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Oskarshamn site investigation

Slug tests in groundwater monitoring wells SSM000222–SSM000230 in soil

Subarea Laxemar

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November 2006

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Keywords: Laxemar, Soil, Quaternary deposits, Slug test, Hydraulic parameters, Soil tubes.

Abstract

The methodology, analyses and results of slug tests performed in 9 groundwater-monitoring wells in the Laxemar area during November 2005 are presented in this report. The specific objective of the performed slug tests is to obtain the hydrogeological and hydrogeochemical characteristics of the soils and describe and relate these to the corresponding characteristics of the bedrock and the groundwater. The data from the tests were evaluated using two similar methods: the Hvorslev method and the Bouwer & Rice method.

The principle of slug tests is to initiate an instantaneous displacement of the water level in a groundwater-monitoring well, and to observe the following recovery of the water level in the well as a function of time. A slug test can be performed by causing a sudden rise of the water level (referred to as a falling-head test), or a sudden fall of the water level (referred to as a rising-head test). In all the wells both falling-head tests and rising-head tests were performed.

The Hvorslev and the Bouwer & Rice methods are both designed to estimate the hydraulic conductivity of an aquifer. The methods assume a fully or partially penetrating well in a confined or unconfined aquifer. In the computer program, a straight-line plot of the logarithm of the ratio h/h_0 versus time is automatically fitted to the measured data. If the semi-logarithmic plot of the measured data gives a concave-upward curve, automatic fitting is inappropriate, and manual curve fitting is recommended. The manual curve fitting method has been used for all analyses in this report.

Sources of uncertainty are: difficulty in predicting the thickness of the aquifer, difficulty in determining whether confined or unconfined conditions prevail, the heterogeneity of the soil etc.

The values of the transmissivity obtained from the analyses with the Hvorslev and the Bouwer & Rice methods varied between $2.6 \cdot 10^{-6}$ m^2/s and $8.0 \cdot 10^{-4}$ m^2/s.

The values of the hydraulic conductivity obtained from the analyses with the Hvorslev and the Bouwer & Rice methods varied between $6.6 \cdot 10^{-6}$ m/s and $3.3 \cdot 10^{-4}$ m/s.

Sammanfattning

Metodik, analys och resultat från de slugtester som utfördes i 9 grundvattenrör i Laxemar-området under november 2005 redovisas i rapporten. Målet med slugtesterna är att erhålla jordens hydrogeologiska och hydrogeokemiska egenskaper och beskriva och relatera dessa till bergets och grundvattnets egenskaper. Data från testerna utvärderades med två liknande metoder: Hvorslev och Bouwer & Rice.

Principen för slugtesterna är att starta en ögonblicklig förändring av vattenytan i grundvatten-röret och samtidigt mäta trycket till dess att vattenytan har återställts till ursprunglig nivå. Slugtesterna kan utföras genom en snabb höjning av vattenytan (s k falling-head test) eller genom en snabb sänkning av vattenytan (s k rising-head test). I samtliga grundvattenrör utfördes båda dessa tester.

Både Hvorslev-metoden och Bouwer & Rice-metoden är avsedda att uppskatta den hydrauliska konduktiviteten hos en akvifer. Metoderna förutsätter ett fullständig eller delvis genomträng-ande rör i en öppen eller sluten akvifer. I dataprogrammet ritas automatiskt en rak linje upp mot de uppmätta värdena i diagrammet (logaritmen av h/h_0 – tidsdiagrammet). Om en konkav kurva erhålls vid uppritandet av de uppmätta värdena, är det olämpligt att använda sig av den automatiskt uppritade linjen, och istället använder man manuell passning av linjen. I den här rapporten användes manuell passning i alla analyser.

Orsaker till att resultaten är osäkra kan vara: akviferens mäktighet är svår att fastställa, om slutna eller öppna förhållanden råder, jordens heterogenitet m m.

Värdena på transmissiviteten som erhölls från analyserna med Hvorslev-metoden och Bouwer & Rice-metoden varierade mellan $2{,}6 \cdot 10^{-6}$ m²/s och $8{,}0 \cdot 10^{-4}$ m²/s.

