 | | Conductivity meter used in HFM20, due to the length of the borehole. |
| | Meas. range | mS/m | 0–11,000 | 0–11,000 | |
| | Resolution | % o.r.** | | 1 | |
| | Accuracy | % o.r.** | ±1 | ±15 | |
| Flow (Spinner) | Output signal | Pulses/s | c 0.1–c 15 | | |
| | Meas. range | L/min | | 2–100 | 115 mm borehole diameter. |
| | | | | 3–100 | 140 mm borehole diameter. |
| | | | | 4–100 | 165 mm borehole diameter. |
| | Resolution*** | L/min | | 0.2 | 140 mm borehole diameter and 100 s sampling time. |
| | Accuracy*** | % o.r.** | | ± 20 | |
| Flow (surface) | Output signal | mA | 4–20 | | Passive. |
| | Meas. range | L/min | 1–150 | 5–c 80**** | Pumping tests. |
| | Resolution | L/min | 0.1 | 0.1 | |
| | Accuracy | % o.r.** | ± 0.5 | ± 0.5 | |

* Includes hysteresis, linearity and repeatability.
** Maximum error in % of actual reading (% o.r.).
*** Applicable to boreholes with a borehole diameter of 140 mm and 100 s sampling time.
**** For injection tests the minimal flow rate is 1 L/min.

Errors in reported borehole data (diameter etc) may significantly increase the error in measured data. For example, the flow logging probe is very sensitive to variations in the borehole diameter, cf Figure 4-3. Borehole deviation and uncertainties in the borehole inclination may also affect the accuracy of measured data.

The flow logging probe is calibrated for different borehole diameters (in reality different pipe diameters), i.e. 111.3, 135.5, 140 and 162 mm. During calibration the probe is installed in a vertically orientated pipe and a water flow is pumped through. The spinner rotations and total discharge are measured. Calibration gives excellent correlation ($R^2 > 0.99$) between total discharge and the number of spinner rotations. The calibration also clearly demonstrates how sensible the probe is to deviations in the borehole diameter, cf Figure 4-3.

In order to avoid problems with varying impeller velocity, the measuring time was shortened from 100 s to 50 seconds for some tests in HFM21 and HFM22 boreholes. The stabilisation time may be up to 30 s at flows close to the lower measurement limit, whereas the stabilisation is almost instantaneous at high flows.

Table 4-2 presents the position of sensors for each test. The following type of sensors is used: pressure (p), temperature (Te), electric conductivity (EC) together with the (lower) level of the submersible pump (Pump). Positions are given in metre from the reference point, i.e. top of casing (ToC), lower part. The sensors measuring temperature and electric conductivity are located in the impeller flow-logging probe and the position is thus varying (top-bottom-top of section) during a test. For specific information about the position at a certain time, the actual data files have to be consulted.

Equipment affecting the wellbore storage coefficient is given in terms of diameter of submerged item. Position is given as “in section” or “above section”. The volume of the submerged pump (~ 4 $dm^3$) is in most cases of minor importance.

In addition, the theoretical wellbore storage coefficient C for the actual test configurations and geometrical data of the boreholes (Table 3-1) was calculated, see Section 5.4.1. These values on C may be compared with the estimated ones from the test interpretations described in Chapter 6.

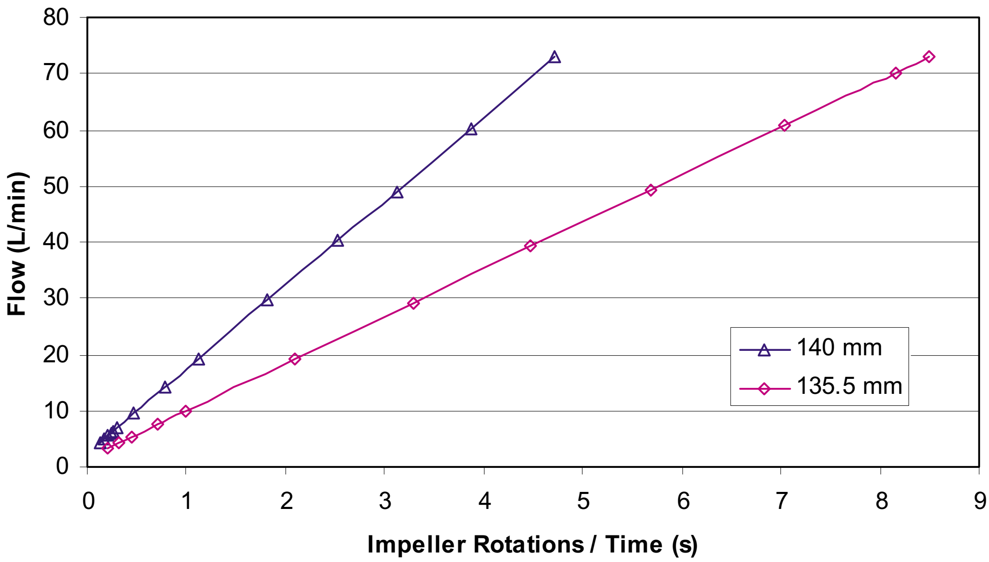



***Figure 4-3.*** *Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

**Table 4-2. Position of sensors (from ToC) and of equipment that may affect wellbore storage for the different hydraulic tests performed.**

| Borehole information | | | | Sensors | | Equipment affecting wellbore storage (WBS) | | | |
|---|---|---|---|---|---|---|---|---|---|
| ID | Test interval (m) | Test config | Test type [1] | Type | Position (m b ToC) | Function | Position [2] relative test section | Outer diameter (mm) | C ($m^3$/Pa) for test [3] |
| HFM20 | 12.03–301.00 | Open hole | 1B | Pump-intake | 7.9 | Pump | In section | | $2.0 \cdot 10^{-6}$ |
| | | | 1B | P (P1) | 5.22 | Pump hose | In section | 37 | |
| | | | 6 | EC-sec | 12.5–295.0 | Signal cable | In section | 8 | |
| | | | 6 | Te-sec | 12.5–295.0 | Signal cable | In section | 13.5 | |
| HFM20 | 121.0–301.0 | Below a single packer | 3 | P (P2) | 94.77 | | | | $1.3 \cdot 10^{-9}$ |
| HFM21 | 12.03–202.0 | Open hole | | Pump-intake | 15.4 | Pump | In section | | $2.0 \cdot 10^{-6}$ |
| | | | 1B | P (P1) | 12.72 | Pump hose | In section | 37 | |
| | | | 6 | EC-sec | 20–195 | Signal cable | In section | 8 | |
| | | | 6 | Te-sec | 20–195 | Signal cable | In section | 13.5 | |
| HFM21 | 14.0–20.0 | Between packers | 3 | P (P2) | 8.64 | Tecalan hose | In section | 6 | $4.2 \cdot 10^{-11}$ |
| | | | | | | Aluminum bar | In section | 20 | |
| | | | | | | Steel wire | In section | 6 | |
| HFM22 | 12.03–221.00 | Open hole | 1B | Pump-intake | 8.4 | Pump | In section | | $2.0 \cdot 10^{-6}$ |
| | | | 1B | P (P1) | 5.72 | Pump hose | In section | 37 | |
| | | | 6 | EC-sec | 12.08–211.2 | Signal cable | In section | 8 | |
| | | | 6 | Te-sec | 12.08–211.2 | Signal cable | In section | 13.5 | |

[1] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller incl. EC-logging (EC-sec) and temperature logging (Te-sec).

[2] Position of equipment that can affect wellbore storage. Position given as “In section” or “Above section”.

[3] Based on the casing diameter or the actual borehole diameter. (Table 3-1 for open-hole tests together with the compressibility of water for the test in isolated sections, respectively (net values.)

# 5 Execution

## 5.1 Preparations

All sensors included in the HTHB system are calibrated at the Geosigma engineering service station in Uppsala. Calibration is generally performed on a yearly basis, but more often if needed. The latest calibration was performed in April 2004. If a sensor is replaced at the test site, calibration of the new sensor can be carried out in the field (except the flow probe) or alternatively, in the laboratory after the measurements.

Functioning checks of the equipment used in the present test campaign were performed before each hydraulic test. The results from the functioning checks are presented in Section 3.3.

Before the tests, cleaning of equipment together with time synchronisation of clocks and data loggers was performed according to the Activity Plan.

## 5.2 Procedure

### 5.2.1 Overview

The pumping tests in HFM20–22 were carried out as single-hole, constant flow rate tests followed by pressure recovery periods. For all tests, the intention was to achieve approximately steady-state conditions in the borehole during the flow logging.

The flow logging was performed while pumping. Discrete flow measurements were made at fixed step lengths (5 m before the first flow anomaly and 2 m after the first flow anomaly), starting from the bottom and upward along the borehole. When a detectable flow anomaly in the borehole was found, the flow probe was lowered and repeated measurements with a shorter step length (0.5 m) were made to determine the detailed position of the anomaly. The flow logging survey was terminated at a short distance below the submersible pump in the borehole.

In HFM20, and HFM21 injection tests were performed below the first detected flow anomaly and above the highest position for flow logging respectively. In HFM22, flow logging could be performed up to the casing length and thus, there was no need for an injection test.

### 5.2.2 Details

***Single-hole pumping and injection tests***

Before the pumping tests, short flow capacity tests were carried out to select an appropriate flow rate or an appropriate drawdown for the tests. All pumping tests and flow meter logging were performed after the boreholes were drilled to full depth, using the HTHB-unit. The pumped water from the boreholes was discharged on the ground, sloping downhill from the pumping borehole.

The main test in each borehole was a c 10 h long pumping test in the open hole in combination with flow logging, followed by a recovery period of c 12 h. In borehole HFM20, a short injection test was performed below a single packer, cf Table 3-2. This test was part of the Activity Plan (AP PF 400-04-75, SKB internal controlling document) to roughly check the hydraulic properties in the interval below the lowest flow anomaly (ID 9 in the Activity Plan). In borehole HFM21, a short injection test was carried out between packers, cf Table 3-2. This injection test was an option in the Activity Plan to roughly check the hydraulic properties in the borehole interval above the highest position for flow logging (Option 1-ID 10 in the Activity Plan).

In general, the sampling frequency of pressure during the pumping and injection tests was according to Table 5-1. The hydraulic tests in borehole HFM21 was performed before the tests in HFM20. The tests in HFM22 were performed during a later measurement campaign.

**Table 5-1. Sampling interval used for pressure registration during the pumping tests.**

| Time interval (s) from start/stop of pumping | Sampling interval (s) |
|---|---|
| 1–300 | 1 |
| 301–600 | 10 |
| 601–3,600 | 60 |
| >3,600 | 600 |

### *Flow logging*

Before start of the flow logging, the probe was lowered to the bottom of the borehole. While lowering along the borehole (max. speed = 0.5 m/s), temperature- and electric conductivity data were sampled. The probe was halted (c 30 s) at every twenty meters to let the temperature and electrical conductivity stabilise, before the measurements.

Flow logging was performed during the long pumping test (10 h), starting from the bottom of the hole going upwards. The logging started when the pressure in the borehole was approximately stable. The time needed to complete the flow logging survey depends on the length and character of the borehole. In general, between 3–7 hours is normal for a percussion borehole of 100–200 m length, cf Section 6.4.

## 5.3 Data handling

Data are downloaded from the logger (Campbell CR 5000) to a laptop with the program PC9000 and are, already in the logger, transformed to engineering units. All files are comma-separated (*.DAT) when copied to a computer. Data files used for transient evaluation are further converted to *.mio-files by the code Camp2mio. The operator can choose the parameters to be included in the conversion (normally pressure and discharge). Data from the flow logging are evaluated in Excel and therefore not necessarily transformed to *.mio-files. A list of the data files from the data logger is presented in Appendix 1.

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

## 5.4 Analyses and interpretation

### 5.4.1 Single-hole pumping tests

Firstly, a qualitative evaluation of actual flow regimes (wellbore storage, pseudo-linear, pseudo-radial and pseudo-spherical flow, respectively) and possible outer boundary conditions during the hydraulic tests was performed. The qualitative evaluation was made from analyses of log-log diagrams of drawdown (or head change/flow rate for constant head tests) and/or recovery data together with the corresponding derivatives versus time. In particular, pseudo-radial flow (2D) is reflected by a constant (horizontal) derivative in the diagrams. Pseudo-linear and pseudo-spherical flow is reflected by a slope of the derivative of 0.5 and –0.5, respectively in a log-log diagram. Apparent no-flow- and constant head boundaries are reflected by a rapid increase and decrease of the derivative, respectively.

From the results of the qualitative evaluation, appropriate interpretation models for the quantitative evaluation of the tests were selected. In most cases, a certain period with pseudo-radial flow could be identified during the pumping tests. Consequently, methods for single-hole, constant-flow rate and constant drawdown tests for radial flow in a porous described in /2/ and /3/ medium were generally used by the evaluation of the tests. For tests indicating a fractured- or borehole storage dominated response, corresponding type curve solutions were used by the routine analyses.

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

The transient analysis was performed using a special version of the aquifer test analysis software AQTESOLV which enables both visual and automatic type curve matching with different analytical solutions for a variety of aquifer types and flow conditions. The evaluation is performed as an iterative process of type curve matching and non-linear regression on the test data. For the flow period as well as the recovery period of the constant flow rate tests, a model presented by Dougherty-Babu (1984) /4/ for constant flow rate tests with radial flow, accounting for wellbore storage and skin effects, was generally used for estimating transmissivity, storativity and skin factor for actual values on the borehole- and casing radius.

The effective casing radius may be estimated from the regression analysis for tests affected by wellbore storage. The wellbore storage coefficient can be calculated from simulated effective casing radius, see below. The effective wellbore radius concept is used to account for negative skin factors. AQTESOLV also includes models for discrete fractures (horizontal and vertical, respectively) intersecting the borehole, causing pseudo-linear flow.

Rather than assuming a fixed value of the storativity of $1 \cdot 10^{-6}$ by the analysis according to the instruction SKB MD 320.004 (SKB internal document), a higher value was occasionally assumed for the actual test, e.g. $5 \cdot 10^{-5}$. This is considered as justified in this case since all tests were performed in the upper part of the bedrock. The nomenclature used for the simulations with the AQTESOLV code is presented in the beginning of Appendix 2.

Estimations of the borehole storage coefficient, C, based on actual borehole geometrical data (net values) according to Equation (5-1), are presented in Table 4-2. The borehole storage coefficient may also be estimated from the early test response with 1:1 slope in a log-log diagram /2/ or alternatively, from the simulated effective casing radius. These values on C may be compared with the net values of the wellbore storage coefficient based on actual borehole geometrical data. The estimated values on C from the test data may differ from the net values due to deviations of the actual geometrical borehole data from the anticipated, e.g. regarding the borehole diameter, or presence of fractures or cavities with significant volumes.

For pumping tests in an open borehole (and in the interval above a single packer) the wellbore storage coefficient may be calculated as:

$$C = \pi\, r_{we}^2/\rho g \tag{5-1}$$

For an isolated pumped section (and the section below a single packer) the corresponding wellbore storage coefficient may be calculated as:

$$C = \pi\, r_w^2 \cdot L_w \cdot c_w \tag{5-2}$$

$r_{we}$ = borehole radius where the changes of the groundwater level occur (either $r_w$ or $r_c$) or alternatively, the simulated effective casing radius

$r_w$ = nominal borehole radius (m)

$r_c$ = inner radius of the borehole casing (m)

$\rho$ = density of water (kg/m$^3$)

$g$ = acceleration of gravity (m/s$^2$)

$L_w$ = section length (m)

$c_w$ = compressibility of water (Pa$^{-1}$)

### 5.4.2 Flow logging

The measured parameters during flow logging (flow, temperature and electric conductivity of the borehole fluid) were firstly plotted versus borehole length. From these plots, flow anomalies were identified along the borehole, i.e. borehole intervals over which changes of flow higher than c 1 L/min occur. The size of the inflow at the flow anomaly is determined by the actual change in flow rate over the interval. In some cases, the flow changes are accompanied by corresponding changes in temperature and/or electric conductivity of the fluid. If the actual borehole diameter differs from the one assumed by the calibration of the flow probe, corrections of the measured borehole flow rates may be necessary, cf Figure 4-3.

Flow logging can only be carried out in the borehole from the bottom of the hole up to a certain distance below the submersible pump. The remaining part of the borehole (i.e. from the pump to the casing) can not be flow-logged although high inflow zones may sometimes be located in this part. Such superficial inflows may be identified by comparing the cumulative flow at the top of the flow-logged interval ($Q_T$) with the discharged flow rate ($Q_p$) from the hole at the surface during the flow logging. If the latter flow rate is significantly higher than the cumulative flow rate, one or several inflow zones are likely to exist above the flow-logged interval.

The transmissivity (T) of the entire borehole is calculated from the analysis of the pumping test during the flow logging. The cumulative transmissivity at the top of the flow-logged interval ($T_{FT} = \Sigma T_i$) was then calculated according to the Methodology description for Impeller flow logging (assuming zero natural flow in the borehole):

$$T_{FT} = \Sigma T_i = T \cdot Q_T / Q_p \tag{5-3}$$

If $Q_T < Q_p$, one or several flow anomalies may be located above the flow-logged interval. In such cases, the (order of magnitude) of the transmissivity of these anomalies may be estimated from Equation (5-4).

The transmissivity of individual flow anomalies ($T_i$) was calculated from the measured inflow ($dQ_i$) at the anomaly and the calculated transmissivity of the entire borehole (T) according to:

$$T_i = T \cdot dQ_i / Q_p \qquad (5\text{-}4)$$

For comparison, estimations of the transmissivities of the identified flow anomalies were also made from the specific flows, simply by dividing the measured inflow ($dQ_i$) at the anomaly by the drawdown ($s_{FL}$) in the hole during the flow logging (assuming negligible head losses). The sum of the specific flows may then be compared with the total transmissivity (and specific flow) of the borehole.

The cumulative transmissivity $T_F(L)$ along borehole length (L) as determined from the flow logging may be calculated according to the methodology description for flow logging:

$$T_F(L) = T \cdot Q(L) / Q_p \qquad (5\text{-}5)$$

where Q(L) = cumulative flow at borehole length L

The threshold value of transmissivity ($T_{min}$) in flow logging may be estimated similar to Equation (5-3):

$$T_{min} = T \cdot Q_{min} / Q_p \qquad (5\text{-}6)$$

In a 140 mm borehole, $Q_{min}$ = 3 L/min, see Table 4-1, whereas $Q_p$ is the actual flow rate during flow logging.

Similarly, the lower measurement limit of transmissivity of a flow anomaly can be estimated from Equation (5-4) using $dQ_{i\ min}$ = 1 L/min ($1.7 \cdot 10^{-5}$ $m^3/s$) which is considered as the minimal change in borehole flow rate to identify a flow anomaly. The upper measurement limit of transmissivity of a flow anomaly corresponds to the transmissivity of the entire borehole.

## 5.5 Nonconformities

The hydraulic test program was mainly according to the Activity Plan with the following exceptions:

- The temperature sensor in the measuring probe stopped working properly during the flow logging in HFM20.
- The pressure sensor P2 showed values deviating from expected during the injection test in HFM21. The sensor was calibrated between the measurements in HFM21 and HFM20 and then worked as expected.
- Water sampling in HFM22 was not performed during the 10 h pumping session but during a separate pumping during approximetaly 8 hours before the first sample and approx. 20 hours before the second sample. Only two samples were collected.
- Flow logging in HFM20 was performed in 10 m steps before the first flow anomaly.

- Flow logging in HFM21 was performed in 4 m steps after the first flow anomaly.
- Flow logging in HFM22 was performed in 10 m steps before the first flow anomaly.

The three latter exceptions were decided by the geohydrologist responsible for the test performance in the field in order to reduce the total measurement time.

Compared to the Methodology Description for single-hole pumping tests (SKB MD 321.003, SKB internal document), only one deviation was made regarding the recommended test times:

- The recommended test time (24 h + 24 h for drawdown/recovery) for the longer pumping tests during flow logging was decreased to c 10 h +12 h due to practical reasons (mainly to avoid uncontrolled pumping over-night and to eliminate the risk of freezing, theft/sabotage etc). Experience from similar tests in other boreholes indicates that c 10 h of pumping and 12 h of recovery in general is sufficient to estimate the hydraulic properties of the borehole regarding, e.g. wellbore storage effects and other disturbing factors.

# 6 Results

## 6.1 Nomenclature and symbols

The nomenclature and symbols used for the results of the pumping tests and flow logging are according to the instruction for analysis of single-hole injection- and pumping tests, SKB MD 320.004, Version 1.0 and the methodology description for impeller flow logging, SKB MD 322.009, Version 1.0, cf Section 3.2. Additional symbols used are explained in the text. The nomenclature for the analyses of the pumping tests by the AQTESOLV code is presented in Appendix 2.

## 6.2 Water sampling

Water samples were taken during the pumping tests in the boreholes and submitted for analysis, see Table 6-1. The results of the water analyses are described in /1/.

**Table 6-1. Water samples taken during the pumping tests in boreholes HFM20 and HFM21 and submitted for analysis.**

| Bh ID | Date and time of sample | Pumped section (m) | Pumped volume ($m^3$) | Sample type | Sample ID no | Remarks |
|---|---|---|---|---|---|---|
| HFM20 | 2004-08-17 10:04 | 12.0–301.0 | 6.4 | WC080 | 8604 | Open-hole test |
| “ | 2004-08-17 15:06 | “ | 26.5 | WC080 | 8606 | Open-hole test |
| “ | 2004-08-17 18:05 | “ | 38.3 | WC080 | 8619 | Open-hole test |
| HFM21 | 2004-08-10 11:00 | 12.0–202.0 | 3.0 | WC080 | 8613 | Open-hole test |
| “ | 2004-08-10 15:12 | “ | 19.0 | WC080 | 8614 | Open-hole test |
| “ | 2004-08-10 19:53 | “ | 36.8 | WC080 | 8615 | Open-hole test |
| HFM22 | 2004-09-24 08:15 | 12.0–221.0 | 53.9 | WC080 | 8642 | Open-hole test |
| “ | 2004-09-24 10:00 | “ | 59.2 | WC080 | 8644 | Open-hole test |

## 6.3 Single-hole pumping tests

Below, the results of the single-hole pumping tests are presented test by test. The atmospheric pressure and precipitation was monitored at the site during the testing periods. However, no corrections of measured data, e.g. for changes of the atmospheric pressure or tidal fluctuations, have been made before the analysis of the data. For the actual single-hole tests such corrections are generally not needed considering the relatively short test time and large drawdown applied in the boreholes. However, for longer tests with a small drawdown applied, such corrections may be necessary.

Drilling records were checked to identify possible interference on the hydraulic test data from drilling or other activities in nearby boreholes during the test periods. These records show that the drilling of KFM06A at drilling site DS6, see Figure 1-1, was in progress during the test periods for HFM20 and HFM21. However, the tests in HFM20 and HFM21 are assumed to be unaffected by this activity due to the long distance between the boreholes. During the measurements in HFM22, gap injection between the casing and the rock wall was made in KFM08A. This activity may have affected the drawdown in HFM22. The gap injection in KFM08A was made during the first hours of pumping in HFM22, during which time the ground water level in HFM22 increases during c 18 min. The gap injection might be an explanation for the increase. The two boreholes are located c 40 m apart, see Figure 1-1.

### 6.3.1 Borehole HFM20: 12.0–301.0 m

General test data for the open-hole pumping test in HFM20 in conjunction with flow logging are presented in Table 6-2. No manual measurements of flow rate were performed during the test.

The atmospheric pressure, air temperature and precipitation during the test period in HFM20 are presented in Figure 6-1. The atmospheric pressure varied c 1 kPa, i.e. only c 4% of the total drawdown of c 2.65 m in the borehole during the test and thus the effect of atmospheric pressure variations on drawdown is considered negligible. During recovery, c 20 mm of rain was received in the area which is also considered as negligible.

**Table 6-2. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM20, in conjunction with flow logging.**

| **General test data** | | | |
|---|---|---|---|
| Borehole | HFM20 (12.0–301.0 m) | | |
| Test type [1] | Constant rate withdrawal and recovery test | | |
| Test section (open borehole/packed-off section) | Open borehole | | |
| Test no | 1 | | |
| Field crew | C Hjerne, J Olausson, GEOSIGMA AB | | |
| Test equipment system | HTHB | | |
| General comment | Single pumping borehole | | |
| | **Nomenclature** | **Unit** | **Value** |
| Borehole length | L | m | 301.0 |
| Casing length | $L_c$ | m | 12.0 |
| Test section – secup | Secup | m | 12.0 |
| Test section – seclow | Seclow | m | 301.0 |
| Test section length | $L_w$ | m | 289.0 |
| Test section diameter [2] | $2{\cdot}r_w$ | mm | top 139<br>bottom 135 |
| Test start (start of pressure registration) | | yymmdd hh:mm | 040816 22:05 |
| Packer expanded | | yymmdd hh:mm:ss | |
| Start of flow period | | yymmdd hh:mm:ss | 040817 08:27:06 |
| Stop of flow period | | yymmdd hh:mm:ss | 040817 18:49:50 |
| Test stop (stop of pressure registration) | | yymmdd hh:mm | 040818 08:45 |
| Total flow time | $t_p$ | min | 622.73 |
| Total recovery time | $t_F$ | min | 835.95 |

| **Pressure data** | **Nomenclature** | **Unit** | **Value** | **GW level (m a s l)** [3] |
|---|---|---|---|---|
| Absolute pressure in test section before start of flow period | $p_i$ | kPa | 123.18 | 0.43 |
| Absolute pressure in test section at stop of flow period | $p_p$ | kPa | 97.19 | –2.29 |
| Absolute pressure in test section at stop of recovery period | $p_F$ | kPa | 118.63 | –0.13 |
| Maximal pressure change in test section during the flow period | $dp_p$ | kPa | 25.99 | |

| **Manual groundwater level measurements** | | | **GW level** | |
|---|---|---|---|---|
| **Date YYYY-MM-DD** | **Time tt:mm.ss** | **Time (min)** | **(m b ToC)** | **(m a s l)** |
| 2004-08-16 | 10:28:00 | –1,319 | 2.51 | 0.47 |
| 2004-08-16 | 16:32:00 | –955 | 2.51 | 0.47 |
| 2004-08-16 | 17:09:00 | –918 | 3.23 | –0.25 |
| 2004-08-16 | 17:29:00 | –898 | 2.81 | 0.17 |
| 2004-08-17 | 08:17:00 | –10 | 2.55 | 0.43 |
| 2004-08-17 | 11:55:00 | 208 | 4.28 | –1.30 |
| 2004-08-17 | 18:48:00 | 621 | 5.28 | –2.29 |
| 2004-08-18 | 08:31:00 | 1,444 | 3.11 | –0.13 |
| 2004-08-18 | 14:36:00 | 1,809 | 3.03 | –0.05 |
| 2004-08-18 | 17:05:00 | 1,958 | 3.02 | –0.04 |

| **Flow data** | **Nomenclature** | **Unit** | **Value** |
|---|---|---|---|
| Flow rate from test section just before stop of flow period | $Q_p$ | $m^3/s$ | $1.10{\cdot}10^{-3}$ |
| Mean (arithmetic) flow rate during flow period [4] | $Q_m$ | $m^3/s$ | $1.10{\cdot}10^{-3}$ |
| Total volume discharged during flow period [4] | $V_p$ | $m^3$ | 41.22 |

[1] Constant head injection and recovery or constant rate withdrawal and recovery or constant drawdown withdrawal and recovery.

[2] Claesson and Nilsson (2004) /6/.

[3] From the manual measurements of groundwater level.

[4] Calculated from integration of the transient flow rate curve during the flow period.

