P-06-151

Oskarshamn site investigation

Hydraulic interference and tracer testing of a rock-soil aquifer system between HLX35 and HLX34, SSM000037, SSM000222 and SSM000223

Subarea Laxemar

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March 2007

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Keywords: Hydrogeology, Groundwater, Pumping test, Tracer test, Dilution measurement, Transmissivity, Storage coefficient, Soil aquifer, Rock aquifer.

Abstract

A field investigation is undertaken in order to study the hydraulic contact between rock and soil aquifer. It is investigated by means of pressure interference and tracer testing. A borehole drilled into a deformation zone was pumped while three soil wells and one borehole were used for response observations. Tracer testing was done with conservative tracers only, in two steps. Firstly, dilution measurements were done in the soil wells under unstressed conditions in order to obtain natural groundwater flow velocities and secondly a forced gradient test was done where tracer was injected in one of the soil wells and recovered in the pumped borehole. A hydraulic contact was confirmed between rock and soil in one of the wells. Aquifer parameters, mainly transmissivity and storage coefficient, were calculated for rock and for soil aquifer. Solute transport parameters were quantified.

Sammanfattning

En fältundersökning har genomförts i syfte att studera den hydrauliska kontakten mellan jordakvifären och bergakvifären. Undersökningen har utförts som ett kombinerat interferenstest och spårförsök.

Ett borrhål som penetrerar en deformationszon har pumpats samtidigt som eventuella responser har observerats i tre jordrör och ett annat borrhål i berg som också penetrerar nämnda deformationszon. Spårförsöket genomfördes i två steg där endast konservativa spårämnen användes. I ett första steg utfördes utspädningsmätningar i jordrören för att bestämma grundvattnets naturliga flödeshastighet. I nästa steg utfördes ett spårförsök mellan borrhålet i berget och ett av jordrören. Härvid pumpades berghålet samtidigt som ett konservativt spårämne injicerades i jordröret. Vattenprover togs från berghålet för analys av spårämnet. En hydraulisk kontakt kunde konstateras mellan jord och berg. Såväl diffusivt som advektivt samt transportparametrar kunde kvantifieras. Akvifärparametrarnas transmissivitet och magasinkoefficient kunde också kvantifieras för såväl jordakvifär som bergakvifären.

Contents

1 Introduction

This document reports the results obtained when performing an interference- and tracer test using borehole HLX35 as pumping hole and borehole HLX34 and SSM000037, SSM000222 and SSM000223 as observation wells. This is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-05-108.

The field activities were performed during 2006-01-10 to 2006-03-06.

In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

The original results from this avtivity are stored in the primary data bases (SICADA and/or GIS) and that they are traceable through by the activity plan number.

The investigation area is shown in Figure 1-1 and Appendix 8 while information of the tested boreholes is in Appendix 3.

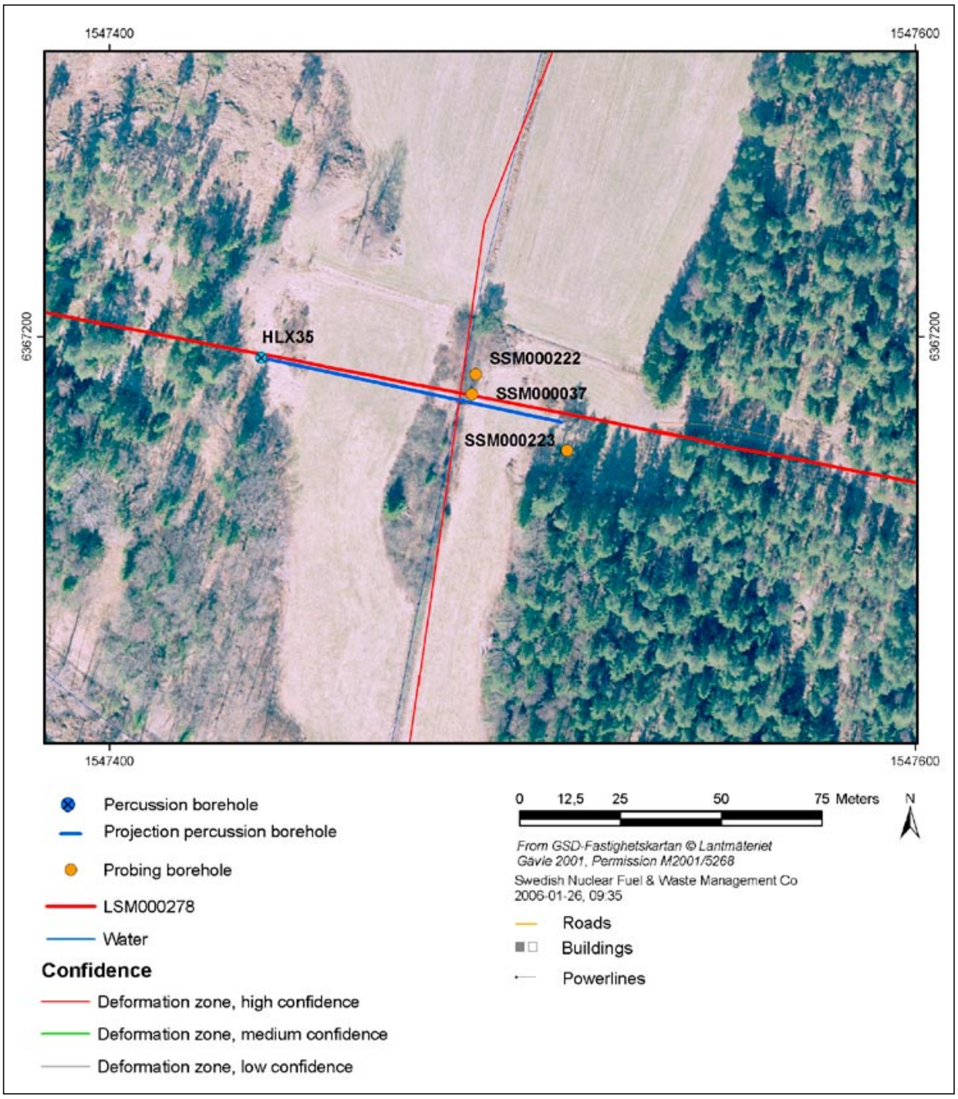

Figure 1-1. *Overview over the test area. The location of borehole HLX34 in relation to the above is shown in Figure 1-3. A general site investigation map showing the location of HLX35 is in Appendix 8.*

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

Activity plan	Number	Version
Interferens- och spårämnestester mellan HLX35 och SSM037, SSM000222 och SSM000223.	AP PS 400-05-108	1.0
Method descriptions	**Number**	**Version**
System för hydrologisk och meteorologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål.	SKB MD 368.010	1.0
Metodbeskrivning för flerhålsspårförsök.	SKB MD 530.006	1.0
Hydrauliska enhålspumptester.	SKB MD 321.003	1.0
Interferenstester.	SKB MD 330.003	1.0

1.1 Hydrogeological setting

1.1.1 Lithology and stratigraphy

The investigation area is situated in Ävrö granite (granite to quartzmonozodiorite), generally porphyritic. Soil aquifer is comprised by a thin 4–7 m till layer overlaying the Ävrö granite bedrock. A deformation zone (NS059A) has been identified in the bedrock whose north-south extension coincides with the small stream Ekerumsån, see Figure 1-1. Three soil wells have been drilled with a 1 m screen making up the contact to the aquifer. In SSM000037 and SSM000222 the screen is at the rock/till contact while in SSM000223 the filter is situated in the till.

Soil wells SSM000222 and SSM000037 are situated in the near proximity (1–2 m) of Ekerumsån while SSM000223 is about 30 m east of the stream, Figure 1-1.

1.1.2 Water levels

Rest groundwater levels are about 1.3 m below ground in SSM000037 and SSM000222 in the sand and till layer respectively. In SSM000223 the level rests a about 2.4 m, in sandy till layer. Hence these aquifers maybe classified as unconfined, Figure 1-2. These wells are situated in topographically low in catchment 9:3 with a size of 0.222 km^2 .

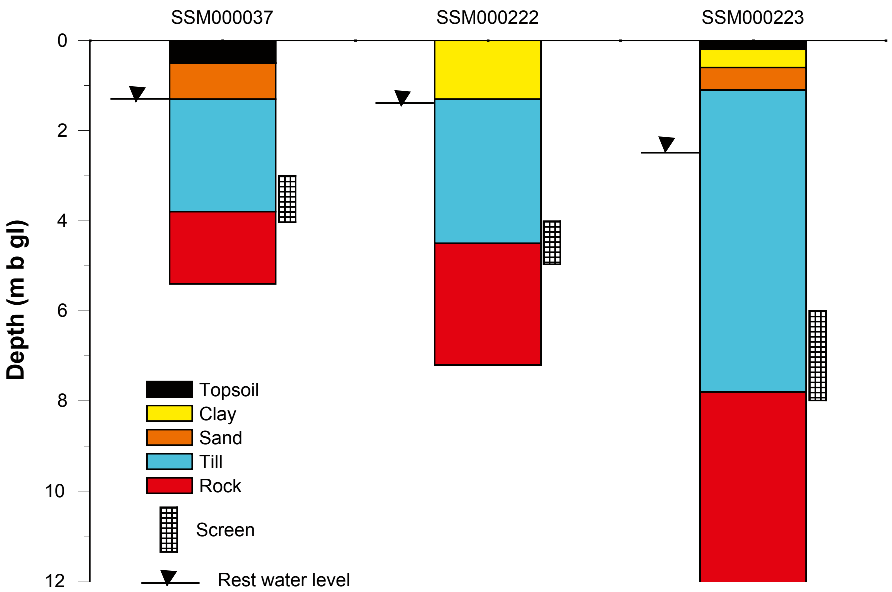

Figure 1-2. Stratigraphy and restwater levels in the soil wells.

The catchment consist of 79% coniferous an mixed forest, 17% cultivated agricultural land and 3% open land. The maximum difference in elevation is 19 m. The aquifer where the soil wells are situated is believed to be recharged from the higher surrounding terrain to the west and the east, Figure 1-3. The initial heads, prior to pumping, are 3 m higher in the rock aquifer than in the soil, Appendix 2.

Further it appears that the head in the stream is slightly higher than in the soil aquifer. It is estimated that the head values in the stream are accurate within ± 0.1 m due to uncertainties in positioning the pressure gauge.

1.1.3 Deformation zone

Boreholes HLX34 and HLX35 were drilled through deformation zone NS059A. The zone as conceptualized in Appendix 2 was inferred from four independent data sources; airborne geophysics /SKB 2006/ based on /Triumf 2004/, ground geophysics /Thunehed et al. 2004/, refraction seismics /Lindqvist 2004/ and drilling /Sigurdsson et al. 2005/. The deformation zone is trending north-south and dipping slightly towards west.

Soil well SSM000223 is apparently drilled at a point in the rock with low seismic velocity which is interpreted as being coincident to deformation zone NS059A. Water strike in borehole HLX35 observed during drilling were at borehole lengths 98.5 m, 125 m and 142 m /Sigurdsson et al. 2005/ and also during flowlogging at borehole lenghts 124 m and 133 m /Rohs 2006/. It is hence conjectured that these may be linked between with the low seismic velocity points, thus allowing to calculate a dip for NS059A of 71° west.

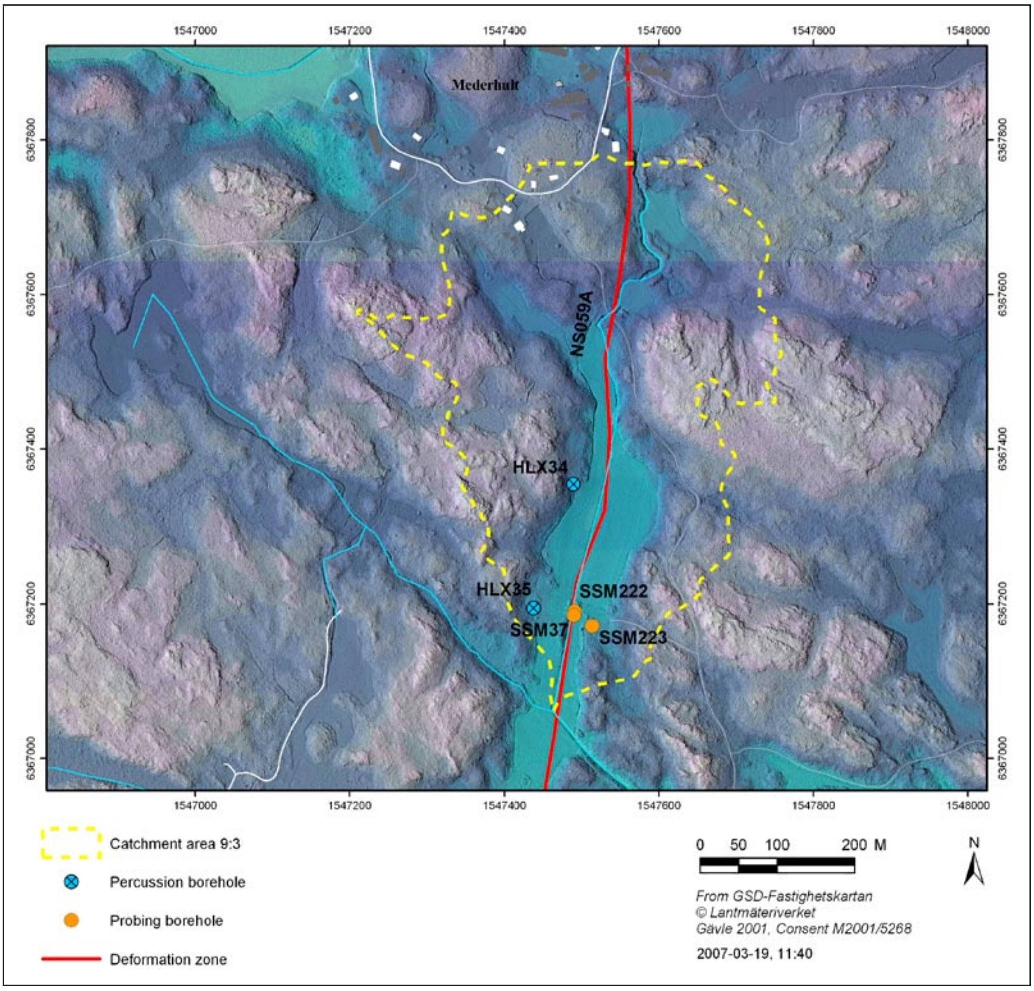

Figure 1-3. Catchment 9:3 of tributary to Ekerumsån and topography.

2 Objective and scope

The objective with the undertaken tests is to investigate the nature of the hydraulic contact between the soil aquifer and the rock aquifer, if any and also to parameterise aquifer- and flowpath properties. Can a hydraulic contact be observed and what is the response for the given hydrogeological setting? This is warranted as a mean to provide the regional modelling exercise with a basis for conceptual understanding and parameterisation of aquifer properties.

The scope of work comprised the following main components:

- Tracer dilution measurements in all three soil wells under natural hydraulic gradient.
- Induce a hydraulic gradient in the soil aquifer by pumping in HLX35.
- Tracer dilution measurements in all three soil wells under forced hydraulic gradient.
- Pressure interference test between bedrock– soil aquifer with HLX35 as pumping borehole and HLX34, SSM000037, SSM000222 and SSM000223 as observation wells.
- Tracer test between HLX35 and SSM000222 and SSM000223 with the purpose to obtain a breakthrough curve at HLX35 and related parameters.

3 Equipment

3.1 Description of equipment/interpretation tools

3.1.1 Hydraulic interference test

The pumping and interference test was performed with an integrated field unit consisting of a container at HLX35 housing a

- submersible pump: Grundfoss SPE5-70, range is about 5–100 L/min,
- absolute pressure transducer: Druck PTX1830, 10 bar range and ± 0.1% accuracy,
- water level dipper,
- flow gauge: Krohne IFM1010 electromagnetic, 0–150 L/min.

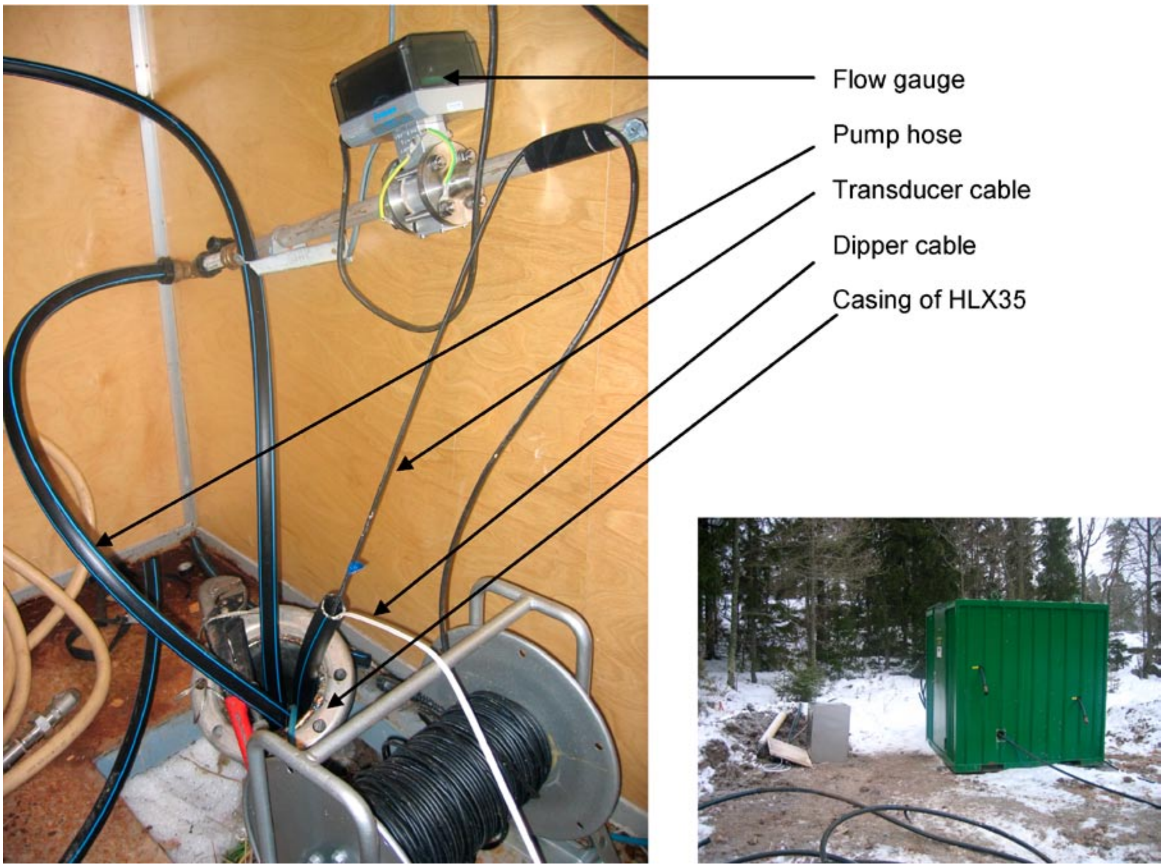

Figure 3-1. Container housing the testing equipment (right) and instrumentation inside (left) in borehole HLX35.

The observation wells were equipped with absolute pressure gauges datalogger as follows:

- SSM000037: 2 bar Druck PTX-1830 gauge 3.7 m b toc with accuracy of ± 0.1% of full scale and Mitec logger
- SSM000222: 30 PSIA LevelTroll integrated gauge and logger 5.0 m b toc with accuracy of ± 0.2% of full scale and resolution of ± 0.01% of full scale
- SSM000223: 30 PSIA LevelTroll integrated gauge and logger 8.0 m b toc with accuracy of ± 0.2% of full scale and resolution of ± 0.01% of full scale
- HLX34: 30 PSIA MiniTroll integrated gauge and logger 10.0 m b toc along the borehole with accuracy of ± 0.2% of full scale and resolution of ± 0.01% of full scale

All pressure gauges were set to log data every 10 seconds during the test.

All gauges are calibrated from the factory. During the test the pressure gauge reading are compared to those from a water level dipper for the purpose of checking sensibility of readout.

Additionally, the Druck pressure gauge was calibrated in September 2005 against different calibration pressures.

The flow gauge was checked against bucket of known volume and stopwatch in April 2005.

3.1.2 Tracer test

The tracer dilution tests and the tracer tests were performed using three identical equipment set-ups, i.e. allowing three sections to be measured simultaneously. A schematic drawing of the tracer test equipment is shown in Figure 3-2. The basic idea is to have an internal circulation in the borehole section. The circulation makes it possible to obtain a homogeneous tracer concentration in the borehole section and to sample the tracer concentration outside the borehole in order to monitor the dilution of the tracer with time.

Circulation is controlled by a down-hole pump with variable speed and measured by a flow meter. Tracer injections are made with a peristaltic pump and sampling is made by continuously extracting a small volume of water from the system through another peristaltic pump (constant leak) to a fractional sampler. The equipment and test procedure is described in detail in SKB MD 368.010, SKB internal document.

In the withdrawal borehole two different equipments were used for sampling. Samples from the outgoing pumped water were taken by an automatic programmable 24-valve sampler, producing discrete 1 litre samples, Figure 3-3. A tube sampler was used for manual sampling at three different depths (94 m, 110 m and 130 m) in the borehole, Figure 3-4. The external and internal diameter of the tube is 6 and 4 mm, respectively. The water content in the tube constitutes one sample, and the volume of each sample was about 100 ml. At the lower end of the tube, a weight is added in order to stretch the tube and thereby prevent fastening.

The tracers used were a fluorescent dye tracer, Uranine (Sodium Fluorescein) from Merck (purum quality) and Rhodamine WT from Holiday Dyes Inc. (techn. quality).