Värdena på den hydrauliska konduktiviteten som erhölls från analyserna med Hvorslev-metoden och Bouwer & Rice-metoden varierade mellan $6{,}6 \cdot 10^{-6}$ m/s och $3{,}3 \cdot 10^{-4}$ m/s.

Contents

1 Introduction

This document reports the methodology, analyses and results of slug tests in soil drilled groundwater monitoring wells, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-05-048 (SKB internal controlling documents). In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

A general programme for site investigations presenting survey methods has been prepared /1/, as well as a site-specific programme for the investigations in the Simpevarp area /2/. The hydrogeological characterization of the Quaternary deposits by means of slug tests form part of the site characterization programme /3/.

The hydraulic tests were carried out during November 2005 following the methodologies described in SKB MD 325.001. A total of 9 observation wells were tested. Their locations is shown in Figure 1-1. Data and results were entered into the SKB site characterization database SICADA.

Most of the tested wells are placed in till, sand or gravel, in the contact zone between soil and bedrock. The composition of the till varies from gravely sandy till to clayey till. At many locations the till is overlain by sand, clay, silt or peat. For information on soil profiles at the location of the groundwater monitoring wells, see /4/.

For information about the site investigations in the Simpevarp area which were performed in 2004 by WSP Group, see /5/ and /6/.

For information about the site investigations in the Laxemar area which were performed in 2004 by WSP Group, see /7/ and /8/.

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

Activity plan	**Number**	**Version**
Typprofilsundersökningar vid platsundersökningen i Oskarshamn, 2005	AP PS 400-05-48	1.0
Method descriptions	**Number**	**Version**
Slugtester i öppna grundvattenrör	SKB MD 325.001	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrsutning	SKB MD 600.004	1.0
Hantering av primärdata vid platsundersökningar	SDP-508	1.0