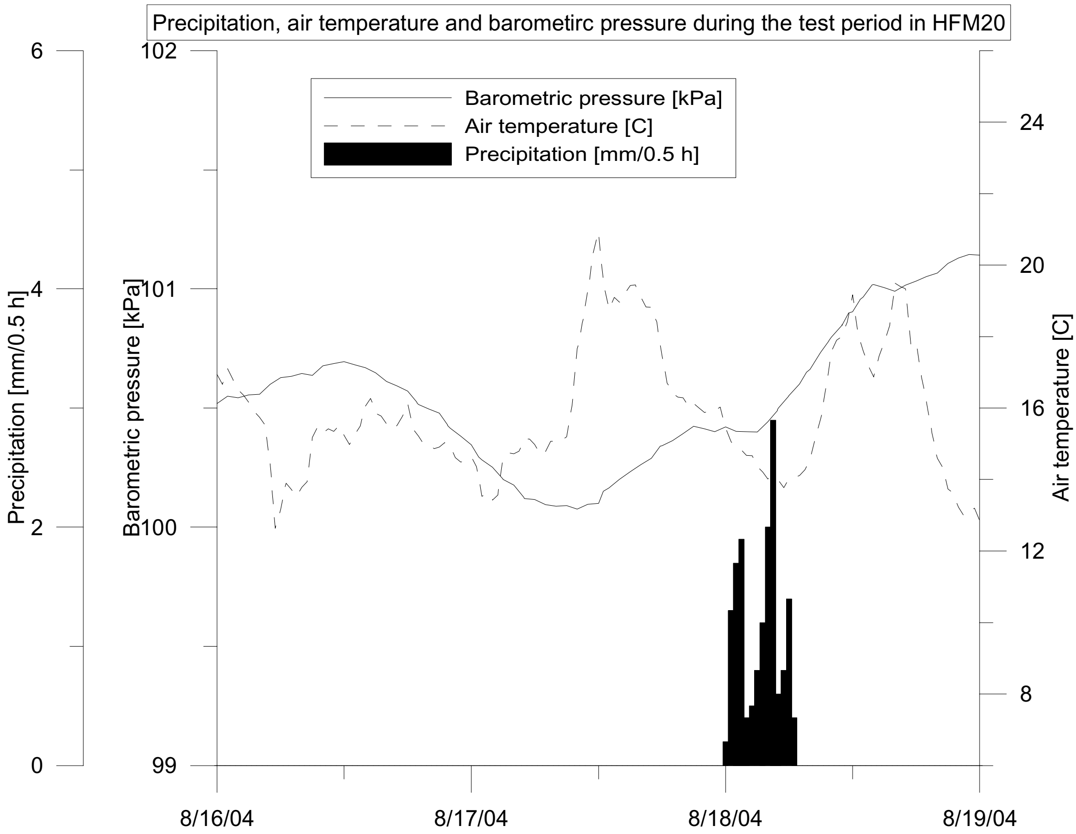



*Figure 6-1. Atmospheric pressure (solid line), air temperature (dashed line) and precipitation (solid bars) at Forsmark during the test period in HFM20.*

### Comments on test

The day before test start, a short capacity test was performed (c 24 min). By the end of the capacity test, the flow rate was c 70.6 L/min and the drawdown c 0.73 m. The actual pumping test was performed as a constant flow rate test (66.2 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. A comparison of the results from the capacity test and pumping test is presented in Table 6-3.

**Table 6-3. Estimated specific capacity from the capacity test and pumping test in borehole HFM20: 12.0–301.0 m.**

| Test | Duration (min) | Flow rate, $Q_p$ (L/min) | Drawdown, $s_w = p_i - p_p$ (m) | Specific capacity, $Q_p/s_w$ (m²/s) |
|---|---|---|---|---|
| Short capacity test | 24 | 70.6 | 0.73 | 0.00160 |
| Pumping test | 623 | 66.2 | 2.65 | 0.00042 |

Table 6-3 indicates that the specific capacity from the pumping test is lower than the specific capacity from the short capacity test. This may be a result of the significantly shorter duration of the capacity test where the drawdown had not yet stabilized.

### *Interpreted flow regimes*

Selected test diagrams according to the instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-1 to A2-9 in Appendix 2.

A pseudo-linear flow regime is indicated from c 1 min to the end of the flow period of c 600 min duration, cf Figures A2-2 to A2-3. This fact indicates flow from a dominating single fracture intersecting the borehole. By the end of the flow period effects of apparent no-flow boundaries or other flow restrictions are indicated.

Also during the recovery period, pseudo-linear flow dominates. No wellbore storage effects are seen.

### *Interpreted parameters*

Transient evaluation of transmissivity was performed for both the flow- and recovery period. The transient, quantitative interpretation of the flow- and recovery period of the test is presented in Figures A2-2 to A2-9 in Appendix 2. The quantitative analysis was performed according to the methods described in Section 5.4.1. The transmissivity was estimated by a model assuming pseudo-radial flow /4/ on both the flow- and recovery period as well as by a model assuming a major horizontal fracture intersecting the borehole /5/. The representative transmissivity (i.e. $T_T$) is considered from the transient evaluation assuming pseudo-radial flow. The high, negative skin factor indicates a major fracture. As shown in Figures A2-4 to A2-5, the transmissivity obtained from the horizontal fracture model (hydraulic conductivity times the section length) shows good agreement with the transmissivity estimated from the pseudo-radial flow model.

The results are shown in the Test Summary Sheets and in Tables 6-19, 6-20 and 6-21 in Section 6.6. The analysis from the flow period was selected as representative for the test.

## 6.3.2 Borehole HFM21: 12.0–202.0 m

General test data for the open-hole pumping test in HFM21 in conjunction with flow logging are presented in Table 6-4. No manual measurements of flow rate were performed.

The barometric pressure, precipitation and air temperature during the test period in HFM21 are presented in Figure 6-2. The atmospheric pressure varied c 1 kPa and the drawdown by end of the flow period was c 30 kPa. The atmospheric pressure variations are c 3% of the total drawdown of c 3.14 m during the test and the effect of atmospheric pressure variations on drawdown is considered negligible. No substantial precipitation took place during the test period.

**Table 6-4. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM21, in conjunction with flow logging.**

| **General test data** | | | | |
|---|---|---|---|---|
| Borehole | HFM21 (12.0–202.0 m) | | | |
| Test type [1] | Constant rate withdrawal and recovery test | | | |
| Test section (open borehole/packed-off section) | Open borehole | | | |
| Test no | 1 | | | |
| Field crew | C Hjerne, K Gokall-Norman, GEOSIGMA AB | | | |
| Test equipment system | HTHB | | | |
| General comment | Single pumping borehole | | | |
| | **Nomenclature** | **Unit** | **Value** | |
| Borehole length | L | m | 202.0 | |
| Casing length | $L_c$ | m | 12.0 | |
| Test section – secup | Secup | m | 12.0 | |
| Test section – seclow | Seclow | m | 202.0 | |
| Test section length | $L_w$ | m | 190.0 | |
| Test section diameter [2] | $2 \cdot r_w$ | mm | top 139<br>bottom 137 | |
| Test start (start of pressure registration) | | yymmdd hh:mm | 040810 09:45 | |
| Packer expanded | | yymmdd hh:mm:ss | | |
| Start of flow period | | yymmdd hh:mm:ss | 040810 10:12:49 | |
| Stop of flow period | | yymmdd hh:mm:ss | 040810 21:03:39 | |
| Test stop (stop of pressure registration) | | yymmdd hh:mm | 040811 08:18 | |
| Total flow time | $t_p$ | min | 650.83 | |
| Total recovery time | $t_F$ | min | 674.55 | |

| **Pressure data** | **Nomen-clature** | **Unit** | **Value** | **GW level (m a s l)** [3] |
|---|---|---|---|---|
| Absolute pressure in test section before start of flow period | $p_i$ | kPa | 168.38 | 0.19 |
| Absolute pressure in test section at stop of flow period | $p_p$ | kPa | 137.58 | –2.92 |
| Absolute pressure in test section at stop of recovery period | $p_F$ | kPa | 165.59 | –0.02 |
| Maximal pressure change in test section during the flow period | $dp_p$ | kPa | 30.8 | |

| **Manual groundwater level measurements**<br>**Date YYYY-MM-DD** | **Time tt:mm.ss** | **Time (min)** | **GW level (m b ToC)** | **(m a s l)** |
|---|---|---|---|---|
| 2004-08-09 | 13:21:00 | –1,252 | 4.19 | 0.41 |
| 2004-08-09 | 16:59:00 | –1,034 | 4.20 | 0.40 |
| 2004-08-10 | 07:30:00 | –163 | 4.22 | 0.38 |
| 2004-08-10 | 07:42:00 | –151 | 4.22 | 0.38 |
| 2004-08-10 | 08:29:00 | –104 | 4.21 | 0.39 |
| 2004-08-10 | 09:22:00 | –51 | 4.48 | 0.16 |
| 2004-08-10 | 09:34:00 | –39 | 4.47 | 0.17 |
| 2004-08-10 | 09:55:00 | –18 | 4.45 | 0.19 |
| 2004-08-10 | 10:08:00 | –5 | 4.45 | 0.19 |
| 2004-08-10 | 10:46:00 | 33 | 7.57 | –2.47 |
| 2004-08-10 | 12:43:00 | 150 | 7.78 | –2.65 |
| 2004-08-10 | 14:22:00 | 249 | 7.86 | –2.72 |
| 2004-08-10 | 14:59:00 | 286 | 7.89 | –2.75 |
| 2004-08-10 | 20:58:00 | 645 | 8.10 | –2.92 |
| 2004-08-11 | 08:13:00 | 1,320 | 4.69 | –0.02 |
| 2004-08-11 | 13:22:00 | 1,629 | 4.61 | 0.05 |
| 2004-08-11 | 14:48:00 | 1,715 | 4.45 | 0.19 |
| 2004-08-11 | 15:03:00 | 1,730 | 4.44 | 0.20 |
| 2004-08-11 | 17:04:00 | 1,851 | 4.54 | 0.11 |

| Flow data | Nomenclature | Unit | Value |
|---|---|---|---|
| Flow rate from test section just before stop of flow period | $Q_p$ | $m^3/s$ | $1.06 \cdot 10^{-3}$ |
| Mean (arithmetic) flow rate during flow period [4] | $Q_m$ | $m^3/s$ | $1.06 \cdot 10^{-3}$ |
| Total volume discharged during flow period [4] | $V_p$ | $m^3$ | 41.24 |

[1] Constant head injection and recovery or constant rate withdrawal and recovery or constant drawdown withdrawal and recovery.

[2] Claesson and Nilsson (2004) /6/.

[3] From the manual measurements of groundwater level.

[4] Calculated from integration of the transient flow rate curve.

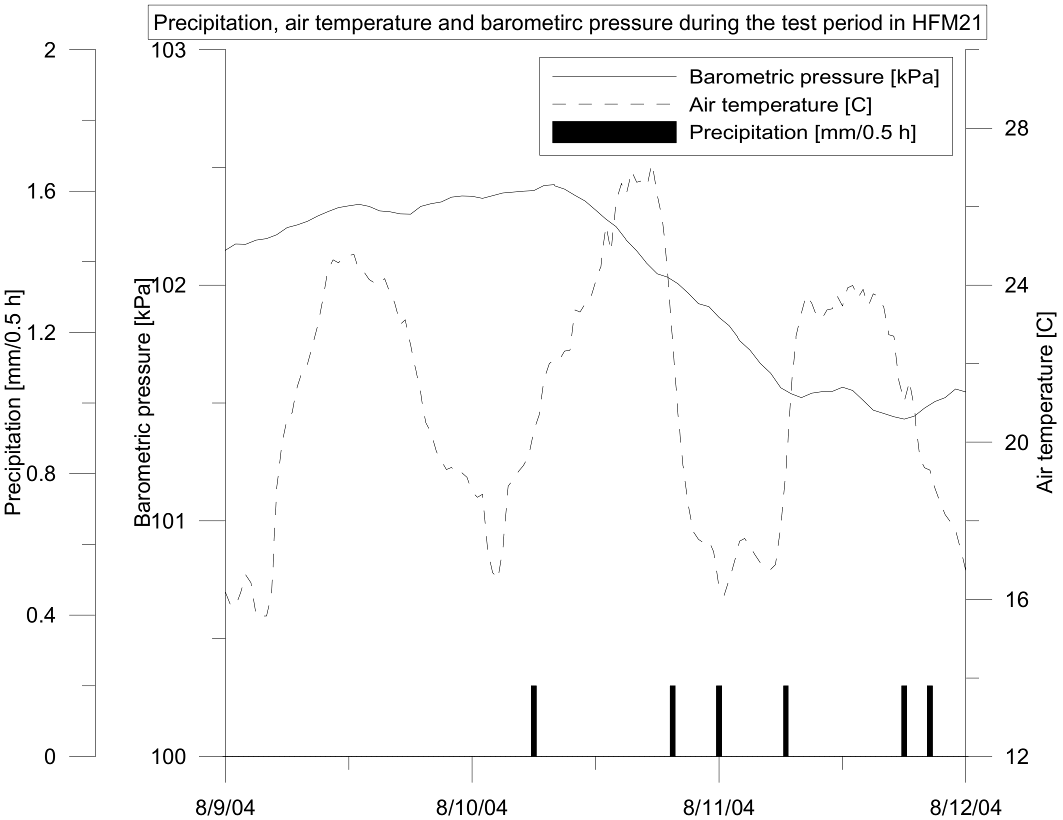



*__Figure 6-2.__ Atmospheric pressure (solid line), air temperature (dashed line) and precipitation (solid bars) at Forsmark during the test period in HFM21.*

### *Comments on test*

At the same day before test start, a short capacity test was performed (c 16 min). By the end of the capacity test, the flow rate was c 62.7 L/min and the drawdown c 2.62 m. The actual pumping test was performed as a constant flow rate test (63.4 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. A comparison of the results from the capacity test and pumping test is presented in Table 6-5.

**Table 6-5. Estimated specific capacity from the capacity test and pumping test in borehole HFM21: 12.0–202.0 m.**

| Test | Duration (min) | Flow rate, $Q_p$ (L/min) | Drawdown, $s_w = p_i – p_p$ (m) | Specific capacity, $Q_p/s_w$ ($m^2/s$) |
|---|---|---|---|---|
| Short capacity test | 16 | 62.7 | 2.62 | $4.0 \cdot 10^{-4}$ |
| Pumping test | 651 | 63.4 | 3.14 | $3.4 \cdot 10^{-4}$ |

Table 6-5 indicates that the specific capacity from the pumping test is slightly lower than the specific capacity from the short capacity test. This may be a result of the significantly shorter duration of the capacity test and that the drawdown had not yet stabilized.

### *Interpreted flow regimes*

Selected test diagrams according to the instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-10 to A2-16 in Appendix 2.

After indicated WBS, a short pseudo-radial flow regime is indicated at intermediate times during the flow period. By the end of this period, effects of an apparent no-flow boundary are seen cf Figures A2-11 to A2-14.

WBS effects dominate the initial phase of the recovery period. Possible pseudo-radial flow is indicated from c 10 min to c 60 min. By the end of the recovery period, a transition to an apparent no-flow boundary occurs, cf Figures A2-13 to A2-14.

### *Interpreted parameters*

The transient, quantitative interpretation of the flow- and recovery period of the test is presented in Figures A2-11 to A2-14 in Appendix 2. Quantitative analysis was applied both on the flow- and recovery period according to the methods described in Section 5.4.1.

The transmissivity was estimated by a model assuming pseudo-radial flow /4/ on both the flow and recovery period.

The results are exposed in the Test Summary Sheets and in Table 6-19, Table 6-20 and Table 6-21 in Section 6.6. The analysis from the flow period was selected as the representative.

The borehole storage coefficient was estimated from the early test response with 1:1 slope in the recovery log-log diagram resulting in $C = 2.2 \cdot 10^{-6}$ $m^3/Pa$. This result is supported by an estimate of borehole storage from Equation (5-1) using the simulated effective casing radius from the test resulting in the same value of C.

## 6.3.3 Borehole HFM22: 12.0–221.0 m

General test data for the open-hole pumping test in HFM22 in conjunction with flow logging are presented in Table 6-6. No manual measurements of flow rate were performed during the test.

The atmospheric pressure, air temperature and precipitation are presented in Figure 6-3. The atmospheric pressure varied c 0.35 kPa, i.e. less than 1% of total drawdown of c 2.92 m during the test and thus the effect of atmospheric pressure variations is negligible. No substantial precipitation took place during the test period.

**Table 6-6. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM22, in conjunction with flow logging.**

| **General test data** | | | | |
|---|---|---|---|---|
| Borehole | HFM22 (12.0–221.0 m) | | | |
| Test type[1] | Constant rate withdrawal and recovery test | | | |
| Test section (open borehole/packed-off section) | Open borehole | | | |
| Test no | 1 | | | |
| Field crew | J. Jönsson, T. Svensson | | | |
| Test equipment system | HTHB | | | |
| General comment | Single pumping borehole | | | |
| | **Nomenclature** | **Unit** | **Value** | |
| Borehole length | L | m | 221.0 | |
| Casing length | $L_c$ | m | 12.0 | |
| Test section – secup | Secup | m | 12.0 | |
| Test section – seclow | Seclow | m | 221.0 | |
| Test section length | $L_w$ | m | 209.0 | |
| Test section diameter [2] | $2 \cdot r_w$ | mm | top 141 bottom 136.2 | |
| | | | | |
| Test start (start of pressure registration) | | yymmdd hh:mm | 040922 09:15 | |
| Packer expanded | | yymmdd hh:mm:ss | | |
| Start of flow period | | yymmdd hh:mm:ss | 040922 09:15:09 | |
| Stop of flow period | | yymmdd hh:mm:ss | 040817 18:49:50 | |
| Test stop (stop of pressure registration) | | yymmdd hh:mm | 040923 10:37 | |
| Total flow time | $t_p$ | min | 606.27 | |
| Total recovery time | $t_F$ | min | 916.50 | |

| **Pressure data** | **Nomen-clature** | **Unit** | **Value** | **GW level (m a s l)** [3] |
|---|---|---|---|---|
| Absolute pressure in test section before start of flow period | $p_i$ | kPa | 147.17 | 0.11 |
| Absolute pressure in test section at stop of flow period | $p_p$ | kPa | 118.49 | –2.88 |
| Absolute pressure in test section at stop of recovery period | $p_F$ | kPa | 146.36 | –0.01 |
| Maximal pressure change in test section during the flow period | $dp_p$ | kPa | 28.67 | |

| **Manual groundwater level measurements** | | | **GW level** | |
|---|---|---|---|---|
| **Date YYYY-MM-DD** | **Time tt:mm.ss** | **Time (min)** | **(m b ToC)** | **(m a s l)** |
| 2004-09-21 | 10:16:00 | –1,379 | 1.66 | 0.12 |
| 2004-09-21 | 16:54:00 | –981 | 1.64 | 0.14 |
| 2004-09-22 | 08:15:00 | –60 | 1.67 | 0.11 |
| 2004-09-22 | 10:25:00 | 70 | 3.98 | –1.87 |
| 2004-09-22 | 15:20:00 | 365 | 4.94 | –2.69 |
| 2004-09-22 | 19:18:00 | 603 | 5.16 | –2.88 |
| 2004-09-23 | 10:26:00 | 1,511 | 1.81 | –0.01 |
| 2004-09-23 | 12:21:00 | 1,626 | 4.71 | –2.49 |

| **Flow data** | **Nomenclature** | **Unit** | **Value** |
|---|---|---|---|
| Flow rate from test section just before stop of flow period | $Q_p$ | $m^3/s$ | 0.00100 |
| Mean (arithmetic) flow rate during flow period [4] | $Q_m$ | $m^3/s$ | 0.00100 |
| Total volume discharged during flow period [4] | $V_p$ | $m^3$ | 36.47 |

[1] Constant head injection and recovery or constant rate withdrawal and recovery or constant drawdown withdrawal and recovery.

[2] Claesson and Nilsson (2004) /6/.

[3] From the manual measurements of groundwater level.

[4] Calculated from integration of the transient flow rate curve.

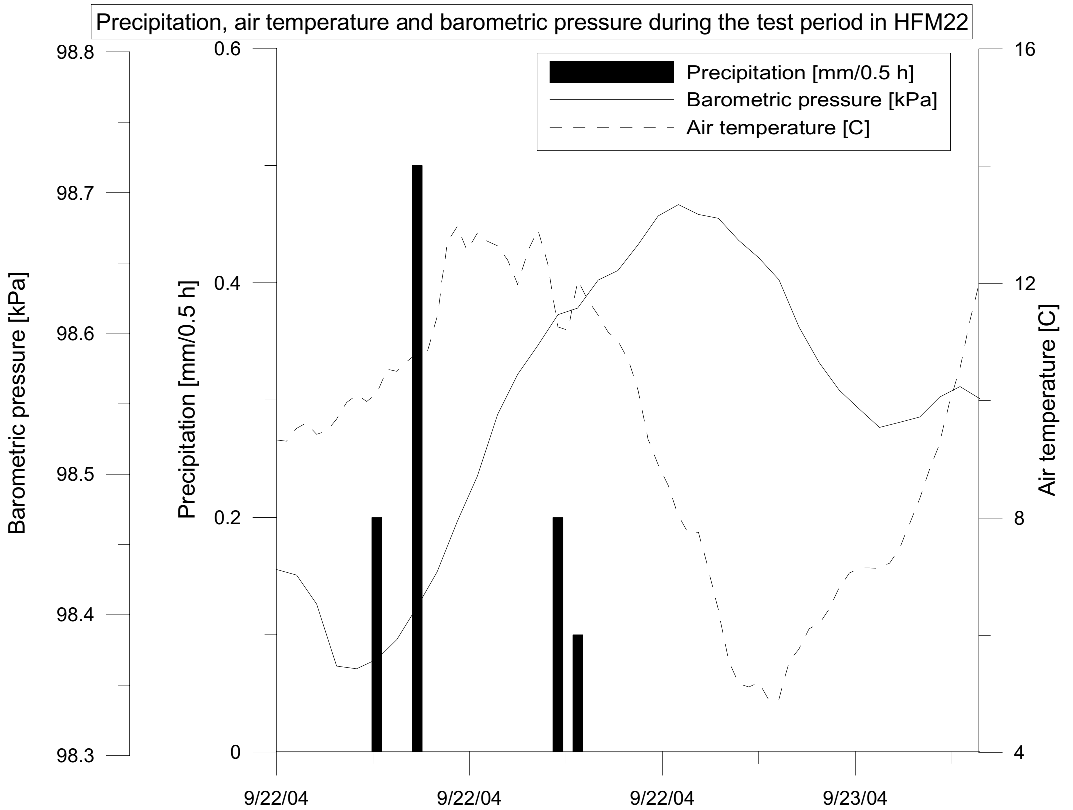



*__Figure 6-3.__ Barometric pressure (solid line), air temperature (dashed line) and precipitation (solid bars) at Forsmark during the test period in HFM22.*

### *Comments on test*

The day before test start, a short capacity test was performed (c 23 min). By the end of the capacity test, the flow rate was c 70.8 L/min and the drawdown c 1.61 m. The actual pumping test was performed as a constant flow rate test (60.1 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. A comparison of the results from the capacity test and pumping test is presented in Table 6-7.

After c 89 minutes of pumping the ground water level in the borehole increased c 0.06 m. After c 121 minutes the level was back to the same level as before 89 min and then continued to decrease. A possible explanation might be the activities in KFM08A where gap injection between the casing and the rock wall took place during the same time. The two boreholes are located c 40 m apart, cf Figure 1-2.

**Table 6-7. Estimated specific capacity from the capacity test and pumping test in borehole HFM22: 12.0–221.0 m.**

| Test | Duration (min) | Flow rate, $Q_p$ (L/min) | Drawdown, $s_w = p_i - p_p$ (m) | Specific capacity, $Q_p/s_w$ ($m^2/s$) |
|---|---|---|---|---|
| Short capacity test | 23 | 70.8 | 1.61 | 0.00073 |
| Pumping test | 606 | 60.1 | 2.92 | 0.00034 |

Table 6-3 indicates that the specific capacity from the pumping test is lower than the specific capacity from the short capacity test. This may be a result of the significantly shorter duration of the capacity test and that the drawdown had not yet stabilized.

#### *Interpreted flow regimes*

Selected test diagrams according to the instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-15 to A2-23 in Appendix 2.

A pseudo-linear flow regime is indicated from c 1 min to c 20 min. From c 40 min to c 300 min of the flow period pseudo-radial flow is interpreted, cf Figures A2-16 to A2-17.

During the recovery period pseudo-linear flow dominates during the first 15 minutes with a transition to apparent pseudo-radial flow after c 40 min. By the end of the recovery period transition to pseudo-spherical (leaky) flow is indicated.

#### *Interpreted parameters*

The transient, quantitative interpretation of the flow- and recovery period of the test is presented in Figures A2-16 to A2-23 in Appendix 2. Quantitative analysis was applied both on the flow- and recovery period according to the methods described in Section 5.4.1.

The transmissivity was estimated by a model assuming pseudo-radial flow /4/ on both the flow and recovery period but also with a model assuming a horizontal fracture intersecting the borehole /5/. The estimation with the model assuming a horizontal fracture is presented as a comparison to the radial model. The calculated transmissivity was similar for the two models. The representative transmissivity (i.e. $T_T$) is considered from the transient evaluation from the flow period assuming pseudo-radial flow.

The results are exposed in the Test Summary Sheets and in Table 6-19, Table 6-20 and Table 6-21 in Section 6.6. The analysis from the flow period was selected as the representative.

## 6.4 Flow logging and injection tests

### 6.4.1 Borehole HFM20

General test data for the flow logging in borehole HFM20 are presented in Table 6-8.

**Table 6-8. General test data, groundwater level and flow data for the flow logging in borehole HFM20.**

| **General test data** | | | | |
|---|---|---|---|---|
| Borehole | HFM20 | | | |
| Test type(s) [1] | 6, L-EC, L-Te | | | |
| Test section | Open borehole | | | |
| Test no | 1 | | | |
| Field crew | C Hjerne, J Olausson, GEOSIGMA AB | | | |
| Test equipment system | HTHB | | | |
| General comments | Single pumping borehole | | | |
| | **Nomenclature** | **Unit** | **Value** | |
| Borehole length | | m | 301.0 | |
| Pump position (lower level) | | m | 8.5 | |
| Flow logged section – secup | | m | 12.5 | |
| Flow logged section – seclow | | m | 295.0 | |
| Test section diameter [2] | 2·rw | mm | top 139<br>bottom 135 | |
| Start of flow period | | yymmdd hh:mm | 040817 08:27 | |
| Start of flow logging | | yymmdd hh:mm | 040817 13:22 | |
| Stop of flow logging | | yymmdd hh:mm | 040817 18:48 | |
| Stop of flow period | | yymmdd hh:mm | 040817 18:49 | |
| **Groundwater level** | **Nomenclature** | **Unit** | **G.w-level (m b ToC)** | **G.w-level (m a s l)** [3] |
| Groundwater level in borehole, at undisturbed conditions , open hole | $h_i$ | m | 2.55 | 0.43 |
| Groundwater level (steady state) in borehole, at pumping rate $Q_p$ | $h_p$ | m | 5.28 | –2.29 |
| Drawdown during flow logging at pumping rate $Q_p$ | $s_{FL}$ | m | 2.73 | |
| **Flow data** | **Nomenclature** | **Unit** | **Flow rate** | |
| Pumping rate at surface | $Q_p$ | $m^3/s$ | $1.1 \cdot 10^{-3}$ | |
| Corrected cumulative flow rate at secup at pumping rate $Q_p$ | $Q_{Tcorr}$ | $m^3/s$ | $1.1 \cdot 10^{-3}$ | |
| Threshold value for borehole flow rate during flow logging | $Q_{Measl}$ | $m^3/s$ | $5 \cdot 10^{-5}$ | |
| Minimal change of borehole flow rate to detect flow anomaly | $dQ_{Anom}$ | $m^3/s$ | $1.7 \cdot 10^{-5}$ | |

[1] 6: Flow logging-Impeller, L-EC: EC-logging, L-TE: temperature logging.
[2] Claesson and Nilsson (2004) /6/.
[3] Calculated from the manual measurements of groundwater level.

### *Comments on test*

The flow logging was made from the bottom of the hole and upward. The step length between flow logging measurements was maximally 10 m in the borehole interval 295–120 m. Above 120 m, the step length was maximally 2 m.

The measured electric conductivity is used as supporting information when interpreting flow anomalies. However, since the temperature sensor failed, the electrical conductivity is not compensated for temperature (see Figure 6-4).