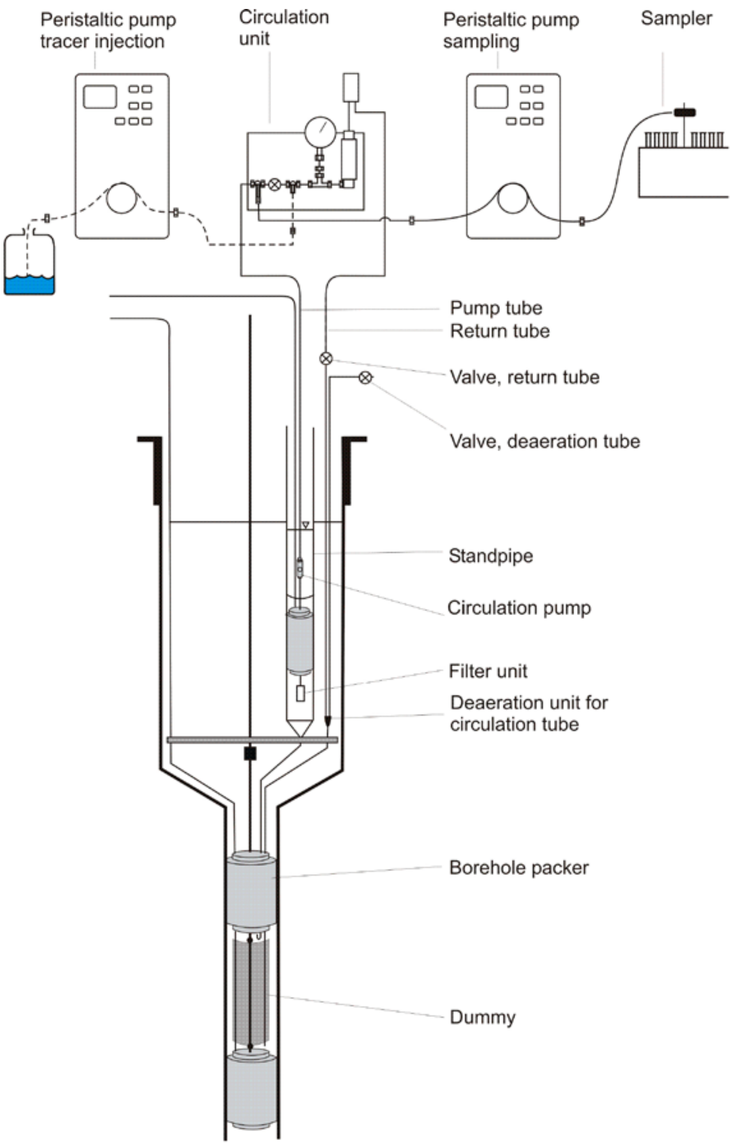

Figure 3-2. *Schematic drawing of the equipment used in tracer dilution measurements.*

Figure 3-3. *The automatic programmable sampler; magnetic valves (left) and control unit (right).*

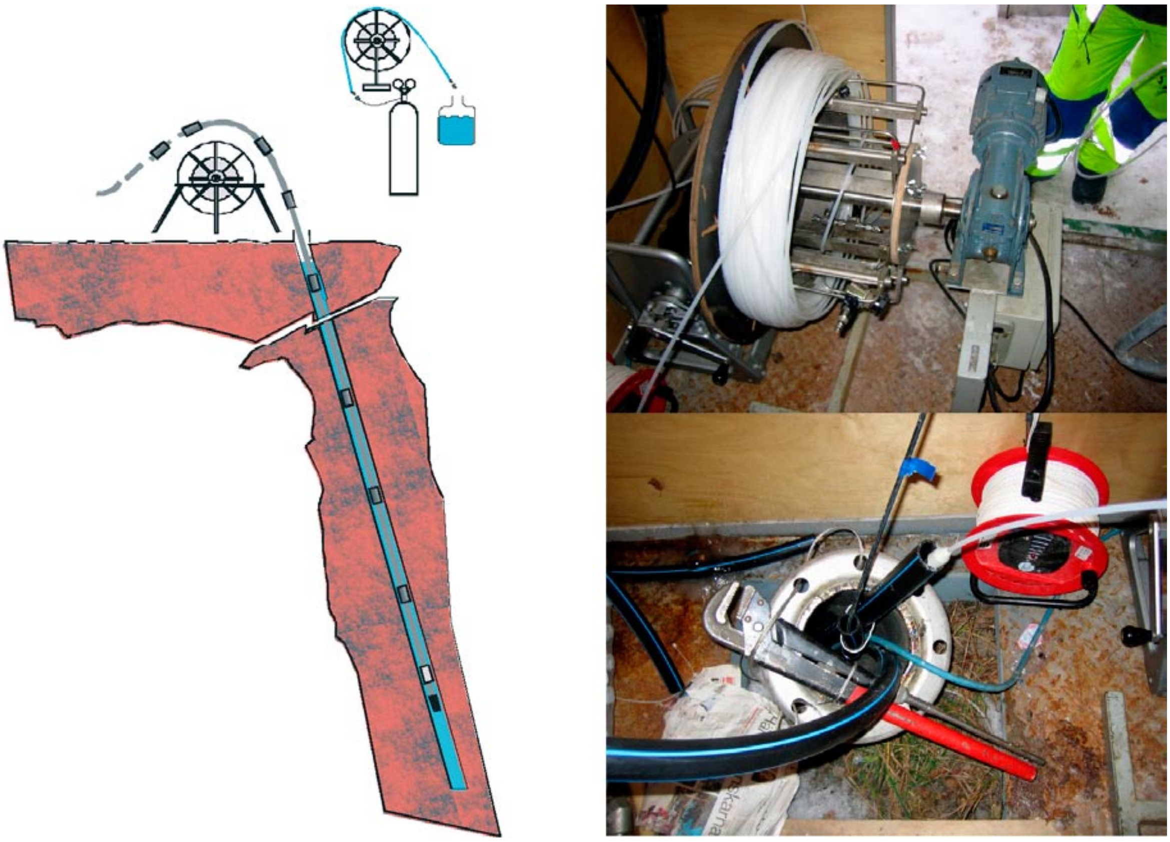

Figure 3-4. *Schematic picture of the tube sampling equipment (left), hose reel (right, above) and lower end of the hose inserted in the PEM-tube at the borehole casing (right, below).*

4 Execution

4.1 General

The testing was executed as a combined pressure interference- and tracer test including the following main tasks:

- Tracer dilution measurements in all three soil wells under natural hydraulic gradient.
- Induce a hydraulic gradient in the soil aquifer by pumping in HLX35.
- Tracer dilution measurements in all three soil wells under forced hydraulic gradient.
- Constant rate pressure interference test between bedrock– soil aquifer with HLX35 as pumping borehole and HLX34, SSM000037, SSM000222 and SSM000223 as observation wells.
- Tracer test between HLX35 and SSM000222 and SSM000223 with the purpose to obtain a breakthrough curve at HLX35 and related parameters.
- Measurement of groundwater head recovery upon pumpstop.

The water level in the stream Ekerumsån was also measured.

In order to measure the water dynamics and transport properties of the aquifer, tracer injections were made in soil wells nearby the pumping borehole HLX35 during the interference test performed. Initially, before the pumping started, tracer dilution tests were performed in the three soil wells, SSM037, SSM000222 and SSM000223, for measurement of the groundwater flow. After three days of pumping, tracers were injected in two of the soil wells, SSM000222 and SSM000223, and the pumping borehole HLX35 was continuously sampled for tracer breakthrough.

The method descriptions used were "System för hydrologisk och meteorologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål." (SKB MD 368.010, SKB internal document) and "Metodbeskrivning för flerhålsspårförsök" (SKB MD 530.006, SKB internal document).

4.2 Preparations

The pumpingtest equipment was calibrated according to 3.1.1 and data loggers were set to log data every 10 seconds .

The preparations included mixing of the tracer stock solution, functionality checks of the equipment and calibration of the peristaltic pumps used for sampling and tracer injections.

4.3 Execution of field work

Pumping was performed in HLX35 with a withdrawal rate of 104 L/min and samples were taken and analysed for tracer breakthrough. Test perfomed are compiled in Table 4-1.

Table 4-1. Tests performed.

Bh ID	Test section (m b toc)	Test type*	Test no	Pump start Date, time (yyyy-mm-dd hh:mm:ss)	Pump stop Date, time (yyyy-mm-dd hh:mm:ss)	Recovery end Date, time (yyyy-mm-dd hh:mm:ss)
HLX35	3–151.8	1B	1	2006-01-16 10:59:18	2006-02-15 11:01:26	2006-03-02 15:48:18
HLX34		2	1	2006-01-16 10:59:18	2006-02-15 11:01:26	2006-03-02 15:48:18
SSM000037		2	1	2006-01-16 10:59:18	2006-02-15 11:01:26	2006-03-02 15:48:18
SSM000222		2	1	2006-01-16 10:59:18	2006-02-15 11:01:26	2006-03-02 15:48:18
SSM000223		2	1	2006-01-16 10:59:18	2006-02-15 11:01:26	2006-03-02 15:48:18

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

Water samples were taken on January 16th (sample #: 10765) and 18th (sample #: 10766) and submitted for class five analysis to the Äspö laboratory. Results from sampling on 18th January are compiled in Table 4-2. A complete record of the analytical results is given in Appendix 8.

Regular measurements of the electrical conductivity of the pumped water were done with the purpose of environmental control. No discharge water with electrical conductivity above 300 mS/m is allowed to be discharged to the ground, it should go to the sea. These measurements showed an increase from 90 mS/m at pumpstart to 150 mS/m at pumpstop. The electric conductivity in the soil aquifer is about 50 mS/m.

For measurements of the groundwater flow, tracer dilution tests were performed in boreholes SSM000037, SSM000222 and SSM000223 both before and during pumping in HLX35.

The tests were made by injecting a slug of tracer in the selected borehole sections and allowing the natural groundwater flow to dilute the tracer. All three sections were injected simultaneously. The tracer solution was continuously circulated and sampled using the equipment described above. After four days the pumping was started in HLX35 and the dilution tests continued for another three days.

Table 4-2. Major ions in water sample from HLX35.

Activity	Start date	Stop date	Idcode	Secup (m)	Seclow (m)	Sample no
Water sampling, class 5	2006-01-18 06:59	2006-01-18 06:59	HLX35	6.03	151.80	10766

Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	SO_4 S (mg/l)	Br (mg/l)
217.0	4.39	21.1	6.5	244.00	203.0	59.10	20.90	0.736
F (mg/l)	**Si (mg/l)**	**Fe (mg/l)**	**Mn (mg/l)**	**Li (mg/l)**	**Sr (mg/l)**	**pH (pH unit)**	**Cond (mS/m)**	**Charge balance (%)**
4.01	6.75	0.0799	0.09280	0.017	0.287	8.19	118.0	–0.43

Boreholes SSM000222 and SSM000223 were chosen for tracer injections. In both boreholes tracer was injected through an “exchange” procedure, i.e. water was also withdrawn from the section during the tracer injection, the same volume as added through the injection. The tracer injections were made as decaying pulse injections, i.e. injection of a tracer pulse in a circulating system without excess pressure. A simple and reasonable assumption is that the amount of tracer that leaves the injection section (and into the transport path) is proportional to the tracer concentration in the injection section. Samples were continuously withdrawn from the injection sections to monitor the tracer injection versus time.

The samples were analysed for dye tracer content at the Geosigma Laboratory using a Jasco FP 777 Spectrofluorometer.

4.4 Data handling/post processing

4.4.1 Hydraulic interference test

Data from all pressure gauges was corrected with respect to atmospheric pressure and converted to groundwater head expressed in metre above sea level. The gauges were from observation wells HLX34, SSM000037, SSM000222, SSM000223 from HLX35 and the stream Ekerumsån. A water density on 1,000 kg/m^3 was used.

4.5 Analyses and interpretations

- Give a brief description of the method of analysis and the underlying theories, with references to the literature and which predictions that are made.
- Describe how the interpretation tool is validated.
- Generally, interpretation should only include data from this specific activity and not data from other activities. Also, no interpretation should be done that expresses influence on the deep repository.

4.5.1 Hydraulic pumping- and interference test

Level data from boreholes, wells, stream and the precipitation were plotted as linear timeseries to assess cofluctuations, if any, and deduce cause/effects processes, see Appendix 1 and 4.

Analysis of pumping and interference test was then done according to method descriptions SKB MD 321.003 v.1 (Metodbeskrivning för hydrauliska enhålstester), SKB MD 330.003 v.1 (Metodbeskrivning för interferenstester) and instruction SKB MD 320.004e v.1 (Instruction for analysis of injection and single hole pumping tests). These SKB internal controlling documents.

Briefly, the analysis is based on diagnostic log-log plot of the drawdown and the derivative of the drawdown in order to understand the different evolving flow regimes during the test. This is utilized to chose an appropriate analytical model from which the aquifers parameters, transmissivity and storage coefficient, are calculated. Observation wells were modeled with the line source solution while for the pumping well the borehole volume was included .

Interference tests between HLX35–SM000223 and HLX35–HLX34 were interpreted for response index, flow regime and aquifer parameter. Of the soil wells only the responses in SSM000223 were partly caused by the pumping in HLX35. SSM000037 and SSM000222 were consequently not possible to analyse.

The test interpretation for flow regimes and aquifer parameters was done with Ecrin v4.02.03 software from Kappa Engineering (France).

Response index follow SKB MD 330.003,

Index 1:

r_s^2/dt_L = normalised distance r_s with respect to the response time [m²/s].

Index 2:

s_p/Q_p = normalised drawdown with respect to the pumping rate [s/m²].

Additionally, a third index was calculated including drawdown and distance. This index is calculated as follows:

Index 2 new:

$(s_p/Q_p)\cdot\ln(r_s/r_0)$ $r_0=1$ and for the pumped borehole $r_s=e^1$ (fictive borehole radius of 2.718).

The classification based on the indices is given as follows:

Index 1 (r_s^2/dt_L)		**Index 2 (s_p/Q_p)**		**Colour code**
$r_s^2/dt_L > 100$ m²/s	Excellent	$s_p/Q_p > 1\cdot10^5$ s/m²	Excellent	Red
$10 < r_s^2/dt_L \leq 100$ m²/s	High	$3\cdot10^4 < s_p/Q_p \leq 1\cdot10^5$ s/m²	High	Yellow
$1 < r_s^2/dt_L \leq 10$ m²/s	Medium	$1\cdot10^4 < s_p/Q_p \leq 3\cdot10^4$ s/m²	Medium	Green
$0.1 < r_s^2/dt_L \leq 1$ m²/s	Low	$s_p/Q_p \leq 1\cdot10^4$ s/m²	Low	Blue
		$s_p < 0.1$ m	No response	Grey

Index 2 new (s_p/Q_p)·ln(r_s/r_0)		**Colour code**
$(s_p/Q_p)\cdot\ln(r_s/r_0) > 5\cdot10^5$ s/m²	Excellent	Red
$5\cdot10^4 < (s_p/Q_p)\cdot\ln(r_s/r_0) \leq 5\cdot10^5$ s/m²	High	Yellow
$5\cdot10^3 < (s_p/Q_p)\cdot\ln(r_s/r_0) \leq 5\cdot10^4$ s/m²	Medium	Green
$5\cdot10^2 < (s_p/Q_p)\cdot\ln(r_s/r_0) \leq 5\cdot10^3$ s/m²	Low	Blue
sp < 0.1 m	No response	Grey

The response indexes which were calculated are compiled in Table 5-2.

4.5.2 Tracer test

Tracer dilution tests

Flow rates were calculated from the decay of tracer concentration versus time through dilution with natural unlabelled groundwater, cf. /Gustafsson 2002/. The so-called "dilution curves" were plotted as the natural logarithm of concentration versus time. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time, t (s):

$$\ln (c/c_0) = -(Q_{bh}/V)\cdot\Delta t \qquad (4\text{-}1)$$

where Q_{bh} (m³/s) is the groundwater flow rate through the borehole section and V (m³) is the volume of the borehole section. By plotting ln (c/c_0) versus t, and by knowing the borehole volume V, Q_{bh} may then be obtained from the straight-line slope. If c_0 is constant, it is sufficient to use ln c in the plot.

The sampling procedure with a constant flow of 4–6 mL/h also creates a dilution of tracer. The sampling flow rate is therefore subtracted from the value obtained from Equation 4-1.

Tracer tests

Tracer mass recovery was calculated for the flow path SSM000223 → HLX35. Before the injection a sample of the stock solution was taken and the tracer concentration of the sample was measured. The injected volume together with the tracer concentration of the stock solution was used to determine the injected mass. The tracer mass recovered in the pumping borehole section was determined by integration of the breakthrough curves for mass flux (mg/h) versus time (h).

The evaluation of the tracer test has also involved computer modelling using a simple one-dimensional advection-dispersion model /Van Genuchten and Alves 1982/. From the computer modelling, dispersivity and mean travel times were determined using an automated parameter estimation program, PAREST /Nordqvist 1994/. PAREST uses a non-linear least square regression where regression statistics (correlation, standard errors and correlation between parameters) also is obtained.

The chosen one-dimensional model assumes a constant fluid velocity and negligible transverse dispersion, cf. Equation 4-2.

$$\partial C/\partial t = D(\partial^2 C/\partial x^2) - v \cdot \partial C/\partial x \qquad (4\text{-}2)$$

where: D = Dispersion coefficient

v = fluid velocity (m/s)

C = concentration of solute

x = distance from injection point (m)

t = time (s)

According to /Ogata and Banks 1961/ and /Zuber 1974/, the dispersion in a radially converging flow field can be calculated with good approximation by equations valid for one-dimensional flow. Although a linear flow model (constant velocity) is used for a converging flow field, it can be demonstrated that breakthrough curves and parameter estimates are similar for Peclet numbers of about 10 and higher.

/Van Genuchten 1982/ gives a solution for step input with dispersion over the injection boundary. The solution of Equation 4-2 then is:

$$C/C_o = \tfrac{1}{2}\,\mathrm{erfc}\,[(x-v\cdot t)/Z] + (V/\pi)^{1/2}\exp[(x-v\cdot t)^2/(4D\cdot t)] \qquad (4\text{-}3)$$

$$\tfrac{1}{2}\,[1+v\cdot x/D+V]\exp[v\cdot x/D]\,\mathrm{erfc}\,[(x+v\cdot t)/Z]$$

where: $Z = 2(D\cdot t)^{1/2}$

$V = v^2 t/D$

Variable injection schemes were simulated by superposition of the solution given in Equation 4-3.

The fit of the breakthrough curves using a three-parameter fit included velocity, v, dispersion coefficient, D, and the so called F-factor which corresponds to injected mass divided by fracture volume, M_{inj}/V_f.

4.6 Nonconformities

Part of the groundwater level data during recovery in HLX35 was lost for the period 15–20 February 2006. Accidentally the data was erased from the logger when retrieving it to the computer.

5 Results

The original results are stored in the primary data bases (SICADA) which is utilised for further interpretation (modelling). The data is traceable in SICADA by the Activity Plan number (AP PS 400-05-108) and the Field Note numbers 978 (pumping- and interference tests) and 1,250 (tracer tests).

The original results are stored in the primary data base SICADA. These data is available for further interpretation and is traceable by the Activity Plan number (AP PS 400-05-108).

5.1 Hydraulic pumping- and interference test

5.1.1 Hydrograph responses

Linear response plots are presented in the Appendices. Appendix 1 shows the coplotting between the hydrographs the pumped borehole HLX35 and the observations wells in soil SSM000037, SSM000222 and SSM000223. Appendix 4 shows the holes colpotted with the precipitation events as measured at the Äspö meteorological station. Appendix 6b shows the response hydrograph of borehole HLX34, situated in the north-south trending deformations zone NS059A. It is evident that HLX35 and 34 exhibit large drawdowns of 11.0 m and 4.3 m respectively, caused by the pumping in HLX35. These are amenable to standard pumping tests evaluations for aquifer parameters and response indexes.

Whereas the responses in the soil wells are clearly influenced by other sources of disturbance. The water level in the soil wells varies between 0.2–0.3 m over the testperiod while the level in Ekerumsån on fluctuates within 0.1 m. There is however a striking resemblance in the pattern of variation amongst all soil wells and the stream. These show an ongoing declining level by the time pumping in HLX35 starts. Attempt to correlate the waterlevel fluctuations in the stream and soil aquifer show a good correspondence with precipitation events, Appendix 4. There are three main precipitation events centered at 21st January, 7th February and 19th February respectivelly. These events all correspond to rising and subsequent decline in water level in the soil wells and the stream.

It is hence believed that precipitation to a large extent controll these waterlevel fluctuations.

5.1.2 Response indexes

A constant flow rate was kept in HLX35 at 104 L/min, actually it increased slightly from are 103.8 to 104.7 L/min. Drawdown and response time for all boreholes are shown in Table 5-1. Point of application in the table is the point in the borehole which is believed to have most of the concta with the observation borehole. Usually this is the main inflow point in the hole. For HLX34 it was calculated as the shortest distance along the presumed deformation zone. For SSM000223, several conceptually different transport paths are plausible, a priori:

a) from soil wells to borehole through the soil and down along the borehole,

b) shortest straight line distance between point of application, and

c) between point of applications through tourtous path controlled by the fracturing in the granite and the soil/rock contact.

Table 5-1. Measured test sections and selected parameters.

Source borehole	Section (m)	Point of application (m)	Flow rate Qm (L/min)	Drawdown at end of pumping (m)	r_{wf} (m)			
HLX35	3.00–151.80	130	104.1	10.68	0.07			
Observation borehole	**Section (m)**		**Distance r_s (m)**	**Drawdown s_p (m)**	**dt_L (s)**	**r_s^2/dt_L (m²/s)**	**s_p/Q_p (s/m²)**	**$(s_p/Q_p)\cdot\ln(r_s/r_0)$ (s/m²)**
HLX34		112	171	4.31	2,820	10.37	2,463	10,201
SSM000037	3.00–4.00	0	53	No response	No response			
SSM000222	4.00–5.00	0	62	No response	No response			
SSM000223	6.00–8.00	0	72[1)]	Disturbed by other influneces	256,100	0.02		
SSM000223	6.00–8.00	7	102[2)]	Disturbed by other influneces	256,100	0.04		
SSM000223	6.00–8.00	7	132[3)]	Disturbed by other influences	256,100	0.07		

[1)] Ground distance.
[2)] Between inflow points.
[3)] Along soil/rock contact to deformation zone NS059A.

The choice of most representative transport path is based on consideration of 1) the conceptual hydrogeological setting presented in Appendix 2 and discussed in Section 1.1, and 2) of the fact that there were only hydraulic responses in SSM000223 and not SSM000037 or SSM000222. These two (SSM000037 and SSM000222) have a stronger covariation with the waterlevel in Ekerumsbäcken than SSM000223 due to its proximity to the stream. Probably this influence of the stream is masking any small influence from the pumping of HLX35. With this in mind option c) above is adopted as most representative distance of 132 m for responses between HLX35 and SSM000223.

5.1.3 Aquifer parameters

As explained in Section 5.1.1, soil wells SSM000037 and SSM000222 do not appear to respond to the pumping in HLX35 at all while observation holes HLX34 and SSM000223 show a clear response at the onset of pumping and at pumpstop. The later also show level fluctuations controlled by other factors than pumping. Hence, aquifer parameters are only calculated for HLX34, HLX35 and SSM000223. Observation boreholes HLX34 and SSM000223 were analysed first in order to calculate a storage coefficient (S) which could be utilised as input to the analysis of the pumped borehole HLX35. The distance between point of application for the pumped and observation holes utilised for the calculation of the storage coefficient (S) is 171 m for HLX34 and 132 m for SSM000223, see Section 5.1.2 and Table 5-1.