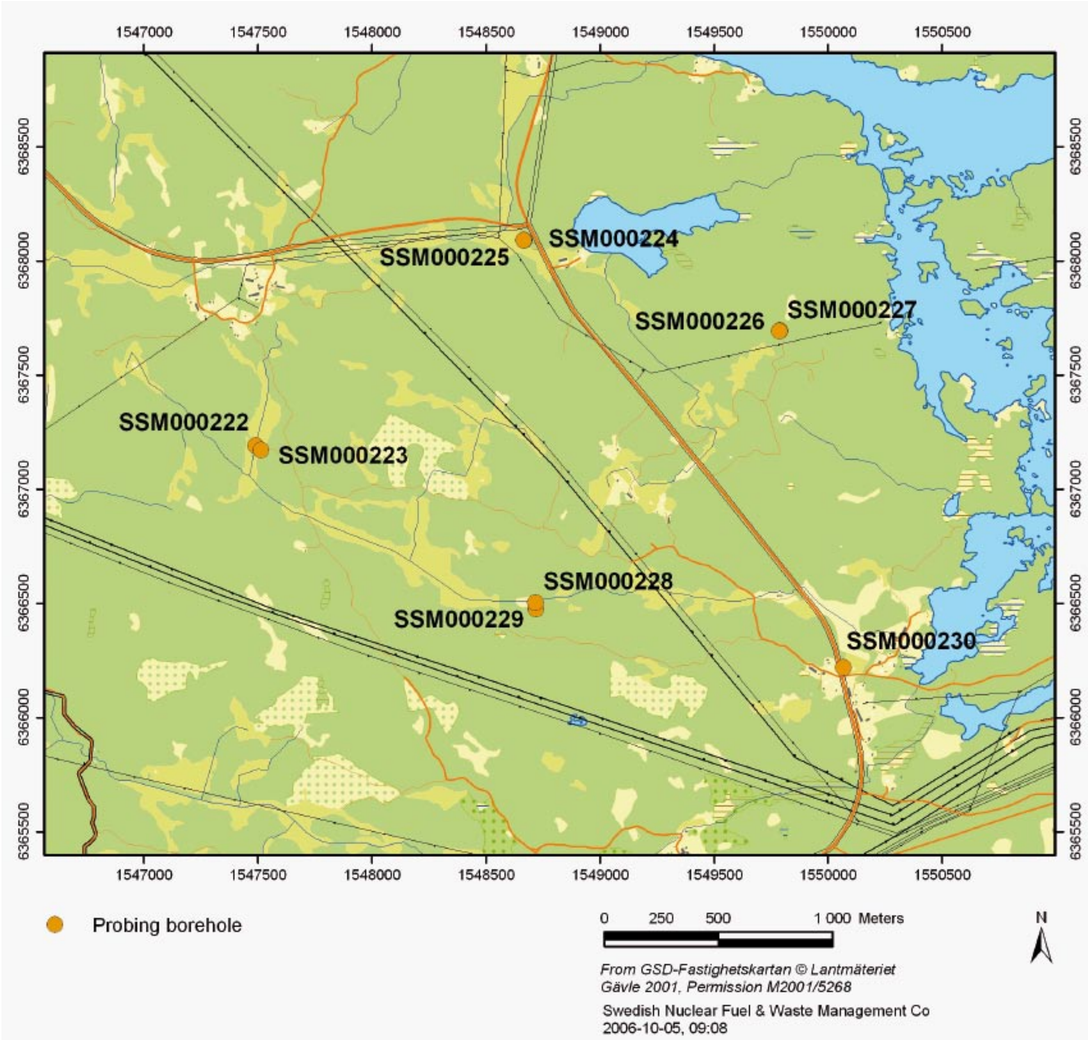

Figure 1-1. *Groundwater monitoring wells in the Laxemar area in which slugtests have been performed.*

2 Objective and scope

2.1 Objective

The objective of the performed slug tests is to characterise the soil with respect to its hydrogeological properties and to describe and relate these to the corresponding characteristics of the bedrock and the groundwater.

2.2 Scope

2.2.1 Boreholes tested

Basic technical data of the groundwater monitoring wells in which the slug tests were performed are shown in Table 2-1. The groundwater monitoring wells consist of a standpipe and a screen made of PEH.

2.2.2 Equipment check

Prior to each slug test, the equipment which was used for logging the water pressure heads during the tests (Van Essen Instrument Diver®) was exposed to air pressure and undisturbed water pressure.

2.2.3 Tests

The performed slug tests are summarized in Table 2-2.

Table 2-1. Technical data of the groundwater monitoring wells.

Groundwater monitoring wells		Standpipe		Screen		
Borehole ID	Borehole diameter (mm)	Inner diameter (mm)	Inclination from vertical plane (°)	Depth to upper screen level[1] (m)	Depth to lower screen level[1] (m)	Screen length (m)
SSM000222	120	50	0	4.0	5.0	1.0
SSM000223	120	50	0	6.0	8.0	2.0
SSM000224	120	50	0	16.0	17.0	1.0
SSM000225	120	50	0	9.0	10.0	1.0
SSM000226	120	50	0	4.0	5.0	1.0
SSM000227	82	50	0	1.0	2.0	1.0
SSM000228	120	50	0	6.0	7.0	1.0
SSM000229	120	50	0	3.0	4.0	1.0
SSM000230	120	50	0	4.0	5.0	1.0

[1] Depth is measured from the top of the standpipe.

Table 2-2. Slug test performed in the groundwater monitoring wells SSM000222–SSM000230.

Groundwater monitoring well	Test start (YYYY-MM-DD hh:mm)	Time of falling-head test (s)	Depth to water level in well prior to slug test[1] (m)	Diver® depth during slug test[1] (m)	Slug length (m)	Filled with water (l)
SSM000222	2005-11-02 14:27	194	1.57	3.50	1.0	–
SSM000223	2005-11-02 15:15	1–3	2.51	4.50	1.0	–
SSM000224	2005-11-02 16:04	1–3	1.99	4.00	1.0	–
SSM000225	2005-11-02 16:32	1–3	2.01	4.00	1.0	–
SSM000226	2005-11-03 11:30	42	1.16	3.00	1.0	–
SSM000227	2005-11-03 12:20	179	1.62	1.90	–	1.5
SSM000228	2005-11-03 09:05	27	2.87	5.00	1.0	–
SSM000229	2005-11-03 09:34	18	3.04	3.50	–	1.5
SSM000330	2005-11-03 10:35	8	4.60	4.90	–	1.5

[1] The depth is measured from the top of the standpipe.