### *Logging results*

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the hole during the flow logging together with the electric conductivity (EC) of the borehole fluid is presented in Figure 6-4. The figure presents one data set of borehole flow rate with calibration constants for a 140 mm pipe (according to the drilling record, the borehole diameter in the upper part is 139 mm) and another with corrected borehole flow rate. The correction is performed as a scaling of all borehole flow rate data to achieve $Q_{Tcorr} = Q_p$. The correction is performed under the assumption of no inflow above the highest position for flow logging. This assumption is considered as good since the flow logging continued up to c 0.5 m below the casing.

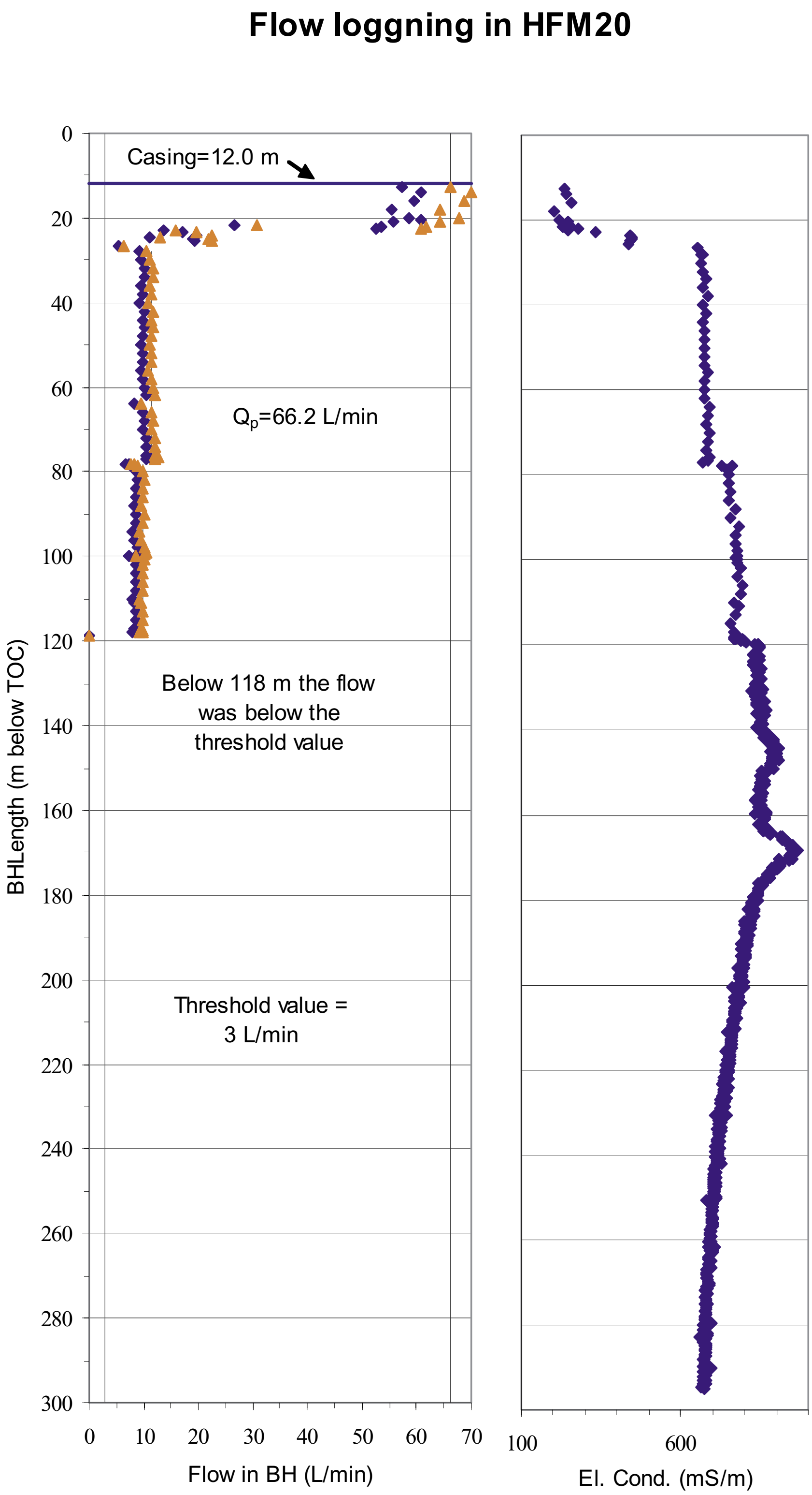



***Figure 6-4.*** *Measured (blue) and corrected (red) inflow distribution together with electrical conductivity (blue) of the borehole fluid along borehole HMF20 during flow logging.*

Figure 6-4 shows the detected inflows at 22.5–28 m, 77–78 m and at 118–118.5 m. The inflow is supported by the EC-measurements.

The results of the flow logging in borehole HFM20 are presented in Table 6-9 below. The measured inflow at the identified flow anomalies ($dQ_i$) together with their estimated percentage of the total flow is presented.

The cumulative transmissivity ($T_{FT}$) at the top of the flow-logged borehole interval was calculated from Equation (5-3) and the transmissivity of individual flow anomalies ($T_i$) from Equation (5-4). Transmissivity for the entire borehole used in Equation (5-4) was taken from the transient evaluation of the flow period of the pumping test in conjunction with the flow logging (cf Section 6.3.1). An estimation of the transmissivity of the interpreted flow anomalies was also made by the specific flow ($dQ_i/s_{FL}$).

**Table 6-9. Results of the flow logging in borehole HFM20. $Q_{Tcorr}$ = cumulative flow at the top of the logged interval, corrected due to the deviation of the actual borehole diameter from the one used for calibration. $Q_p$ = pumped flow rate from borehole, $s_{FL}$ = drawdown during flow logging. T = transmissivity from the pumping test.**

| **HFM20** **Flow anomalies** | | $Q_{Tcorr} = 1.1 \cdot 10^{-3}$ (m³/s) | $T = 6.94 \cdot 10^{-5}$ (m²/s) | $s_{FL}$ = 2.65 m | $Q_p = 1.1 \cdot 10^{-3}$ (m³/s) | |
|---|---|---|---|---|---|---|
| **Interval (m b ToC)** | **B.h. length (m)** | **$dQ_{icorr}$ [1] (m³/s)** | **$T_i$ (m²/s)** | **$dQ_{icorr}/s_{FL}$ (m²/s)** | **$dQ_{icorr}/Q_p$ (%)** | **Supporting information** |
| 22.5–28 | 5.5 | $9.12 \cdot 10^{-4}$ | $5.73 \cdot 10^{-5}$ | $3.44 \cdot 10^{-4}$ | 82.8 | EC |
| 77–78 | 1 | $2.83 \cdot 10^{-5}$ | $1.78 \cdot 10^{-6}$ | $1.07 \cdot 10^{-5}$ | 2.5 | EC |
| 118–118.5 | 0.5 | $1.63 \cdot 10^{-4}$ | $1.03 \cdot 10^{-5}$ | $6.16 \cdot 10^{-5}$ | 14.7 | EC |
| **Total** | | **$1.1 \cdot 10^{-3}$** | **$6.94 \cdot 10^{-5}$** | **$4.16 \cdot 10^{-4}$** | **100** | |
| Difference | | $Q_p - Q_{Tcorr} = 0$ | – | – | | |

[1] The corrected flow is based on the assumption that all inflow occurs within the flow logged interval, i.e. QT= $Q_p = \Sigma dQ_{icorr}$ and that the difference in flow is only due to the borehole diameter.

### *Injection test in the lower part of the borehole*

To confirm the results from the flow logging, a short injection test was performed in the lower part of the borehole, below the first detected anomaly. The measured section was between 121.0–301.0 m, i.e. 180 m long. The injection test was performed with a constant head of c 19 m. The injected flow rate was calculated from water level readings in the injection container together with time readings. The results of the injection test are presented in Table 6-10 below. Only steady-state evaluation of the transmissivity by Moye's formula was made. The measurement limits and accuracy regarding this injection test is unclear since alternative equipment was used for the test (cf Section 4.1). An overview plot of the injection test is presented in Figure A2-24.

**Table 6-10. Results of the injection test in the section 121.0–301.0 m in borehole HFM20 in conjunction with flow logging.**

| Injection test in upper part of borehole HFM20 | Nomen-clature | Unit | Value |
|---|---|---|---|
| Injection rate at surface | $Q_p$ | $m^3/s$ | $9.17 \cdot 10^{-6}$ |
| Absolute pressure in borehole before start of flow period | $p_i$ | kPa | 1,009.2 |
| Absolute pressure in test section before stop of flow period | $p_p$ | kPa | 1,192.3 |
| Absolute pressure in test section at stop of recovery period | $p_F$ | kPa | 1,009.4 |
| Pressure change by the end of flow period | $dp_p$ | kPa | 183.0 |
| Specific flow | $Q_p/ dp_p$ | $m^2/s$ | $4.91 \cdot 10^{-7}$ |
| Transmissivity (Moye) | $T_M$ | $m^2/s$ | $6.39 \cdot 10^{-7}$ |

### *Summary of results*

Table 6-11 presents a summary of the results from the pumping test in conjunction with flow logging and corrected results from the flow logging together with the results of the injection test in the lower part of the borehole. The results in Table 6-11 are consistent and show that the major part of the borehole transmissivity is restricted to the flow-logged interval. The difference between the specific flow and the transmissivity is about 10 times and is most likely due to a dominating pseudo-linear flow regime in the borehole during the pumping test.

**Table 6-11. Compilation of results from the different hydraulic tests performed in borehole HFM20.**

| Test type | Interval (m) | Specific flow Q/s ($m^2/s$) | T ($m^2/s$) |
|---|---|---|---|
| Flow logging | 12.5–295.0 | $4.16 \cdot 10^{-4}$ | $6.94 \cdot 10^{-5}$ |
| Pumping test | 12.0–301.0 | $4.15 \cdot 10^{-4}$ | $6.94 \cdot 10^{-5}$ |
| Injection test in the lower part of the borehole | 121.0–301.0 | $4.91 \cdot 10^{-7}$ | $6.39 \cdot 10^{-7}$ |

Figure 6-5 presents the cumulative transmissivity $T_F(L)$ along the borehole length (L) from the flow logging calculated from Equation (5-5). Since the width of the flow anomaly in the borehole is not known in detail, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated threshold value of T and the total transmissivity of the borehole are also presented in the figure, cf Section 5.4.2.

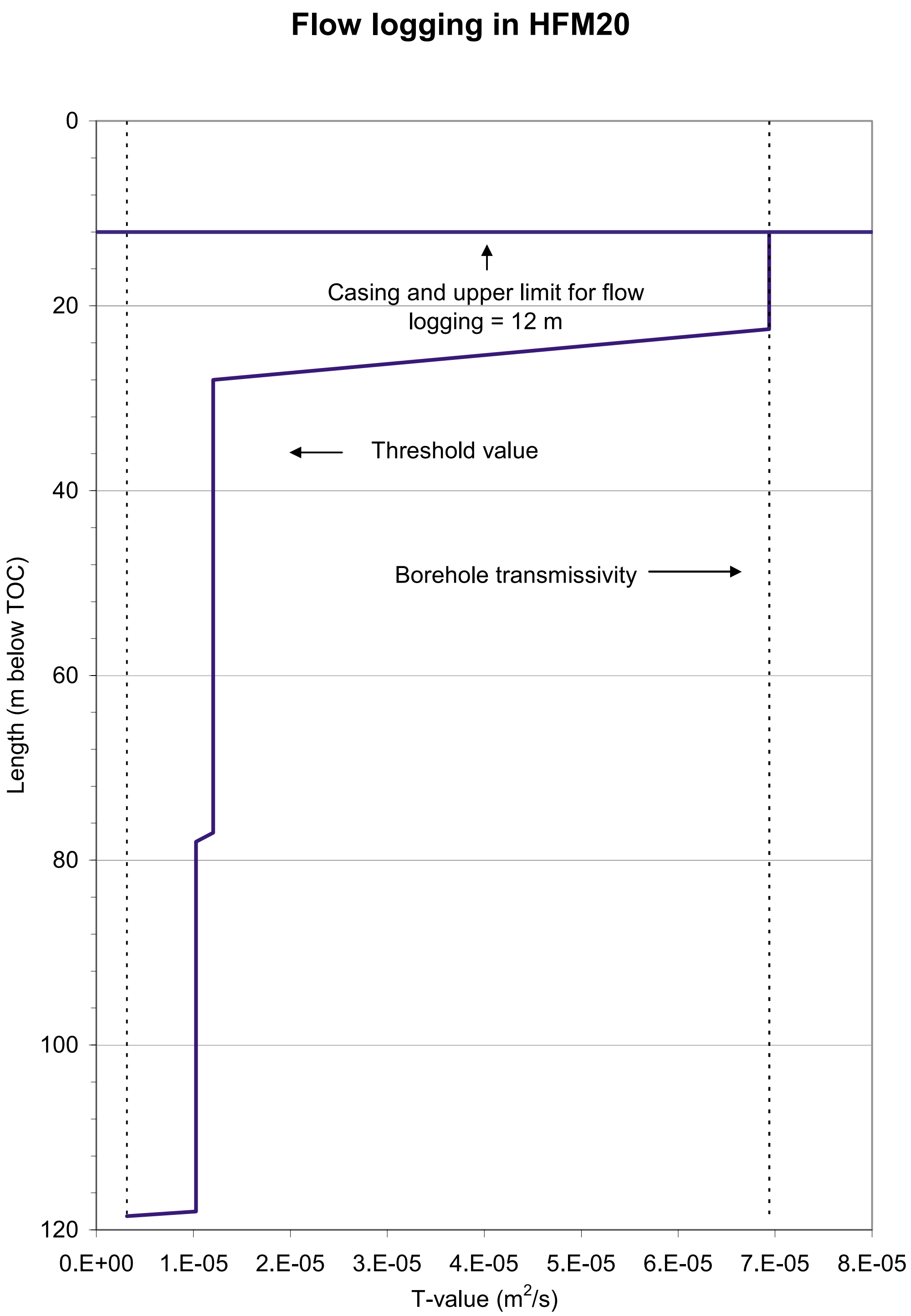



***Figure 6-5.*** *Calculated, cumulative transmissivity along the flow logged interval of borehole HFM20. The total borehole transmissivity was calculated from the pumping test during flow logging.*

### 6.4.2 Borehole HFM21

General test data for the flow logging in borehole HFM21 are presented in Table 6-12.

**Table 6-12. General test data, groundwater level and flow data for the flow logging in borehole HFM21.**

| General test data | | | | |
|---|---|---|---|---|
| Borehole | HFM21 | | | |
| Test type(s) [1] | 6, L-EC, L-Te | | | |
| Test section | Open borehole | | | |
| Test no | 1 | | | |
| Field crew | C Hjerne, K Gokall-Norman, GEOSIGMA AB | | | |
| Test equipment system | HTHB | | | |
| General comments | Single pumping borehole | | | |
| | **Nomenclature** | **Unit** | **Value** | |
| Borehole length | | m | 202.0 | |
| Pump position (lower level) | | m | 16.0 | |
| Flow logged section – secup | | m | 20.0 | |
| Flow logged section – seclow | | m | 195.0 | |
| Test section diameter [2] | 2·rw | mm | top 139<br>bottom 137 | |
| Start of flow period | | yymmdd hh:mm | 040810 10:12 | |
| Start of flow logging | | yymmdd hh:mm | 040810 15:00 | |
| Stop of flow logging | | yymmdd hh:mm | 040810 20:56 | |
| Stop of flow period | | yymmdd hh:mm | 040810 21:03 | |
| **Groundwater level [3]** | **Nomen-clature** | **Unit** | **G.w-level (m b ToC)** | **G.w-level (m a s l) [3]** |
| Groundwater level in borehole, at undisturbed conditions , open hole | $h_i$ | m | 4.45 | 0.19 |
| Groundwater level (steady state) in borehole, at pumping rate $Q_p$ | $h_p$ | m | 8.10 | –2.92 |
| Drawdown during flow logging at pumping rate $Q_p$ | $s_{FL}$ | m | 3.65 [3] | |
| **Flow data** | **Nomen-clature** | **Unit** | **Flow rate** | |
| Pumping rate at surface | $Q_p$ | $m^3$ /s | $1.06 \cdot 10^{-3}$ | |
| Corrected cumulative flow rate at secup at pumping rate $Q_p$ | $Q_{Tcorr}$ | $m^3$ /s | $1.06 \cdot 10^{-3}$ | |
| Threshold value for borehole flow rate during flow logging | $Q_{Measl}$ | $m^3$ /s | $5 \cdot 10^{-5}$ | |
| Minimal change of borehole flow rate to detect flow anomaly | $dQ_{Anom}$ | $m^3$ /s | $1.7 \cdot 10^{-5}$ | |

[1] 6: Flow logging-Impeller, L-EC: EC-logging, L-TE: temperature logging.
[2] Claesson and Nilsson (2004) /6/.
[3] Calculated from the manual measurements of groundwater level.

#### *Comments on test*

The flow logging was made from the bottom of the hole and upwards. The step length between flow logging measurements was maximally 5 m in the borehole interval 195–165 m. In the borehole interval 165–67 m, the step length was maximally 2 m. The maximum step interval was increased to 4 m above 67 m in order to reduce the total measuring time for the flow logging.

The measured electric conductivity is used as supporting information when interpreting flow anomalies and for this purpose the electrical conductivity is compensated for temperature (see Figure 6-6).

### *Logging results*

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the hole during the flow logging together with the electric conductivity (EC) of the borehole fluid is presented in Figure 6-6.

In Figure 6-6 an apparent increase in borehole flow rate with borehole length is indicated. This is a result of the decrease in borehole diameter with depth. According to the drilling record the borehole diameter at the top is 139 mm and at the bottom 137 mm.

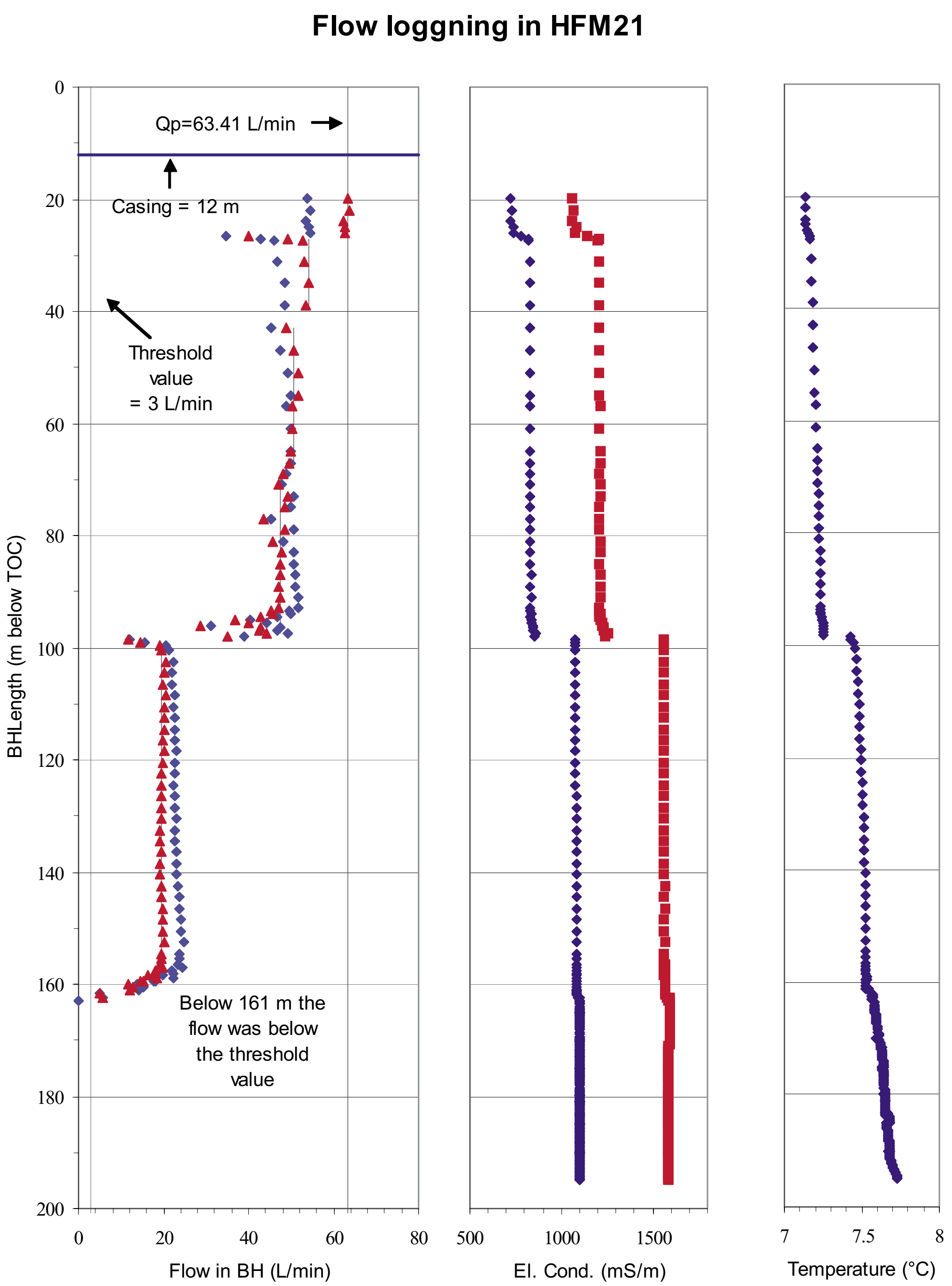



***Figure 6-6.*** *Measured (blue) and corrected (red) inflow distribution together with electrical conductivity (blue), temperature-compensated electric conductivity (red) and temperature (Te) distribution of the borehole fluid along borehole HMF21 during flow logging.*

In Figure 6-6 one un-corrected data set of borehole flow rate with calibration constants for a 140 mm pipe and one data set corrected for the changing borehole diameter is presented.

Using the logging in the undisturbed borehole together with known calibration constants at two certain borehole diameters it is possible to estimate a relationship between the proportionality factor (gain) in the calibration equation and borehole length.

Flow logging was performed up to c 20 m below TOC. An injection test conducted between 14–20 m indicated that the section is of very low conductivity. Based on the results from the injection test a scaling of all borehole flow rate data is performed to achive $Q_{Tcorr} = Q_p$. The correction is performed under the assumption that no inflow above the highest position for flow logging. This assumption is considered as fairly good since the injection test is made up to 2 m below the casing.

Figure 6-6 shows that inflows were detected at 26–27 m, 38.9–42.9m, 67–69 m, 97.5–99.5 m and at 157–163 m. The inflows at 26–27 m, 97.5–99.5 m and 157–163 m is supported by the EC-measurements.

The results of the flow logging in borehole HFM21 are presented in Table 6-13 below. The measured inflow at the identified flow anomaly ($dQ_i$) together with its estimated percentage of the total flow is presented.

The cumulative transmissivity ($T_{FT}$) at the top of the flow-logged borehole interval was calculated from Equation (5-3) and the transmissivity of individual flow anomalies ($T_i$) from Equation (5-4). Transmissivity for the entire borehole used in Equation (5-4) was taken from the transient evaluation of the injection period for the pumping test performed in conjunction with the flow logging (cf Section 6.3.1). An estimation of the transmissivity of the interpreted flow anomaly was also made by the specific flow ($dQ_i/s_{FL}$).

**Table 6-13. Results of the flow logging in borehole HFM21. $Q_{Tcorr}$ = cumulative flow at the top of the logged interval, corrected due to the deviation of the actual borehole diameter from the one used for calibration. $Q_p$ = pumped flow rate from borehole, $s_{FL}$ = drawdown during flow logging. T = transmissivity from the pumping test.**

| **HFM21 Flow anomalies** | | $Q_{Tcorr} = 1.06 \cdot 10^{-3}$ (m³/s) | $T = 6.8 \cdot 10^{-4}$ (m²/s) | $s_{FL}$ = 3.14m | $Q_p = 1.06 \cdot 10^{-3}$ (m³/s) | |
|---|---|---|---|---|---|---|
| **Interval (m b ToC)** | **B.h. length (m)** | **$dQ_{icorr}$ [1] (m³/s)** | **$T_i$ (m²/s)** | **$dQ_{icorr}/s_{FL}$ (m²/s)** | **$dQ_{icorr}/Q_p$ (%)** | **Supporting information** |
| 26–27 | 1 | $1.57 \cdot 10^{-4}$ | $1.01 \cdot 10^{-4}$ | $4.99 \cdot 10^{-5}$ | 14.9 | EC, T |
| 38.9–42.9 | 4 | $5.50 \cdot 10^{-5}$ | $3.54 \cdot 10^{-5}$ | $1.75 \cdot 10^{-5}$ | 5.3 | |
| 67–69 | 2 | $5.33 \cdot 10^{-5}$ | $3.43 \cdot 10^{-5}$ | $1.70 \cdot 10^{-5}$ | 5.1 | |
| 97.5–99 | 2 | $4.69 \cdot 10^{-4}$ | $3.01 \cdot 10^{-4}$ | $1.49 \cdot 10^{-4}$ | 44.2 | EC, T |
| 157–163 | 6 | $3.23 \cdot 10^{-4}$ | $2.08 \cdot 10^{-4}$ | $1.03 \cdot 10^{-4}$ | 30.5 | EC, T |
| **Total** | | **$1.06 \cdot 10^{-3}$** | **$6.8 \cdot 10^{-4}$** | **$3.37 \cdot 10^{-4}$** | **100** | |
| Difference | | $Q_p - Q_{Tcorr} = 0$ | | | | |

[1] The corrected flow is based on the assumption that all inflow occurs within the flow logged interval, i.e. QT= $Q_p = \Sigma dQ_{icorr}$ and that the difference in flow is only due to the borehole diameter.

### *Injection test in the upper part of the borehole*

To confirm the results from the flow logging, a short injection test was performed in the uppermost part of the borehole. The measured section was between 14.0–20.0 m, i.e. 6 m long. The injection test was performed with a constant head of c 16 m. The injected flow rate was below the practical measurement limit of 0.5 L/min. The results of the injection test are presented in Table 6-14 below. Only a steady-state evaluation of the transmissivity by Moye's formula was made (based on the measurement limit as $Q_p$). An overview of the injection test is presented in Figure A2-25.

**Table 6-14. Results of the injection test in the section 14.0–20.0 m in borehole HFM21 in conjunction with flow logging.**

| Injection test in upper part of borehole HFM21 | Nomenclature | Unit | Value |
|---|---|---|---|
| Injection rate at surface | $Q_p$ | $m^3/s$ | $<8.33 \cdot 10^{-6}$ |
| Absolute pressure in borehole before start of flow period | $p_i$ | kPa | 155.4 |
| Absolute pressure in test section before stop of flow period | $p_p$ | kPa | 316.0 |
| Absolute pressure in test section at stop of recovery period | $p_F$ | kPa | 268.7 |
| Pressure change by the end of flow period | $dp_p$ | kPa | 160.6 |
| Specific flow | $Q_p/ dp_p$ | $m^2/s$ | $<5.09 \cdot 10^{-7}$ |
| Transmissivity (Moye) | $T_M$ | $m^2/s$ | $<3.86 \cdot 10^{-7}$ |

### *Summary of results*

Table 6-15 presents a summary of the results from the pumping test in conjunction with flow logging and corrected results from the flow logging together with the results of the injection test in the upper part of the borehole. The results in Table 6-15 are consistent and show that the major part of the borehole transmissivity is restricted to the flow-logged interval.

**Table 6-15. Compilation of results from the different hydraulic tests performed in borehole HFM21.**

| Test type | Interval (m) | Specific flow Q/s ($m^2/s$) | T ($m^2/s$) |
|---|---|---|---|
| Flow logging | 21.0–205.0 | $3.37 \cdot 10^{-4}$ | $6.8 \cdot 10^{-4}$ |
| Pumping test | 12.0–202.0 | $3.36 \cdot 10^{-4}$ | $6.8 \cdot 10^{-4}$ |
| Injection test in upper part of the borehole | 14.0–20.0 | $<5.09 \cdot 10^{-7}$ | $<3.86 \cdot 10^{-7}$ |

Figure 6-7 presents the cumulative transmissivity $T_F(L)$ along the borehole length (L) from the flow logging calculated from Equation (5-5). Since the width of the flow anomaly in the borehole is not known in detail, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The anomalies at 38.9–42.9 m and 67–69 m were not detected during measurements but during the evaluation, hence the step length between the flow logging measurements is 2 m from 27.5–97.5 m. Based on $dQ_i$ being larger than 1 L/min between the anomalies in the interval 27.5–97.5 m the anomalies are judged to be real inflows. The estimated threshold value of T and the total transmissivity of the borehole are also presented in the figure, cf Section 5.4.2.