Below is a qualitative discussion of the main points in the performed analysis for each borehole. Derived aquifer parameters are compiled in Table 5-2. In Appendix 6 there is a full presentation input data, diagnostic log-log plot, semi-log plot and history plot, all with measured data and simulated responses

SSM000223

Due to the large disturbances on the waterlevel induces by precipitation only the drawdown phase was amenable for analysis. Furthermore for the simulations only the first part of the drawdown data , from start of pumping to first precipitation event, was utilised to simulate against. Diagnostic log-log plot show a radial flow regime which could be fitted reasonably well with the analytical Theis model. Derived aquifer parameters are given in Table 5-2.

Table 5-2. Derived aquifer parameters (nomenclature table is in Appendix 7 for explanations).

Parameter	Unit	HLX35 pump bh	HLX34 obs bh	SSM000223 observation well
Test parameters				
Secup	[m b toc]	6.1	9.1	6
Seclow	[m b toc]	151.8	151.8	8
L	[m]	145	142.7	2
Q_p	[L/min]	104	0	0
Q_p	[m³/s]	$1.7333 \cdot 10^{-3}$	0	0
dh_p	[m]	11	4.27	n/a due to external disturbances
t_p	[min]	43,206	43,206	43,206
t_F	[min]	22,877	15,678	15,677
h_0	[m.a.s.l.]	13.89	14.23	10.97
h_i	[m.a.s.l.]	14.04	14.26	10.95
h_p	[m.a.s.l.]	3.36	9.95	n/a due to external disturbances
h_f	[m.a.s.l.]	14.27	14.48	n/a due to external disturbances
Calculated parameters from the drawdown phase				
Flow regime	[–]	Double porosity	Double porosity	Radial (IARF)
C	m³/pa	$3.6 \cdot 10^{-6}$	Line source	Line source
ξ	[–]	–5.8	–	–
T	[m²/s]	$1.1 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$3.9 \cdot 10^{-3}$
K	[m/s]	$7.7 \cdot 10^{-7}$	$6.6 \cdot 10^{-7}$	$2.0 \cdot 10^{-3}$
S	[–]	–	$1.5 \cdot 10^{-4}$	$8.1 \cdot 10^{-3}$
ω	[–]	0.08	0.5	–
λ	[–]	$8.0 \cdot 10^{-7}$	$1.5 \cdot 10^{-6}$	–
Calculated parameters from the recovery phase				
Flow regime	[–]	Double porosity	Double porosity	Analysis n/a due to external disturbance
C	m³/pa	$5.6 \cdot 10^{-7}$	Line source	–
ξ	[–]	–5.6	–	–
T	[m²/s]	$1.2 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	–
K	[m/s]	$8.2 \cdot 10^{-7}$	$6.6 \cdot 10^{-7}$	–
S	[–]	–	$1.6 \cdot 10^{-4}$	–
ω	[–]	0.07	0.21	–
λ	[–]	$8.0 \cdot 10^{-7}$	$1.9 \cdot 10^{-6}$	–

HLX34

The diagnostic log-log plots revealed that flow regime were close to radial flow according to the Theis model but that possibly there is additional flow component . The best match of both drawdown, recovery as well as history data are with a pseudo steady state double porosity model. Consistent values were derived of transmissivity and storage coefficient. The drawdown phase approaches steady state conditions. Derived aquifer parameters are given in Table 5-2.

HLX35

The diagnostic log-log plots show reveal an initial radial flow followed by a delayed yield type of behaviour. Conceptually both a double porosity and a radial composite flow regime are plausible in this hydrogeological environment. Indeed both model could be matched quite well to the drawdown and recovery data but better consitencies between drawdown and recovery were achived with the double porosity concept. This is consitent with the fractured rock and also conforms to the result in HLX34. Consistent values were derived of transmissivity. The storage coefficient derived from the interference test with HLX34 was utilised as input to the analysis of the test in HLX35, $S = 1.5 \cdot 10^{-4}$. Derived aquifer parameters are given in Table 5-2.

5.2 Tracer test

5.2.1 Dilution measurements

Tracer dilution measurements were performed in boreholes SSM000037, SSM000222 and SSM000223 both before and during pumping in HLX35. The results are presented in Table 5-3 and the dilution graphs are shown in Figure 5-1.

Table 5-3. Results from tracer dilution measurements.

Borehole	Volume (L)	Qnatural (mL/h)	Qstressed (mL/h)
SSM037	5.27	46	53
SSM000222	7.03	14	8
SSM000223	10.4	6,400	990

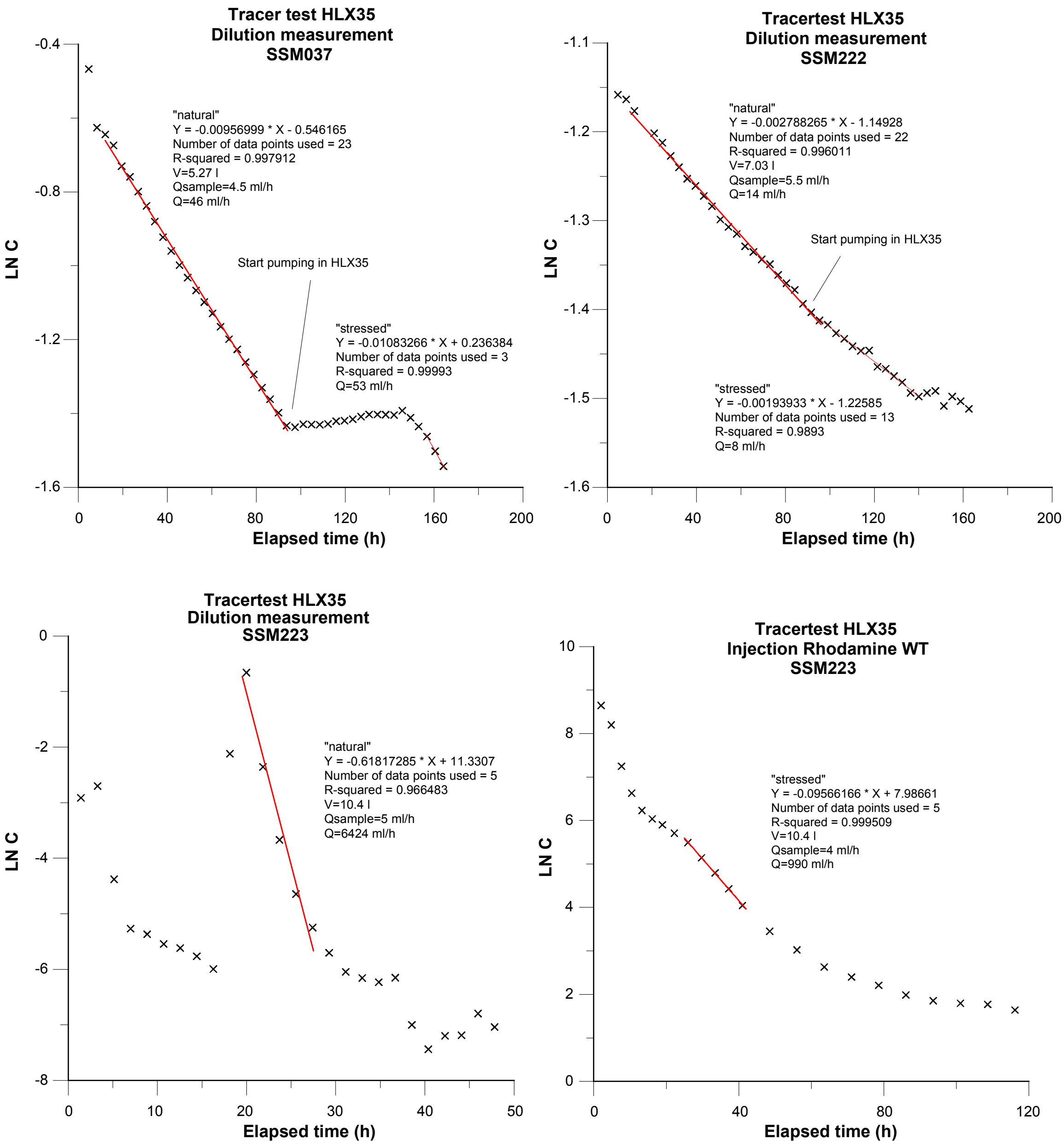

Figure 5-1. *Tracer dilution graphs (Logarithm of concentration versus time) for the measured boreholes SSM000037, SSM000222 and SSM000223 including straight-line fits. Note that the axis scales differ between the plots.*

Notable is that the gradient seems to be reversed or partly reversed in all three soil wells when the pumping started in HLX35. As seen in the dilution graph (Figure 5-1), the tracer concentration in SSM037 increased after the pumping started, implying that tracer that earlier had left the borehole was withdrawn when the gradient and flow direction was reversed due to pumping in HLX35. In SSM000222 and SSM000223 the flow was decreased during the pumping phase, which also indicates a change in gradient/flow direction. In SSM000223 the dilution was very high during natural conditions and when the pumping started there was not tracer enough left in the borehole for detection. Therefore, the groundwater flow during stressed conditions in SSM000223 is determined from the dilution of the tracer injected in the tracer test.

5.2.2 Tracer test

Tracer injections were performed in boreholes SSM000222 and SSM000223. In Table 5-4 tracer injection data is presented together with the distance between injection borehole and pumping borehole HLX35. The distances are calculated at half the length of each borehole.

HLX35 was pumped with a withdrawal rate of 104 L/min and the water was continuously sampled for tracer breakthrough.

Tracer breakthrough in HLX35 was detected from the injection of Rhodamine WT in borehole SSM000223, see Figure 5-2. Only the samples taken by the automatic 24-valve sampler showed tracer breakthrough. No tracer breakthrough was detected from the injection of Uranine in borehole SSM000222.

Table 5-4. Tracer injection data (measured values).

Borehole	Volume (L)	Distance to HLX35 (m)	Tracer	C_{00} of solution[1)] (mg/L)	C_i in soil well[2)] (mg/L)	Inj. Mass[3)] (g)
SSM000222	7.03	62	Uranine	9,750	Not performed	48
SSM000223	10.4	72	RhodamineWT	8,455	5,684	75

[1)] Concentration of the solution utilised prior to injection in the well.
[2)] Initial concentration in the soil well, 2 hours after injection start.
[3)] Injected mass corrected for tracer withdrawal during injection exchange procedure and sampling.

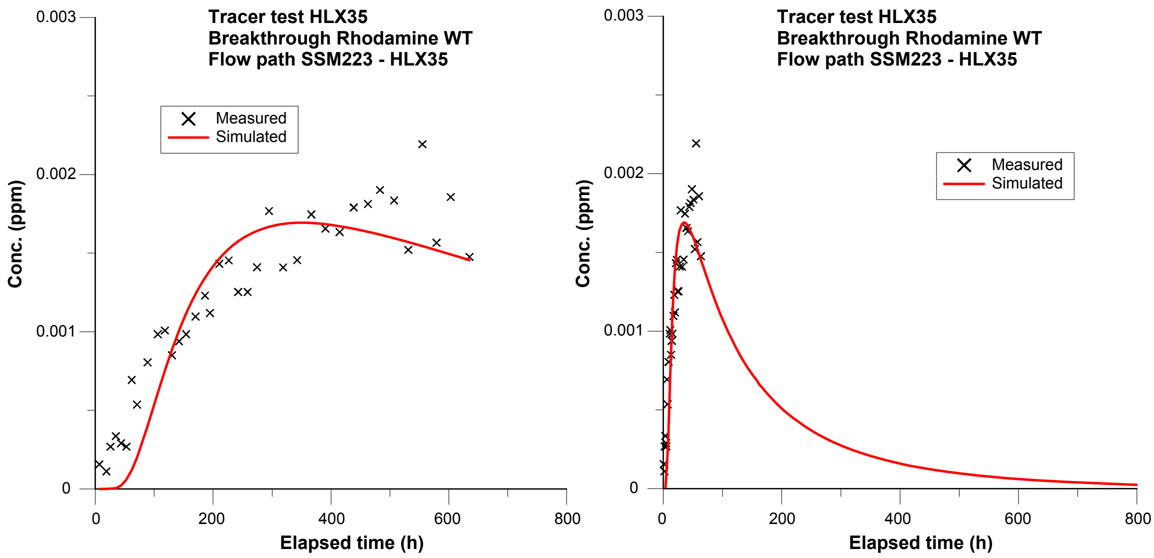

Figure 5-2. Measured data and model simulations of tracer breakthrough (concentration versus time) in HLX35 from the injection of Rhodamine WT in SSM000223.

Tracer mass recovery for Rhodamine WT was 7% when sampling was stopped 635 hours after the injection.

The breakthrough curve was evaluated using the one-dimensional advection-dispersion model described in Section 4.4. The best-fit run is shown in Figure 5-2 (left) and the parameters determined from the model run are presented in Table 5-5. The regression statistics show high standard errors which could be expected due to the scattered breakthrough data. The parameters obtained were then used to simulate the breakthrough curve ahead, Figure 5-2 (right). After 8,000 hours the recovery would then be 24%.

Table 5-5. Evaluated parameters using PAREST (one-dimensional advection-dispersion model) for the flow path SSM000223 → HLX35. Values within brackets are standard errors in percent.

Injection borehole	Tracer	Distance (m)	v (m/s)	t_m (h)	D/v (m)	F
SSM000223	Rhodamine WT	72 (ground distance)	$2.06 \cdot 10^{-5}$ (49)	970	69 (17)	$6.56 \cdot 10^{-5}$ (55)
		102 (between inflow pont)	$3.09 \cdot 10^{-5}$ (45)	916	89 (17)	$6.15 \cdot 10^{-5}$ (51)
		132 (along contact soil/rock to DZ)	$3.15 \cdot 10^{-5}$ (64)	1,165	159 (17)	$8.06 \cdot 10^{-5}$ (71)

6 Summary and discussions

A field investigation was undertaken in order to study the hydraulic contact between rock and soil aquifer by means of pressure interference and tracer testing.

A borehole drilled into a deformation zone was pumped while three soil wells and one borehole were used for response observations. Tracer testing was performed with conservative tracers only, in two steps. Firstly, dilution measurements were done in the soil wells under unstressed conditions in order to obtain natural groundwater flow velocities and secondly a forced gradient test was done where tracer was injected in one of the soil wells and recovered in the pumped borehole.

A hydraulic contact between rock and soil could be established through these works by means of both diffusive and advective transport.

It is believed that the transport took place through the deformation zone NS059A which essentially appear to be in direct contact with the soil aquifer at SSM000223. The simultaneous apparent lack of response in the soil wells SSM000037 and SSM00022 indicates a very local influence by the pumping in the rock to the soil, at least with respect to the durations, distances and disturbances applied in this test. A hydraulically active rock/soil contact is basically governed by the presence of a high permeability feature in the rock, such as the deformations zone.

It could also be established that the amount of water level fluctuation in the soil at SSM000223 was of the same amount as fluctuations caused by natural recharge/discharge processes.

The works also allowed a quantification of aquifer properties and solute transport parameters. In summary, the main observations emanating from this study are as follow:

- Hydraulic pressure interference from HLX35 was observed at HLX34 with a response index $r_s^2/dt_L = 10$ and at SSM000223 with a response index $r_s^2/dt_L = 0.07$. No interference was observed at SSM000037 nor SSM000222.
- Double porosity flowregime was observed in the rock supporting the fracture zone- intact rock concept and a homogeneous radial flow in the soil aquifer.
- Obtained T-values are $1 \cdot 10^{-4}$ m^2/s for the deformation zone and $4 \cdot 10^{-3}$ m^2/s for the soil aquifer.
- Obtained S-values are $1 \cdot 10^{-4}$ for the deformation zone and $8 \cdot 10^{-3}$ for the soil aquifer.
- Water levels in the soil were much influenced by recharge events due to precipitation.
- A relatively high natural groundwater flowrate of 107 mL/min was measured at SSM000223 which is situated at the foot of the forested slope bordering the arable land and much lower rates in the wells in the middle of the field, close to the stream. Hence, the natural flow rates are very much topgraphically controlled, and not so much by the stratigraphy.
- The hydraulic gradient seemed to be reversed or partly reversed in the soil wells when pumping started in HLX35.
- Tracer breakthrough was detected in HLX35 from the injection of Rhodamine WT in SSM000223.
- No tracer breakthrough was detected from the injection of Uranine in SSM000222.
- Recovery (Rhodamine WT) was 7% after 635 hours of sampling.
- From model simulation of the breakthrough curve (Rhodamine WT) a mean travel time of 970 hours and a dispersivity of 69 m were obtained. However, the standard errors were high due to the scattered breakthrough data. By simulating the breakthrough curve ahead a recovery of 24% was reached after 8,000 hours.

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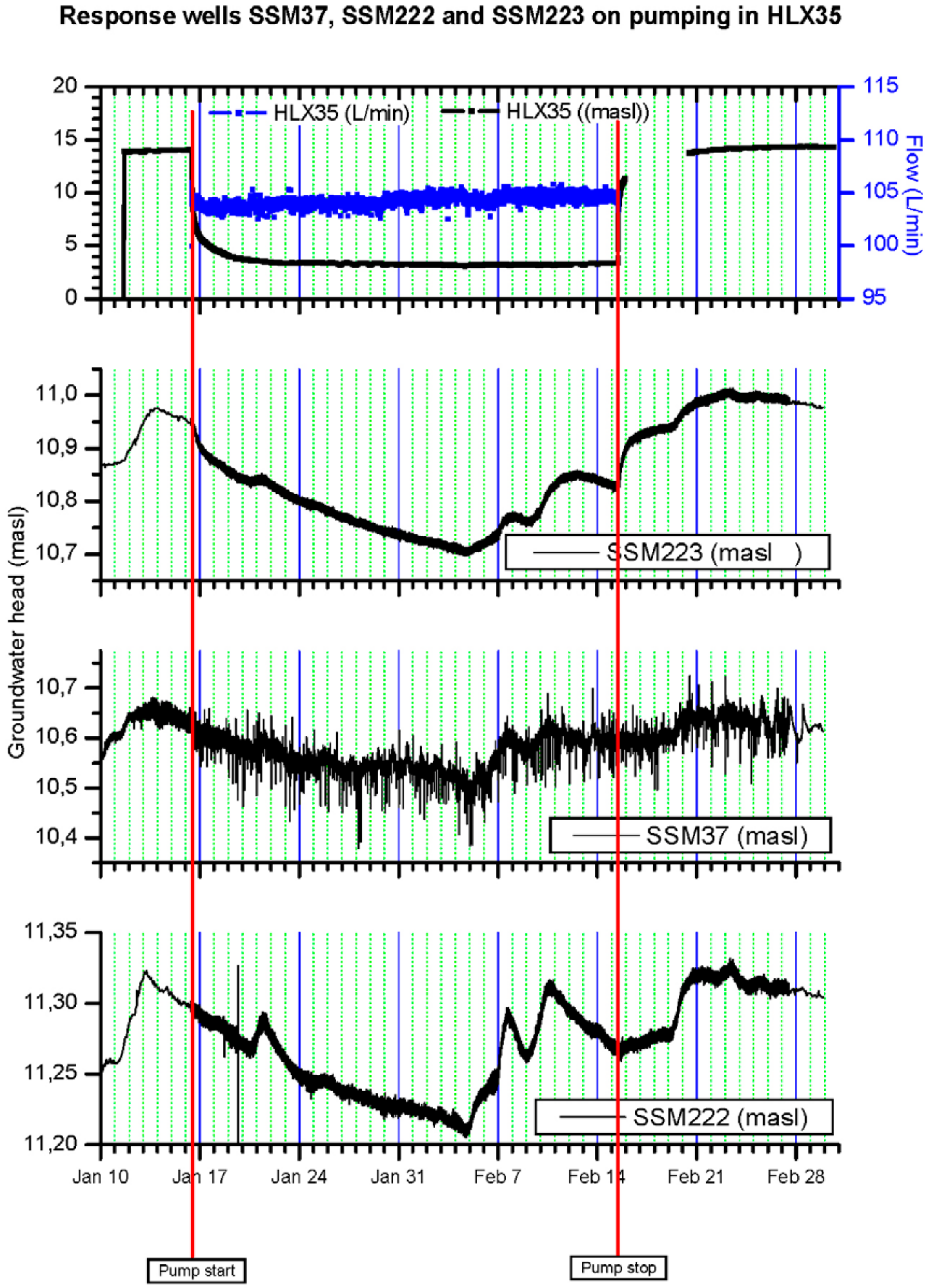
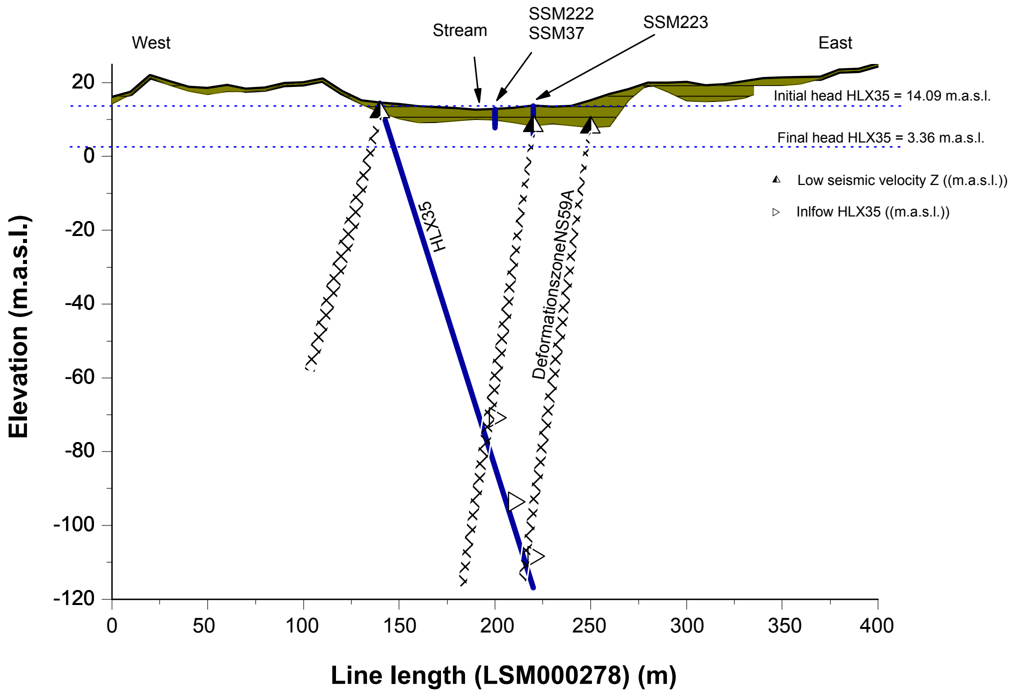
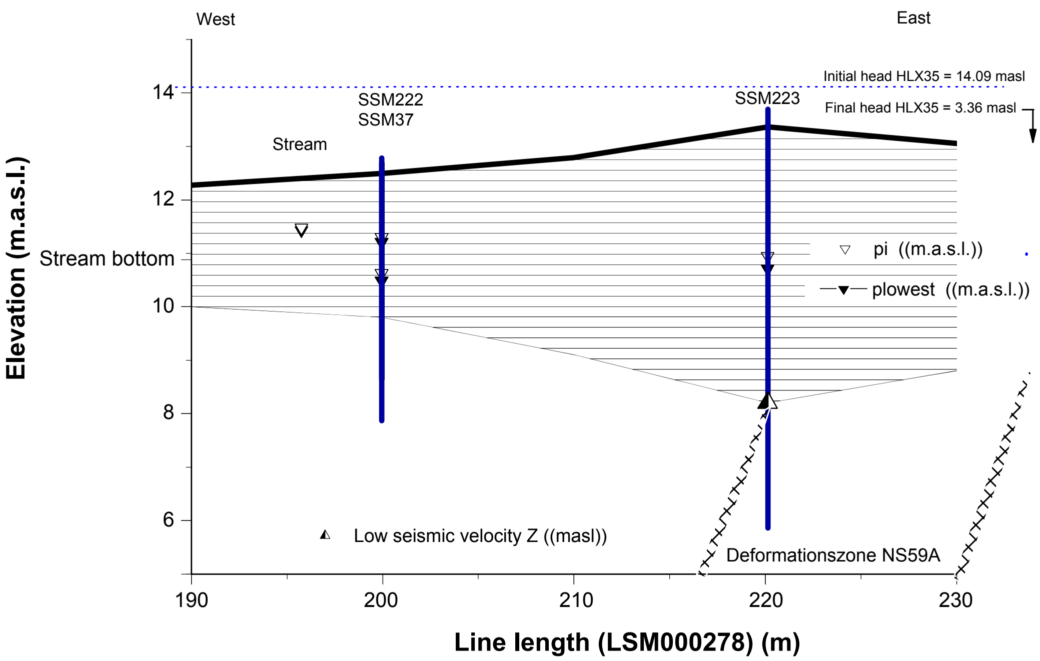
Appendix 1