3 Equipment

3.1 Description of equipment

For the slug tests, the following equipment was used:

- Van Essen Instrument Diver® with built-in pressure transducer and connecting cable.
- Portable PC.
- Slug and wire.
- Wire stopper.
- Light and sound indicator.

3.2 Sensors and slug

General sensor data on the Diver® and data on the slug used for the test:

Diver®:

- Material: stainless steel.
- Material pressure sensor: ceramic.
- Diameter: 22 mm.
- Length: 230 mm.
- Measurement range: 0–500 cm water column.
- Resolution: 0.2 cm.
- Accuracy: ± 0.1% of measurement range.
- Wire ∅: 1 mm.

Slug and wire:

- Slug ∅: 40 mm.
- Slug length: 1.0 m.
- Slug wire ∅: 6 mm.

Table 3-1. The position of the pressure transducer in the Diver®, the wire length[2] and the slug length for each test.

Monitoring well	Diver® depth[1] (m)	Wire length[2] (m)	Slug length (m)	Filled with water (l)
SSM000222	3.50	1.93	1.00	–
SSM000223	4.50	1.99	1.00	–
SSM000224	4.00	2.01	1.00	–
SSM000225	4.00	1.99	1.00	–
SSM000226	3.00	1.84	1.00	–
SSM000227	1.90	0.28	–	1.5
SSM000228	5.00	2.13	1.00	–
SSM000229	3.50	0.46	–	1.5
SSM000230	4.90	0.30	–	1.5

[1] The depth is measured from the top of the standpipe.

[2] The length of wire in contact with the water.

4 Execution

4.1 General

The testing was performed according to the method description SKB MD 325.001 (Slugtester i öppna grundvattenrör). Briefly, this was done by inducing an instantaneous change in water level and recording the recovery back toward equilibrium. This recovery is a measure of the aquifer properties and allows the calculation of transmissivity.

4.2 Preparations

During a different field test, the water level changes measured by the Divers® were compared to the water level changes measured by a handheld water-level meter. The Divers® measurements were similar to those measured by the handheld water-level meter.

Equipment checks were also performed in connection with each slug test (see Chapter 3.2).

Prior to each slug test, the pipes were examined to ensure that no sediment remained at the bottom of the pipe. If any sediment was found, it was removed with a suction pipe.

4.3 Test principle

The principle of slug tests is to initiate an instantaneous displacement of the water level in the well by insert or remove a dummy of known volume or insert a known amount of water, and to observe the following recovery of the water level as a function of time. A slug test can be performed by causing a sudden rise of the water level (referred to as a falling-head test), or a sudden fall of the water level (referred to as a rising-head test). In all the wells both falling-head tests and rising-head tests were performed. The sampling interval of the pressure measurements during the tests was 1 second.

Falling-head test

The Diver® is lowered into the well. The Diver® causes a small displacement of the groundwater level, so the test begins after the water level has recovered. The light and sound indicator is used to check that the water level is fully recovered. The slug is then rapidly lowered into the well, causing a sudden rise of the water level. As the water level recovers, the Diver® measures the pressure every second. When the water level is fully recovered, the rising-head test commences. For wells with a very quick recovery (less than 5 minutes), another two tests are performed.

Rising-head test

The rising-head test follows the same principle as the falling-head test but in this case the slug is rapidly withdrawn from the well, causing a sudden drop in the water level. As the water level recovers, the Diver® measures the pressure every second until the water level is fully recovered. For wells with a very quick recovery (less than 5 minutes), another two tests are performed.

Instead of using a slug to cause a sudden rise in the water level an exact amount of water (1.5 l) was quickly poured into well SSM000227, SSM000229 and SSM000230.

Table 6-2 shows the hydraulic conductivity and transmissivity results from the slug tests.