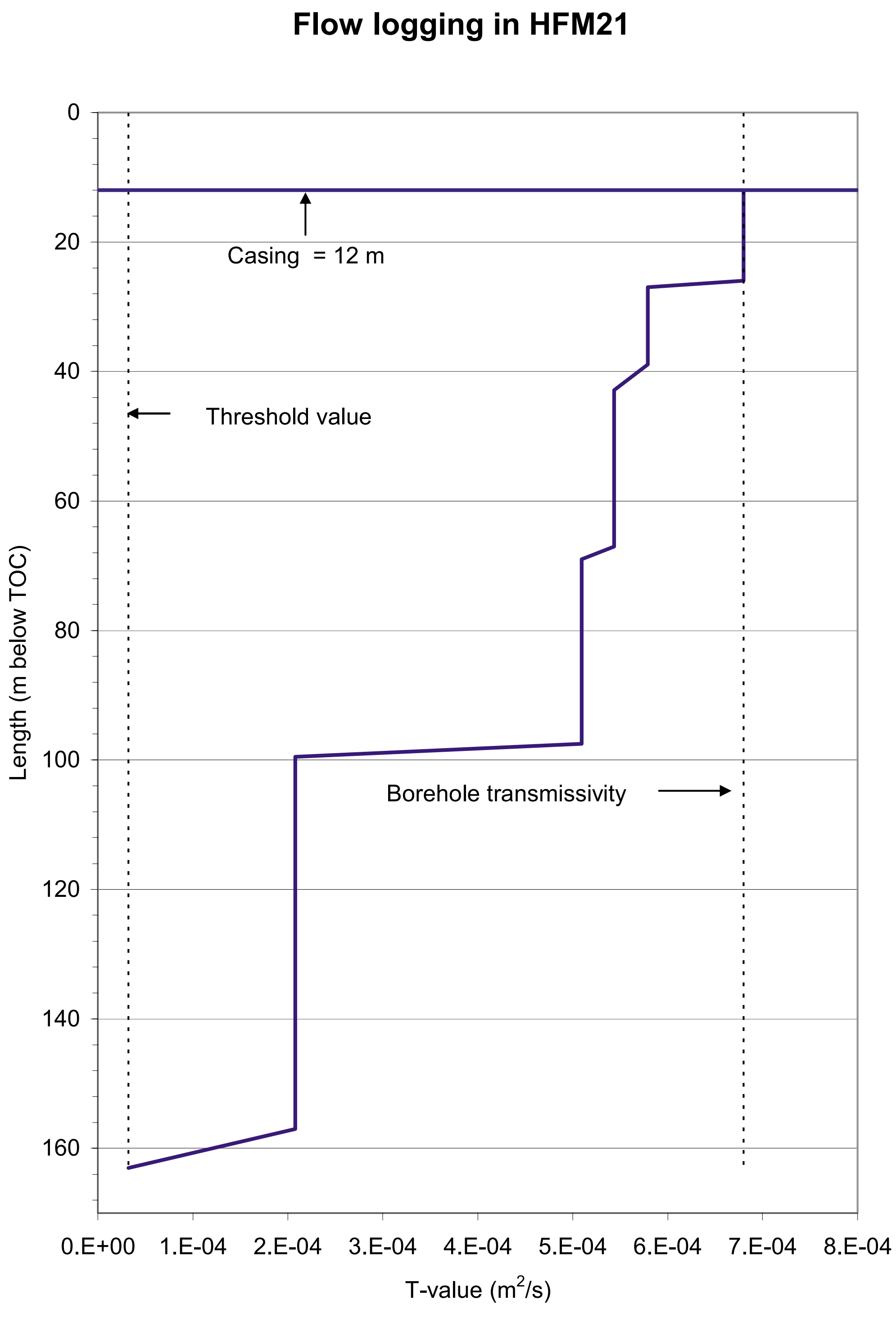



***Figure 6-7.*** *Calculated, cumulative transmissivity along the flow logged interval of borehole HFM21. The total borehole transmissivity was calculated from the pumping test during flow logging.*

### 6.4.3 Borehole HFM22

General test data for the flow logging in borehole HFM22 are presented in Table 6-16.

**Table 6-16. General test data, groundwater level and flow data for the flow logging in borehole HFM22.**

| General test data | | | | |
|---|---|---|---|---|
| Borehole | HFM22 | | | |
| Test type(s) [1] | 6, L-EC, L-Te | | | |
| Test section | Open borehole | | | |
| Test no | 1 | | | |
| Field crew | J. Jönsson, T. Svensson | | | |
| Test equipment system | HTHB | | | |
| General comments | Single pumping borehole | | | |
| | **Nomenclature** | **Unit** | **Value** | |
| Borehole length | | m | 221.0 | |
| Pump position (lower level) | | m | 9.0 | |
| Flow logged section – secup | | m | 12.1 | |
| Flow logged section – seclow | | m | 211.2 | |
| Test section diameter [2] | 2·rw | mm | top 141 bottom 136.2 | |
| | | | | |
| Start of flow period | | yymmdd hh:mm | 040922 09:15 | |
| Start of flow logging | | yymmdd hh:mm | 040922 15:23 | |
| Stop of flow logging | | yymmdd hh:mm | 040922 18:45 | |
| Stop of flow period | | yymmdd hh:mm | 040922 19:21 | |
| **Groundwater level** | **Nomenclature** | **Unit** | **G.w-level (m b ToC)** | **G.w-level (m a s l) [3]** |
| Groundwater level in borehole, at undisturbed conditions , open hole | $h_i$ | m | 1.67 | |
| Groundwater level (steady state) in borehole, at pumping rate $Q_p$ [3] | $h_p$ | m | 5.16 | |
| Drawdown during flow logging at pumping rate $Q_p$ | $s_{FL}$ | m | 3.49 | |
| **Flow data** | **Nomenclature** | **Unit** | **Flow rate** | |
| Pumping rate at surface | $Q_p$ | $m^3$ /s | $1.00 \cdot 10^{-3}$ | |
| Corrected cumulative flow rate at secup at pumping rate $Q_p$ | $Q_{Tcorr}$ | $m^3$ /s | | |
| Threshold value for borehole flow rate during flow logging | $Q_{Measl}$ | $m^3$ /s | $5 \cdot 10^{-5}$ | |
| Minimal change of borehole flow rate to detect flow anomaly | $dQ_{Anom}$ | $m^3$ /s | | |

[1] 6: Flow logging-Impeller, L-EC: EC-logging, L-TE: temperature logging.
[2] Claesson and Nilsson (2004) /6/.
[3] Calculated from the manual measurements of groundwater level.

#### *Comments on test*

The flow logging was made from the bottom of the hole and upwards. The step length between flow logging measurements was maximally 10 m in the borehole interval 221–70 m. Above 70 m, the step length was maximally 2 m.

The measured electric conductivity is used as supporting information when interpreting flow anomalies. However the conductivity meter was not connected until 85.5 m.

### *Logging results*

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the hole during the flow logging together with the electric conductivity (EC) of the borehole fluid is presented in Figure 6-8.

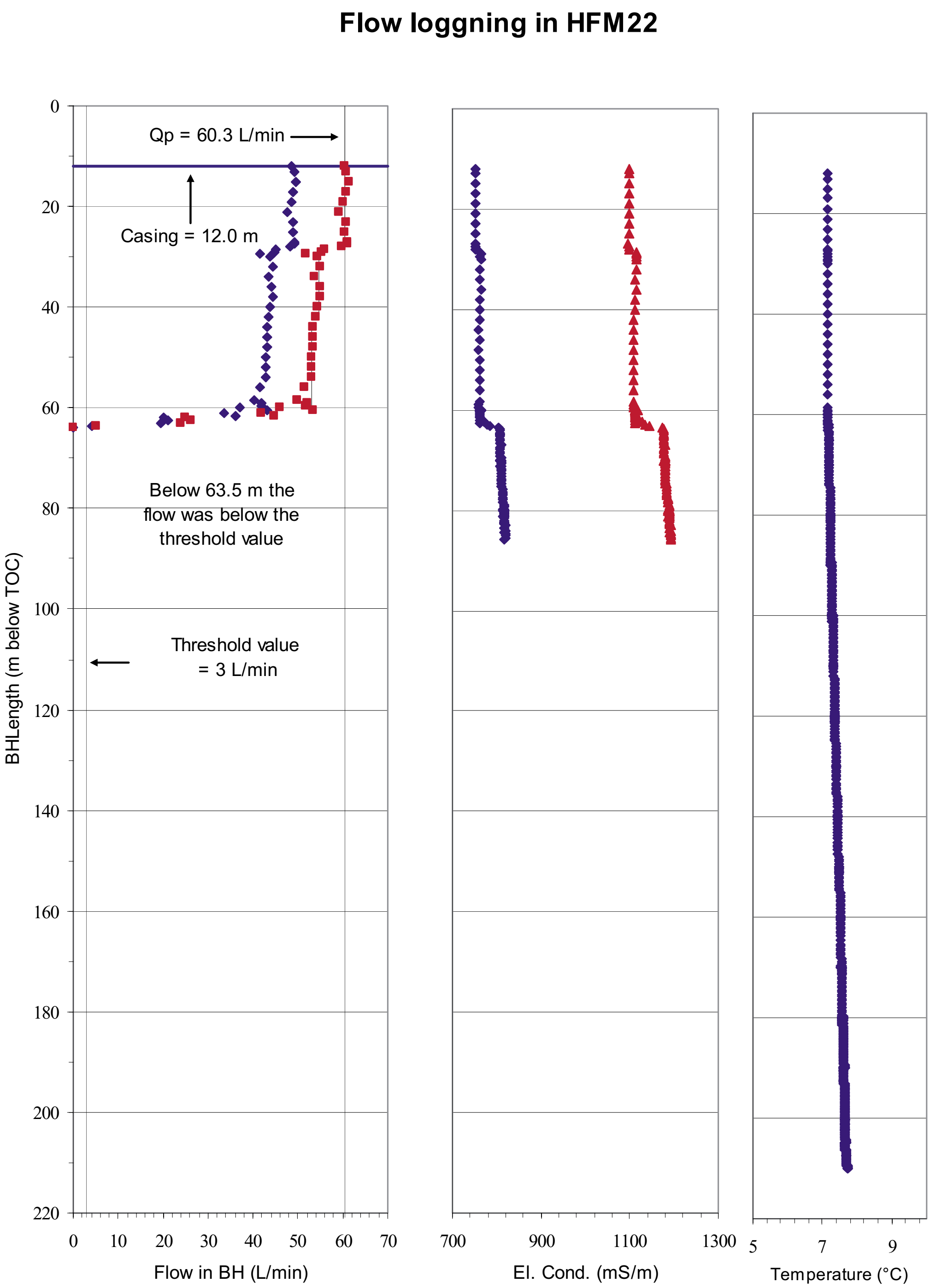



***Figure 6-8.*** *Measured (blue) and corrected (red) inflow distribution together with electrical conductivity (blue), temperature compensated electrical conductivity (red) and temperature of the borehole fluid along borehole HMF22 during flow logging.*

The figure presents one data set of borehole flow rate with calibration constants for a 140 mm pipe (according to the drilling record, the borehole diameter in upper part is 139 mm) and another with corrected borehole flow rate. The correction is performed as a scaling of all borehole flow rate data to achieve $Q_{Tcorr} = Q_p$. The correction is performed under the assumption of no inflow above the highest position for flow logging. This assumption is considered fairly good since the flow logging continued up to 0.5 m from the casing.

Figure 6-8 shows the detected inflows at 28–29 m, 42–44 m and at 60.5–63.5 m. The inflow is supported by the EC-measurements.

The results of the flow logging in borehole HFM22 are presented in Table 6-17 below. The measured inflow at the identified flow anomalies ($dQ_i$) together with their estimated percentage of the total flow is presented.

The cumulative transmissivity ($T_{FT}$) at the top of the flow-logged borehole interval was calculated from Equation (5-3) and the transmissivity of individual flow anomalies ($T_i$) from Equation (5-4). Transmissivity for the entire borehole used in Equation (5-4) was taken from the transient evaluation of the injection period for the pumping test performed in conjunction with the flow logging (cf Section 6.3.1). An estimation of the transmissivity of the interpreted flow anomaly was also made by the specific flow ($dQ_i/s_{FL}$).

**Table 6-17. Results of the flow logging in borehole HFM22. $Q_{Tcorr}$=cumulative flow at the top of the logged interval, corrected due to the deviation of the actual borehole diameter from the one used for calibration. $Q_p$=pumped flow rate from borehole, $s_{FL}$= drawdown during flow logging. T=transmissivity from the pumping test.**

| **HFM22**<br>**Flow anomalies** | | $Q_{Tcorr}$ =1.01·10$^{-3}$<br>(m³/s) | T=1.64·10$^{-4}$<br>(m²/s) | $s_{FL}$= 2.92 m | $Q_p$=1.01·10$^{-3}$<br>(m³/s) | |
|---|---|---|---|---|---|---|
| **Interval (m b ToC)** | **B.h. length (m)** | **$dQ_{icorr}$ [1] (m³/s)** | **$T_i$ (m²/s)** | **$dQ_{icorr}/s_{FL}$ (m²/s)** | **$dQ_{icorr}/Q_p$ (%)** | **Supporting information** |
| 28–29 | 1 | 9.17·10$^{-5}$ | 1.49·10$^{-5}$ | 3.14·10$^{-5}$ | 9.12 | EC |
| 42–44 | 2 | 3.17·10$^{-5}$ | 5.16·10$^{-6}$ | 1.08·10$^{-5}$ | 3.15 | EC |
| 60.5–64 | 3.5 | 8.82·10$^{-4}$ | 1.44·10$^{-4}$ | 3.02·10$^{-4}$ | 87.76 | EC |
| **Total** | | **1.01·10$^{-3}$** | **3.44·10$^{-4}$** | **1.64·10$^{-4}$** | **100** | |
| Difference | | $Q_p$–$Q_{Tcorr}$=0 | | | | |

[1] The corrected flow is based on the assumption that all inflow occurs within the flow logged interval, i.e. QT= $Q_p$=$\Sigma dQ_{icorr}$ and that the difference in flow is only due to the borehole diameter.

### *Summary of results*

Table 6-18 presents a summary of the results from the pumping test and corrected results from the flow logging together with the results of the injection test in the lower part of the borehole. The results in Table 6-18 are consistent and show that the borehole transmissivity is restricted to the flow-logged interval.

**Table 6-18. Compilation of results from the different hydraulic tests performed in borehole HFM22.**

| **Test type** | **Interval (m)** | **Specific flow Q/s (m²/s)** | **T (m²/s)** |
|---|---|---|---|
| Flow logging | 12.08–211.2 | 1.64·10$^{-4}$ | 1.64·10$^{-4}$ |
| Pumping test | 12.0–221.0 | 3.42·10$^{-4}$ | 1.64·10$^{-4}$ |

Figure 6-9 presents the cumulative transmissivity $T_F(L)$ along the borehole length (L) from the flow logging calculated from Equation (5-5). Since the width of the flow anomaly in the borehole is not known in detail, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated threshold value of T and the total transmissivity of the borehole are also presented in the figure, cf Section 5.4.2.

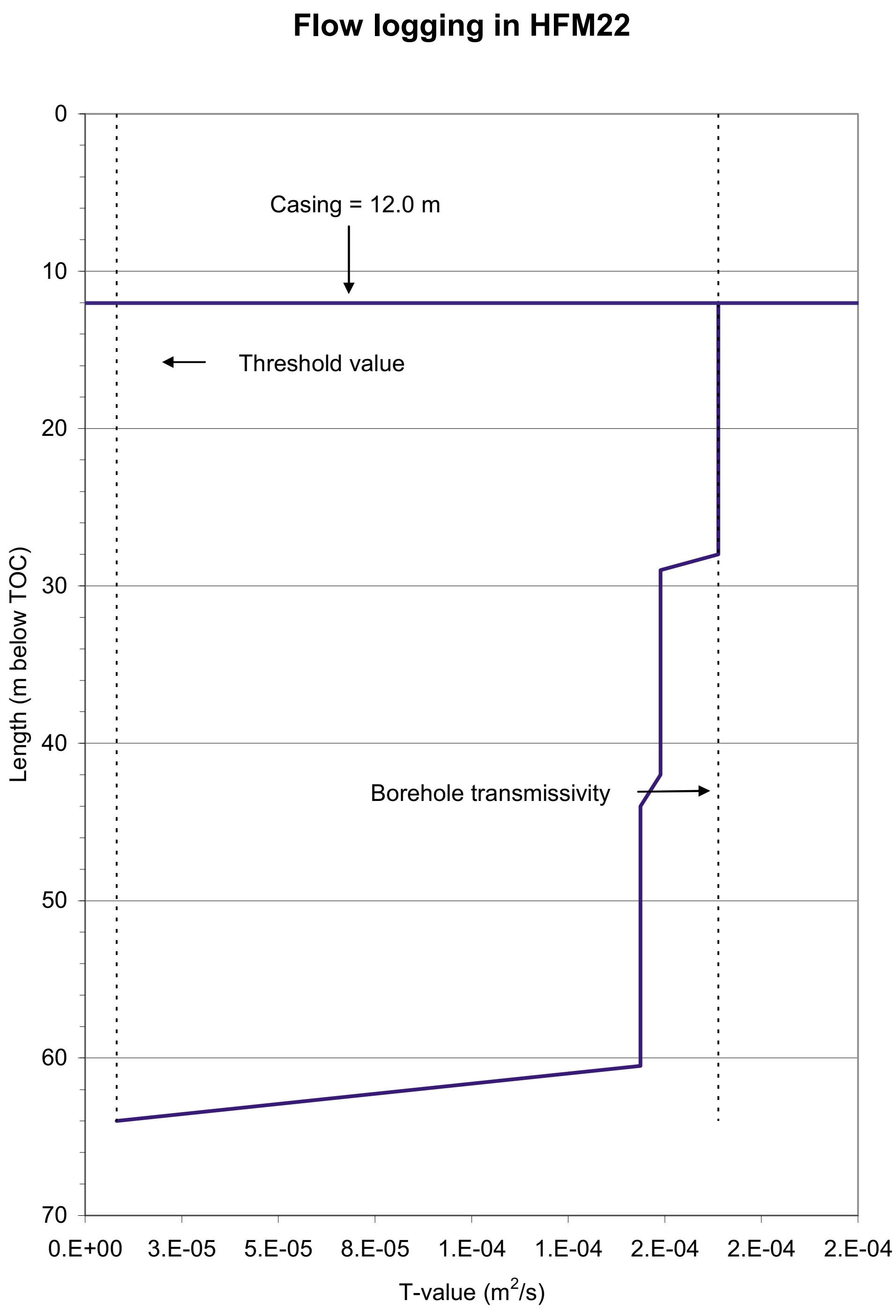



*Figure 6-9. Calculated, cumulative transmissivity along the flow logged interval of borehole HFM22. The total borehole transmissivity was calculated from the pumping test during flow logging.*

## 6.5 Summary of hydraulic tests

A compilation of measured test data from the hydraulic tests carried out in the test campaigns is presented in Table 6-19. In Table 6-20 and Table 6-21, hydraulic parameters calculated from the tests in HFM20–22 are shown. The results of the flow logging are presented in Section 6.4.

The lower measurement limit for the HTHB system, presented in the tables below, is expressed in terms of specific flow (Q/s). For pumping tests, the practical lower limit is based on the minimal flow rate Q, for which the system is designed (5 L/min) and an estimated maximal allowed drawdown for practical purposes (c 50 m) in a percussion borehole, cf Table 4-1. These values correspond to a practical lower measurement limit of Q/s-L=$2\cdot10^{-6}$ $m^2/s$ of the pumping tests. For injection tests, the practical lower measurement limit is based on the minimal flow rate Q, for which the system is designed (1 L/min) and a head of 20 m according to the methodology description for injection tests (SKB MD 323.001, SKB internal document). These values correspond to a practical lower measurement limit of Q/s-L=$8\cdot10^{-7}$ $m^2/s$ of the injection tests.

Similarly, the practical, upper measurement limit of the HTHB-system is estimated from the maximal flow rate (c 80 L/min) and a minimal drawdown of c 0.5 m, which is considered significant in relation to e.g. background fluctuations of the pressure before and during the test. These values correspond to an estimated, practical upper measurement limit of Q/s-U=$2\cdot10^{-3}$ $m^2/s$ for both pumping tests and injection tests.

**Table 6-19. Summary of test data for the open-hole pumping tests performed with the HTHB system in boreholes HFM20–22 in the Forsmark candidate area.**

| Borehole ID | Section (m) | Test type [1] | $p_i$ (kPa) | $p_p$ (kPa) | $p_F$ (kPa) | $Q_p$ ( $m^3/s$) | $Q_m$ ($m^3/s$) | $V_p$ ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| HFM20 | 12.0–301.0 | 1B | 123.18 | 97.19 | 118.63 | $1.10\cdot10^{-3}$ | $1.10\cdot10^{-3}$ | 41.22 |
| HFM21 | 12.0–202.0 | 1B | 168.38 | 137.58 | 165.59 | $1.06\cdot10^{-3}$ | $1.06\cdot10^{-3}$ | 41.24 |
| HFM22 | 12.0–221.0 | 1B | 147.17 | 118.49 | 146.36 | $1\cdot10^{-3}$ | $1\cdot10^{-3}$ | 36.47 |

[1] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller. L-EC: EC-logging, L-Te: temperature logging.

**Table 6-20. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed with the HTHB system in boreholes HFM20–22 in the Forsmark candidate area.**

| Borehole ID | Section (m) | Flow anomaly interval (m) | Test type [1] | Q/s ($m^2/s$) | $T_M$ ($m^2/s$) | $T_T$ ($m^2/s$) | $T_i$ ($m^2/s$) | S* (–) |
|---|---|---|---|---|---|---|---|---|
| HFM20 | 12.0–301.0 | | 1B | $4.2 \cdot 10^{-3}$ | $4.15 \cdot 10^{-4}$ | $6.94 \cdot 10^{-5}$ | | $5.00 \cdot 10^{-5}$ |
| HFM20 | 121.0–301.0 | | 3 | $4.91 \cdot 10^{-7}$ | $6.39 \cdot 10^{-7}$ | | | |
| HFM20 | 12.5–295.0 (f) | 22.5–28 | 6 | $3.44 \cdot 10^{-4}$ | | | $5.73 \cdot 10^{-5}$ | |
| HFM20 | 12.5–295.0 (f) | 77–78 | 6 | $1.07 \cdot 10^{-5}$ | | | $1.78 \cdot 10^{-6}$ | |
| HFM20 | 12.5–295.0 (f) | 118–118.5 | 6 | $6.16 \cdot 10^{-5}$ | | | $1.03 \cdot 10^{-5}$ | |
| HFM21 | 12.0–202.0 | | 1B | $3.37 \cdot 10^{-4}$ | $3.38 \cdot 10^{-4}$ | $6.8 \cdot 10^{-4}$ | | $5.00 \cdot 10^{-5}$ |
| HFM21 | 14.0–20.0 | | 3 | $<5.09 \cdot 10^{-7}$ | $<3.86 \cdot 10^{-7}$ | | | |
| HFM21 | 20.0–195.0 (f) | 26–27 | 6 | $4.99 \cdot 10^{-5}$ | | | $1.01 \cdot 10^{-4}$ | |
| HFM21 | 20.0–195.0 (f) | 38.9–42.9 | 6 | $1.75 \cdot 10^{-5}$ | | | $3.54 \cdot 10^{-5}$ | |
| HFM21 | 20.0–195.0 (f) | 67–69 | 6 | $1.70 \cdot 10^{-5}$ | | | $3.43 \cdot 10^{-5}$ | |
| HFM21 | 20.0–195.0 (f) | 97.5–99 | 6 | $1.49 \cdot 10^{-4}$ | | | $3.01 \cdot 10^{-4}$ | |
| HFM21 | 20.0–195.0 (f) | 157–163 | 6 | $1.03 \cdot 10^{-4}$ | | | $2.08 \cdot 10^{-4}$ | |
| HFM22 | 12.0–221.0 | | 1B | $3.4 \cdot 10^{-3}$ | $3.42 \cdot 10^{-4}$ | $1.64 \cdot 10^{-4}$ | | $5.00 \cdot 10^{-5}$ |
| HFM22 | 12.1–211.0 | 28–29 | 6 | $3.14 \cdot 10^{-5}$ | | | $1.49 \cdot 10^{-5}$ | |
| HFM22 | 12.1–211.0 | 42–44 | 6 | $1.08 \cdot 10^{-5}$ | | | $5.16 \cdot 10^{-6}$ | |
| HFM22 | 12.1–211.0 | 64–60.5 | 6 | $3.02 \cdot 10^{-4}$ | | | $1.44 \cdot 10^{-4}$ | |

(f) = flow logged interval.

[1)] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller.