Response hydrographs for HLX35, SSM000037, SSM000222 and SSM000223



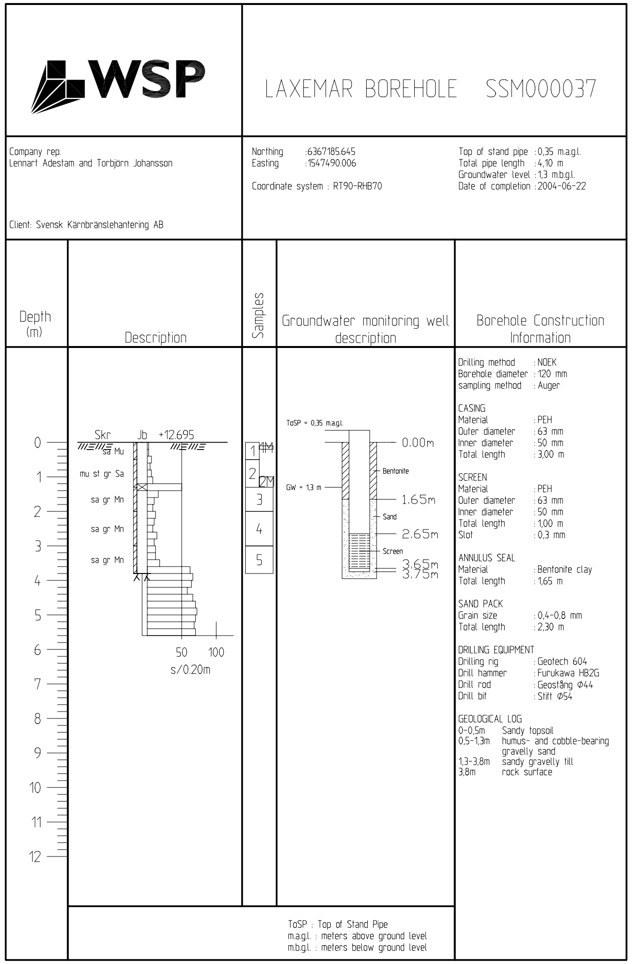
Geological cross section of the tested site

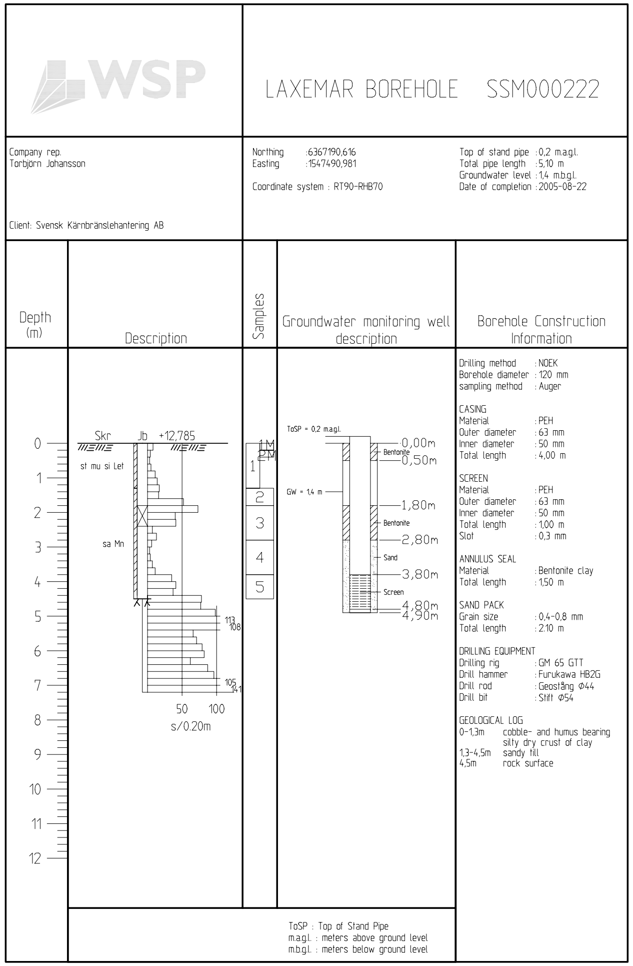


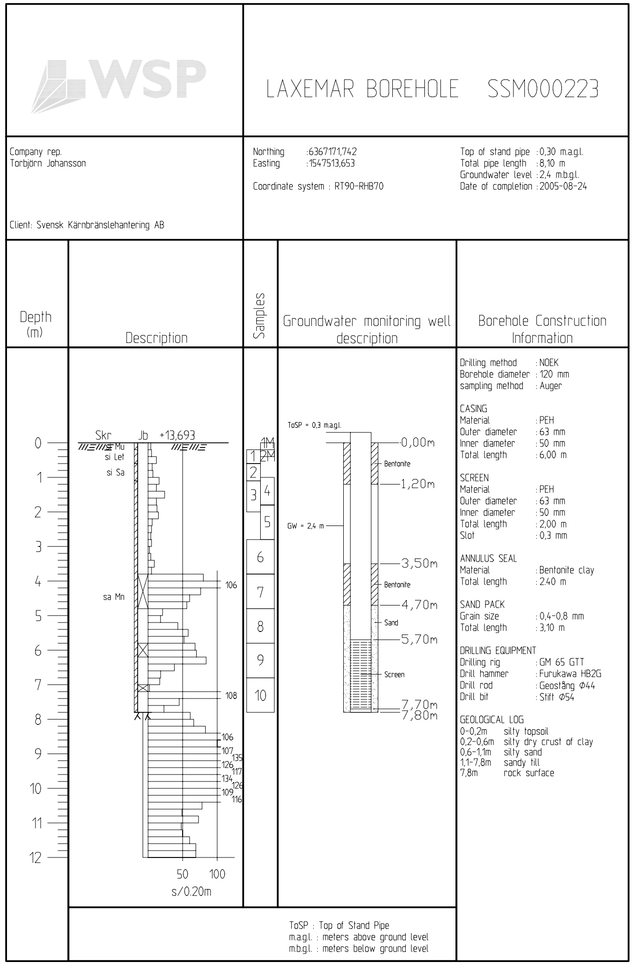


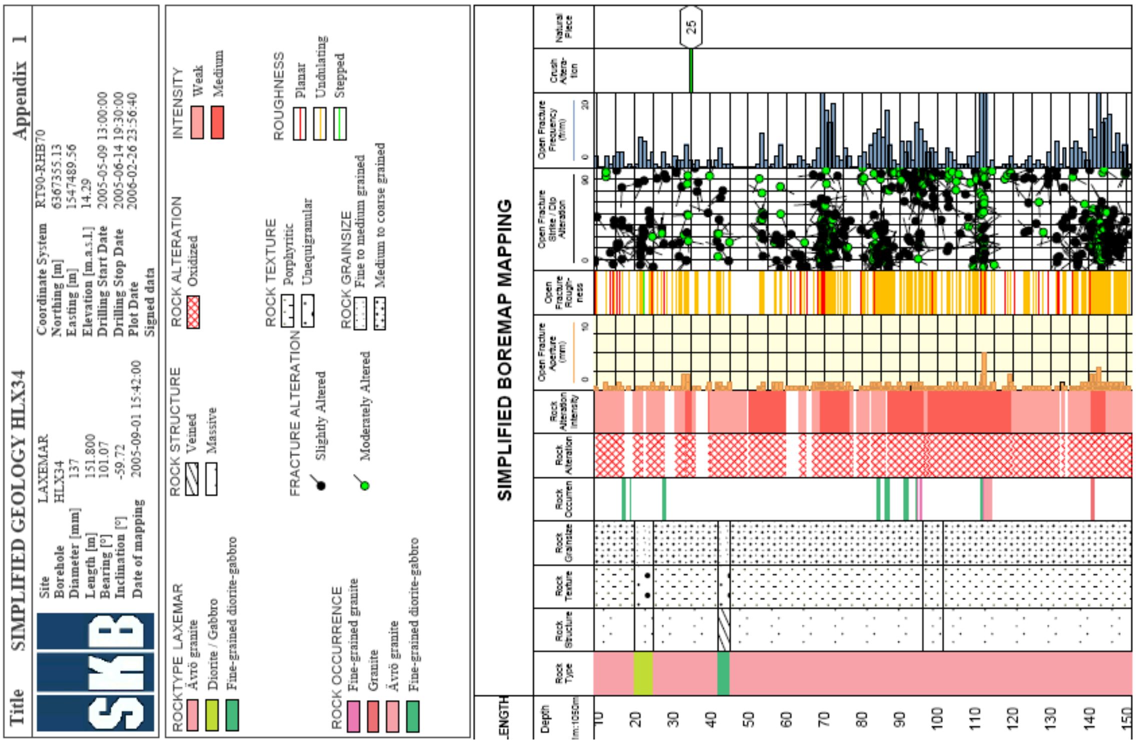
Appendix 3

Stratigraphy and lithology








Title SIMPLIFIED GEOLOGY HLX34
Appendix 1
Site LAXEMAR
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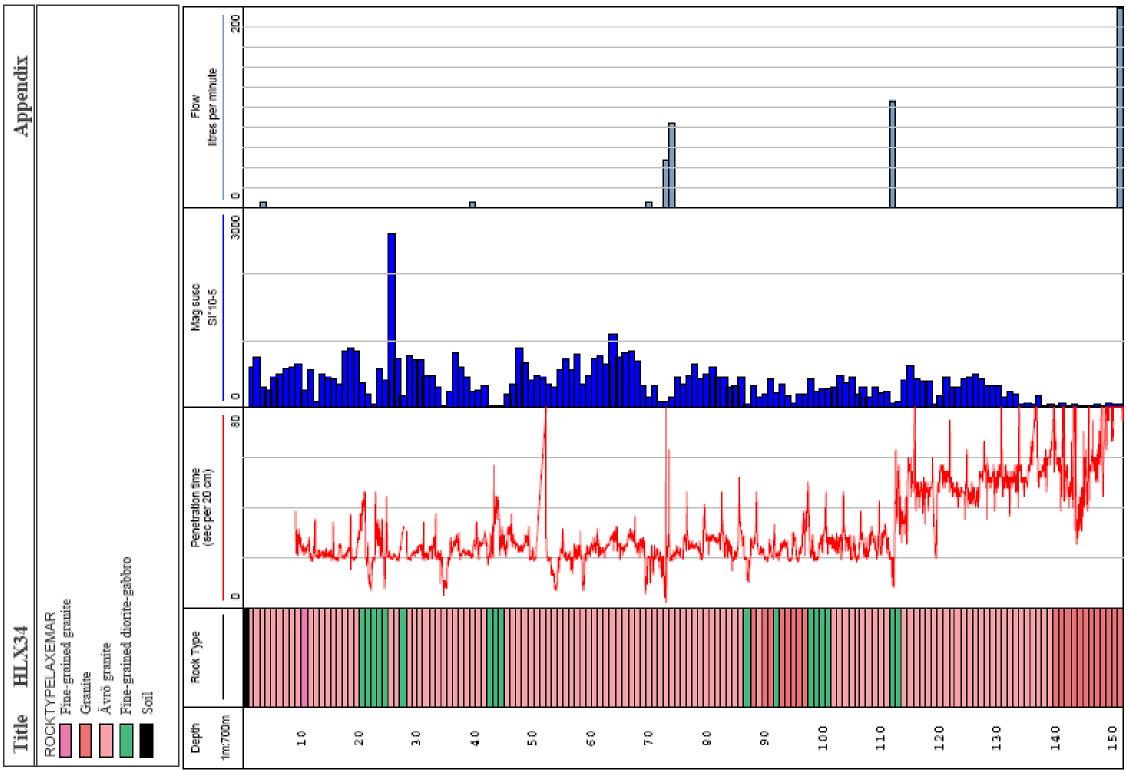
Diameter [mm] 137
Length [m] 151.800
Bearing [°] 101.07
Inclination [°] -59.72
Date of mapping 2005-09-01 15:42:00
Coordinate System RT90-RHB70
Northing [m] 6367355.13
Easting [m] 1547489.56
Elevation [m.a.s.l.] 14.29
Drilling Start Date 2005-05-09 13:00:00
Drilling Stop Date 2005-06-14 19:30:00
Plot Date 2006-02-26 23:56:40
Signed data
ROCKTYPE LAXEMAR
Ävrö granite
Diorite / Gabbro
Fine-grained diorite-gabbro
ROCK OCCURRENCE
Fine-grained granite
Granite
Ävrö granite
Fine-grained diorite-gabbro
ROCK STRUCTURE
Veined
Massive
FRACTURE ALTERATION
Slightly Altered
Moderately Altered
ROCK ALTERATION
Oxidized
ROCK TEXTURE
Porphyritic
Unequigranular
ROCK GRAINSIZE
Fine to medium grained
Medium to coarse grained
INTENSITY
Weak
Medium
ROUGHNESS
Planar
Undulating
Stepped
SIMPLIFIED BOREMAP MAPPING
LENGTH
Depth
1m:1050m
Rock Type
Rock Structure
Rock Texture
Rock Grainsize
Rock Occurrence
Rock Alteration
Rock Alteration Intensity
Open Fracture Aperture (mm)
Open Fracture Roughness
Open Fracture Strike / Dip Alteration
Open Fracture Frequency (1/m)
Crush Alteration
Natural Piece
25


Title HLX34
Appendix
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Fine-grained granite
Granite
Ävrö granite
Fine-grained diorite-gabbro
Soil
Depth
1m:700m
Rock Type
Penetration time (sec per 20 cm)
Mag susc SI*10-5
Flow litres per minute
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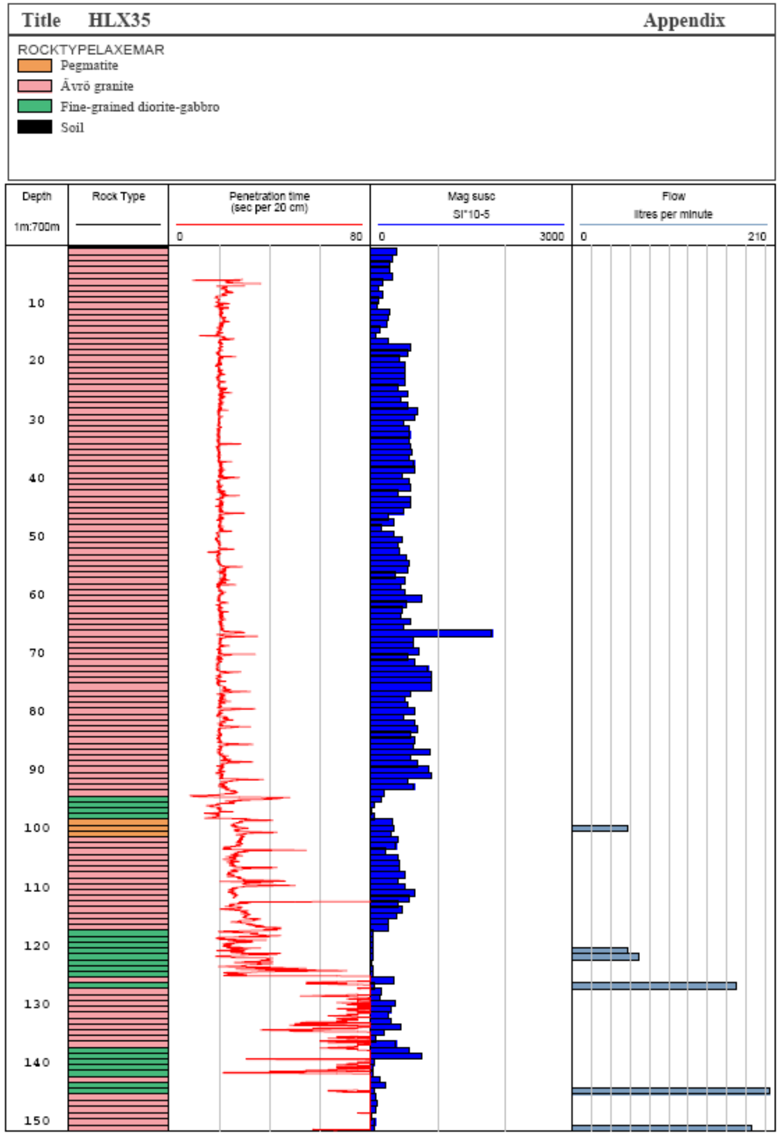
80
3000
200