4.3.1 Test procedure

The test procedure is briefly described below:

1. Cleaning of equipment that is lowered into the well.
2. Measurement of the depth from the top of the standpipe to the bottom of the well.
3. Determination of the slug and wire length. The objective is to cause as much initial displacement of the water level as possible. In the majority of the performed tests, a shallow undisturbed water level meant that the slug length had to be restricted to 1.00 m, in order to prevent water from rising over the top of the rising pipe in the falling-head tests.
4. Logging the pressure in air, and thereafter the undisturbed water level in the well, with the Diver®.
5. Performance of falling-head test: Rapid lowering of the slug into the well (fixed with a wire stop). Sampling frequency of the Diver®: 1 measurement per second. Measurement of the recovery of the water level in the well with a water-level meter.
6. Performance of rising-head test: Withdrawal of the slug from the well when the water level has recovered after the falling-head test. Sampling frequency of the Diver®: 1 measurement per second.
7. Termination of slug tests approximately 1 h after start of the rising-head test.

4.4 Data handling

Raw data from the Diver® (internal *.mon format) was saved on a portable PC, using the computer program EnviroMon Ver. 1.45. After each test, the saved *.mon files were exported from EnviroMon to *.csv (comma-separated format).

Prior to the data evaluation for the generation of primary data files, all files in *.csv format were imported to MS Excel and saved in *.xls format. The data was processed in MS Excel, in order to produce data files for the estimation of transmissivity and hydraulic conductivity (see Sections 5.4 and 6). The data processing in MS Excel involved (1) correction of the pressure data for the barometric pressure (obtained by keeping the Diver® in the open air prior to each slug test), and (2) identification of the exact starting time of the test for the analysis (removal of the initial oscillation effects, which usually lasted on the order of 1–10 seconds after lowering the slug into the well).

A list of all the generated raw and primary data files is given in Appendix 1. The raw data files (**.mon*) were delivered in digital format to the Activity Leader, as were the results of the evaluation (HY670 - PLU Slug_Laxemar.xls) for quality control and storage in the SICADA database.

4.5 Analyses and interpretation

The following section gives an overview of the methods used for analysis and interpretation of the slug test data.

The computer program Aquifer Test Version 3.5 was used for all the slug test analyses; see /9/. The program allows for both automatic and manual fitting of a straight-line plot to the measured data.

4.5.1 The Hvorslev and the Bouwer & Rice methods

The Hvorslev method and the Bouwer & Rice method are both designed to estimate the hydraulic conductivity of an aquifer. The methods assume a fully or partially penetrating well in a confined or unconfined aquifer. A straight-line plot of the logarithm of the ratio h/h_0 versus time is automatically fitted to the measured data. If the semi-logarithmic plot of the measured data gives a concave-upward curve, automatic fitting is inappropriate, and manual curve fitting is recommended. The manual curve fitting method has been used for all analyses in this report. The theory of the Hvorslev method and the Bouwer & Rice method and practical recommendations for their applications are given in /10/.

The program Aquifer Test Version 3.5 recommend to use Bouwer & Rice for unconfined or leaking confined aquifer and to use Hvorslev for confined aquifer. The analyses in this report have been made with the Hvorslev method for confined conditions and the Bouwer & Rice method for unconfined conditions. In well SSM000226 confined conditions prevail since a layer of clay is on top of the aquifer.

Bouwer-Rice equation used for hydraulic conductivity in computer program Aquifer test as follows:

$$K = \frac{r^2 \cdot \ln\left(\frac{R_{cont}}{R}\right)}{2 \cdot L} \cdot \frac{1}{t} \cdot \ln\left(\frac{h_0}{h_t}\right)$$

where:

r = piezometar radius (or r_{eff} if water level change is within the screened interval),

R_{cont} = contributing radial distance over which the difference in head, h_0, is dissipated in the aquifer,

R = radius measured from centre of well to undisturbed aquifer material,

L = length of the screen,

t = time,

h_t = displacement as a function of time (h_t/h_0 must always be less than one, i.e. water level must always approach the static water level as time increases),

h_0 = initial displacement,

b = length from bottom of well screen to top of the aquifer,

B = aquifer thickness.