In Table 6-19, Table 6-20 and Table 6-21, the parameter explanations are according to the instruction for injection- and single-hole pumping tests. The parameters are also explained in the text above, except the following:

Q/s = specific flow for the borehole and flow anomalies (for the latter ones, the corrected specific flow for the borehole diameter is listed)

$T_M$ = steady-state transmissivity calculated from Moye's formula

$T_T$ = judged best estimate of transmissivity (from transient evaluation of hydraulic test or from Moye's formula)

$T_i$ = estimated transmissivity of flow anomaly

S* = assumed value on storativity used in single-hole tests

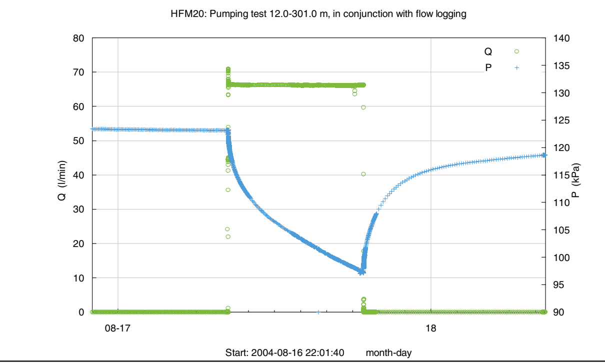
**Table 6-21. Summary of calculated hydraulic parameters of the borehole from hydraulic test performed with the HTHB system in boreholes HFM20-22 in the Forsmark candidate area.**

| Borehole ID | Section (m) | Test type | S* (–) | C (m3/Pa) | ζ (–) |
|---|---|---|---|---|---|
| HFM20 | 12.0–301.0 | 1B | $5.00 \cdot 10^{-5}$ | | –7.8 |
| HFM21 | 12.0–202.0 | 1B | $5.00 \cdot 10^{-5}$ | $2.2 \cdot 10^{-6}$ | 2.3 |
| HFM22 | 12.0–221.0 | 1B | $5.00 \cdot 10^{-5}$ | | –5.8 |

## Test Summary Sheet

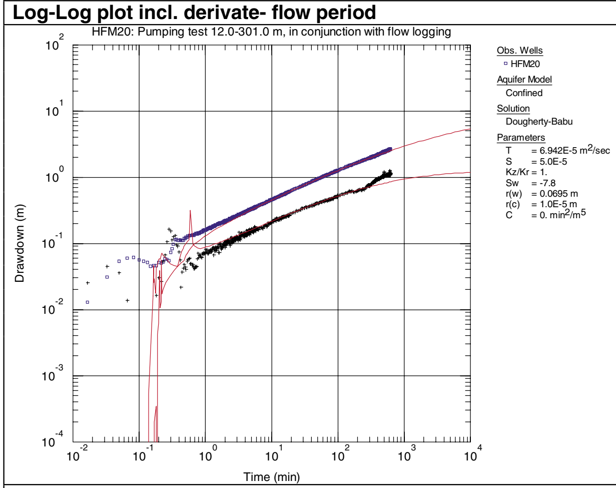
| | | | |
|---|---|---|---|
| Project: | PLU | Test type: | 1B |
| Area: | Forsmark | Test no: | 1 |
| Borehole ID: | HFM20 | Test start: | |
| Test section (m): | 12.0-301.0 | Responsible for test performance: | Geosigma AB<br>C. Hjerne |
| Section diameter, $2 \cdot r_w$ (m): | top 0.139<br>bottom 0.135 | Responsible for test evaluation: | Geosigma AB<br>J-E Ludvigson |

**Linear plot Q and p**

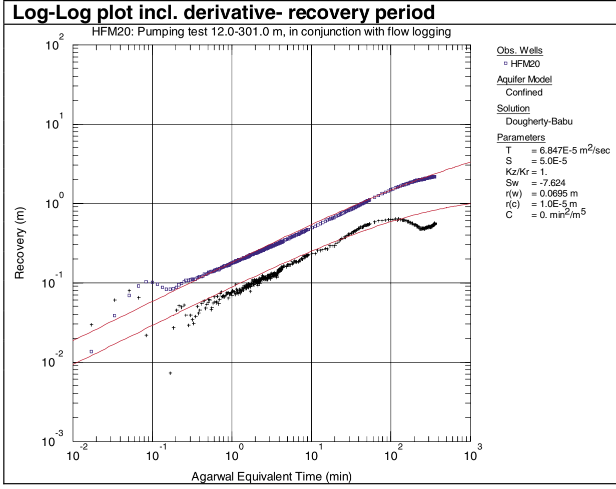



| **Flow period** | | **Recovery period** | |
|---|---|---|---|
| **Indata** | | **Indata** | |
| $p_0$ (kPa) | 123.18 | | |
| $p_i$ (kPa ) | 123.18 | | |
| $p_p$(kPa) | 97.19 | $p_F$ (kPa ) | 118.63 |
| $Q_p$ ($m^3$/s) | $1.10 \cdot 10^{-3}$ | | |
| tp (min) | 623 | $t_F$ (min) | 836 |
| S* | $5.00 \cdot 10^{-5}$ | S* | $5.00 \cdot 10^{-5}$ |
| $EC_w$ (mS/m) | | | |
| $Te_w$(gr C) | | | |
| Derivative fact. | | Derivative fact. | |
| | | | |
| **Results** | | **Results** | |
| Q/s ($m^2$/s) | $4.2 \cdot 10^{-3}$ | | |
| $T_{Moye}$($m^2$/s) | $4.15 \cdot 10^{-4}$ | | |
| Flow regime: | PLF | Flow regime: | PLF |
| $t_1$ (min) | 1 | $dt_{e1}$ (min) | 0.4 |
| $t_2$ (min) | 600 | $dt_{e2}$ (min) | 100 |
| $T_w$ ($m^2$/s) | $6.94 \cdot 10^{-5}$ | $T_w$ ($m^2$/s) | $6.85 \cdot 10^{-5}$ |
| $S_w$ (-) | | $S_w$ (-) | |
| $K_{sw}$ (m/s) | | $K_{sw}$ (m/s) | |
| $S_{sw}$ (1/m) | | $S_{sw}$ (1/m) | |
| C ($m^3$/Pa) | | C ($m^3$/Pa) | |
| $C_D$ (-) | | $C_D$ (-) | |
| ξ (-) | -7.8 | ξ (-) | -7.6 |
| | | | |
| $T_{GRF}$($m^2$/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: | PLF | C ($m^3$/Pa) | PLF |
| $t_1$ (min) | 10 | $C_D$ (-) | |
| $t_2$ (min) | 600 | ξ (-) | -7.8 |
| $T_T$ ($m^2$/s) | $6.94 \cdot 10^{-5}$ | | |
| S (-) | $5.00 \cdot 10^{-5}$ | | |
| $K_s$ (m/s) | | | |
| $S_s$ (1/m) | | | |

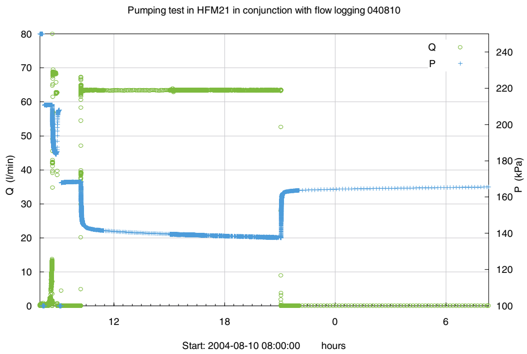
**Comments:**

A pseudo-linear flow regime is indicated from c. 1 min to the end of the flow period.
Pseudo-linear flow is also indicated during the recovery period from c. 0.4 min to 100 min. No WBS effects are seen.

## Test Summary Sheet

| | | | |
|---|---|---|---|
| Project: | PLU | Test type: | 1B |
| Area: | Forsmark | Test no: | 1 |
| Borehole ID: | HFM21 | Test start: | |
| Test section (m): | 12.0-221.0 | Responsible for test performance: | Geosigma AB<br>C. Hjerne |
| Section diameter, $2 \cdot r_w$ (m): | top 0.139 m<br>bottom 0.137 m | Responsible for test evaluation: | Geosigma AB<br>J-E Ludvigson |

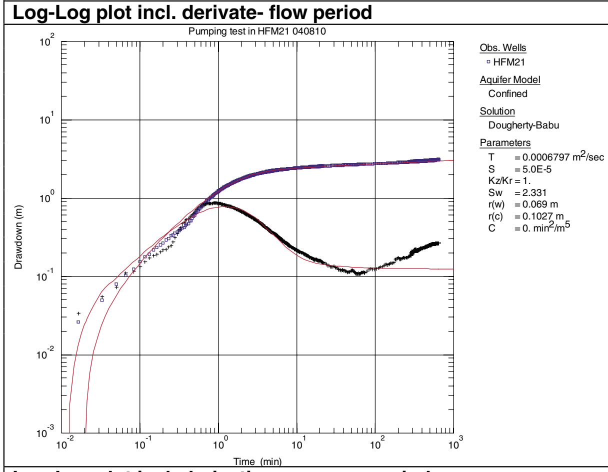
**Linear plot Q and p**



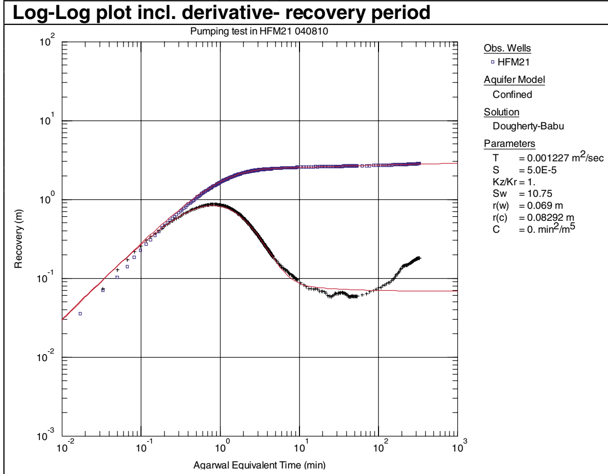

**Indata**

| Flow period | | Recovery period | |
|---|---|---|---|
| **Indata** | | | |
| $p_0$ (kPa) | 168.38 | | |
| $p_i$ (kPa ) | 168.38 | | |
| $p_p$(kPa) | 137.58 | $p_F$ (kPa ) | 165.59 |
| $Q_p$ ($m^3$/s) | $1.06 \cdot 10^{-3}$ | | |
| tp (min) | 651 | $t_F$ (min) | 675 |
| S* | $5.00 \cdot 10^{-5}$ | S* | $5.00 \cdot 10^{-5}$ |
| $EC_w$ (mS/m) | | | |
| $Te_w$(gr C) | | | |
| Derivative fact. | | Derivative fact. | |
| | | | |
| **Results** | | **Results** | |
| Q/s ($m^2$/s) | $3.4 \cdot 10^{-4}$ | | |
| $T_{Moye}$($m^2$/s) | $3.38 \cdot 10^{-4}$ | | |
| Flow regime: | PRF | Flow regime: | PRF->PSF |
| $t_1$ (min) | 10 | $dt_{e1}$ (min) | 10 |
| $t_2$ (min) | 60 | $dt_{e2}$ (min) | 60 |
| $T_w$ ($m^2$/s) | $6.8 \cdot 10^{-4}$ | $T_w$ ($m^2$/s) | $1.23 \cdot 10^{-3}$ |
| $S_w$ (-) | | $S_w$ (-) | |
| $K_{sw}$ (m/s) | | $K_{sw}$ (m/s) | |
| $S_{sw}$ (1/m) | | $S_{sw}$ (1/m) | |
| C ($m^3$/Pa) | $3.4 \cdot 10^{-6}$ | C ($m^3$/Pa) | $2.2 \cdot 10^{-6}$ |
| $C_D$ (-) | | $C_D$ (-) | |
| ξ (-) | 2.3 | ξ (-) | 10.75 |
| | | | |
| $T_{GRF}$($m^2$/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.**

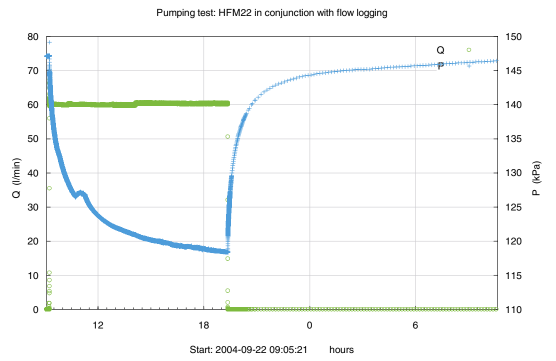
| | | | |
|---|---|---|---|
| Flow regime: | PRF | C ($m^3$/Pa) | $2.2 \cdot 10^{-6}$ |
| $t_1$ (min) | 10 | $C_D$ (-) | |
| $t_2$ (min) | 600 | ξ (-) | 2.3 |
| $T_T$ ($m^2$/s) | $6.8 \cdot 10^{-4}$ | | |
| S (-) | $5.00 \cdot 10^{-5}$ | | |
| $K_s$ (m/s) | | | |
| $S_s$ (1/m) | | | |

Comments:
A pseudo-radial flow regime is indicated during drawdown, from c. 10 min-60min. By the end of the flow period an apparent no-flow boundary is indicated.
During recovery wellbore storage initially dominates the recovery period followed by a transition to pseudo-radial or pseudo-spherical flow regime.

## Test Summary Sheet

| | | | |
|---|---|---|---|
| Project: | PLU | Test type: | 1B |
| Area: | Forsmark | Test no: | 1 |
| Borehole ID: | HFM22 | Test start: | |
| Test section (m): | 12.0-301.0 | Responsible for test performance: | Geosigma AB<br>J. Jönsson |
| Section diameter, $2 \cdot r_w$ (m): | top 0.141<br>bottom 0.136 | Responsible for test evaluation: | Geosigma AB<br>J-E Ludvigson |

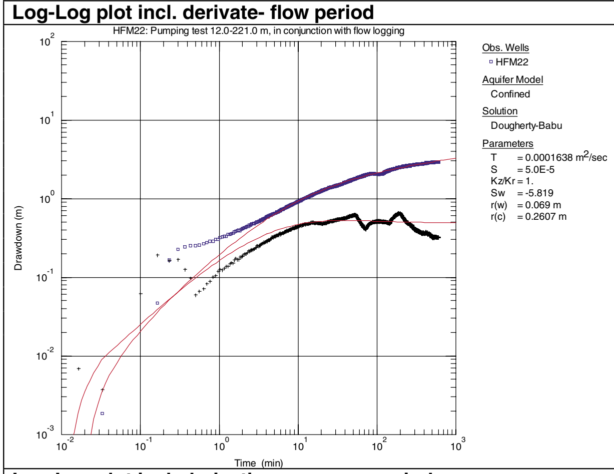
**Linear plot Q and p**



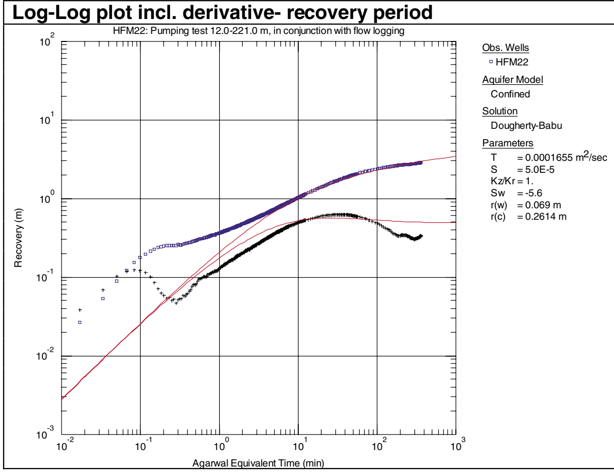

**Indata**

| Flow period | | Recovery period | |
|---|---|---|---|
| **Indata** | | | |
| $p_0$ (kPa) | 147.17 | | |
| $p_i$ (kPa ) | 147.17 | | |
| $p_p$(kPa) | 146.36 | $p_F$ (kPa ) | 118.49 |
| $Q_p$ ($m^3/s$) | $1.00 \cdot 10^{-3}$ | | |
| tp (min) | 606 | $t_F$ (min) | 917 |
| S* | $5.00 \cdot 10^{-5}$ | S* | $5.00 \cdot 10^{-5}$ |
| $EC_w$ (mS/m) | | | |
| $Te_w$(gr C) | | | |
| Derivative fact. | | Derivative fact. | |
| | | | |
| **Results** | | **Results** | |
| Q/s ($m^2/s$) | | | |
| $T_{Moye}$($m^2/s$) | $3.42 \cdot 10^{-4}$ | | |
| Flow regime: | PLF->PRF | Flow regime: | PLF->PRF |
| $t_1$ (min) | 40 | $dt_{e1}$ (min) | 40 |
| $t_2$ (min) | 300 | $dt_{e2}$ (min) | 80 |
| $T_w$ ($m^2/s$) | $1.64 \cdot 10^{-4}$ | $T_w$ ($m^2/s$) | $1.66 \cdot 10^{-4}$ |
| $S_w$ (-) | | $S_w$ (-) | |
| $K_{sw}$ (m/s) | | $K_{sw}$ (m/s) | |
| $S_{sw}$ (1/m) | | $S_{sw}$ (1/m) | |
| C ($m^3$/Pa) | | C ($m^3$/Pa) | |
| $C_D$ (-) | | $C_D$ (-) | |
| ξ (-) | -5.8 | ξ (-) | -5.6 |
| | | | |
| $T_{GRF}$($m^2/s$) | | $T_{GRF}$($m^2/s$) | |
| $S_{GRF}$(-) | | $S_{GRF}$(-) | |
| $D_{GRF}$ (-) | | $D_{GRF}$ (-) | |

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




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




**Interpreted formation and well parameters.**

| | | | |
|---|---|---|---|
| Flow regime: | PLF->PRF | C ($m^3$/Pa) | |
| $t_1$ (min) | 40 | $C_D$ (-) | |
| $t_2$ (min) | 300 | ξ (-) | -5.8 |
| $T_T$ ($m^2/s$) | $1.64 \cdot 10^{-4}$ | | |
| S (-) | | | |
| $K_s$ (m/s) | | | |
| $S_s$ (1/m) | | | |

**Comments:**

A pseudo-linear flow regime is indicated initially during the drawdown period with a transition io a pseudo-radial flow regime after c. 40 min. During the recovery period a short pseudo-radial flow regime is indicated beween c. 40-80 min transiting to pseudo.spherical flow by the end.

# 8 References


1 **Nilsson D, 2004.** Forsmark site investigation. Sampling and analyses of groundwater in percussion drilled boreholes. Results from the percussion boreholes HFM20 to HFM22. SKB P-05-48. Svensk Kärnbränslehantering AB.

2 **Almén K-E, Andersson J-E, Carlsson L, Hansson K, Larsson N-Å, 1986.** Hydraulic testing in crystalline rock. A comparative study of single-hole test methods. SKB TR 86-27, Svensk Kärnbränslehantering AB.

3 **Morosini M, Almén K-E, Follin S, Hansson K, Ludvigson J-E, Rhén I, 2001.** Metoder och utrustningar för hydrauliska enhålstester. Metod och programaspekter för geovetenskapliga platsundersökningar. Tekniskt Dokument TD-01-63, Svensk Kärnbränslehantering AB.

4 **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.

5 **Gringarten A C, Ramey H J, 1974.** Unsteady- state pressure distributions created by a well with a single horizontal fracture, partial penetration, or restricted entry. Soc. Pet. Eng. J. (Aug. 1974) pp 413–426, Trans, AIME, 257.

6 **Claesson L-Å, Nilsson G, 2004.** Forsmark site investigation. Drilling of two flushing water wells, HFM21 and HFM22, one groundwater monitoring well in solid bedrock, HFM20 and one groundwater monitoring well in soil, SFM0076. SKB P-04-245. Svensk Kärnbränslehantering AB.

## List of test data files

Files are named “bhnamn_secup_yymmdd_XX”, where yymmdd is the date of test start, secup is top of section and XX is the original file name from the HTHB data logger. If necessary, a letter is added (a, b, c, ..) after “secup” to separate identical names. XX can be one of five alternatives: Ref_Da containing constants of calibration and background data, FlowLo containing data from pumping test in combination with flow logging. Spinne contains data from spinner measurements, Inject contains data from injection test and Pumpin from pumping tests (no combined flow logging).

| Bh ID | Test section (m) | Test type[1] | Test no | Test start Date, time YYYY-MM-DD tt:mm:ss | Test stop Date, time YYYY-MM-DD tt:mm:ss | Datafile, start Date, time YYYY-MM-DD tt:mm:ss | Datafile, stop Date, time YYYY-MM-DD tt:mm:ss | Data files of raw and primary data | Content (parameters)[2] | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| HFM20 | 12.03–301.0 | 1B | 1 | 2004-08-16 22:01:40 | 2004-08-18 08:45:47 | 2004-08-16 14:39:08 | 2004-08-18 08:45:47 | HFM20_12.0_040816_ FlowLo00.DAT | P, Q, Te, EC | Ett kapacitetstest genomfördes 040816 med pumpstart kl. 16:46:18 /CaH |
| | | | | | | 2004-08-16 14:39:08 | 2004-08-18 08:45:47 | HFM20_12.0_040816_Ref_ Da00.DAT | | |
| | 20.0–195.0 | 6 | | 2004-08-17 15:03:43 | 2004-08-17 18:48:17 | 2004-08-17 15:03:43 | 2004-08-17 18:48:17 | HFM20_12.5_040817_ Spinne00.DAT | P, Q, T, EC, SP | |
| | | | | | | 2004-08-17 13:19:58 | 2004-08-17 18:49:16 | HFM20_12.5_040817_Ref_ Da00.DAT | | |
| | 121.0–301.0 | 3 | | 2004-08-18 14:36:13 | 2004-08-18 15:53:51 | 2004-08-18 14:36:13 | 2004-08-18 15:53:51 | HFM20_121.0_040818_ Inject00.DAT | P | Flöde registrerades manuellt/CaH |
| | | | | | | 2004-08-18 14:36:13 | 2004-08-18 15:53:51 | HFM20_121.0_040818_Ref_ Da00.DAT | | |
| HFM21 | 12.03–202.0 | 1B | | 2004-08-10 09:45:02 | 2004-08-11 09:31:12 | 2004-08-09 17:32:11 | 2004-08-11 09:31:12 | HFM21_12.0_040809_ FlowLo00.DAT | P, Q, T, EC | Ett kapacitetstest genomfördes 040810 med pumpstart kl. 08:39:49 /CaH |
| | | | | | | 2004-08-09 17:32:11 | 2004-08-11 09:31:12 | HFM21_12.0_040809_Ref_ Da00.DAT | | |
| | 20.0–195.0 | 6 | | 2004-08-10 15:01:48 | 2004-08-10 20:56:15 | 2004-08-10 15:43:02 | 2004-08-10 20:56:15 | HFM21_20.0_040810_ Spinne00.DAT | P, Q, T, EC, SP | |

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 2004-08-09 15:01:48 | 2004-08-11 21:03:18 | HFM21_20.0_040810_Ref_ Da00.DAT | | |
| | 14.0–20.0 | 3 | | 2004-08-11 13:20:18 | 2004-08-11 15:25:09 | 2004-08-11 13:20:18 | 2004-08-11 15:25:09 | HFM21_14.0_040811_ Inject00.DAT | P, Q | |
| | | | | | | 2004-08-11 13:20:18 | 2004-08-11 15:25:09 | HFM21_14.0_040811_Ref_ Da00.DAT | | |
| HFM22 | 12.03–221.0 | 1B | | 2004-09-22 09:05:21 | 2004-09-23 10:38:29 | 2004-09-21 11:21:20 | 2004-09-23 10:38:29 | HFM22_12.0b_040921_ FlowLo00.DAT | P, Q, T, EC | Ett kapacitetstest genomfördes 040921 med pumpstart kl. 17:00:05 /JJ |
| | | | | | | 2004-09-21 10:36:06 | 2004-09-23 10:39:36 | HFM22_12.0b_040921_Ref_ Da00.DAT | | |
| | 12.0–221.2 | 6 | | 2004-09-22 16.53:08 | 2004-09-22 18:45:08 | 2004-09-22 16:53:08 | 2004-09-23 18:45:08 | HFM22_12.0_040922_ Spinne00.DAT | P, Q, T, EC, SP | |
| | | | | | | 2004-09-22 08.15:22 | 2004-09-23 10:39:36 | HFM22_12.0_040922_Ref_ Da00.DAT | | |

1: 1A: Pumping test-wire-line equipment., 1B: Pumping test-submersible pump, 1C: Pumping test-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, Logging-EC: L-EC, Logging temperature: L-T, Logging single point resistance: L-SPR.

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

## Diagram of test responses

**Nomenclature in AQTESOLV:**

T = transmissivity ($m^2/s$)
S = storativity (–)
$K_Z/K_r$ = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)
$S_w$ = skin factor
r(w) = borehole radius (m)
r(c) = effective casing radius (m)
C = well loss constant (not used, set to 0)

### *Pumping test in HFM20:12.0–301.0 m*

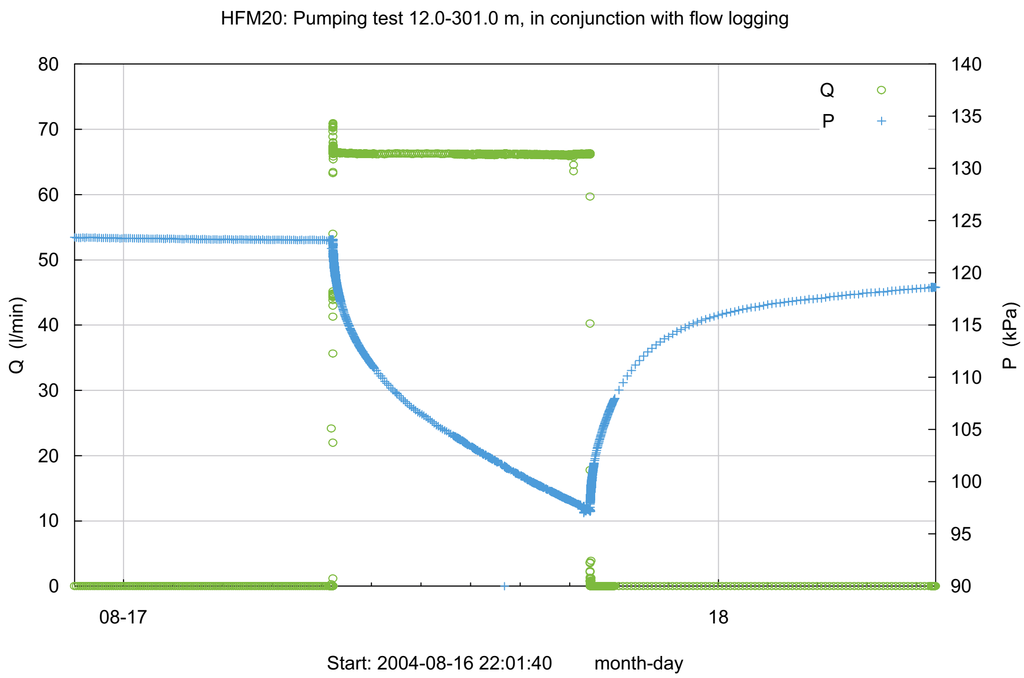



***Figure A2-1.*** *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM20 in conjunction with flow logging.*

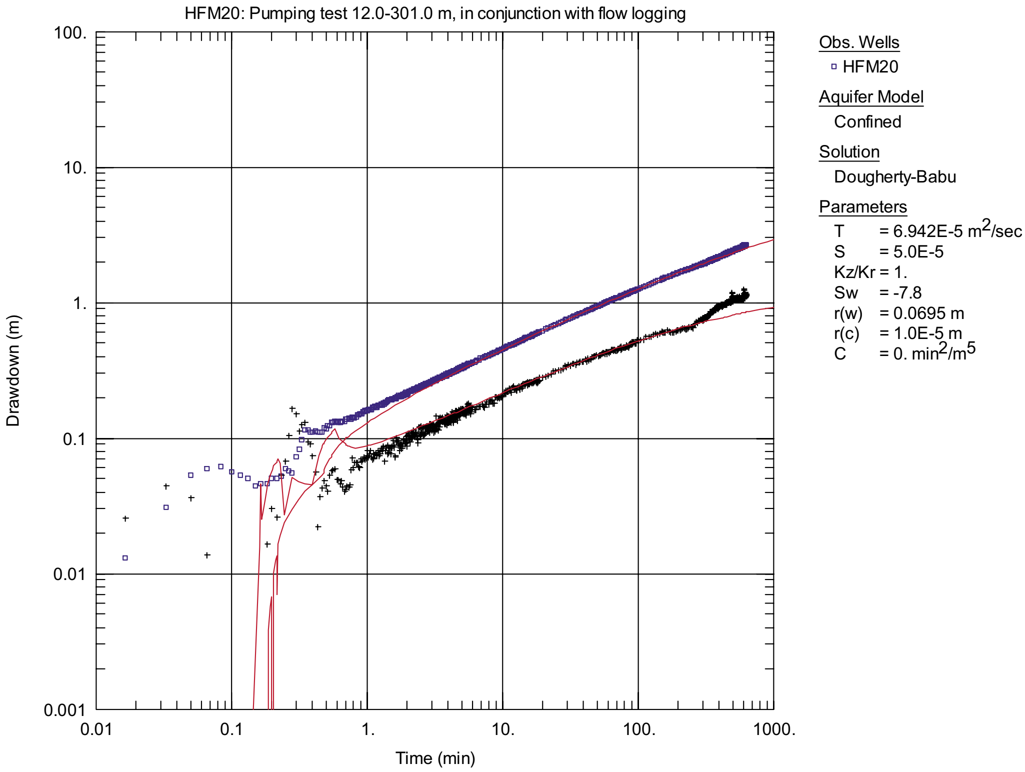



***Figure A2-2.*** *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM20.*

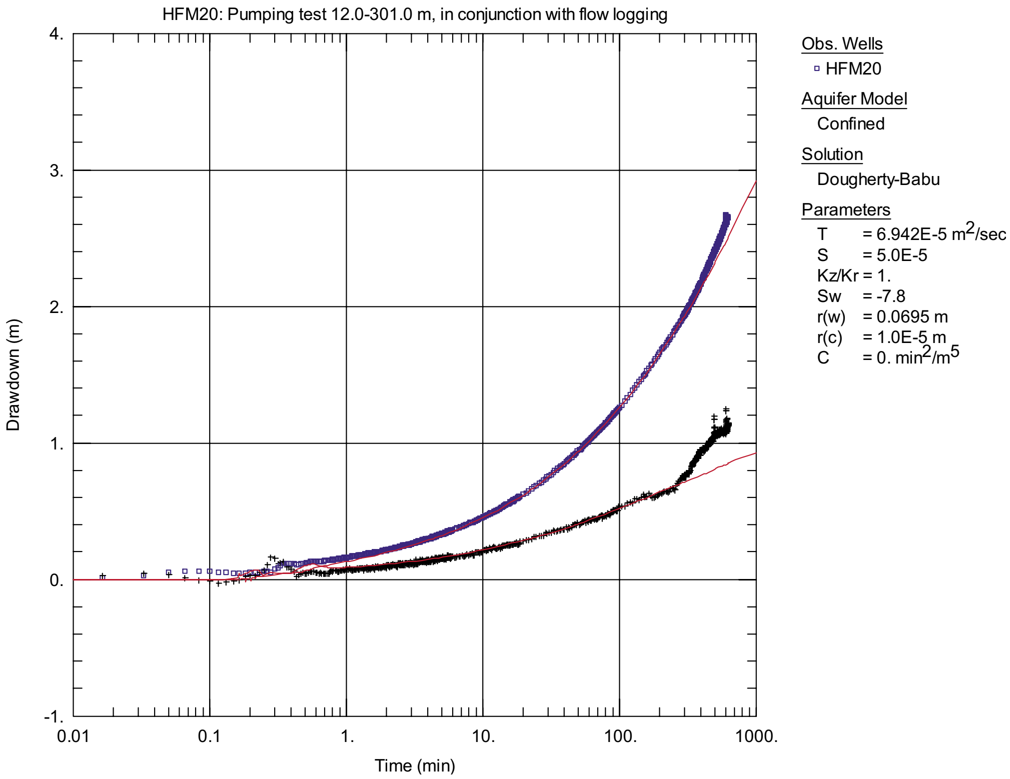



***Figure A2-3.*** *Lin-log plot of drawdown (blue □) and drawdown -derivative (black +) versus time during the open-hole pumping test in HFM20.*