Title HLX35
Appendix
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Pegmatite
Ävrö granite
Fine-grained diorite-gabbro
Soil
Depth
1m:700m
Rock Type
Penetration time (sec per 20 cm)
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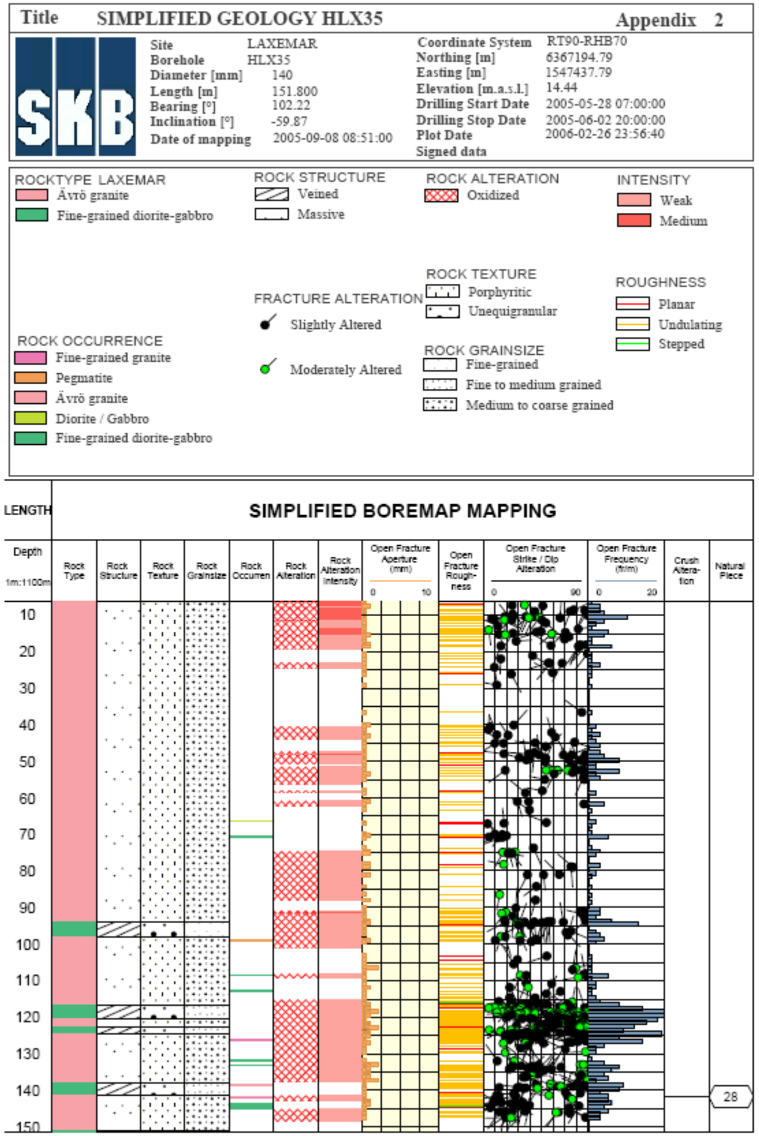
Mag susc SI*10-5
0 3000
Flow litres per minute
0 210
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150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Appendix 2
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Length [m] 151.800
Bearing [°] 102.22
Inclination [°] -59.87
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Coordinate System RT90-RHB70
Northing [m] 6367194.79
Easting [m] 1547437.79
Elevation [m.a.s.l.] 14.44
Drilling Start Date 2005-05-28 07:00:00
Drilling Stop Date 2005-06-02 20:00:00
Plot Date 2006-02-26 23:56:40
Signed data
ROCKTYPE LAXEMAR
Ävrö granite
Fine-grained diorite-gabbro
ROCK STRUCTURE
Veined
Massive
ROCK ALTERATION
Oxidized
INTENSITY
Weak
Medium
FRACTURE ALTERATION
Slightly Altered
Moderately Altered
ROCK TEXTURE
Porphyritic
Unequigranular
ROUGHNESS
Planar
Undulating
Stepped
ROCK OCCURRENCE
Fine-grained granite
Pegmatite
Ävrö granite
Diorite / Gabbro
Fine-grained diorite-gabbro
ROCK GRAINSIZE
Fine-grained
Fine to medium grained
Medium to coarse grained
LENGTH
SIMPLIFIED BOREMAP MAPPING
Depth
1m:1100m
Rock Type
Rock Structure
Rock Texture
Rock Grainsize
Rock Occurren
Rock Alteration
Rock Alteration Intensity
Open Fracture Aperture (mm)
0 10
Open Fracture Rough-ness
Open Fracture Strike / Dip Alteration
0 90
Open Fracture Frequency (fr/m)
0 20
Crush Altera-tion
Natural Piece
28
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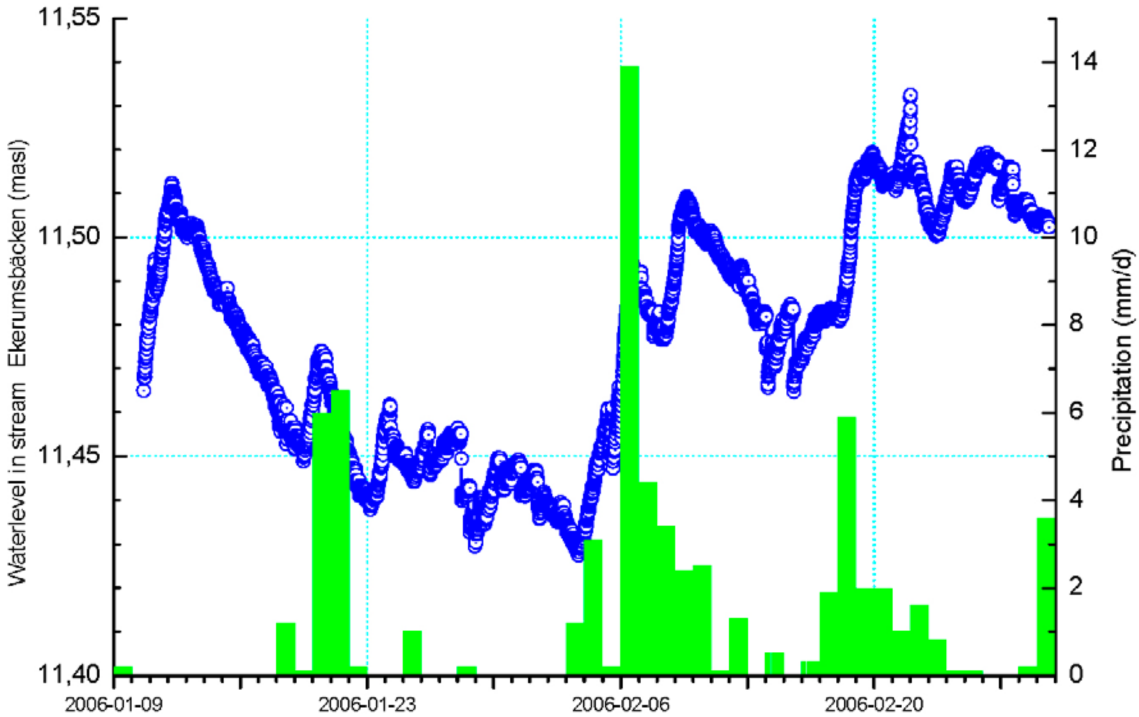
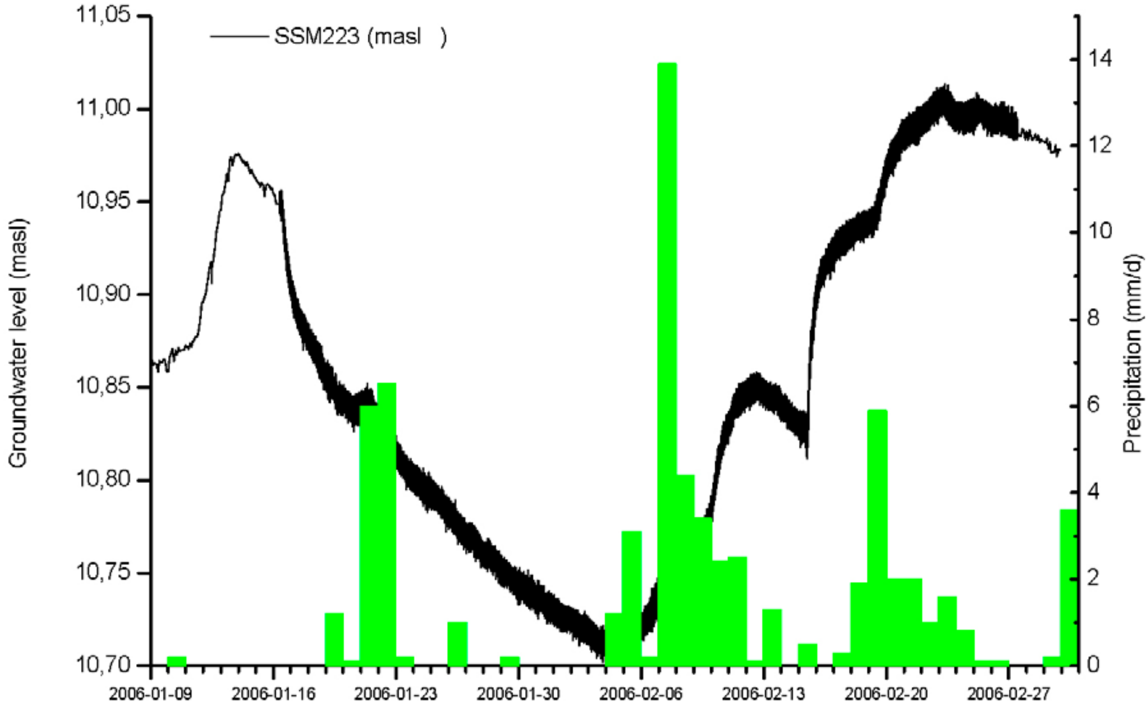
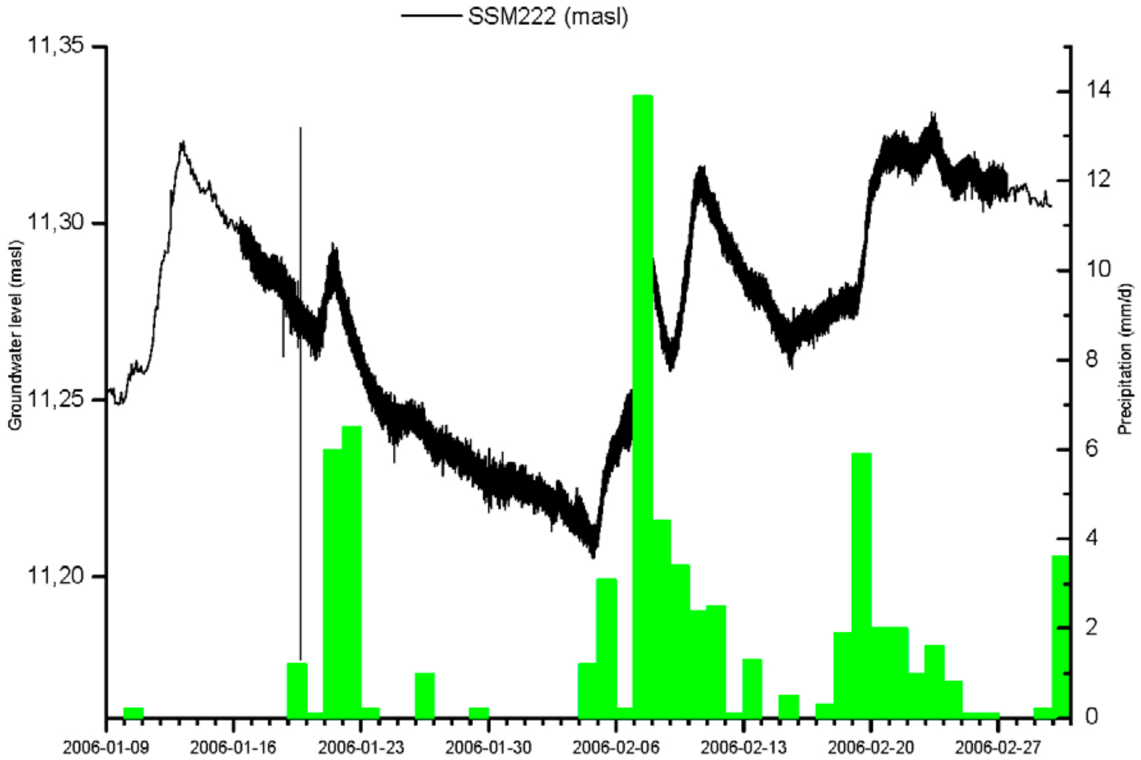
Appendix 4

Response hydrographs and precipitation for the stream Ekerumsån and for soil wells SSM000223, SSM000222 and SSM000037



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Groundwater level (masl)
Precipitation (mm/d)
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11,30
11,25
11,20
14
12
10
8
6
4
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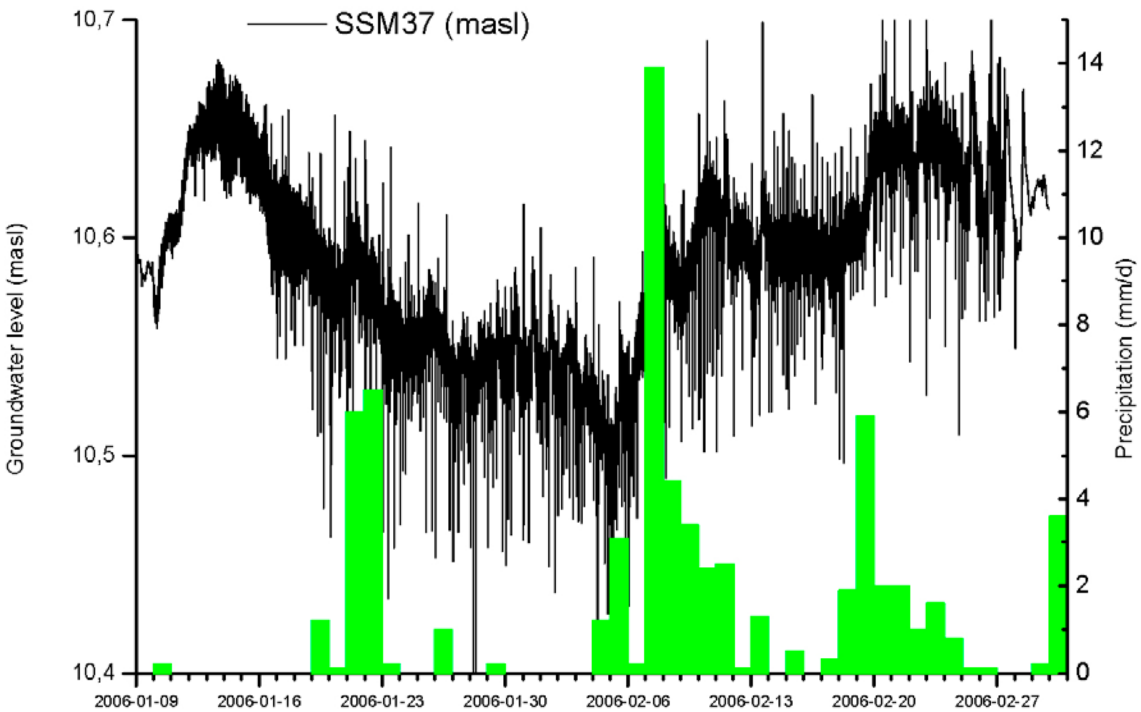
2006-02-20
2006-02-27


SSM37 (masl)
Groundwater level (masl)
Precipitation (mm/d)
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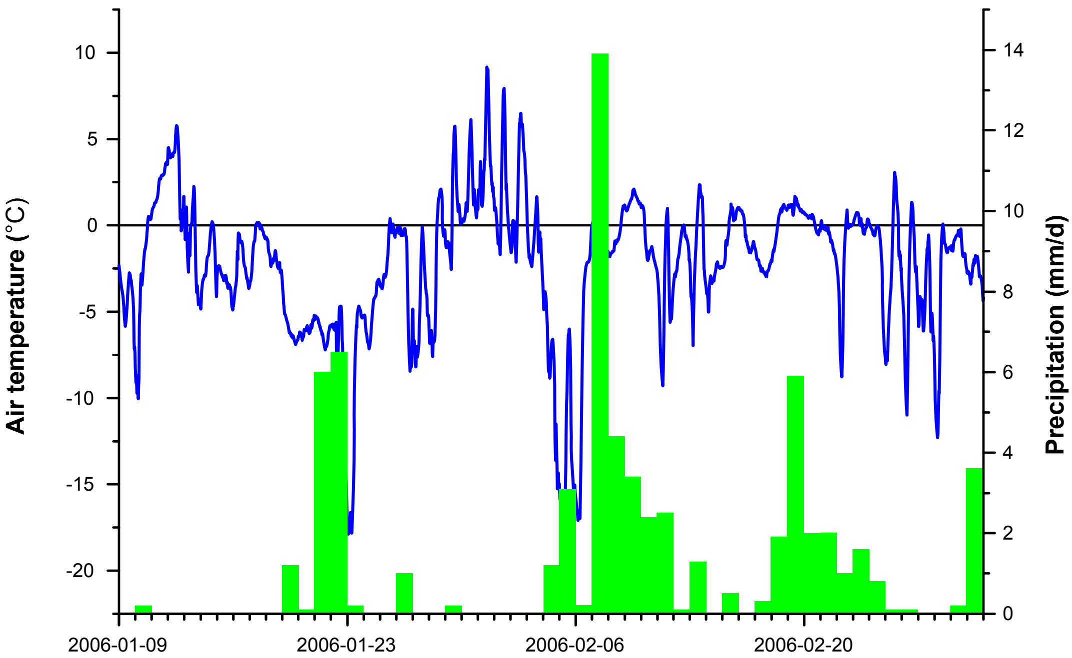
10,6
10,5
10,4
14
12
10
8
6
4
2
0
2006-01-09
2006-01-16
2006-01-23
2006-01-30
2006-02-06
2006-02-13
2006-02-20
2006-02-27

Air temperature and precipitation measured at Äspö meteorological station situated 4 km due east of the test site



Appendix 6

Analysis of pumping and interference tests in SSM000223, HLX34 and HLX35

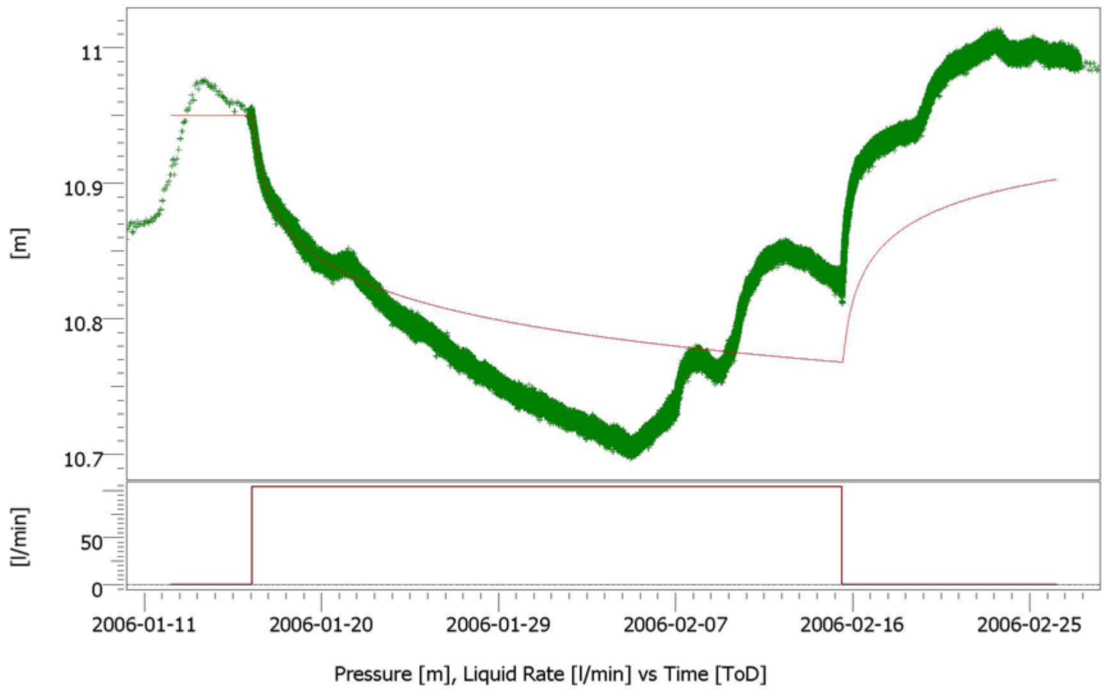
For each of these boreholes, analysis and simulations are done for the drawdown phase, the recovery phase and the complete flow/pressure history.

Borehole/soil well	Analysed phase
a) SSM000223	Drawdown phase
b) HLX34	Drawdown phase
c) HLX34	Recovery phase
d) HLX35	Drawdown phase
e) HLX35	Recovery phase

Main Results	Dd1
Company Svensk Kärnbränslehantering AB Well Observation well SSM223	Field Laxemar Test Name / # Interferenstest HLX35pump

Test date / time	2006-01-10
Formation interval	1-8m
Perforated interval	6-8m
Gauge type / #	LevelTroll 30PSIA strain gauge
Gauge depth	8m below top of casing
Field crew	Jan Henriksson, NEA
Analysis	Mansueto Morosini, SKB
TEST TYPE	Interference
Well distance	132 m
Well Radius rw	0.25 m
Pay Zone h	2 m
Water Salt (ppm)	10000
Form. compr.	4.35113E-10 Pa-1
Reservoir T	12 °C
Reservoir P	152.957 m
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	4.35113E-10 Pa-1
Selected Model	
Model Option	Standard Model
Well	Line source
Reservoir	Homogeneous
Boundary	Infinite
Main Model Parameters	
TMatch	2.74E-5 [sec]-1
PMatch	14 [m]-1
S	0.00814
T	0.00389 m2/s
K	0.00195 m/s
Pi	10.95 m
Well distance	132 m
Model Parameters	
Reservoir & Boundary parameters	
Pi	10.95 m
T	0.00389 m2/s
K	0.00195 m/s
S	0.00814
Derived & Secondary Parameters	
Rinv	1990 m
Test. Vol.	23496.8 MMm3

History plot	Dd1
Company Svensk Kärnbränslehantering AB Well Observation well SSM223	Field Laxemar Test Name / # Interferenstest HLX35pump



SSM223 051215-060302 production #1

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	10.9463 m
Pi	10.95 m
Smoothing	0.2

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	2.74E-5 [sec]-1
PMatch	14 [m]-1
S	0.00814
T	0.00389 m2/s
K	0.00195 m/s
Pi	10.95 m
Well distance	132 m

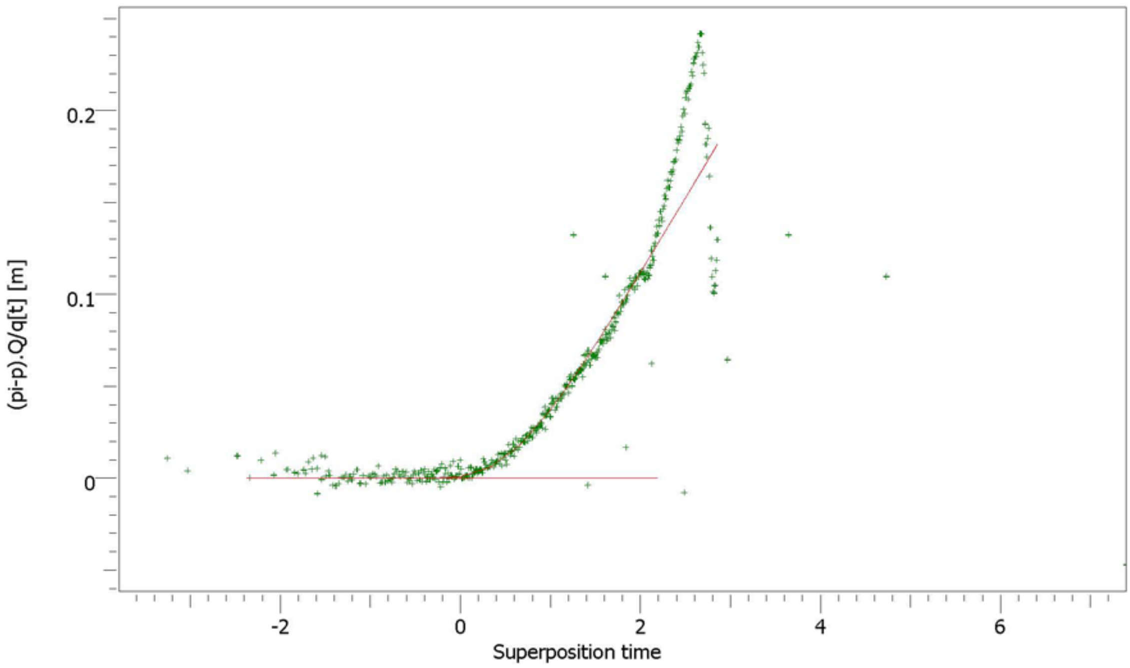
Model Parameters
Reservoir & Boundary parameters

Pi	10.95 m
T	0.00389 m2/s
K	0.00195 m/s
S	0.00814

Derived & Secondary Parameters

Rinv	1990 m
Test. Vol.	23496.8 MMm3

Semi-Log plot	Dd1
Company Svensk Kärnbränslehantering AB Well Observation well SSM223	Field Laxemar Test Name / # Interferenstest HLX35pump



SSM223 051215-060302 production #1
Rate 104.274 l/min
Rate change 104.274 l/min
P@dt=0 10.9463 m
Pi 10.95 m
Smoothing 0.2

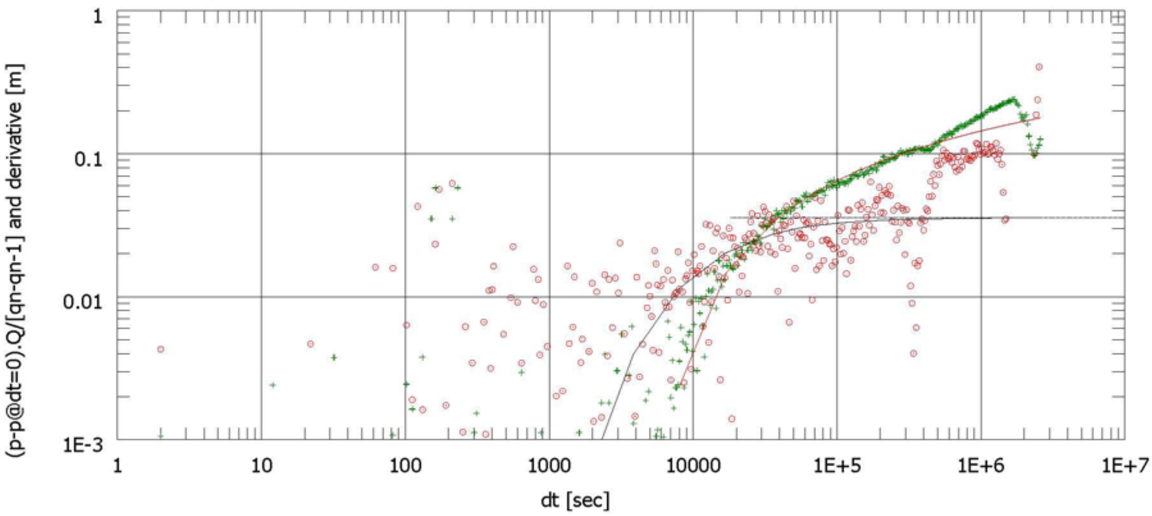
Selected Model
Model Option Standard Model
Well Line source
Reservoir Homogeneous
Boundary Infinite