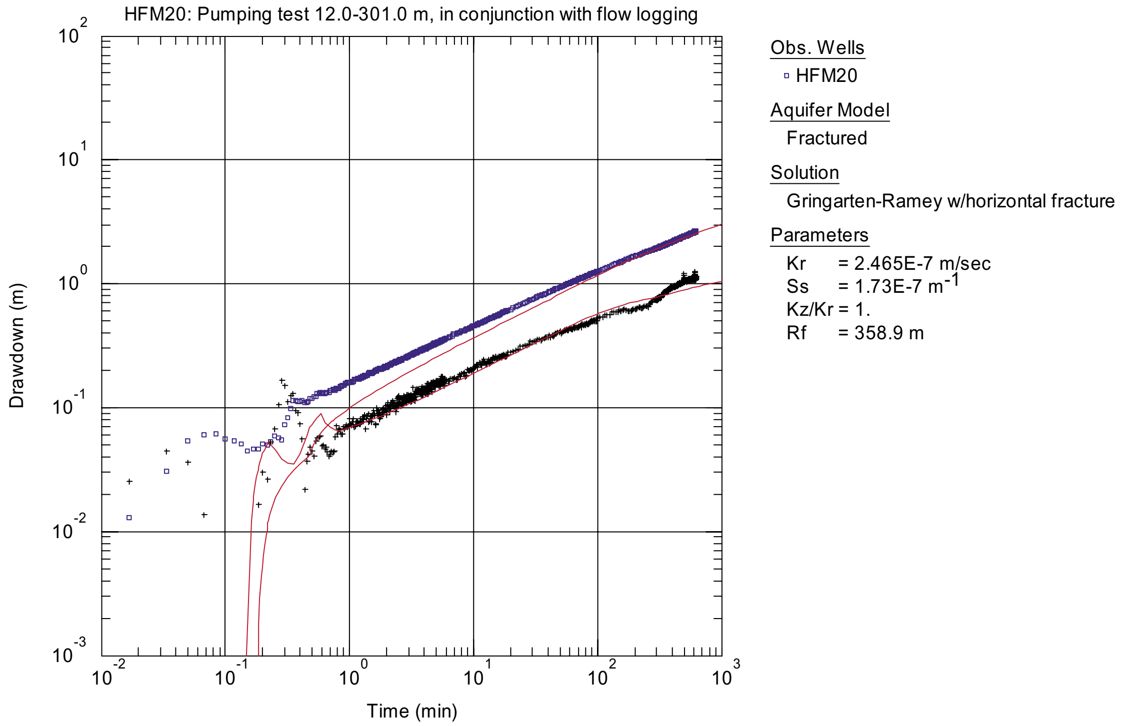



***Figure A2-4.*** *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM20. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 289 m. (Open hole interval)*

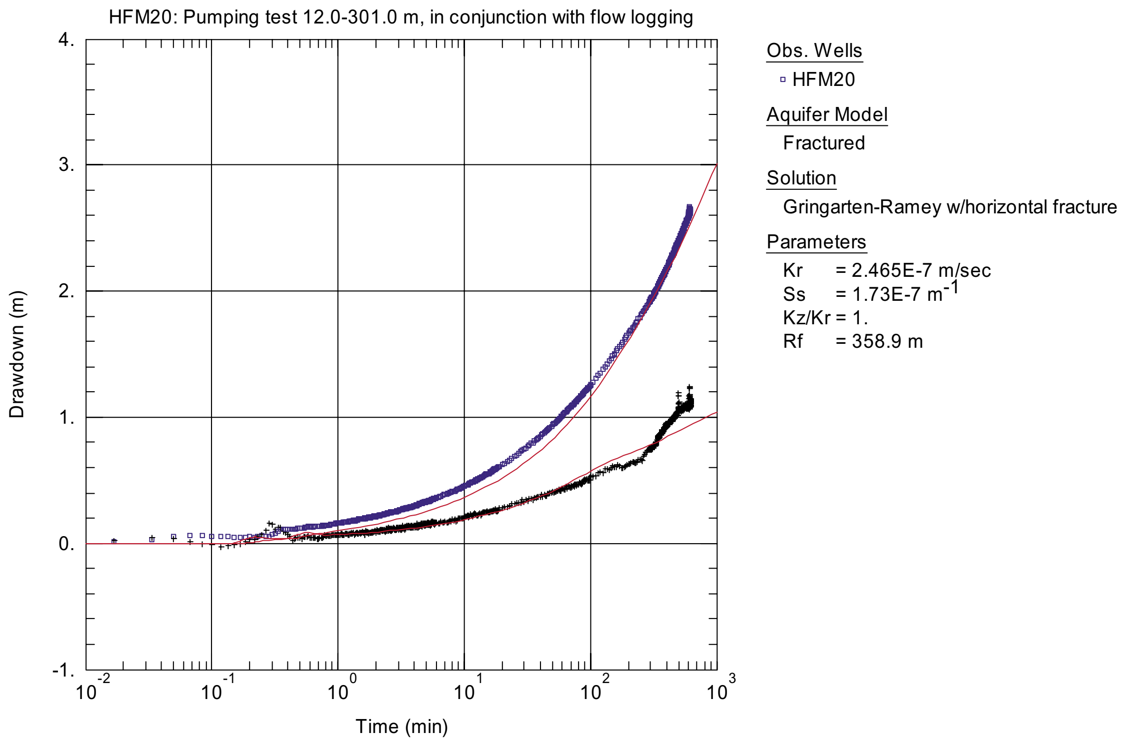



***Figure A2-5.*** *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM20. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 289 m. (Open hole interval)*

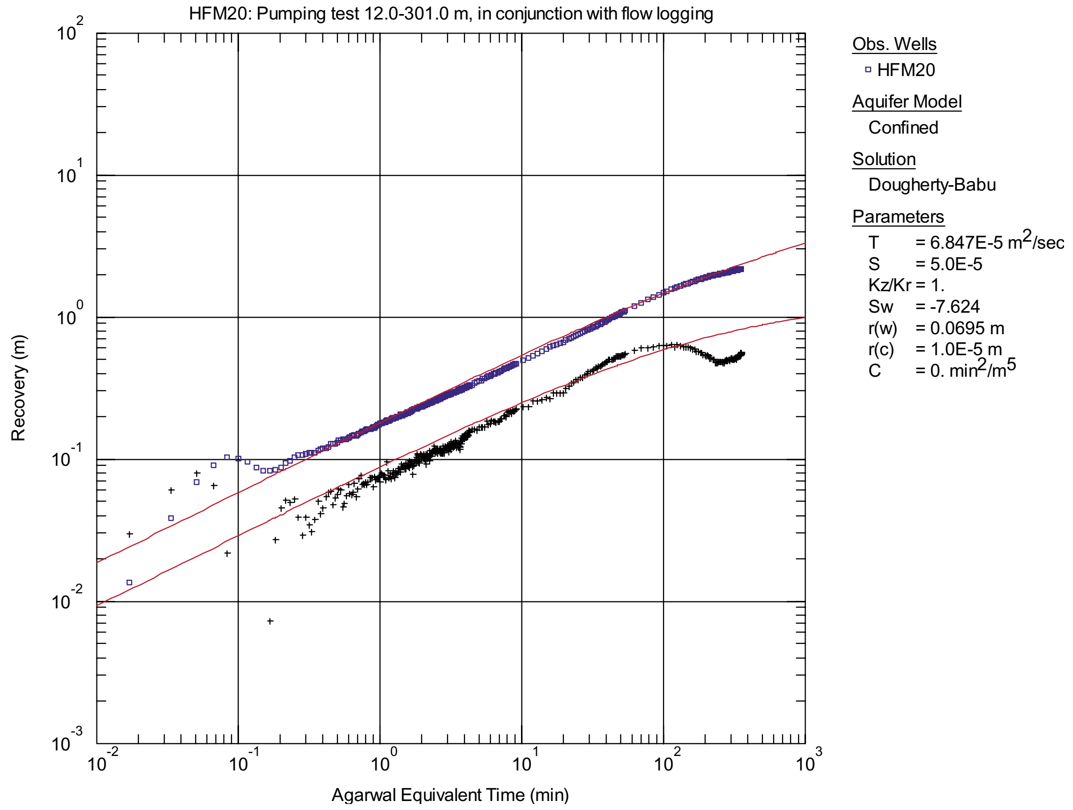



***Figure A2-6.** Log-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM20.*

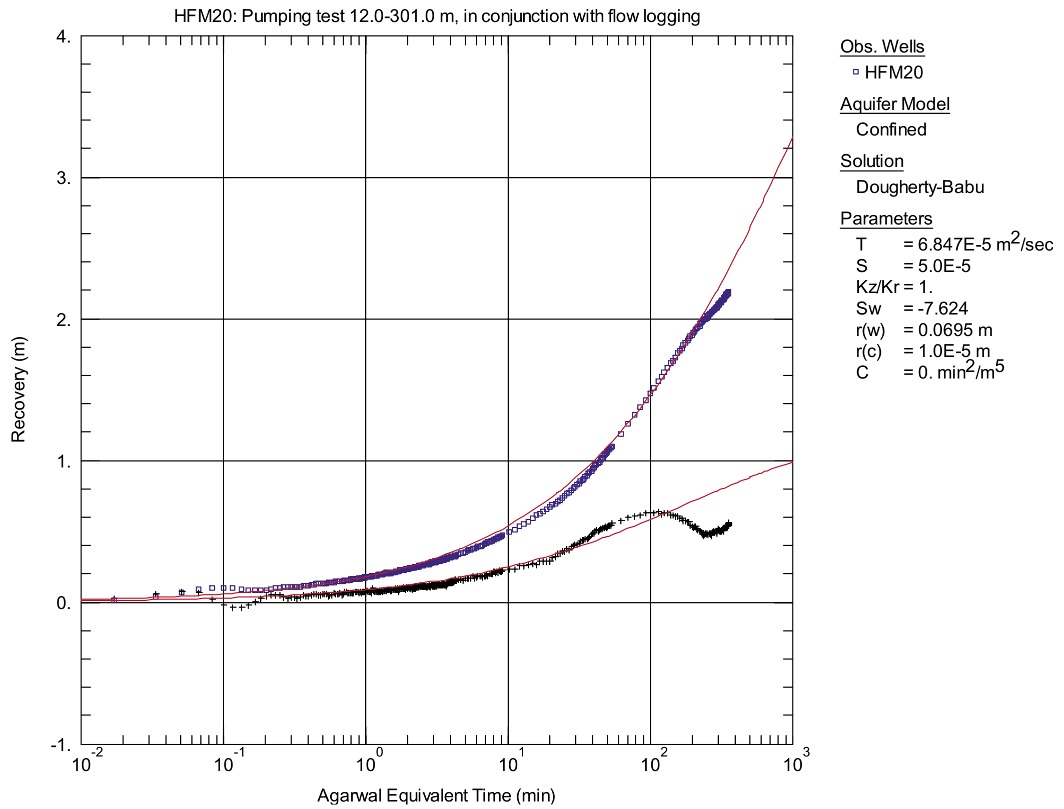



***Figure A2-7.** Lin-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM20.*

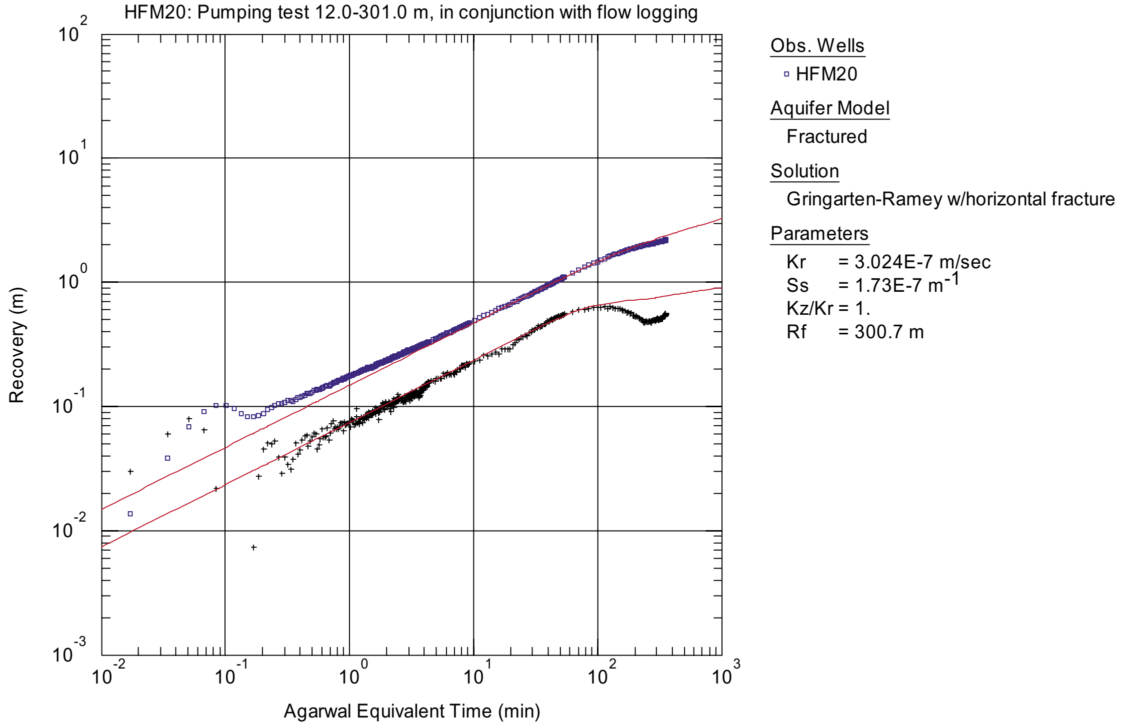



***Figure A2-8.*** *Log-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM20. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 289 m.*

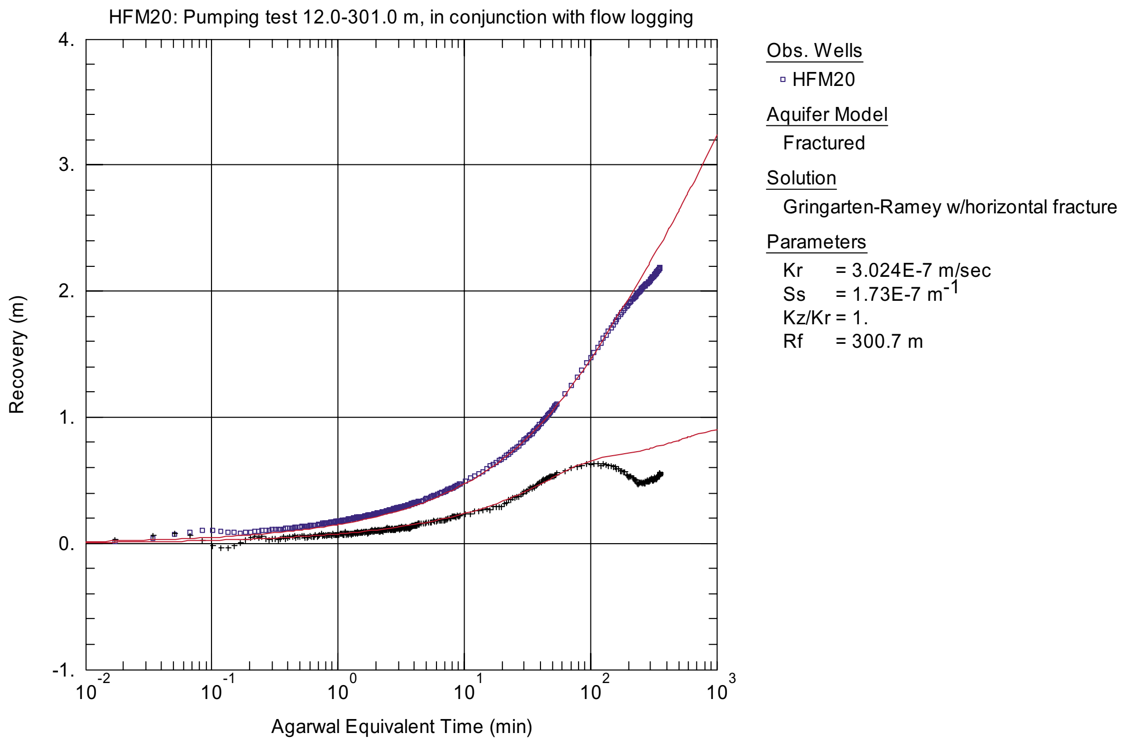



***Figure A2-9.*** *Lin-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM20. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 289 m.*

### *Pumping test in HFM21:12.0–202.0 m*

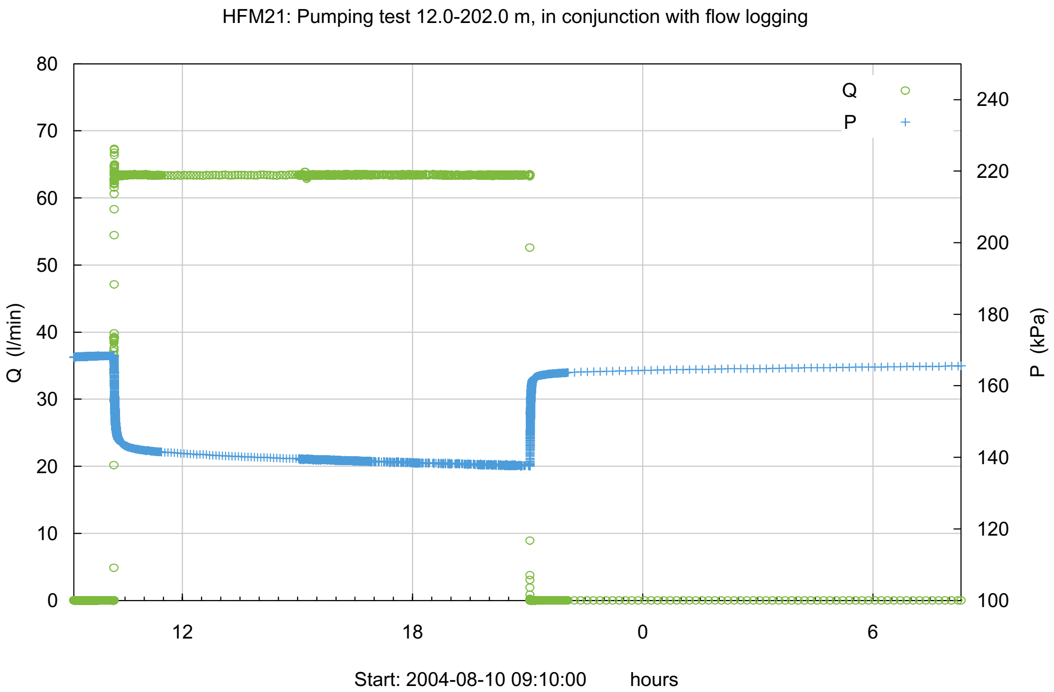



***Figure A2-10.*** *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM21 in conjunction with flow logging.*

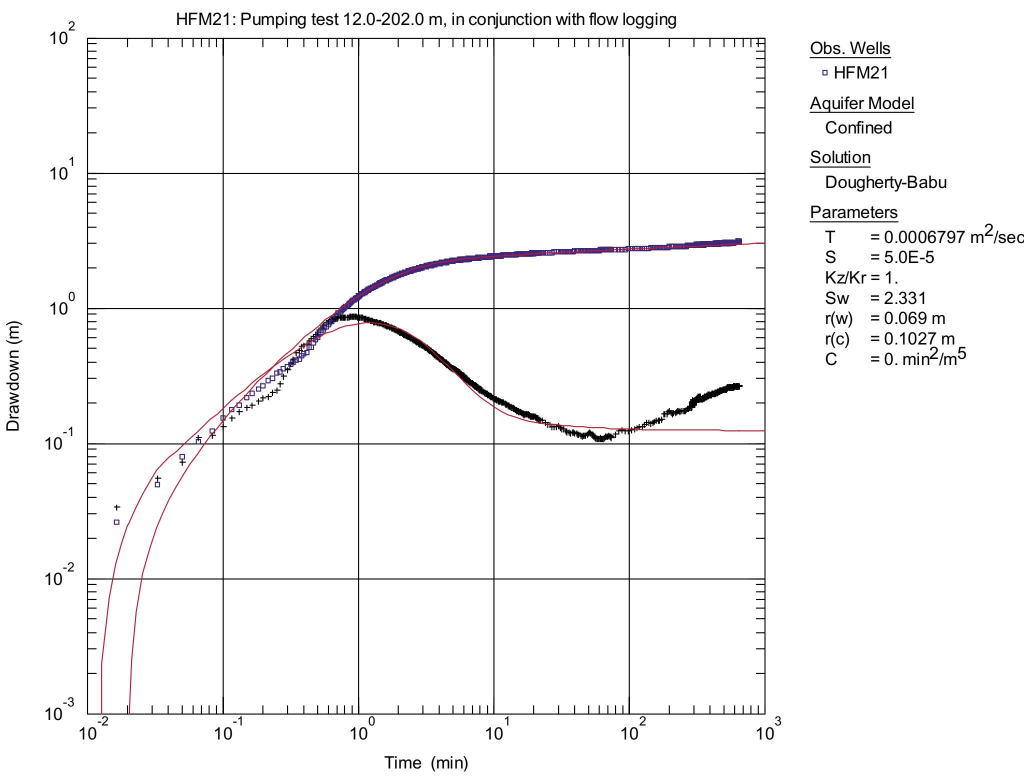



***Figure A2-11.*** *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM21.*

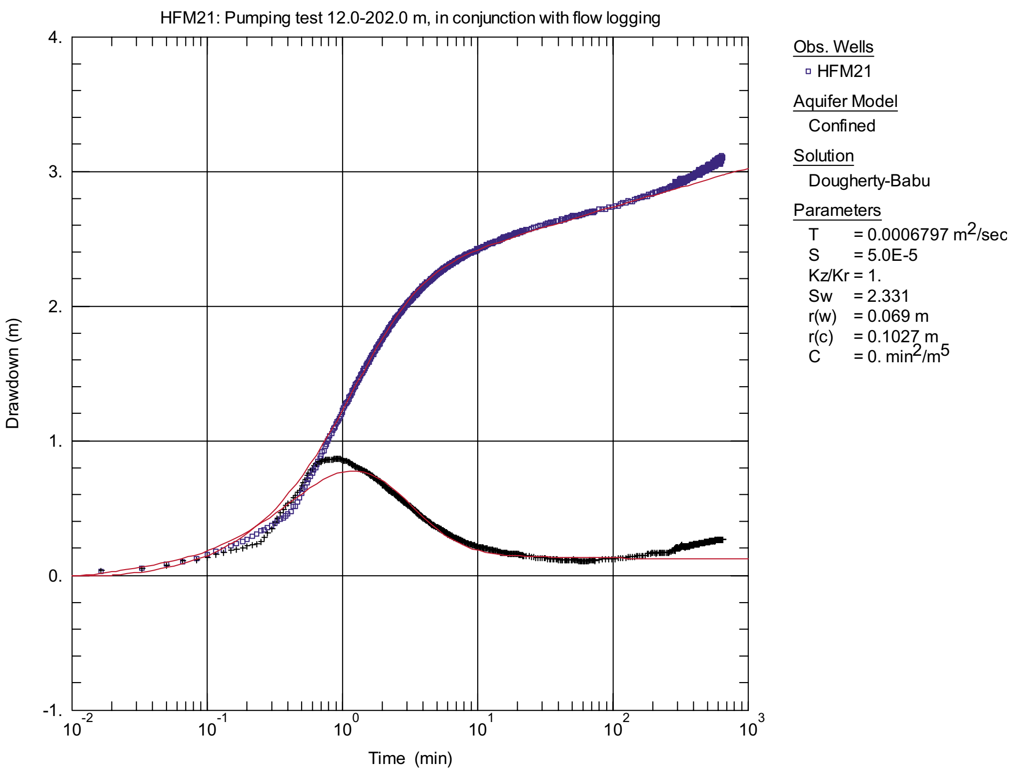



***Figure A2-12.*** *Lin-log plot of drawdown (blue □) and drawdown derivative (green +) versus time during the open-hole pumping test in HFM21.*

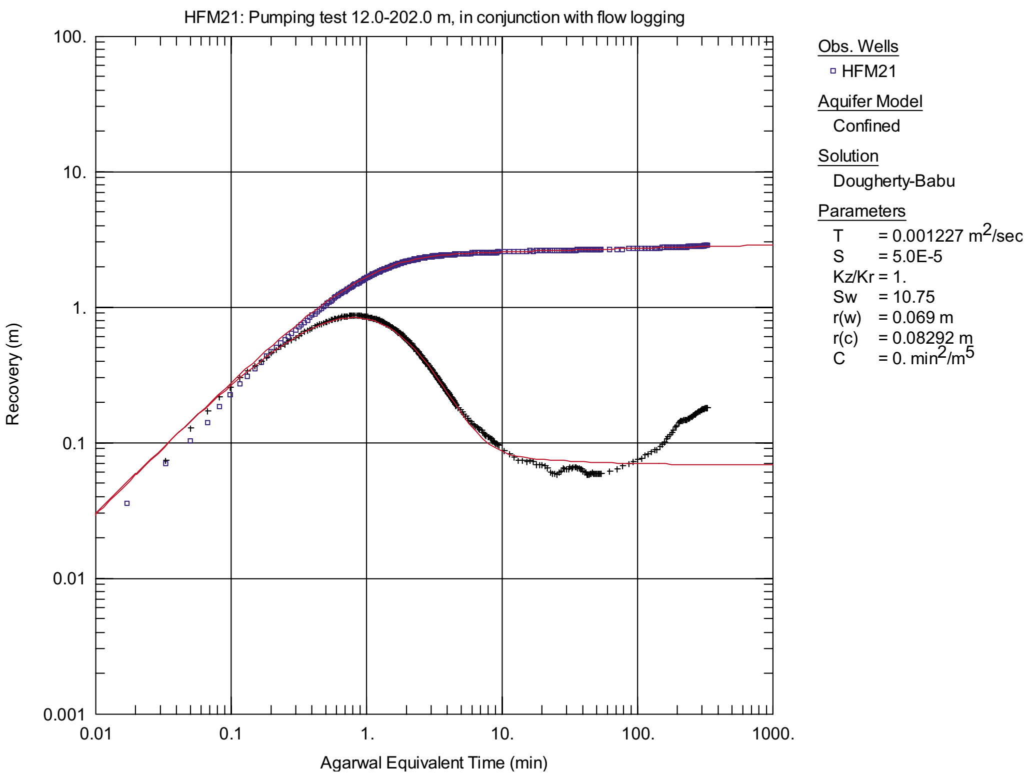



***Figure A2-13.*** *Log-log plot of pressure recovery (blue □) and - derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM21.*

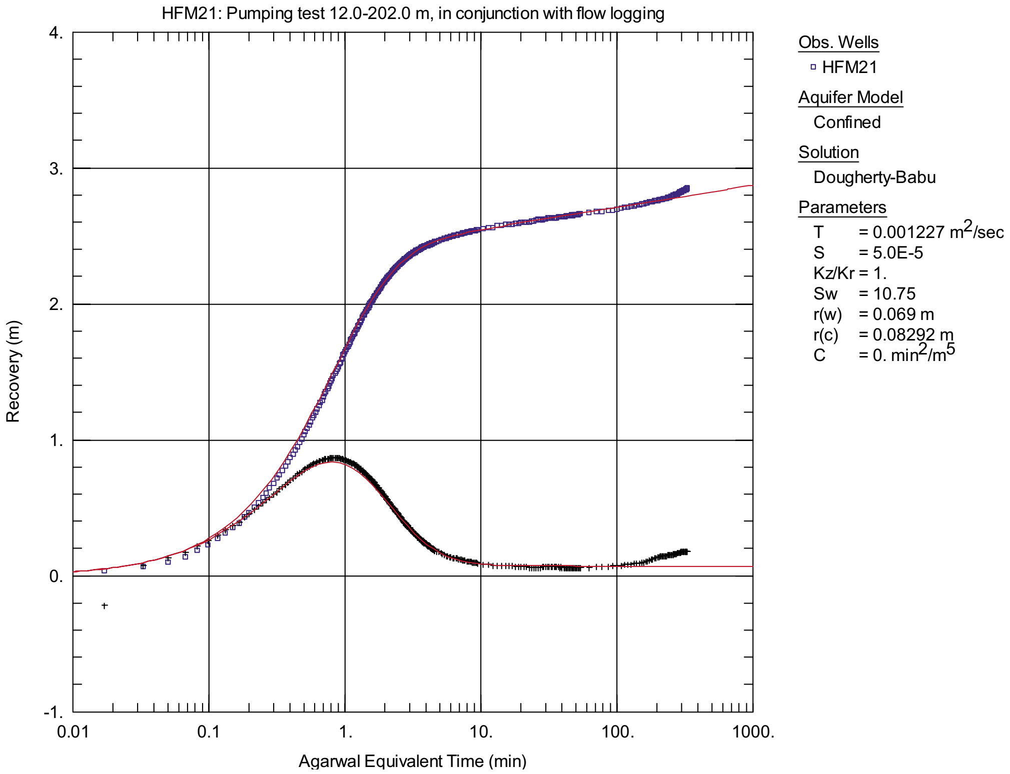



***Figure A2-14.*** *Lin-log plot of pressure recovery (blue □) and - derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM21.*

### Pumping test in HFM22: 12.0–221.0 m

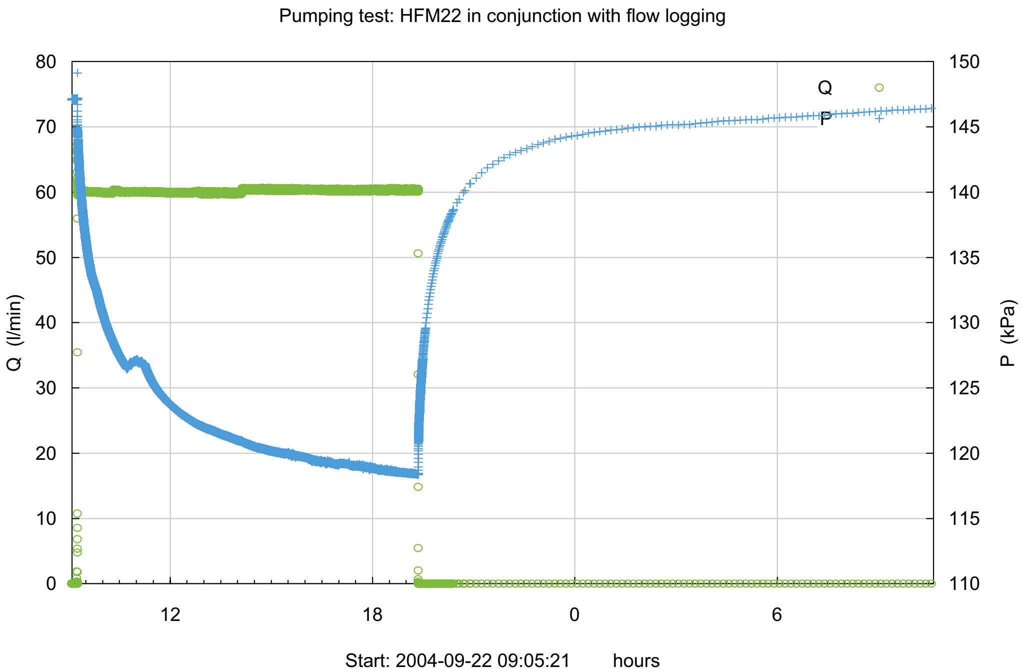



***Figure A2-15.*** *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM22 in conjunction with flow logging.*

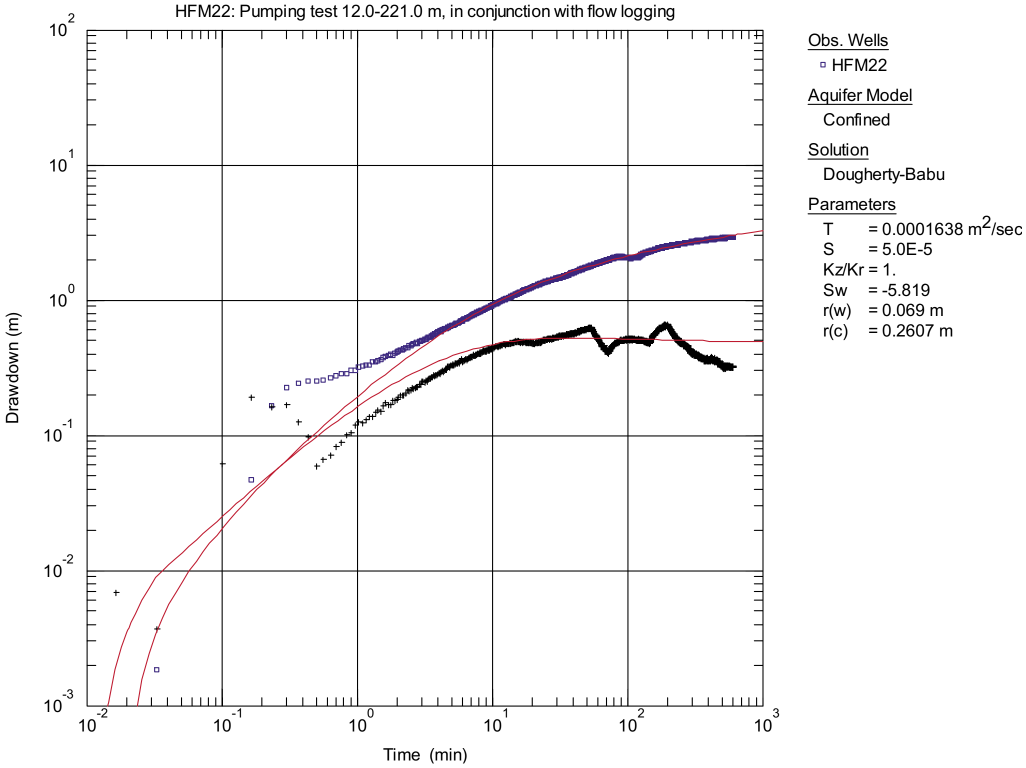



***Figure A2-16.*** *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM22.*

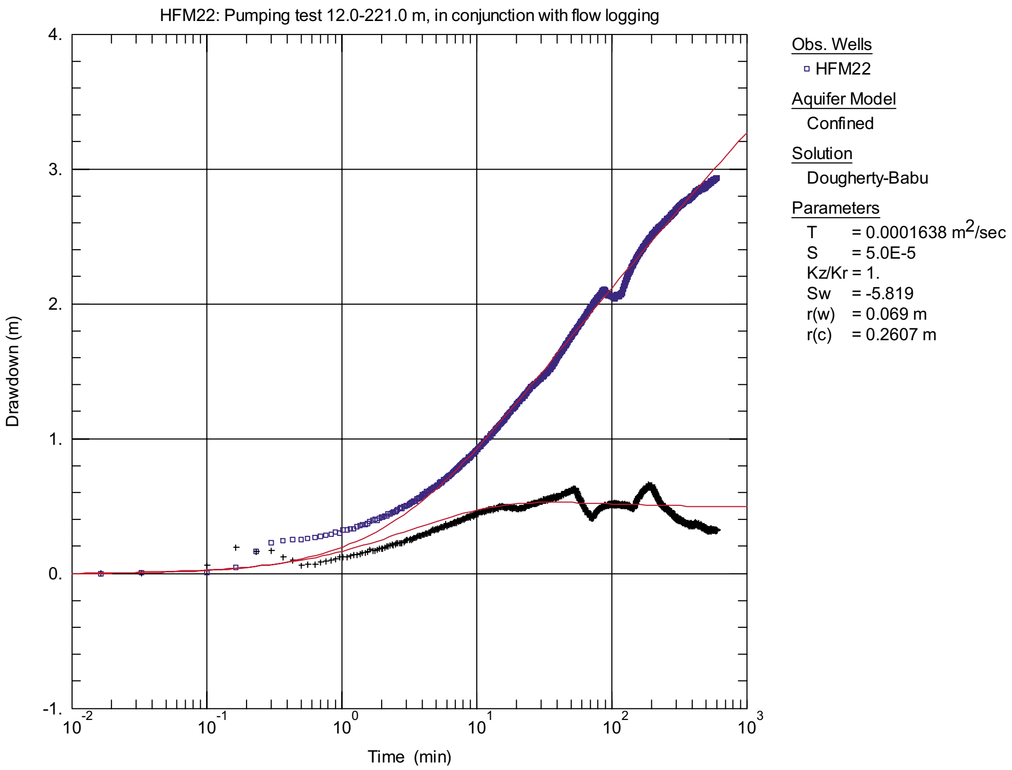



***Figure A2-17.*** *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM22.*

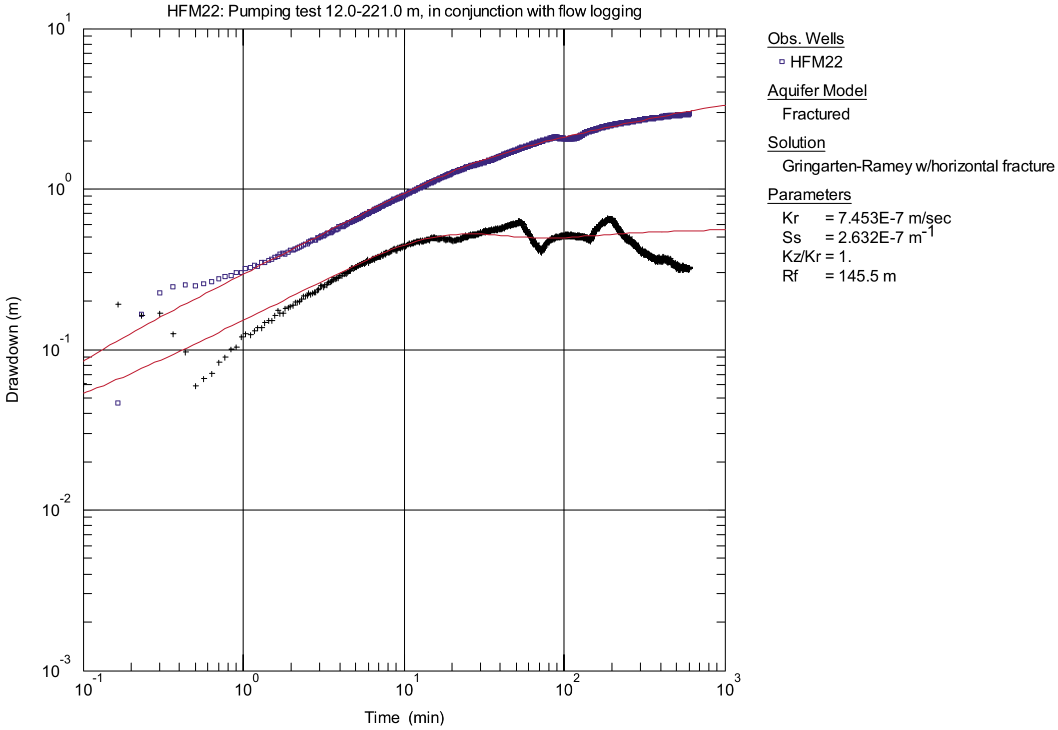



***Figure A2-18.*** *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM22. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 209 m. (Open borehole interval).*

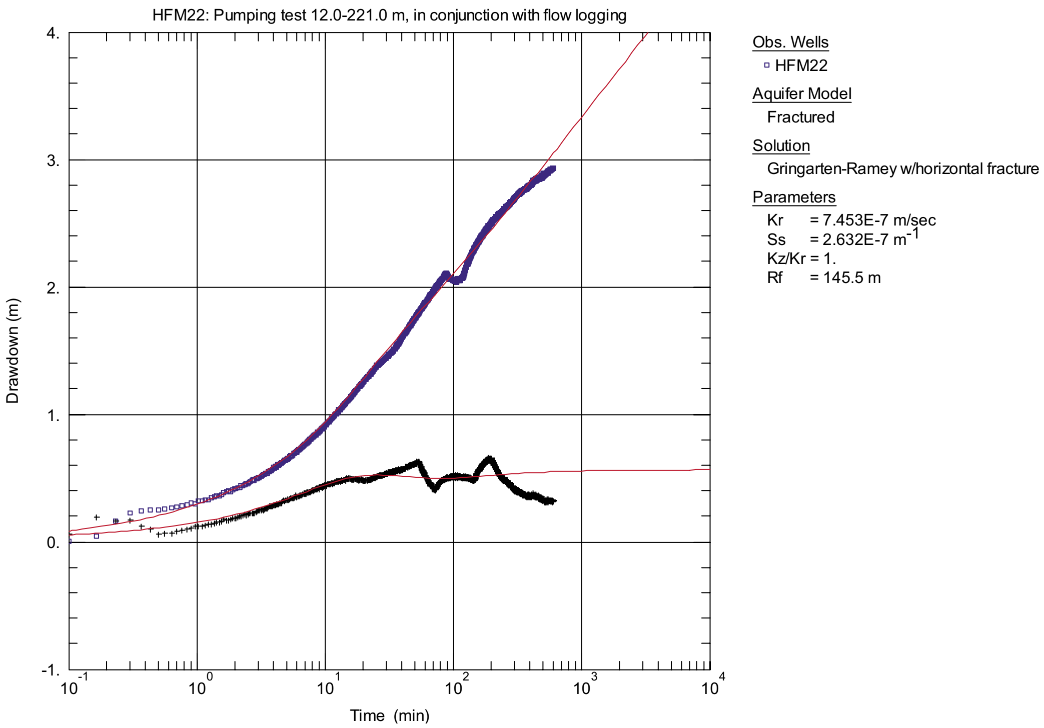



***Figure A2-19.*** *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM22. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 209 m. (Open borehole interval).*

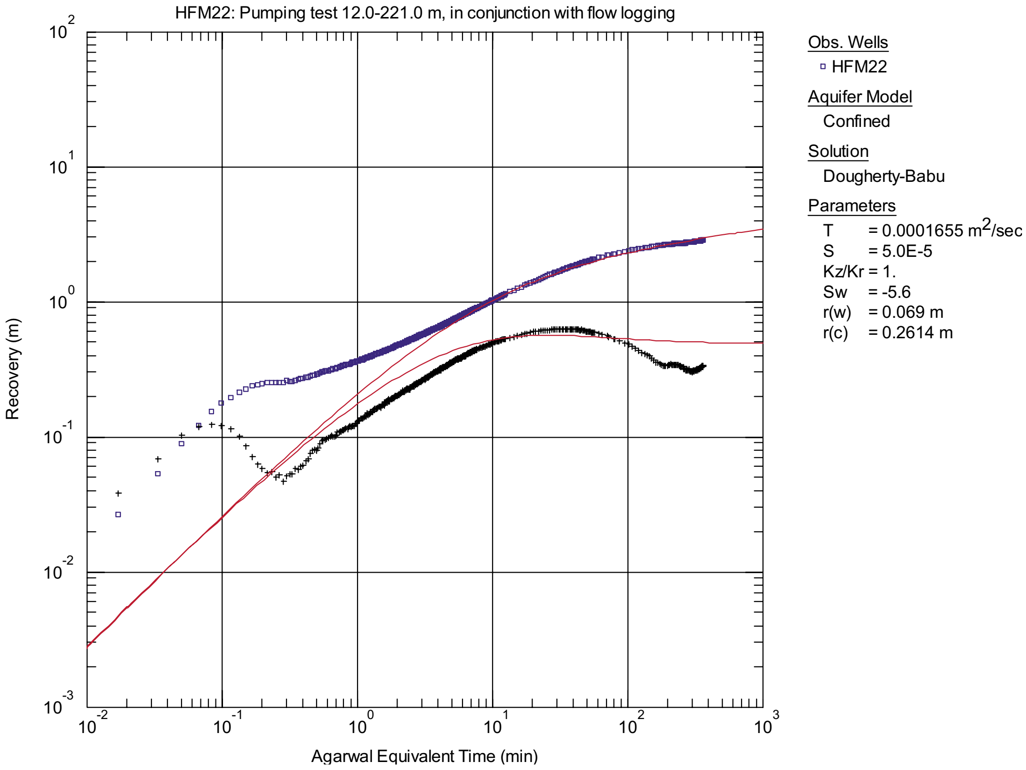



***Figure A2-20.*** *Log-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM22.*

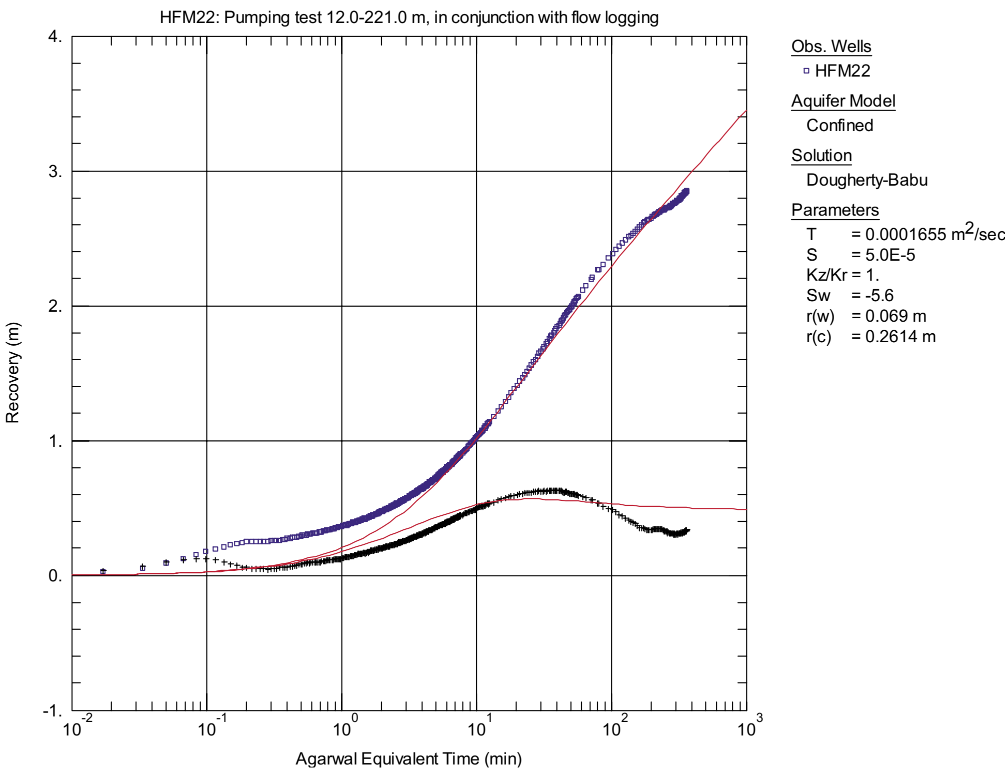



***Figure A2-21.*** *Lin-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM22.*

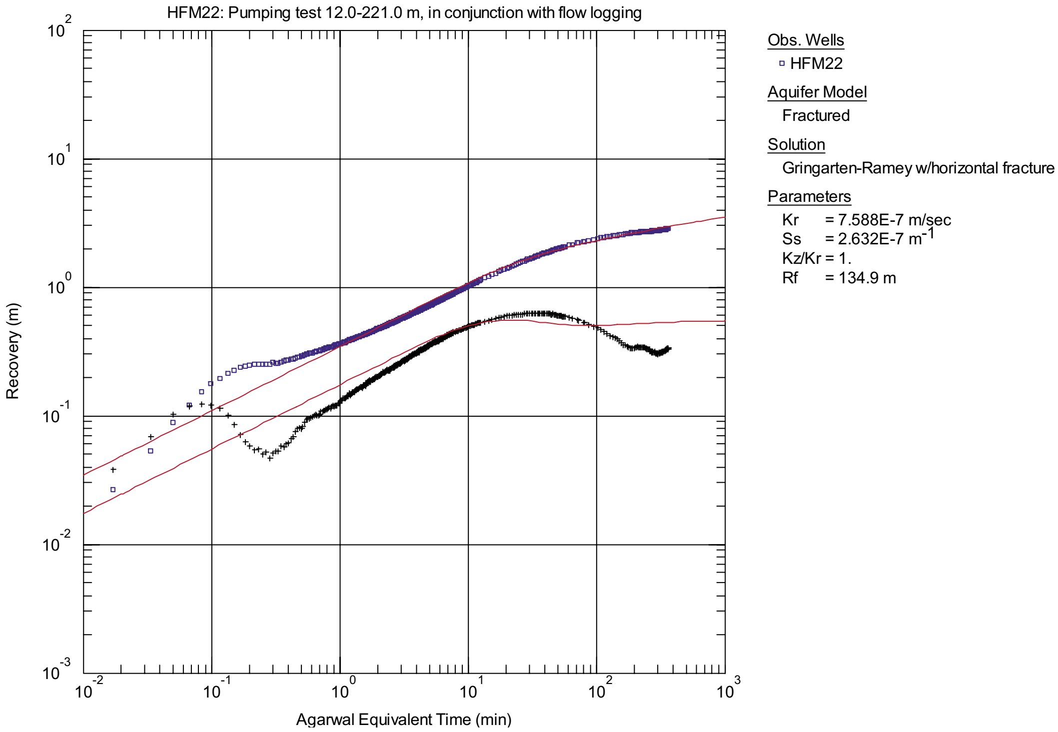



***Figure A2-22.*** *Log-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM22. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 209 m. (Open borehole interval).*

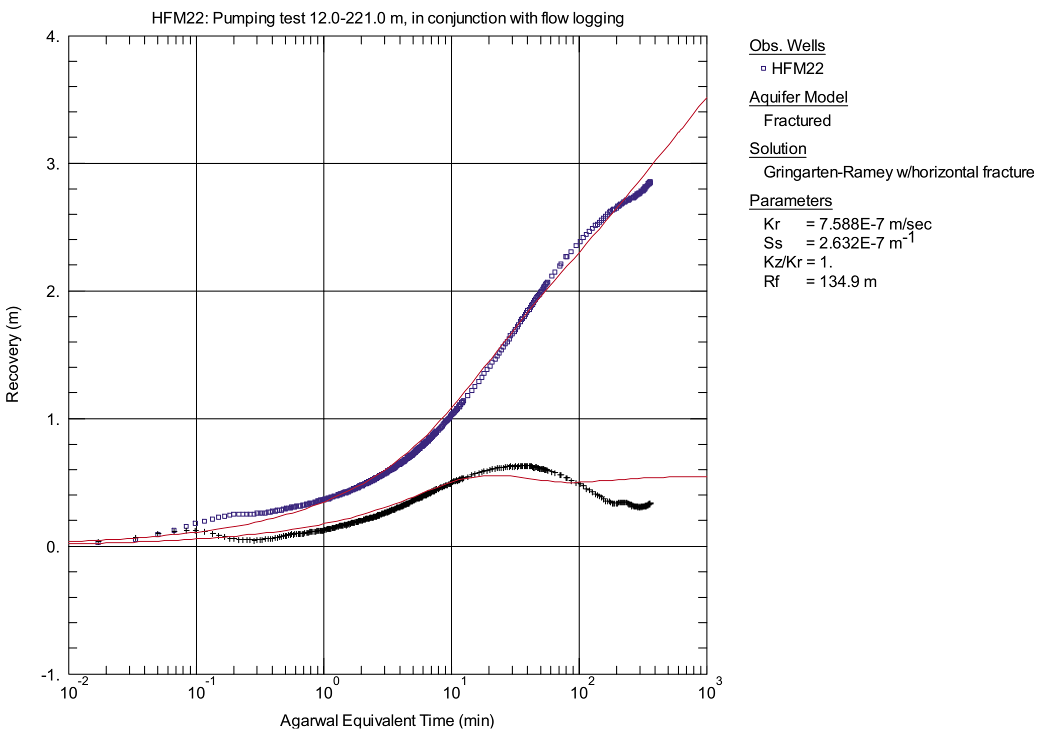



***Figure A2-23.*** *Lin-log plot of pressure recovery (blue □) and – derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM22. Displaying fit to alternative solution, Gringarten-Ramey, the values for $K_r$ and $S_s$ are under assumption of the formation thickness 209 m. (Open borehole interval).*

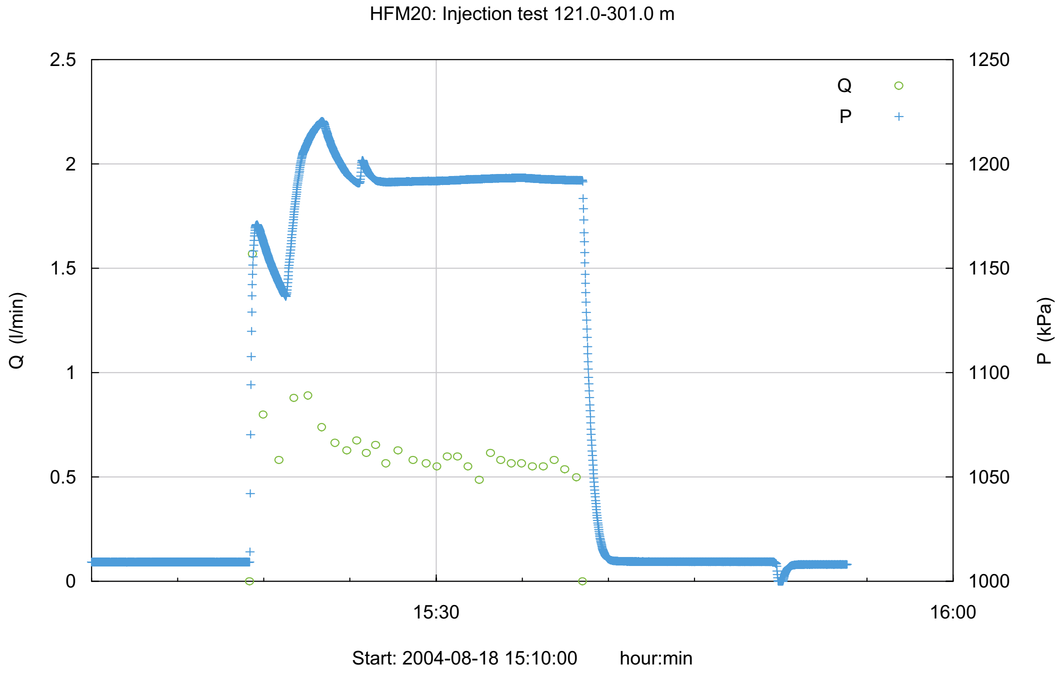



***Figure A2-24.*** *Linear plot of flow rate (Q) and pressure (p) versus time during the injection test in the interval 180.0–301.0 m in HFM20.*