Main Model Parameters
TMatch 2.74E-5 [sec]-1
PMatch 14 [m]-1
S 0.00814
T 0.00389 m2/s
K 0.00195 m/s
Pi 10.95 m
Well distance 132 m

Model Parameters
Reservoir & Boundary parameters
Pi 10.95 m
T 0.00389 m2/s
K 0.00195 m/s
S 0.00814

Derived & Secondary Parameters
Rinv 1990 m
Test. Vol. 23496.8 MMm3

Log-Log plot	Dd1
Company Svensk Kärnbränslehantering AB Well Observation well SSM223	Field Laxemar Test Name / # Interferenstest HLX35pump



SSM223 051215-060302 production #1

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	10.9463 m
Pi	10.95 m
Smoothing	0.2

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	2.74E-5 [sec]-1
PMatch	14 [m]-1
S	0.00814
T	0.00389 m2/s
K	0.00195 m/s
Pi	10.95 m
Well distance	132 m

Model Parameters

Reservoir & Boundary parameters

Pi	10.95 m
T	0.00389 m2/s
K	0.00195 m/s
S	0.00814

Derived & Secondary Parameters

Rinv	1990 m
Test. Vol.	23496.8 MMm3

Company	Svensk Kärnbränslehantering AB
Well	Observation well SSM223
Field	Laxemar
Test Name / #	Interferenstest HLX35pump

Test date / time	2006-01-10
Formation interval	1-8m
Perforated interval	6-8m
Gauge type / #	LevelTroll 30PSIA strain gauge
Gauge depth	8m below top of casing
Field crew	Jan Henriksson, NEA
Analysis	Mansueto Morosini, SKB
TEST TYPE	Interference
Well distance	132 m
Well Radius rw	0.25 m
Pay Zone h	2 m
Water Salt (ppm)	10000
Form. compr.	4.35113E-10 Pa-1
Reservoir T	12 °C
Reservoir P	152.957 m
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	4.35113E-10 Pa-1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	6.69E-4 [sec]-1
PMatch	32.9 [m]-1
S	7.86E-4
T	0.00916 m2/s
K	0.00458 m/s
Pi	10.95 m
Well distance	132 m

Model Parameters

Well & Wellbore parameters (Active well)

Skin	7.44

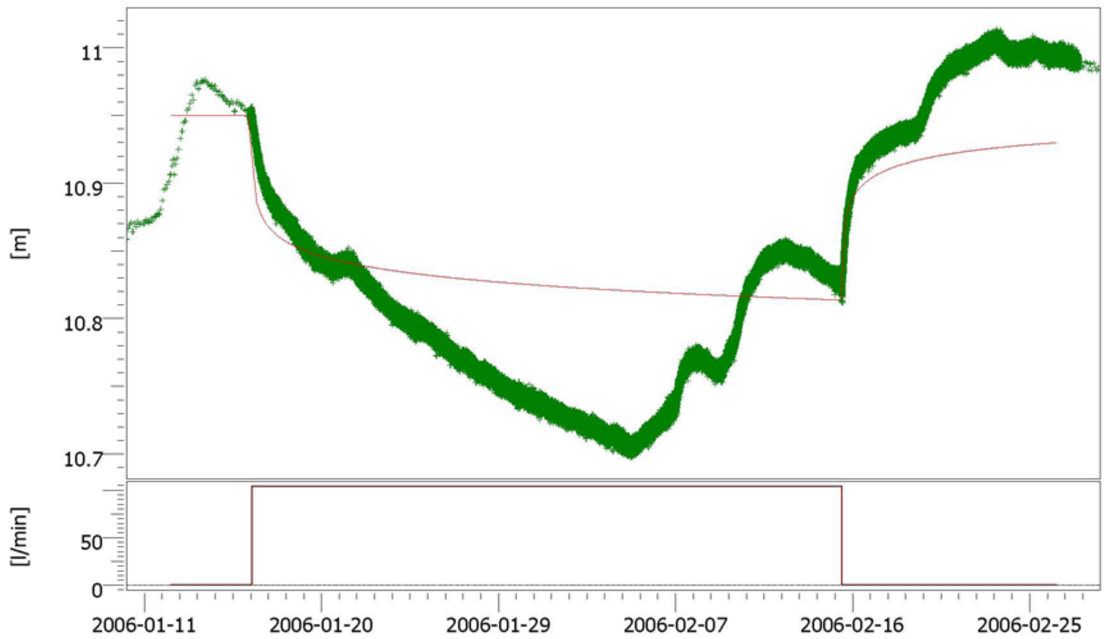
Reservoir & Boundary parameters

Pi	10.95 m
T	0.00916 m2/s
K	0.00458 m/s
S	7.86E-4

Derived & Secondary Parameters

Rinv	5900 m
Test. Vol.	19980.5 MMm3

History plot	Bu1
Company Svensk Kärnbränslehantering AB Well Observation well SSM223	Field Laxemar Test Name / # Interferenstest HLX35pump



Pressure [m], Liquid Rate [l/min] vs Time [ToD]

SSM223 051215-060302 build-up #1

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	10.8276 m
Pi	10.95 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	6.69E-4 [sec]-1
PMatch	32.9 [m]-1
S	7.86E-4
T	0.00916 m2/s
K	0.00458 m/s
Pi	10.95 m
Well distance	132 m

Model Parameters

Well & Wellbore parameters (Active well)

Skin	7.44

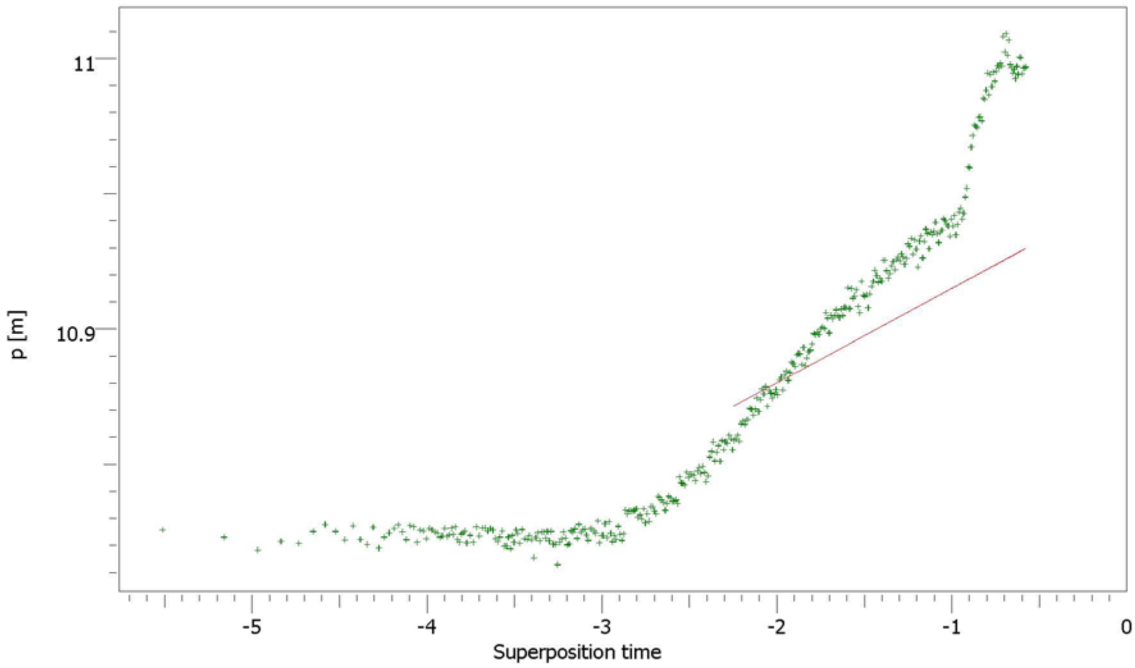
Reservoir & Boundary parameters

Pi	10.95 m
T	0.00916 m2/s
K	0.00458 m/s
S	7.86E-4

Derived & Secondary Parameters

Rinv	5900 m
Test. Vol.	19980.5 MMm3

Semi-Log plot	Bu1
Company Svensk Kärnbränslehantering AB Well Observation well SSM223	Field Laxemar Test Name / # Interferenstest HLX35pump



SSM223 051215-060302 build-up #1

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	10.8276 m
Pi	10.95 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	6.69E-4 [sec]-1
PMatch	32.9 [m]-1
S	7.86E-4
T	0.00916 m2/s
K	0.00458 m/s
Pi	10.95 m
Well distance	132 m

Model Parameters

Well & Wellbore parameters (Active well)

Skin	7.44

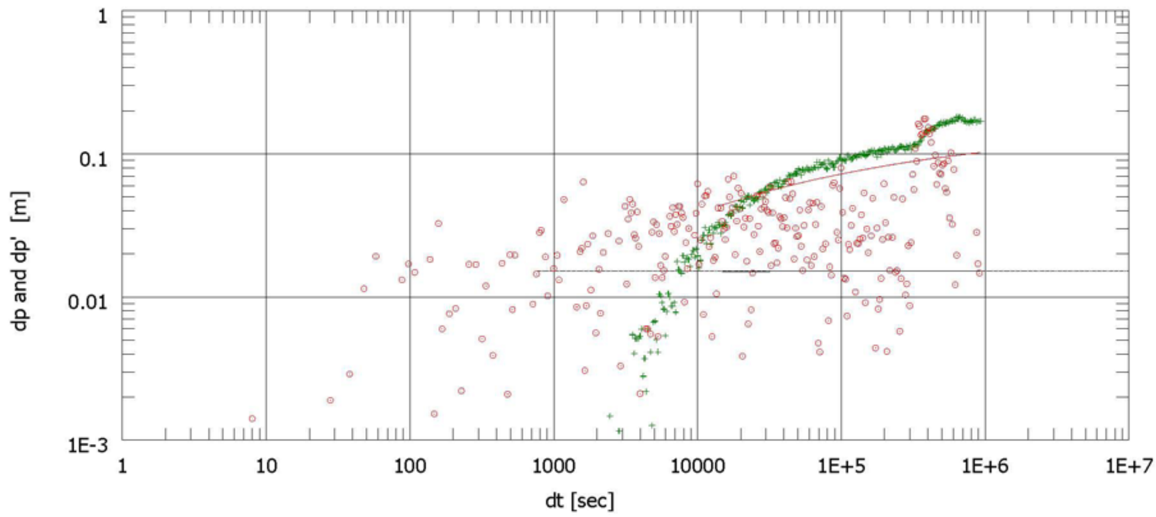
Reservoir & Boundary parameters

Pi	10.95 m
T	0.00916 m2/s
K	0.00458 m/s
S	7.86E-4

Derived & Secondary Parameters

Rinv	5900 m
Test. Vol.	19980.5 MMm3

Log-Log plot	Bu1
Company Svensk Kärnbränslehantering AB Well Observation well SSM223	Field Laxemar Test Name / # Interferenstest HLX35pump



SSM223 051215-060302 build-up #1

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	10.8276 m
Pi	10.95 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	6.69E-4 [sec]-1
PMatch	32.9 [m]-1
S	7.86E-4
T	0.00916 m2/s
K	0.00458 m/s
Pi	10.95 m
Well distance	132 m

Model Parameters

Well & Wellbore parameters (Active well)

Skin	7.44

Reservoir & Boundary parameters

Pi	10.95 m
T	0.00916 m2/s
K	0.00458 m/s
S	7.86E-4

Derived & Secondary Parameters

Rinv	5900 m
Test. Vol.	19980.5 MMm3

Main Results	Dd1_2porPSS
Company Svensk Kärnbränslehantering AB Well HLX34 obs	Field Laxemar Test Name / # Interferenstest HLX35pump

Test date / time	2006-01-10
Formation interval	9 - 151.8m
Perforated interval	9 - 151.8m
Gauge type / #	MiniTroll 30 PSIA, Ser#: 18807
Gauge depth	10m
Field Crew	Jan Henriksson, NEA
Analysis	Mansueto Morosini, SKB
Activityplan	AP PS 400-06-108
TEST TYPE	Interference
Well distance	168.5 m
Well Radius rw	0.07 m
Pay Zone h	152.8 m
Water Salt (ppm)	10000
Form. compr.	4.35113E-10 Pa-1
Reservoir T	12 °C
Reservoir P	152.957 m
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	4.35113E-10 Pa-1

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	2.41E-5 [sec]-1
PMatch	0.364 [m]-1
S	1.48E-4
T	1.01E-4 m2/s
K	6.64E-7 m/s
Pi	14.24 m
Well distance	168 m

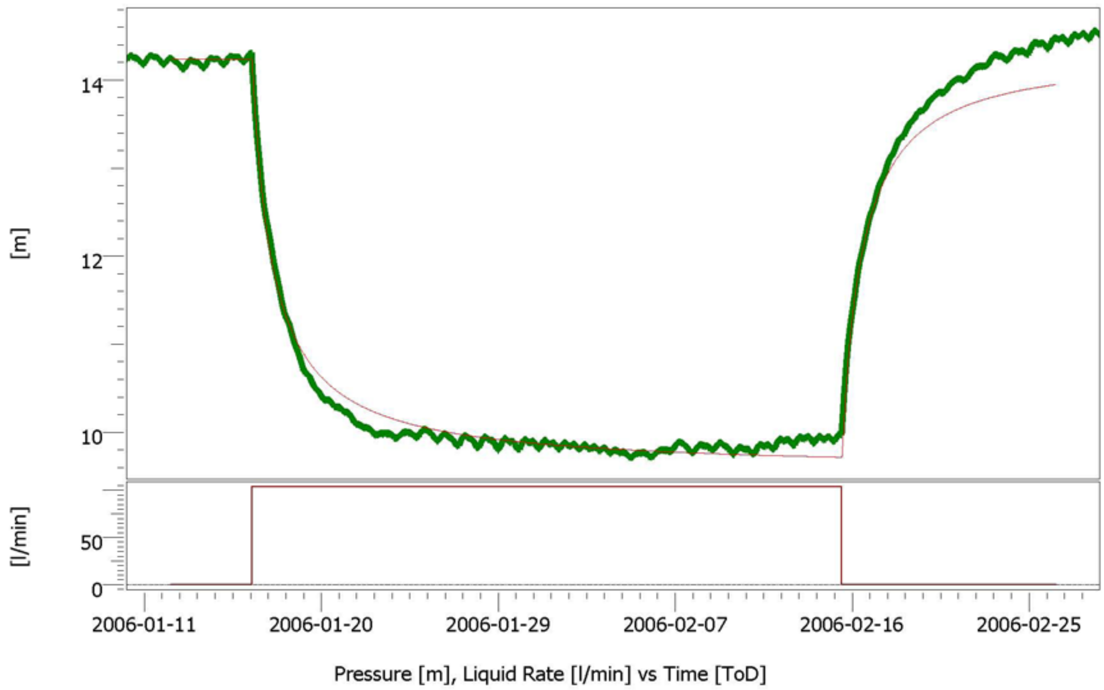
Model Parameters

Reservoir & Boundary parameters

Pi	14.24 m
T	1.01E-4 m2/s
K	6.64E-7 m/s
S	1.48E-4
Omega	0.472
Lambda	1.54E-6
L - Constant P.	454 m

Derived & Secondary Parameters

History plot	Dd1_2porPSS
Company Svensk Kärnbränslehantering AB Well HLX34 obs	Field Laxemar Test Name / # Interferenstest HLX35pump



HLX34 051215-060302 production #1

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	14.3044 m
Pi	14.24 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	2.41E-5 [sec]-1
PMatch	0.364 [m]-1
S	1.48E-4
T	1.01E-4 m2/s
K	6.64E-7 m/s
Pi	14.24 m
Well distance	168 m

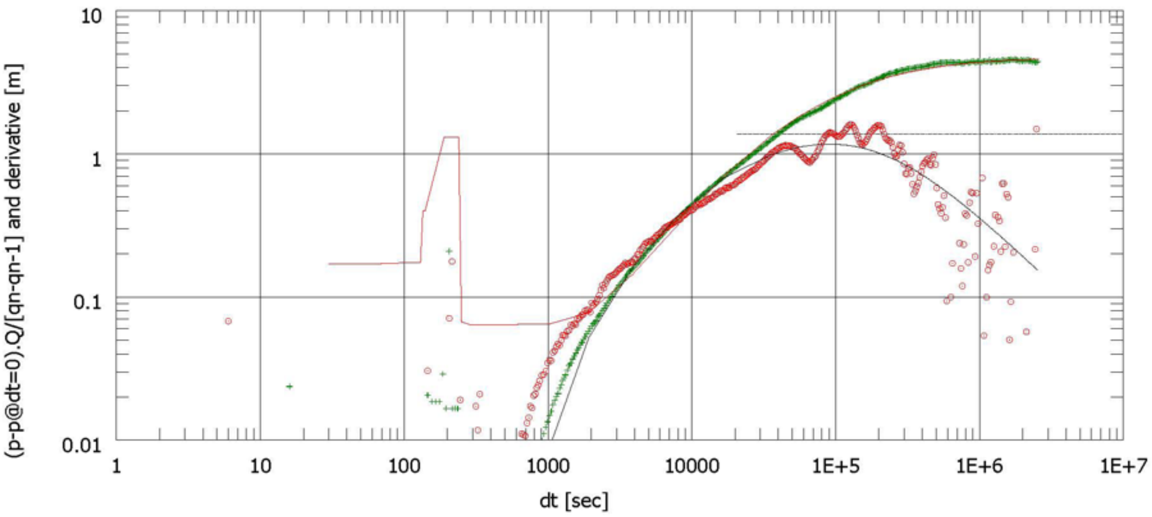
Model Parameters

Reservoir & Boundary parameters

Pi	14.24 m
T	1.01E-4 m2/s
K	6.64E-7 m/s
S	1.48E-4
Omega	0.472
Lambda	1.54E-6
L - Constant P.	454 m

Derived & Secondary Parameters

Log-Log plot	Dd1_2porPSS
Company Svensk Kärnbränslehantering AB Well HLX34 obs	Field Laxemar Test Name / # Interferenstest HLX35pump



HLX34 051215-060302 production #1

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	14.3044 m
Pi	14.24 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	2.41E-5 [sec]-1
PMatch	0.364 [m]-1
S	1.48E-4
T	1.01E-4 m2/s
K	6.64E-7 m/s
Pi	14.24 m
Well distance	168 m

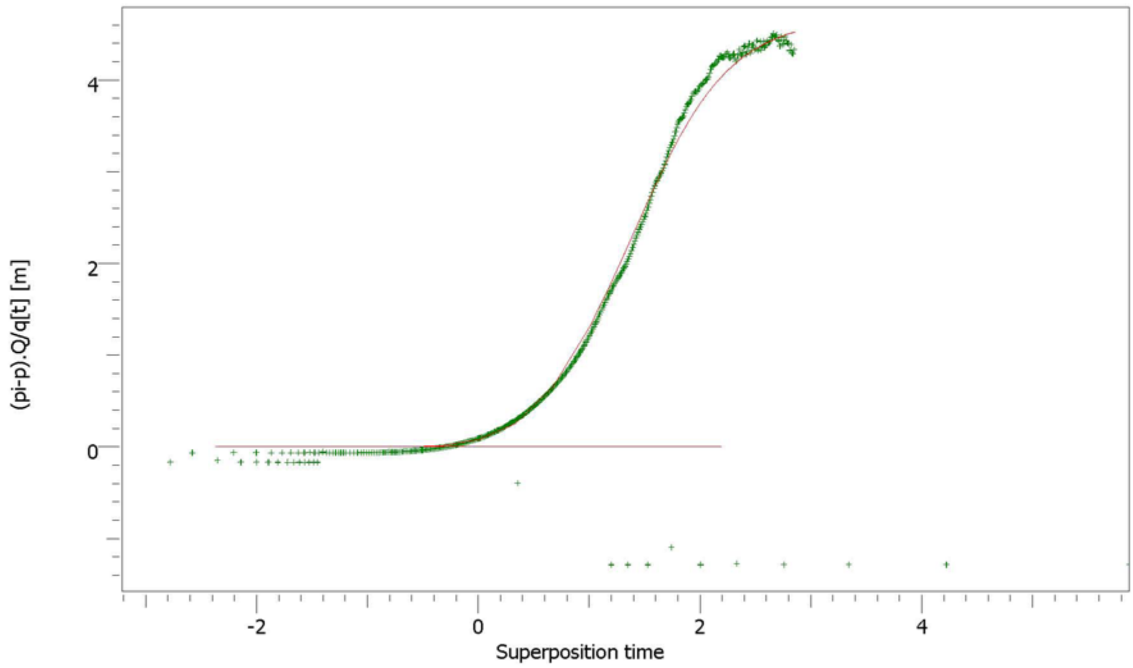
Model Parameters

Reservoir & Boundary parameters

Pi	14.24 m
T	1.01E-4 m2/s
K	6.64E-7 m/s
S	1.48E-4
Omega	0.472
Lambda	1.54E-6
L - Constant P.	454 m

Derived & Secondary Parameters

Semi-Log plot	Dd1_2porPSS
Company Svensk Kärnbränslehantering AB Well HLX34 obs	Field Laxemar Test Name / # Interferenstest HLX35pump



HLX34 051215-060302 production #1

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	14.3044 m
Pi	14.24 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	2.41E-5 [sec]-1
PMatch	0.364 [m]-1
S	1.48E-4
T	1.01E-4 m2/s
K	6.64E-7 m/s
Pi	14.24 m
Well distance	168 m