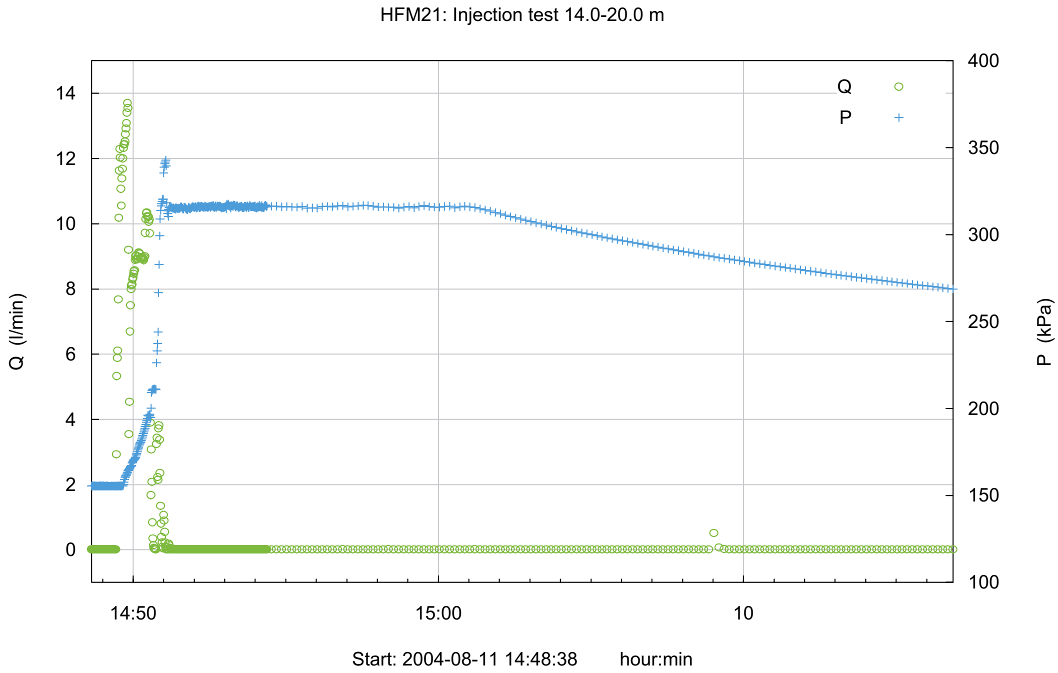



***Figure A2-25.*** *Linear plot of flow rate (Q) and pressure (p) versus time during the injection test in the interval 14.0–20.0 m in HFM21.*

# Appendix 3

## Result tables to Sicada database

### *Result Table for Single-hole tests for submission to the Sicada database*

### Singlehole tests, pumping and injection, s_hole_test_d; general information.

| idcode | start_date | stop_date | secup | seclow | section_no | test_type | formation_type | start_flow_period | stop_flow_period | flow_rate_end_qp | value_type_qp | mean_flow_rate_qm | q_measl_l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HFM20 | 20040816 22:01 | 20040818 08:45 | 12.03 | 301.00 | | 1B | 1 | 20040817 08:27 | 20040817 18:49 | 1.10E–03 | 0 | 1.10E–03 | 8.3E–05 |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 12.03 | 202.00 | | 1B | 1 | 20040810 10:12 | 20040810 21:03 | 1.03E–03 | 0 | 1.06E–03 | 8.3E–05 |
| HFM22 | 20040922 09:05 | 20040923 10:38 | 12.03 | 221.00 | | 1B | 1 | 20040922 09:15 | 20040922 19:21 | 1.00E–03 | 0 | 1.00E–03 | 8.3E–05 |

### cont.

| q_measl_u | 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 | reference | comments | lp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.7E–03 | 41.2 | 623 | 836 | 0.43 | –2.29 | –0.13 | 123.18 | 97.19 | 118.63 | | | | | | | |
| 1.7E–03 | 41.2 | 651 | 675 | 0.19 | –2.92 | –0.02 | 168.38 | 137.58 | 165.59 | | | | | | | |
| 1.7E–03 | 36.5 | 606 | 917 | 1.67 | 5.16 | –1.57 | 147.17 | 118.49 | 146.36 | | | | | | | |

### Singlehole tests, pumping and injection, s_hole_test_ed1; Basic evaluation.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HFM20 | 20040816 22:01 | 20040818 08:45 | 12.00 | 301.00 | | 1B | 1 | | | 4.15E–04 | 0 | | | |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 12.00 | 202.00 | | 1B | 1 | | | 3.28E–04 | 0 | | | |
| HFM22 | 20040922 09:05 | 20040923 10:38 | 12.00 | 221.00 | | 1B | 1 | | | 3.42E–04 | 0 | | | |

**cont.**

| transmissivity_moye | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.15E–04 | 0 | 0 | | 289.00 | | | | | | | | 6.94E–05 | 0 | 1 |
| 3.38E–04 | 0 | 0 | | 190.00 | | | | | | | | 6.80E–04 | 0 | 1 |
| 3.40E–04 | 0 | 0 | | 209.00 | | | | | | | | 1.64E–04 | 0 | 1 |

**cont.**

| l_measl_q_s | u_measl_q_s | storativity_s | assumed_s | leakage_coeff | hydr_cond_ksf | value_type_ksf | l_measl_ksf | u_measl_ksf | spec_storage_ssf | assumed_ssf | c | cd | skin | dt1 | dt2 | t1 | t2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.E–06 | 2.E–03 | | | | | | | | | | | | –7.8 | | | 60 | 36,000 |
| 2.E–06 | 2.E–03 | | | | | | | | | | 2.2E–06 | | 2.3 | | | 600 | 3,600 |
| 2.E–06 | 2.E–03 | | | | | | | | | | | | –5.8 | | | 2,400 | 18,000 |

**cont.**

| dte1 | dte2 | p_horner | transmissivity_t_nlr | storativity_s_nlr | value_type_t_nlr | bc_t_nlr | c_nlr | cd_nlr | skin_nlr | transmissivity_t_grf | value_type_t_grf | bc_t_grf | storativity_s_grf | flow_dim_grf | comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| Column | Datatype | Unit | Column Description |
|---|---|---|---|
| site | CHAR | | Investigation site name. |
| activity_type | CHAR | | Activity type code. |
| start_date | DATE | | Date (yymmdd hh:mm:ss). |
| stop_date | DATE | | Date (yymmdd hh:mm:ss). |
| project | CHAR | | Project code. |
| idcode | CHAR | | Object or borehole identification code. |
| secup | FLOAT | m | Upper section limit (m). |
| seclow | FLOAT | m | Lower section limit (m). |
| section_no | INTEGER | number | Section number. |
| test_type | CHAR | | Test type code (1–7), see table description! |
| formation_type | CHAR | | Formation type code. 1: Rock, 2: Soil (superficial deposits). |
| lp | FLOAT | m | Hydraulic point of application for test section, see descr. |
| seclen_class | FLOAT | m | Planned ordinary test interval during test campaign. |
| spec_capacity_q_s | FLOAT | m**2/s | Specific capacity (Q/s) of test section, see table descript. |
| value_type_q_s | CHAR | | 0:true value, –1:Q/s < lower meas limit, 1:Q/s > upper meas limit. |
| transmissivity_tq | FLOAT | m**2/s | Tranmissivity based on Q/s, see table description. |
| value_type_tq | CHAR | | 0:true value, –1:TQ < lower meas limit, 1:TQ > upper meas limit. |
| bc_tq | CHAR | | Best choice code. 1 means TQ is best choice of T, else 0. |
| transmissivity_moye | FLOAT | m**2/s | Transmissivity, TM, based on Moye (1967). |
| bc_tm | CHAR | | Best choice code. 1 means Tmoye is best choice of T, else 0. |
| value_type_tm | CHAR | | 0:true value, –1:TM < lower meas limit, 1:TM > upper meas limit. |
| hydr_cond_moye | FLOAT | m/s | K_M: Hydraulic conductivity based on Moye (1967). |
| formation_width_b | FLOAT | m | b:Aquifer thickness repr. for T(generally b=Lw), see descr. |
| width_of_channel_b | FLOAT | m | B:Inferred width of formation for evaluated TB. |
| tb | FLOAT | m**3/s | TB:Flow capacity in 1D formation of T and width B, see descr. |
| l_measl_tb | FLOAT | m**3/s | Estimated lower meas limit for evaluated TB, see description. |
| u_measl_tb | FLOAT | m**3/s | Estimated upper meas limit of evaluated TB, see description. |
| sb | FLOAT | m | SB:S=storativity, B=width of formation, 1D model, see descript. |
| assumed_sb | FLOAT | m | SB* : Assumed SB, S=storativity, B=width of formation, see... |
| leakage_factor_lf | FLOAT | m | Lf:1D model for evaluation of Leakage factor. |
| transmissivity_tt | FLOAT | m**2/s | TT:Transmissivity of formation, 2D radial flow model, see... |
| value_type_tt | CHAR | | 0:true value, –1:TT < lower meas limit, 1:TT > upper meas limit. |
| bc_tt | CHAR | | Best choice code. 1 means TT is best choice of T, else 0. |
| l_measl_q_s | FLOAT | m**2/s | Estimated lower meas. limit for evaluated TT, see table descr |
| u_measl_q_s | FLOAT | m**2/s | Estimated upper meas. limit for evaluated TT, see description. |
| storativity_s | FLOAT | | S:Storativity of formation based on 2D rad flow, see descr. |
| assumed_s | FLOAT | | Assumed Storativity, 2D model evaluation, see table descr. |
| leakage_coeff | FLOAT | 1/s | K'/b':2D rad flow model evaluation of leakage coeff, see desc. |
| hydr_cond_ksf | FLOAT | m/s | Ksf:3D model evaluation of hydraulic conductivity, see desc. |
| value_type_ksf | CHAR | | 0:true value, –1:Ksf < lower meas limit, 1:Ksf > upper meas limit. |
| l_measl_ksf | FLOAT | m/s | Estimated lower meas.limit for evaluated Ksf, see table desc. |
| u_measl_ksf | FLOAT | m/s | Estimated upper meas.limit for evaluated Ksf, see table descr. |
| spec_storage_ssf | FLOAT | 1/m | Ssf:Specific storage, 3D model evaluation, see table descr. |
| assumed_ssf | FLOAT | 1/m | Ssf*:Assumed Spec.storage, 3D model evaluation, see table des. |
| c | FLOAT | m**3/pa | C: Wellbore storage coefficient; flow or recovery period. |

| Column | Datatype | Unit | Column Description |
|---|---|---|---|
| cd | FLOAT | | CD: Dimensionless wellbore storage coefficient. |
| skin | FLOAT | | Skin factor;best estimate of flow/recovery period, see descr. |
| dt1 | FLOAT | s | Estimated start time of evaluation, see table description. |
| dt2 | FLOAT | s | Estimated stop time of evaluation. see table description. |
| t1 | FLOAT | s | Start time for evaluated parameter from start flow period. |
| t2 | FLOAT | s | Stop time for evaluated parameter from start of flow period. |
| dte1 | FLOAT | s | Start time for evaluated parameter from start of recovery. |
| dte2 | FLOAT | s | Stop time for evaluated parameter from start of recovery. |
| p_horner | FLOAT | kPa | p*:Horner extrapolated pressure, see table description. |
| transmissivity_t_nlr | FLOAT | m**2/s | T_NLR Transmissivity based on None Linear Regression... |
| storativity_s_nlr | FLOAT | | S_NLR=storativity based on None Linear Regression, see.. |
| value_type_t_nlr | CHAR | | 0:true value, –1:T_NLR < lower meas limit, 1: > upper meas limit |
| bc_t_nlr | CHAR | | Best choice code. 1 means T_NLR is best choice of T, else 0. |
| c_nlr | FLOAT | m**3/pa | Wellbore storage coefficient, based on NLR, see descr. |
| cd_nlr | FLOAT | | Dimensionless wellbore storage constant, see table descrip. |
| skin_nlr | FLOAT | | Skin factor based on Non Linear Regression, see desc. |
| transmissivity_t_grf | FLOAT | m**2/s | T_GRF:Transmissivity based on Genelized Radial Flow, see... |
| value_type_t_grf | CHAR | | 0:true value, –1:T_GRF < lower meas limit, 1: > upper meas limit. |
| bc_t_grf | CHAR | | Best choice code. 1 means T_GRF is best choice of T, else 0. |
| storativity_s_grf | FLOAT | | S_GRF:Storativity based on Generalized Radial Flow, see des. |
| flow_dim_grf | FLOAT | | Inferred flow dimesion based on Generalized Rad. Flow model. |
| comment | VARCHAR | no_unit | Short comment to the evaluated parameters. |
| error_flag | CHAR | | If error_flag = ”*” then an error occured and an error. |
| in_use | CHAR | | If in_use = ”*” then the activity has been selected as. |
| sign | CHAR | | Signature for QA data accknowledge (QA – OK) |

## *Result table for flow logging at the Forsmark site investigation for submission to the Sicada database*

### Plu_impeller_basic_d

| idcode | start_date | stop_date | secup | seclow | section_no | start_flowlogging | stop_flowlogging | l | test_type |
|---|---|---|---|---|---|---|---|---|---|
| HFM20 | 20040816 22:01 | 20040818 08:45 | 12.5 | 295 | | 20040817 13.22 | 20040817 18:48 | | 6 |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 20 | 195 | | 20040810 15:00 | 20040810 20.56 | | 6 |
| HFM22 | 20040922 09:05 | 20040923 10:38 | 12.1 | 211.2 | | 20040922 15.23 | 20040922 18:45 | | 6 |

### cont.

| forma-tion_type | q_measl_l | q_measl_u | pump_flow_q1 | pump_flow_q2 | dur_flow_phase_tp1 | dur_flow_phase_tp2 | dur_flow-log_tfl_1 | dur_flow-log_tfl_2 | draw-down_s1 | draw-down_s2 | initial_head_ho | hydraulic_head_h1 | hydraulic_head_h2 | reference | comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.00E–05 | 1.67E–03 | 1.10E–03 | | 37,380 | | 19,560 | | –1.98 | | 0.43 | –2.29 | | | |
| 1 | 5.00E–05 | 1.67E–03 | 1.06E–03 | | 39,060 | | 21,360 | | –2.84 | | 0.19 | –2.92 | | | |
| 1 | 5.00E–05 | 1.67E–03 | 1.00E–03 | | 36,360 | | 12,120 | | 3.49 | | 1.67 | 5.16 | | | |

| Column | Datatype | Unit | Column Description |
|---|---|---|---|
| site | CHAR | | Investigation site name. |
| start_date | DATE | | Date (yymmdd hh:mm:ss). |
| stop_date | DATE | | Date (yymmdd hh:mm:ss). |
| start_flowlogging | DATE | yyyymmdd | Date and time of flowlogging start (YYYY-MM-DD hh:mm:ss). |
| stop_flowlogging | DATE | yyyymmdd | Date and time of flowlogging stop (YYYY-MM-DD hh:mm:ss). |
| l | FLOAT | m | Corrected borehole length during logging, see table descr. |
| test_type | CHAR | | Type of test, (1–7); see table description. |
| formation_type | CHAR | | 1: Rock, 2: Soil (supeficial deposits). |
| q_measl_l | FLOAT | m**3/s | Estimated lower measurement limit of borehole flow, see des. |
| q_measl_u | FLOAT | m**3/s | Estimated upper measurement limit of borehole flow, see desc. |
| pump_flow_q1 | FLOAT | m**3/s | Flow rate at surface during flow logging period 1. |
| pump_flow_q2 | FLOAT | m**3/s | Flow rate at surface during flow logging period 2. |
| dur_flow_phase_tp1 | FLOAT | s | Duration of flow period 1. |
| dur_flow_phase_tp2 | FLOAT | s | Duration of flow period 2. |
| dur_flowlog_tfl_1 | FLOAT | s | Duration of the flowlogging survey 1. |
| dur_flowlog_tfl_2 | FLOAT | s | Duration of the flowlogging survey 2 |
| drawdown_s1 | FLOAT | m | Representative drawdown in borehole during flowlog period 1. |
| drawdown_s2 | FLOAT | m | Representative drawdown in borehole during flowlog period 2. |
| initial_head_ho | FLOAT | m.a.s.l. | Initial hydraulic head (open borehole), see table description. |
| hydraulic_head_h1 | FLOAT | m.a.s.l. | Represen. hydr.head during flow period 1, see table descr. |
| hydraulic_head_h2 | FLOAT | m.a.s.l. | Represen. hydr.head during flow period 2, see table descr. |
| reference | CHAR | | SKB report number for reports describing data and evaluation. |
| comments | VARCHAR | | Short comment to the evaluated parameters (optional). |

**Plu_impell_mail_res**

| idcode | start_date | stop_date | secup | seclow | section_ no | l | cum_ flow_q0 | cum_ flow_q1 | cum_ flow_q2 | cum_ flow_q1t | cum_ flow_q2t | corr_cum_ flow_q1c | corr_cum_ flow_q2c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HFM20 | 20040816 22:01 | 20040818 08:45 | 12.5 | 295 | | | | | | 9.55E–04 | | | |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 20 | 195 | | | | | | 9.55E–04 | | | |
| HFM22 | 20040922 09:05 | 20040923 10:38 | 12.1 | 211.2 | | | | | | 8.11E–04 | | | |

**cont.**

| corr_cum_ flow_q1tc | corr_cum_ flow_q2tc | corr_com_ flow_q1tcr | corr_com_ flow_q2tcr | transmissi- tivy_hole_t | value_ type_t | bc_t | cum_trans- missivity_tf | value_ type_tf | bc_tf | l_measl_tf | cum_trans- missivity_tft | value_ type_tft | bc_tft | u_measl_ tf | reference | comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.55E–04 | | 1.10E–03 | | 6.94E–05 | 0 | 1 | 6.94E–05 | 0 | 1 | 2.E–06 | 6.94E–05 | 0 | 1 | 2.E–03 | | |
| 9.55E–04 | | 1.06E–03 | | 6.80E–04 | 0 | 1 | 6.80E–04 | 0 | 1 | 2.E–06 | 6.80E–04 | 0 | 1 | 2.E–03 | | |
| 8.11E–04 | | 1.00E–03 | | 1.64E–04 | 0 | 1 | 1.64E–04 | 0 | 1 | 2.E–06 | 1.64E–04 | 0 | 1 | 2.E–03 | | |

| Column | Datatype | Unit | Column Description |
|---|---|---|---|
| site | CHAR | | Investigation site name. |
| activity_type | CHAR | | Activity type code. |
| start_date | DATE | | Date (yymmdd hh:mm:ss). |
| stop_date | DATE | | Date (yymmdd hh:mm:ss). |
| project | CHAR | | Project code. |
| idcode | CHAR | | Object or borehole identification code. |
| secup | FLOAT | m | Upper section limit (m). |
| seclow | FLOAT | m | Lower section limit (m). |
| section_no | INTEGER | number | Section number. |
| l | FLOAT | m | Corrected borehole length. |
| cum_flow_q0 | FLOAT | m**3/s | Undisturbed cumulative flow rate, see table description. |
| cum_flow_q1 | FLOAT | m**3/s | Cumulative flow rate at pumping flow Q1/head h1, see descr. |
| cum_flow_q2 | FLOAT | m**3/s | Cumulative flow rate at pumping flow Q2/head h2, see descr. |
| cum_flow_q1t | FLOAT | m**3/s | Cumulative flow at the top of measured interval, pump flow Q1 |
| cum_flow_q2t | FLOAT | m**3/s | Cumulative flow at the top of measured interval, pump flow Q2 |
| corr_cum_flow_q1c | FLOAT | m**3/s | Corrected cumulative flow q1 at pump flow Q1, see tabledescr. |
| corr_cum_flow_q2c | FLOAT | m**3/s | Corrected cumulative flow q2 at pump flow Q2, see tabledescr. |
| corr_cum_flow_q1tc | FLOAT | m**3/s | Corrected cumulative flow q1T at pump flow Q1, see... |
| corr_cum_flow_q2tc | FLOAT | m**3/s | Corrected cumulative flow q2T at pump flow Q2, see... |
| corr_com_flow_q1tcr | FLOAT | m**3/s | Corrected q1Tc for estimated borehole radius (rwa). |
| corr_com_flow_q2tcr | FLOAT | m**3/s | Corrected q2Tc for estimated borehole radius (rwa). |
| transmissitivy_hole_t | FLOAT | m**2/s | T: Transmissivity of the entire hole, see table description |
| value_type_t | CHAR | | 0:true value, –1:T < lower meas limit, 1:T > upper meas limit. |
| bc_t | CHAR | | Best choice code: 1 means T is best transm. choice, else 0. |
| cum_transmissivity_tf | FLOAT | m**2 | T_F: Cumulative transmissivity, see table description. |
| value_type_tf | CHAR | | 0:true value, –1:TF < lower meas limit, 1:TF > upper meas limit. |
| bc_tf | CHAR | | Best choice code: 1 means TF is best transm. choice, else 0. |
| l_measl_tf | FLOAT | m**2/s | Lower measurement limit of T_F, see table description. |
| cum_transmissivity_tft | FLOAT | m**2 | T_FT: Cumulative transmissivity, see table description. |
| value_type_tft | CHAR | | 0:true value, –1:TFT < lower meas limit, 1:TFT > upper meas limit. |
| bc_tft | CHAR | | Best choice code: 1 means TFT is best transm. choice, else 0. |
| u_measl_tf | FLOAT | m**2/s | Upper measurement limit of T_F, see table description. |
| reference | CHAR | | SKB number for reports describing data and results. |
| comments | CHAR | | Short comment to evaluated data (optional). |
| error_flag | CHAR | | If error_flag = ”*” then an error occured and an error. |
| in_use | CHAR | | If in_use = ”*” then the activity has been selected as |
| sign | CHAR | | Signature for QA data accknowledge (QA – OK). |

**plu_impeller_anomaly**

| idcode | start_date | stop_date | secup | seclow | section_no | l_a_upper | l_a_lower | fluid_temp_tea | fluid_elcond_eca | fluid_salinity_tdsa | dq1 | dq2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HFM20 | 20040816 22:01 | 20040818 08:45 | 12.5 | 295 | | 22.50 | 28.00 | | | | 7.89E–04 | |
| HFM20 | 20040816 22:01 | 20040818 08:45 | 12.5 | 295 | | 77.00 | 78.00 | | | | 3.33E–05 | |
| HFM20 | 20040816 22:01 | 20040818 08:45 | 12.5 | 295 | | 118.00 | 118.50 | | | | 1.33E–04 | |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 20 | 195 | | 26.00 | 27.00 | | | | | |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 20 | 195 | | 38.90 | 42.90 | | | | | |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 20 | 195 | | 67.00 | 69.00 | | | | | |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 20 | 195 | | 97.50 | 99.00 | | | | | |
| HFM21 | 20040810 09:45 | 20040811 09:31 | 20 | 195 | | 157.00 | 163.00 | | | | | |
| HFM22 | 20040922 09:05 | 20040923 10:38 | 12.1 | 211.2 | | 28.00 | 29.00 | | | | 7.37E–05 | |
| HFM22 | 20040922 09:05 | 20040923 10:38 | 12.1 | 211.2 | | 42.00 | 44.00 | | | | 2.57E–05 | |
| HFM22 | 20040922 09:05 | 20040923 10:38 | 12.1 | 211.2 | | 60.50 | 64.00 | | | | 7.11E–04 | |

**cont.**

| r_wa | dq1_corrected | dq2_corrected | spec_cap_dq1c_s1 | spec_cap_dq2c_s2 | value_type_dq1_s1 | value_type_dq2_s2 | ba | transmissivity_tfa | value_type_tfa | bc_tfa | l_measl_tfa | u_measl_tfa | comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.07 | 9.18E–04 | | 3.44E–04 | | 0 | | 5.5 | 5.73E–05 | 0 | 1 | 1.05E–06 | 6.94E–05 | Assumption QT=QP |
| 0.07 | 2.83E–05 | | 1.07E–05 | | 0 | | 1.0 | 1.78E–06 | 0 | 1 | 1.05E–06 | 6.94E–05 | Assumption QT=QP |
| 0.07 | 1.63E–04 | | 6.16E–05 | | 0 | | 0.5 | 1.03E–05 | 0 | 1 | 3.16E–06 | 6.94E–05 | Assumption QT=QP |
| 0.07 | 1.57E–04 | | 4.99E–05 | | 0 | | 1.0 | 1.01E–04 | 0 | 1 | 1.07E–05 | 6.80E–04 | Assumption QT=QP |
| 0.07 | 5.50E–05 | | 1.75E–05 | | 0 | | 4.0 | 3.54E–05 | 0 | 1 | 1.07E–05 | 6.80E–04 | Assumption QT=QP |
| 0.07 | 5.33E–05 | | 1.70E–05 | | 0 | | 2.0 | 3.43E–05 | 0 | 1 | 1.07E–05 | 6.80E–04 | Assumption QT=QP |
| 0.07 | 4.69E–04 | | 1.49E–04 | | 0 | | 2.0 | 3.01E–04 | 0 | 1 | 1.07E–05 | 6.80E–04 | Assumption QT=QP |
| 0.07 | 3.23E–04 | | 1.03E–04 | | 0 | | 6.0 | 2.08E–04 | 0 | 1 | 3.21E–05 | 6.80E–04 | Assumption QT=QP |
| 0.07 | 9.17E–05 | | 3.14E–05 | | 0 | | 1.0 | 1.49E–05 | 0 | 1 | 2.73E–06 | 1.64E–04 | Assumption QT=QP |
| 0.07 | 3.17E–05 | | 1.08E–05 | | 0 | | 2.0 | 5.16E–06 | 0 | 1 | 2.73E–06 | 1.64E–04 | Assumption QT=QP |
| 0.07 | 8.82E–04 | | 3.02E–04 | | 0 | | 3.5 | 1.44E–04 | 0 | 1 | 8.16E–06 | 1.64E–04 | Assumption QT=QP |

| Column | Datatype | Unit | Column Description |
|---|---|---|---|
| site | CHAR | | Investigation site name. |
| activity_type | CHAR | | Activity type code. |
| start_date | DATE | | Date (yymmdd hh:mm:ss) |
| stop_date | DATE | | Date (yymmdd hh:mm:ss). |
| project | CHAR | | Project code. |
| idcode | CHAR | | Object or borehole identification code. |
| secup | FLOAT | m | Upper section limit (m). |
| seclow | FLOAT | m | Lower section limit (m). |
| section_no | INTEGER | number | Section number. |
| l_a_upper | FLOAT | m | Borehole length to upper limit of inferred flow anomaly. |
| l_a_lower | FLOAT | m | Borehole length to lower limit of inferred flow anomaly. |
| fluid_temp_tea | FLOAT | oC | Measured borehole fluid temperature at inferred anomaly. |
| fluid_elcond_eca | FLOAT | mS/m | Measured fluid el conductivity of borehole fluid at anomaly. |
| fluid_salinity_tdsa | FLOAT | mg/l | Calculated total dissolved solids of fluid at anomaly, see. |
| dq1 | FLOAT | m**3/s | Flow rate of inferred flow anomaly at pump flow Q1or head h1. |
| dq2 | FLOAT | m**3/s | Flow rate of inferred flow anomaly at pump flowQ2 or head h2. |
| r_wa | FLOAT | m | Estimated borehole radius. |
| dq1_corrected | FLOAT | m**3/s | Corrected flow rate of anomaly at pump flow Q1 or see descr. |
| dq2_corrected | FLOAT | m**3/s | Corrected flow rate of anomaly at pump flow Q2, or see descr |
| spec_cap_dq1c_s1 | FLOAT | m**2/s | dq1/s1.Spec. capacity of anomaly at pump flow Q1 or .., see. |
| spec_cap_dq2c_s2 | FLOAT | m**2/s | dq2/s2.Spec. capacity of anomaly at pump flow Q2 or., see des. |
| value_type_dq1_s1 | CHAR | | 0:true value, –1: < lower meas limit, 1: > upper meas limit. |
| value_type_dq2_s2 | CHAR | | 0:true value, –1: < lower meas limit, 1: > upper meas limit. |
| ba | FLOAT | m | Representative thickness of anomaly for TFa, see description. |
| transmissivity_tfa | FLOAT | m**2/s | Transmissivity of inferred flow anomaly. |
| value_type_tfa | CHAR | | 0:true value, –1:TFa < lower meas limit, 1:TFa > upper meas limit. |
| bc_tfa | CHAR | | Best choice code.1 means TFa is best choice of T, else 0. |
| l_measl_tfa | FLOAT | m**2/s | Lower measurement limit of TFa, see table description. |
| u_measl_tfa | FLOAT | m**2/s | Upper measurement limit of TFa, see table description. |
| comments | CHAR | | Short comment on evaluated parameters. |
| error_flag | CHAR | | If error_flag = ”*” then an error occured and an error. |
| in_use | CHAR | | If in_use = ”*” then the activity has been selected as. |
| sign | CHAR | | Signature for QA data accknowledge (QA – OK). |