Model Parameters

Reservoir & Boundary parameters

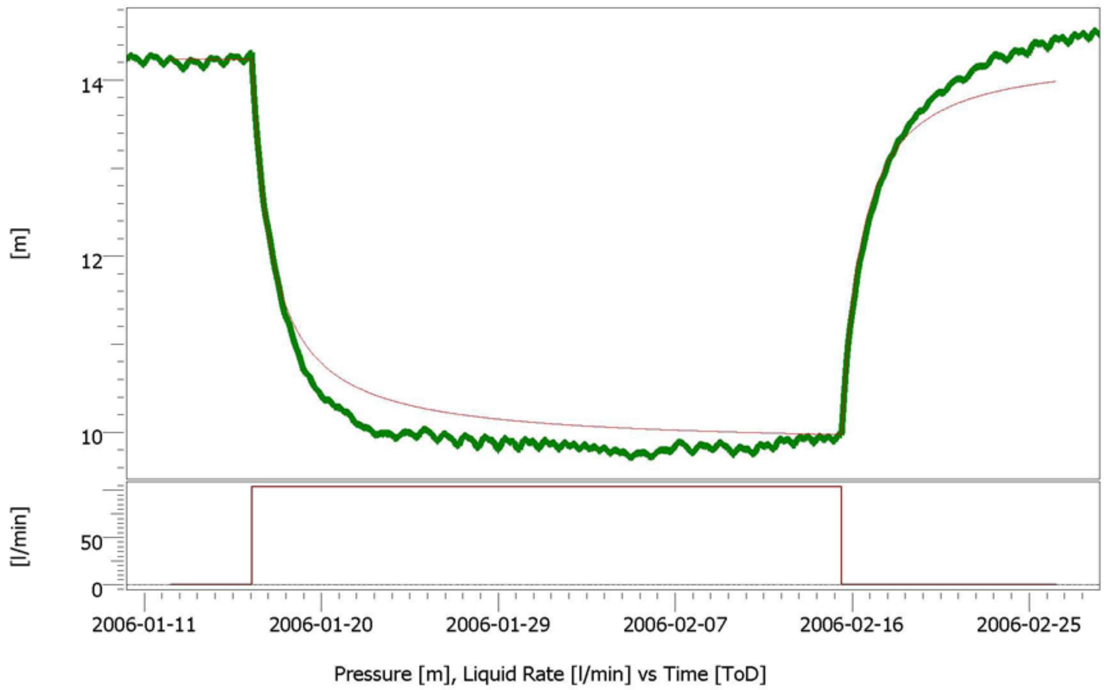
Pi	14.24 m
T	1.01E-4 m2/s
K	6.64E-7 m/s
S	1.48E-4
Omega	0.472
Lambda	1.54E-6
L - Constant P.	454 m

Derived & Secondary Parameters

Ecrin v4.02.03 HLX34obs_masl 2007-03-14 Page 4/8

Test date / time	2006-01-10
Formation interval	9 - 151.8m
Perforated interval	9 - 151.8m
Gauge type / #	MiniTroll 30 PSIA, Ser#: 18807
Gauge depth	10m
Field Crew	Jan Henriksson, NEA
Analysis	Mansueto Morosini, SKB
Activityplan	AP PS 400-06-108
TEST TYPE	Interference
Well distance	168.5 m
Well Radius rw	0.07 m
Pay Zone h	152.8 m
Water Salt (ppm)	10000
Form. compr.	4.35113E-10 Pa-1
Reservoir T	12 °C
Reservoir P	152.957 m
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	4.35113E-10 Pa-1
Selected Model	
Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault
Main Model Parameters	
TMatch	2.27E-5 [sec]-1
PMatch	0.365 [m]-1
S	1.57E-4
T	1.02E-4 m2/s
K	6.65E-7 m/s
Pi	14.24 m
Well distance	168 m
Model Parameters	
Reservoir & Boundary parameters	
Pi	14.24 m
T	1.02E-4 m2/s
K	6.65E-7 m/s
S	1.57E-4
Omega	0.21
Lambda	1.92E-6
L - Constant P.	411 m
Derived & Secondary Parameters	

History plot	Bu1_2porPSS
Company Svensk Kärnbränslehantering AB Well HLX34 obs	Field Laxemar Test Name / # Interferenstest HLX35pump



HLX34 051215-060302 build-up #1

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	9.97824 m
Pi	14.24 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	2.27E-5 [sec]-1
PMatch	0.365 [m]-1
S	1.57E-4
T	1.02E-4 m2/s
K	6.65E-7 m/s
Pi	14.24 m
Well distance	168 m

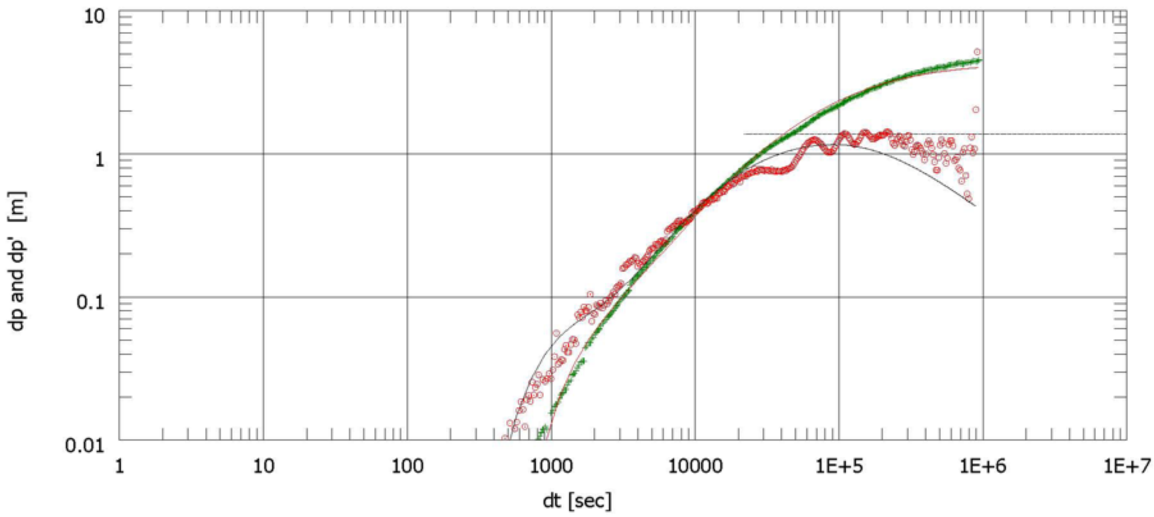
Model Parameters

Reservoir & Boundary parameters

Pi	14.24 m
T	1.02E-4 m2/s
K	6.65E-7 m/s
S	1.57E-4
Omega	0.21
Lambda	1.92E-6
L - Constant P.	411 m

Derived & Secondary Parameters

Log-Log plot	Bu1_2porPSS
Company Svensk Kärnbränslehantering AB Well HLX34 obs	Field Laxemar Test Name / # Interferenstest HLX35pump



HLX34 051215-060302 build-up #1

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	9.97824 m
Pi	14.24 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	2.27E-5 [sec]-1
PMatch	0.365 [m]-1
S	1.57E-4
T	1.02E-4 m2/s
K	6.65E-7 m/s
Pi	14.24 m
Well distance	168 m

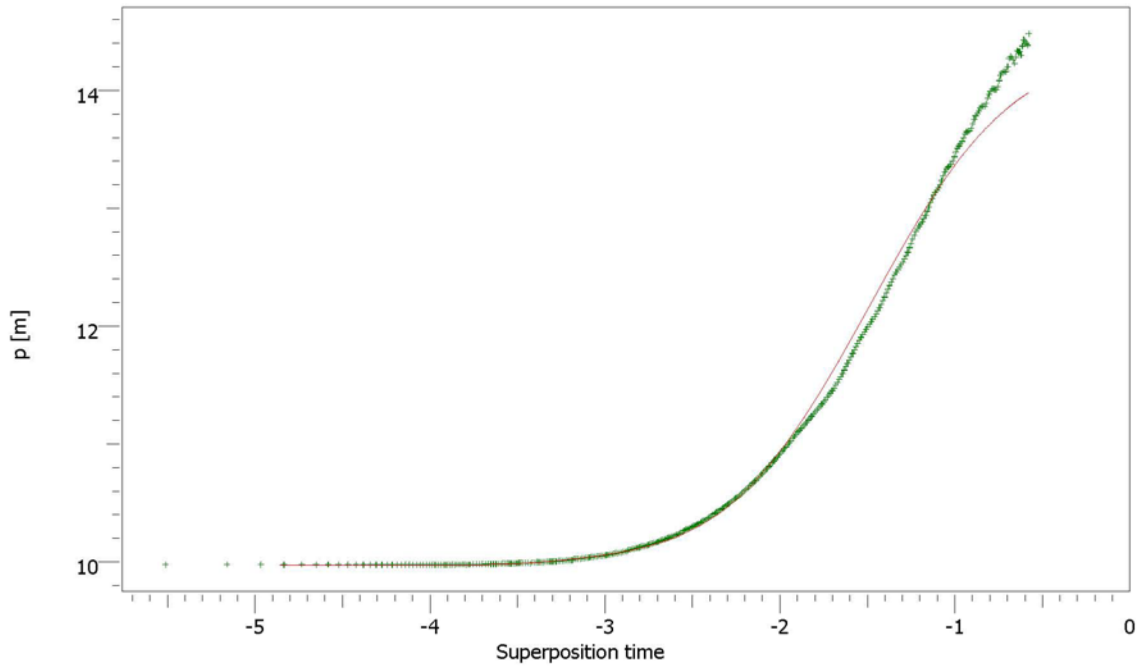
Model Parameters

Reservoir & Boundary parameters

Pi	14.24 m
T	1.02E-4 m2/s
K	6.65E-7 m/s
S	1.57E-4
Omega	0.21
Lambda	1.92E-6
L - Constant P.	411 m

Derived & Secondary Parameters

	Semi-Log plot	Bu1_2porPSS
SKB	Company Svensk Kärnbränslehantering AB Well HLX34 obs	Field Laxemar Test Name / # Interferenstest HLX35pump



HLX34 051215-060302 build-up #1

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	9.97824 m
Pi	14.24 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Line source
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	2.27E-5 [sec]-1
PMatch	0.365 [m]-1
S	1.57E-4
T	1.02E-4 m2/s
K	6.65E-7 m/s
Pi	14.24 m
Well distance	168 m

Model Parameters

Reservoir & Boundary parameters

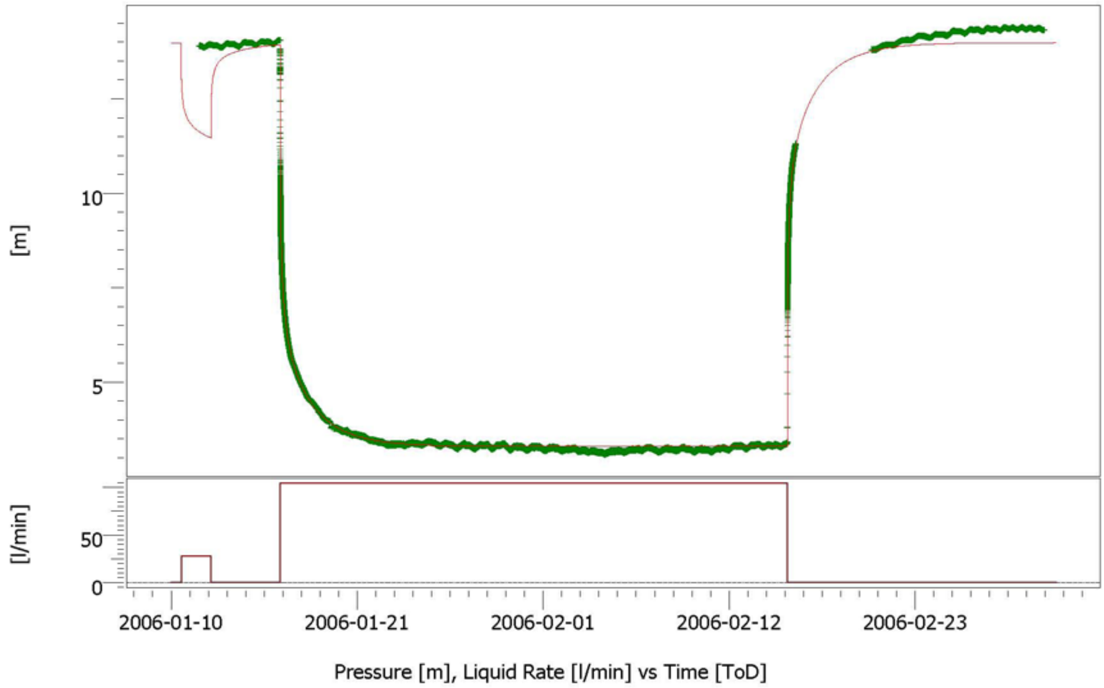
Pi	14.24 m
T	1.02E-4 m2/s
K	6.65E-7 m/s
S	1.57E-4
Omega	0.21
Lambda	1.92E-6
L - Constant P.	411 m

Derived & Secondary Parameters

SKB	Main Results	Dd2_2por
	Company Svensk Kärnbränslehantering AB Well HLX35	Field Laxemar Test Name / # Interference test HLX35pump

Test date / time	2005-01-10
Formation interval	6.10 - 151.8m borehole length
Perforated interval	6.10 - 151.8m borehole length
Gauge type / #	MiniTroll 30PSIA starin gauge
Gauge depth	10.0m below top of casing
Field crew	Jan Henriksson, NEA
Analysis	Mansueto Morosini, SKB
Activityplan	AP PS 400-06-108
TEST TYPE	Standard
Porosity Phi (%)	5
Well Radius rw	0.07 m
Pay Zone h	145 m
Water Salt (ppm)	10000
Form. compr.	8.70226E-10 Pa-1
Reservoir T	10 °C
Reservoir P	150 m
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	2E-9 Pa-1
Selected Model	
Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	Circle, Constant P.
Main Model Parameters	
TMatch	0.0201 [sec]-1
PMatch	0.408 [m]-1
C	3.59E-6 m3/Pa
Total Skin	-5.82
T	1.12E-4 m2/s
K	7.75E-7 m/s
Pi	13.98 m
Model Parameters	
Well & Wellbore parameters (HLX35)	
C	3.59E-6 m3/Pa
Skin	-5.82
Reservoir & Boundary parameters	
Pi	13.98 m
T	1.12E-4 m2/s
K	7.75E-7 m/s
Omega	0.0825
Lambda	8.03E-7
Re - Constant P.	1840 m
Derived & Secondary Parameters	
Delta P (Total Skin)	-14.2613 m
Delta P Ratio (Total Skin)	-1.34211 Fraction

History plot	Dd2_2por
Company Svensk Kärnbränslehantering AB Well HLX35	Field Laxemar Test Name / # Interference test HLX35pump



HLX35pump_Head_masl_exported from Origin production #2

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	14.052 m
Pi	13.98 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	Circle, Constant P.

Main Model Parameters

TMatch	0.0201 [sec]-1
PMatch	0.408 [m]-1
C	3.59E-6 m3/Pa
Total Skin	-5.82
T	1.12E-4 m2/s
K	7.75E-7 m/s
Pi	13.98 m

Model Parameters

Well & Wellbore parameters (HLX35)

C	3.59E-6 m3/Pa
Skin	-5.82

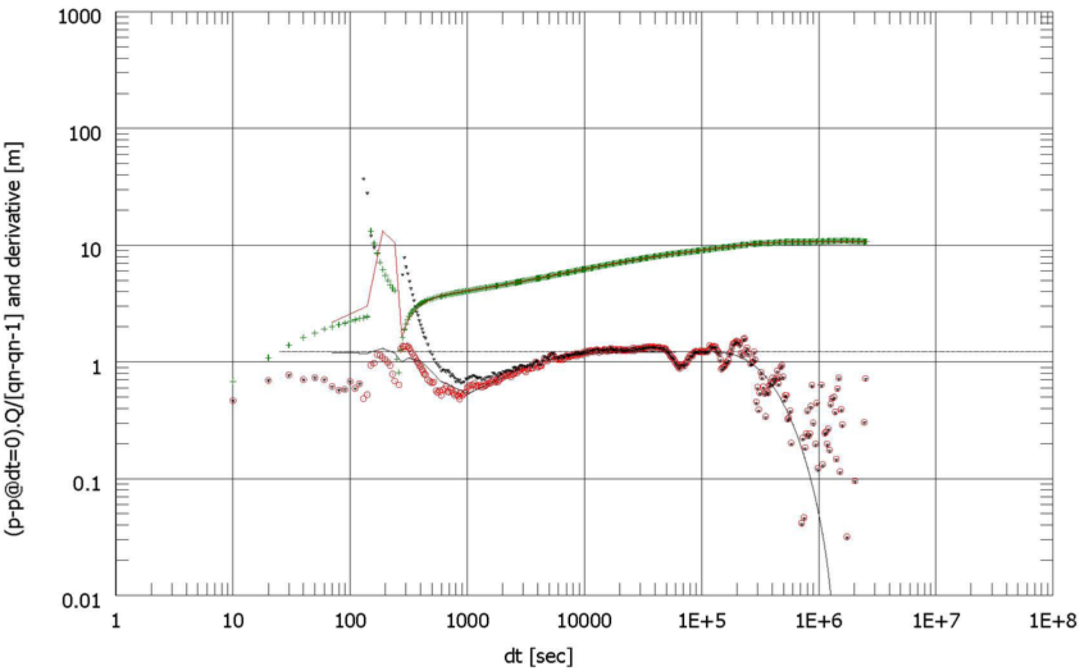
Reservoir & Boundary parameters

Pi	13.98 m
T	1.12E-4 m2/s
K	7.75E-7 m/s
Omega	0.0825
Lambda	8.03E-7
Re - Constant P.	1840 m

Derived & Secondary Parameters

Delta P (Total Skin)	-14.2613 m
Delta P Ratio (Total Skin)	-1.34211 Fraction

Log-Log plot	Dd2_2por
Company Svensk Kärnbränslehantering AB Well HLX35	Field Laxemar Test Name / # Interference test HLX35pump



HLX35pump_Head_masl_exported from Origin production #2

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	14.052 m
Pi	13.98 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	Circle, Constant P.

Main Model Parameters

TMatch	0.0201 [sec]-1
PMatch	0.408 [m]-1
C	3.59E-6 m3/Pa
Total Skin	-5.82
T	1.12E-4 m2/s
K	7.75E-7 m/s
Pi	13.98 m

Model Parameters

Well & Wellbore parameters (HLX35)

C	3.59E-6 m3/Pa
Skin	-5.82

Reservoir & Boundary parameters

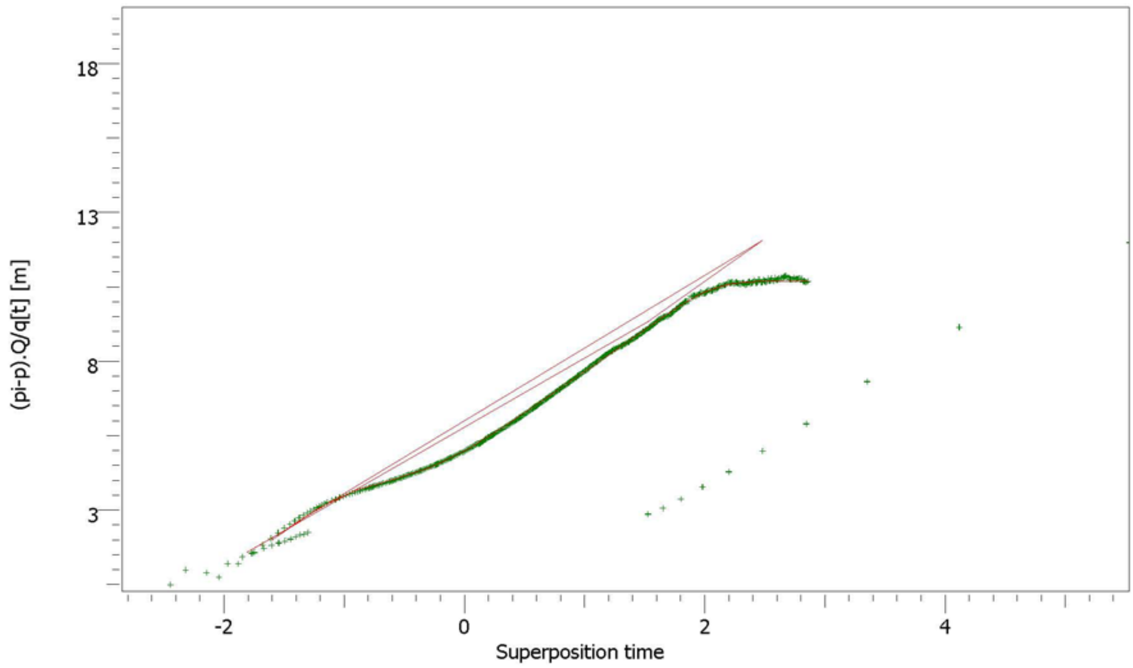
Pi	13.98 m
T	1.12E-4 m2/s
K	7.75E-7 m/s
Omega	0.0825
Lambda	8.03E-7
Re - Constant P.	1840 m

Derived & Secondary Parameters

Delta P (Total Skin)	-14.2613 m
Delta P Ratio (Total Skin)	-1.34211 Fraction

Ecrin v4.02.03 HLX35pump_masl_070315 — 2007-03-15 — Page 3/8

Semi-Log plot	Dd2_2por
Company Svensk Kärnbränslehantering AB Well HLX35	Field Laxemar Test Name / # Interference test HLX35pump



HLX35pump_Head_masl_exported from Origin production #2

Rate	104.274 l/min
Rate change	104.274 l/min
P@dt=0	14.052 m
Pi	13.98 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	Circle, Constant P.

Main Model Parameters

TMatch	0.0201 [sec]-1
PMatch	0.408 [m]-1
C	3.59E-6 m3/Pa
Total Skin	-5.82
T	1.12E-4 m2/s
K	7.75E-7 m/s
Pi	13.98 m

Model Parameters

Well & Wellbore parameters (HLX35)

C	3.59E-6 m3/Pa
Skin	-5.82

Reservoir & Boundary parameters

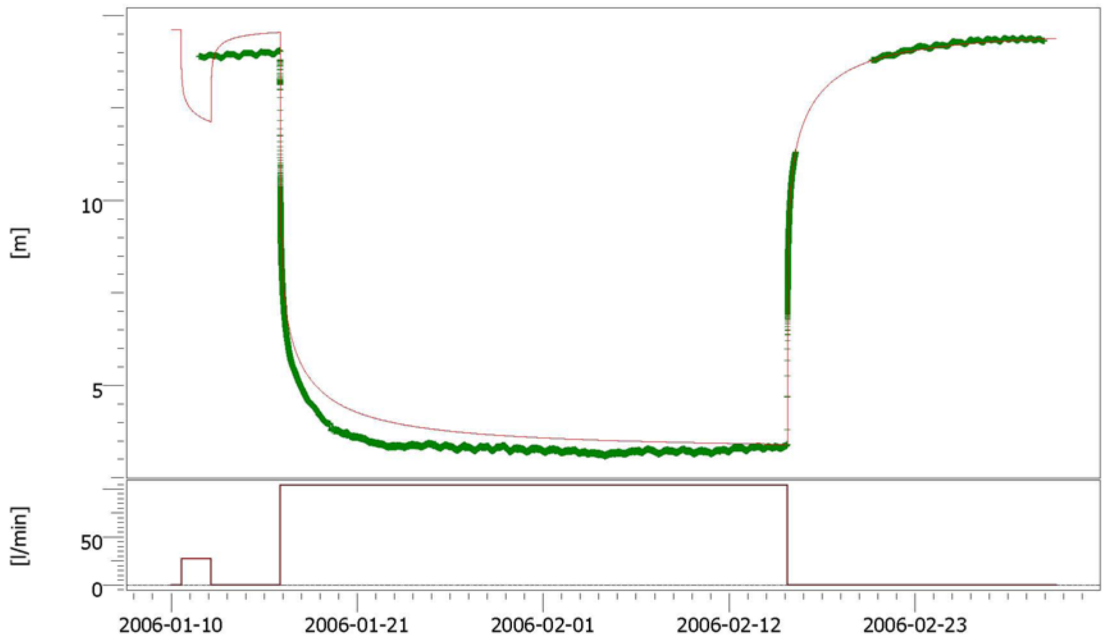
Pi	13.98 m
T	1.12E-4 m2/s
K	7.75E-7 m/s
Omega	0.0825
Lambda	8.03E-7
Re - Constant P.	1840 m

Derived & Secondary Parameters

Delta P (Total Skin)	-14.2613 m
Delta P Ratio (Total Skin)	-1.34211 Fraction

Test date / time	2005-01-10
Formation interval	6.10 - 151.8m borehole length
Perforated interval	6.10 - 151.8m borehole length
Gauge type / #	MiniTroll 30PSIA starin gauge
Gauge depth	10.0m below top of casing
Field crew	Jan Henriksson, NEA
Analysis	Mansueto Morosini, SKB
Activityplan	AP PS 400-06-108
TEST TYPE	Standard
Porosity Phi (%)	5
Well Radius rw	0.07 m
Pay Zone h	145 m
Water Salt (ppm)	10000
Form. compr.	8.70226E-10 Pa-1
Reservoir T	10 °C
Reservoir P	150 m
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	2E-9 Pa-1
Selected Model	
Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	One fault
Main Model Parameters	
TMatch	0.137 [sec]-1
PMatch	0.434 [m]-1
C	5.61E-7 m3/Pa
Total Skin	-5.63
T	1.2E-4 m2/s
K	8.24E-7 m/s
Pi	14.624 m
Model Parameters	
Well & Wellbore parameters (HLX35)	
C	5.61E-7 m3/Pa
Skin	-5.63
Reservoir & Boundary parameters	
Pi	14.624 m
T	1.2E-4 m2/s
K	8.24E-7 m/s
Omega	0.0739
Lambda	7.96E-7
L - Constant P.	1380 m
Derived & Secondary Parameters	
Delta P (Total Skin)	-12.9819 m
Delta P Ratio (Total Skin)	-1.18257 Fraction

History plot	Bu2_2por
Company Svensk Kärnbränslehantering AB Well HLX35	Field Laxemar Test Name / # Interference test HLX35pump



Pressure [m], Liquid Rate [l/min] vs Time [ToD]

HLX35pump_Head_masl_exported from Origin build-up #2

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	3.40379 m
Pi	14.624 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	0.137 [sec]-1
PMatch	0.434 [m]-1
C	5.61E-7 m3/Pa
Total Skin	-5.63
T	1.2E-4 m2/s
K	8.24E-7 m/s
Pi	14.624 m

Model Parameters

Well & Wellbore parameters (HLX35)

C	5.61E-7 m3/Pa
Skin	-5.63

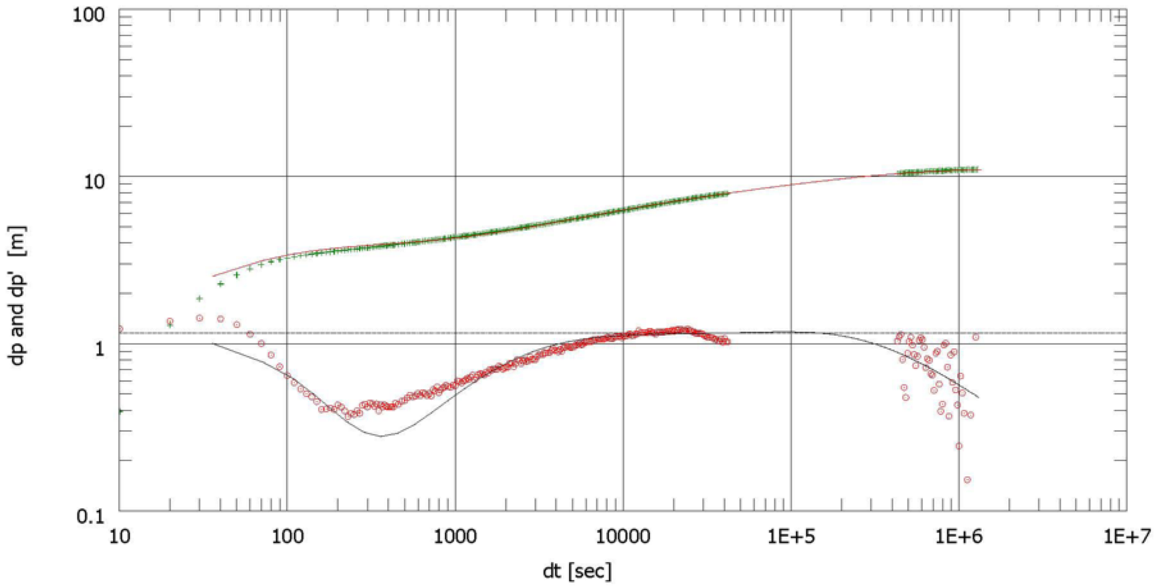
Reservoir & Boundary parameters

Pi	14.624 m
T	1.2E-4 m2/s
K	8.24E-7 m/s
Omega	0.0739
Lambda	7.96E-7
L - Constant P.	1380 m

Derived & Secondary Parameters

Delta P (Total Skin)	-12.9819 m
Delta P Ratio (Total Skin)	-1.18257 Fraction

Log-Log plot	Bu2_2por
Company Svensk Kärnbränslehantering AB Well HLX35	Field Laxemar Test Name / # Interference test HLX35pump



HLX35pump_Head_masl_exported from Origin build-up #2

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	3.40379 m
Pi	14.624 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	One fault

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TMatch	0.137 [sec]-1
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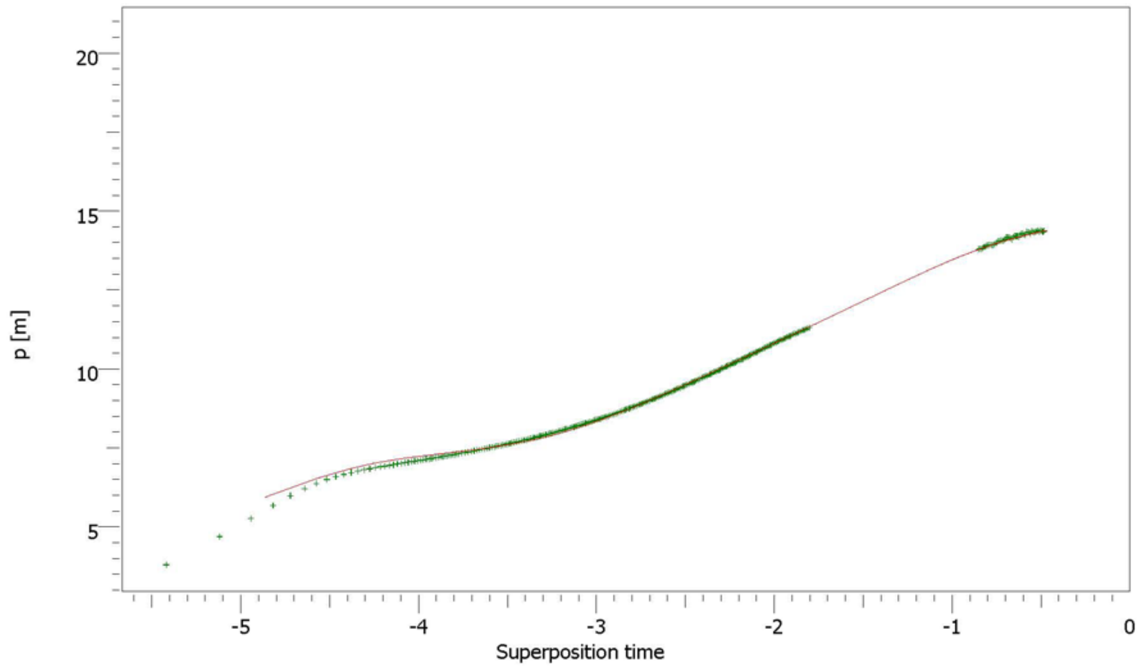
T	1.2E-4 m2/s
K	8.24E-7 m/s
Omega	0.0739
Lambda	7.96E-7
L - Constant P.	1380 m

Derived & Secondary Parameters

Delta P (Total Skin)	-12.9819 m
Delta P Ratio (Total Skin)	-1.18257 Fraction

Semi-Log plot	Bu2_2por
Company Svensk Kärnbränslehantering AB Well HLX35	Field Laxemar Test Name / # Interference test HLX35pump



HLX35pump_Head_masl_exported from Origin build-up #2

Rate	0 l/min
Rate change	104.274 l/min
P@dt=0	3.40379 m
Pi	14.624 m
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Two porosity PSS
Boundary	One fault

Main Model Parameters

TMatch	0.137 [sec]-1
PMatch	0.434 [m]-1
C	5.61E-7 m3/Pa
Total Skin	-5.63
T	1.2E-4 m2/s
K	8.24E-7 m/s
Pi	14.624 m

Model Parameters

Well & Wellbore parameters (HLX35)

C	5.61E-7 m3/Pa
Skin	-5.63

Reservoir & Boundary parameters

Pi	14.624 m
T	1.2E-4 m2/s
K	8.24E-7 m/s
Omega	0.0739
Lambda	7.96E-7
L - Constant P.	1380 m

Derived & Secondary Parameters

Delta P (Total Skin)	-12.9819 m
Delta P Ratio (Total Skin)	-1.18257 Fraction

Appendix 7

Nomenclature

Yellow marked parameters are used in SICADA while the other appear only in the P-report.

Parameter	Explanation	Unit
b	Representative aquifer thickness for inferred transmissivity, generally estimated as test section length L_w.	m
B	Inferred width of formation for evaluated TB.	m
L	Corrected borehole length.	m
L_0	Uncorrected borehole length.	m
L_c	Length of borehole casing.	m
L_p	Hydraulic point of application for a test section, based on the geometric midpoint of test section or the main point of transmissivity distribution in test section.	m
L_w	Test section length.	m
r_c	Inner radius of borehole casing.	m
r_w	Nominal radius of borehole or well.	m
r_{wa}	Estimated borehole radius.	m
r_{wf}	Effective radius of borehole or well in the test section. (Considering of skin factor).	m
r_i	Influence radius.	m
r_D	Dimensionless radius, $r_D = r/r_w$.	–
z	Level above(+)/below(–) reference point. Positive direction upwards.	m
z_s	Level of sensor measuring response in borehole section.	m
Q	Flow rate.	m^3/s
Q_p	Flow rate at the end of flow (i.e. injection or pumping) period.	m^3/s
Q_m	Arithmetic mean of flow rate during flow period.	m^3/s
$Q_{measl\text{-}L}$	Estimated lower measurement limit for flow rate.	m^3/s
$Q_{measl\text{-}U}$	Estimated upper measurement limit for flow rate.	m^3/s
V	Volume.	m^3
V_w	Water volume in test section.	m^3
V_p	Total water volume pumped or injected during flow period.	m^3
t	Time from start of flow period.	s
t_{ps}	Duration of packer sealing (from packer sealing to start of flow period).	s
t_p	Duration of flow period.	s
t_{pp}	Pseudo-duration of flow period for constant head test ($t_{pp} = V_p/Q_p$).	s
t_F	Duration of recovery period.	s
t_1	Start time for evaluated parameter from start of flow period.	s
t_2	Stop time for evaluated parameter from start of flow period.	s
dt	Time from start of recovery period.	s
dt_e	Agarwal equivalent time.	s
dt_{e1}	Start time for evaluated parameter from start of recovery period.	s
dt_{e2}	Stop time for evaluated parameter from start of recovery period.	s
t_D	Dimensionless time, $t_D = T \cdot t / (S \cdot r_w^2)$.	–
p	Water pressure at certain depth below ground surface in open borehole or sealed-off test section.	kPa
p_{atm}	Atmospheric pressure.	kPa
p_{abs}	Absolute pressure; $p_{abs} = p_{atm}+p_g$.	kPa
p_g	Gauge pressure; Difference pressure between absolute pressure and atmospheric pressure.	kPa

Parameter	Explanation	Unit
p_0	Groundwater pressure in open borehole (before packer sealing).	kPa
p_i	Groundwater pressure in test section at start of flow period.	kPa
p_f	Groundwater pressure in test section during flow period.	kPa
p_p	Groundwater pressure in test section at stop of flow period.	kPa
p_s	Groundwater pressure in test section during recovery period.	kPa
p_F	Groundwater pressure in test section at stop of recovery period.	kPa
p_e	Groundwater pressure in open borehole (after packer release).	kPa
p_{ai}	Groundwater pressure above test section at start of flow period.	kPa
p_{ap}	Groundwater pressure above test section at stop of flow period.	kPa
p_{aF}	Groundwater pressure above test section at stop of recovery period.	kPa
p_{bi}	Groundwater pressure below test section at start of flow period.	kPa
p_{bp}	Groundwater pressure below test section at stop of flow period.	kPa
p_{bF}	Groundwater pressure below test section at stop of recovery period.	kPa
p^*	Horner extrapolated pressure (used as an estimation of natural pressure of the test section).	kPa
p_D	Dimensionless pressure, $p_D = 2\pi \cdot T \cdot p/(Q \cdot \rho_w \cdot g)$.	–
dp	Absolute pressure difference.	kPa
dp_f	$dp_f = \lvert p_i - p_f \rvert$ pressure difference between pressure at start of flow period and pressure during flow period.	kPa
dp_s	$dp_s = \lvert p_p - p_s \rvert$ pressure difference between pressure at stop of flow period and pressure during recovery period.	kPa
dp_p	$dp_p = \lvert p_i - p_p \rvert$ pressure difference between pressure at start of flow period and pressure at stop flow period.	kPa
dp_F	$dp_F = \lvert p_p - p_F \rvert$ pressure difference between pressure at stop of flow period and pressure at stop recovery period.	kPa
h	Hydraulic head (piezometric head) at certain depth below ground surface in open borehole or sealed-off test section.	m
h_0	Hydraulic head measured as water level in open borehole (before packer expansion).	m
h_i	Hydraulic head in test section at start of flow period.	m
h_f	Hydraulic head in test section during flow period.	m
h_p	Hydraulic head in test section at stop of flow period.	m
h_s	Hydraulic head in test section during recovery period.	m
h_F	Hydraulic head in test section at stop of recovery period.	m
dh	Absolute hydraulic head difference.	m
dh_f	$dh_f = \lvert h_i - h_f \rvert$ hydraulic head difference between pressure at start of flow period and pressure during flow period.	m
dh_s	$dh_s = \lvert h_p - h_s \rvert$ hydraulic head difference between pressure at stop of flow period and pressure during recovery period.	m
dh_p	$dh_p = \lvert h_i - h_p \rvert$ hydraulic head difference between pressure at start of flow period and pressure at stop flow period.	m
dh_F	$dh_F = \lvert h_p - h_F \rvert$ hydraulic head difference between pressure at stop of flow period and pressure at stop recovery period.	m
s	Drawdown of water level during hydraulic test.	m
s_p	Drawdown in test section at stop of flow period.	m
Te_w	Measured borehole fluid temperature in the test section (representative for evaluated parameters, in general the last temperature value).	°C
EC_w	Measured electric conductivity of the borehole fluid in the test section (representative for evaluated parameters, in general the last EC value).	mS/m
TDS_w	Calculated total dissolved solids of the borehole fluid in the test section, based on EC-measurement.	mg/L
TDS_{wm}	Measured total dissolved solids of the borehole fluid in the test section, based on water sampling and chemical analysis.	mg/L
Q/s	Specific capacity, generally estimated from Q_p, s_p or dh_p.	m^2/s

Parameter	Explanation	Unit
$Q/s_{measl-L}$	Estimated lower measurement limit for Q/s or evaluated T (T_T, T_Q, T_M).	m^2/s
$Q/s_{measl-U}$	Estimated upper measurement limit for Q/s or evaluated T (T_T, T_Q, T_M).	m^2/s
D	Inferred flow dimension. Considered best estimate from transient evaluation of flow period or recovery period.	–
D_{GRF}	Inferred flow dimension, based on the Generalized Radial Flow model /Barker 1988/. Considered best estimate from transient evaluation of flow period or recovery period.	–
TB	Flow capacity in 1D formation of width B and transmissivity T based on transient evaluation. Considered best estimate from transient evaluation of flow period or recovery period.	m^3/s
$TB_{measl-L}$	Estimated lower measurement limit for evaluated TB.	m^3/s
$TB_{measl-U}$	Estimated upper measurement limit for evaluated TB.	m^3/s
T	Transmissivity of formation, based on 2D radial flow model.	m^2/s
T_M	Transmissivity, based on /Moye 1967/.	m^2/s
T_Q	Transmissivity, based on Q/s and a function T = f(Q/s), see e.g. /Rhén et al. 1997/ s. 190. The function used should be refered to in "Comments".	m^2/s
T_T	Transmissivity of formation, based on 2D radial flow model. Considered best estimate from transient evaluation of flow period or recovery period.	m^2/s
T_R	Representative transmissivity (T_T, T_Q, T_M) for the borehole section from the routine (basic) evaluation.	m^2/s
T_{NLR}	Transmissivity, based on Non Linear Regression of the entire test sequence.	m^2/s
T_{GRF}	Transmissivity, based on the Generalized Radial Flow model /Barker 1988/. Considered best estimate from transient evaluation of flow period or recovery period.	m^2/s
T_{Tf}	Transmissivity of single fracture. Considered best estimate from transient evaluation of flow period or recovery period.	m^2/s
K	Hydraulic conductivity of formation, based on 2D radial flow model. Considered best estimate from transient evaluation of flow period or recovery period.	m/s
K_{sf}	Hydraulic conductivity of formation, based on 3D spherical flow model. Considered best estimate from transient evaluation of flow period or recovery period.	m/s
$K_{sf-measl-L}$	Estimated lower measurement limit for evaluated K_{sf}.	m/s
$K_{sf-measl-U}$	Estimated upper measurement limit for evaluated K_{sf}.	m/s
K_m	Hydraulic conductivity for rock matrix (double porosity). Considered best estimate from transient evaluation of flow period or recovery period.	m/s
K_f	Average hydraulic conductivity of fracture system (double porosity). Considered best estimate from transient evaluation of flow period or recovery period.	m/s
K´/b´	Leakage coefficient evaluated from 2D radial flow model. K´ = hydraulic conductivity across the aquitard, b´ = water saturated thickness of aquitard (leaky formation). Considered best estimate from transient evaluation of flow period or recovery period.	1/s
SB	Storage capacity of 1D formation of width B and storativity S based on transient evaluation. Considered best estimate from transient evaluation of flow period or recovery period.	m
SB*	Assumed storage capacity of 1D formation of width B and storativity S based on transient evaluation.	m
S	Storativity (Storage coefficient) of formation based on 2D radial flow model. Considered best estimate from transient evaluation of flow period or recovery period.	–
S*	Assumed storativity of formation based on 2D radial flow model.	–
S_S	Specific storage of formation based on 2D radial flow model. Considered best estimate from transient evaluation of flow period or recovery period.	1/m
S_f	Average storativity of fracture system (double porosity). Considered best estimate from transient evaluation of flow period or recovery period.	–
S_m	Storativity of rock matrix (double porosity). Considered best estimate from transient evaluation of flow period or recovery period.	–
S_{NLR}	Storativity, based on Non Linear Regression of the entire test sequence.	–
S_{GRF}	Storativity, based on Generalised Radial Flow model. Considered best estimate from transient evaluation of flow period or recovery period.	–
S_{sf}	Specific storage of formation based on 3D spherical flow model. Considered best estimate from transient evaluation of flow period or recovery period.	1/m

Parameter	Explanation	Unit
S_{sf}*	Assumed specific storage of formation based on 3D spherical flow model.	1/m
c_f	Hydraulic resistance of aquitard across an aquitard perpendicular to a 2D formation. $c_f = b'/K'$ where b' = water saturated thickness of aquitard (leaky formation) and K' = hydraulic conductivity across the aquitard.	s
L_f	Leakage factor. $L_f = (K \cdot b \cdot c_f)^{0.5}$ where K represents the aquifer conditions. $c_f = b'/K'$ based on 1D linear flow model. Considered best estimate from transient evaluation of flow period or recovery period.	m
ξ	Skin factor. Considered best estimate from transient evaluation of flow period or recovery period.	–
ξ_{NLR}	Skin factor, based on Non Linear Regression of entire test sequence.	–
C_M	Geometric factor in Moye's formula, $C = [1+\ln(L_w/2r_w)]/2\pi$.	–
C	Wellbore storage coefficient. Considered best estimate from transient evaluation of flow period or recovery period.	m^3/Pa
C_D	Dimensionless wellbore storage coefficient, $C_D = C \cdot \rho_w g / (2\pi \cdot S \cdot r_w^2)$.	–
C_{NLR}	Wellbore storage coefficient, based on Non Linear Regression of entire test sequence.	m^3/Pa
$C_{D,\,NLR}$	Dimensionless wellbore storage coefficient, based on Non Linear Regression of entire test sequence.	–
ω	Storativity ratio, $\omega = S_f/(S_f + S_m)$, the relation between fracture storage coefficient and total storage coefficient (double porosity). Considered best estimate from transient evaluation of flow period or recovery period.	–
ω_{NLR}	Storativity ratio, based on Non Linear Regression of entire test sequence (double porosity).	–
λ	Interporosity flow coefficient, $\lambda = \alpha \cdot (K_m/K_f) \cdot r_w^2$ (double porosity). Considered best estimate from transient evaluation of flow period or recovery period.	–
α	Block shape parameter.	$1/m^2$
λ_{NLR}	Interporosity flow coefficient, based on Non Linear Regression of entire test sequence (double porosity).	–

Map of site investigation subarea Laxemar