Since the contributing radius (R_{cont}) of the aquifer is seldom known, Bouwer-Rice developed empirical curves to account for this radius by three coefficients (A, B, C) which are all functions of the ratio of L/R.

Coefficients A and B are used for partially penetrating wells ($b < B$), and coefficient C is used only for fully penetrating wells ($b = B$).

For Hvorslev method (if the length of the screen is more than 8 times the radius of the well screen), the following formula applies:

$$K = \frac{r^2 \cdot \ln \frac{L_e}{R}}{2 \cdot L_e \cdot T_0}$$

where:

r = radius of the well casing.

L_e = length of the well screen.

R = radius of the well.

T_0 = time it takes for the water level to rise or fall to 37 percent of the initial change.

For further reading about the methods and computer program, see /9/ and /10/.

4.6 Nonconformities

There were no nonconformities.

5 Results

5.1 Nomenclature and symbols

The nomenclature and symbols used for the results presented in the following sections are as follows:

h_0 (mwc): Meter water column at measuring point prior to the slug test.

dh_0* (m): Expected initial displacement.

dh_0_p (m): Initial displacement for falling-head test.

dh_0*/dh_0_p: Ratio between expected and actual displacement.

hp (mwc): Meter water column at the measuring point at the end of a falling-head test.

5.2 Slug test results

The results of the performed slug tests are summarized in Table 5-1 below.

The expected displacement is calculated from the known volume of the dummy or of the known amount of water inserted in the well.

For some wells the initial displacement is greater than the expected displacement. The reason for this is unclear, but the initial displacement has been ignored in the analyses. The first seconds after the slug has been lowered or withdrawn from the well the water level fluctuates and therefore these first seconds are not used in the analyses.

The conductivity, K, is the result of the analysis representing the K over the screened interval. The transmissivity for the interpreted aquifer, T can then be calculated by multiply K with the aquifer thickness, B. The aquifer thickness refers to the distance between groundwater level and bedrock in the unconfined case, and the distance between bottom of the clay layer and bedrock in the confined case.

Table 5-1. Summary of the results of the slug tests.

Well ID	h_0 (mwc)	dh_0* (m)	dh_0_p (m)	dh_0*/dh_0_p	hp (mwc)
SSM000222	2.97	0.65	0.91	0.71	2.97
SSM000223	–	–	–	–	–
SSM000224	–	–	–	–	–
SSM000225	–	–	–	–	–
SSM000226	3.13	0.65	0.34	1.91	3.15
SSM000227	1.20	0.76	0.19	4.0	1.21
SSM000228	3.14	0.65	0.68	0.96	3.16
SSM000229	1.39	0.76	0.10	7.6	1.40
SSM000230	1.21	0.76	0.09	8.4	1.22

5.3 Evaluation results

Table 5-2 (below) presents the results of the slug test analyses according to the Hvorslev and the Bouwer & Rice methods. The results show the hydraulic conductivity (K), aquifer thickness (B) and transmissivity (T) for each monitoring well.

In wells SSM000223, SSM000224 and SSM000225, the time period of the slug test is too short to evaluate. Estimation of hydraulic conductivity, K, is based on type of soil stratum and from normal values of K /11/. A soil layer consisting of sandy till (SSM000223) should have a quite low conductivity but considering the short time period of the slug test the conductivity is estimated higher than normal.

5.4 Original data

The original results are stored in SKB's primary data base (SICADA) and the data will be used for further interpretation (modelling). The data is traceable in SICADA by the Activity Plan number (AP PS 400-05-48).

Table 5-2. Results evaluated with the Hvorslev and the Bouwer & Rice methods.

Groundwater monitoring well	Hydraulic conductivity over screened interval K (m/s)	Screen length L (m)	Transmissivity of screened interval T (m^2/s)	Aquifer thickness B (m)	Transmissivity of interpreted aquifer T (m^2/s)	Method of analysis
SSM000222	1.4E–05	1	1.4E–05	3.43	4.8E–05	Bouwer & Rice
SSM000223	5E–05[1]	2	1E–04[1]	5.49	3E–04[1]	Not measured! Calculated from standard reference K-values for given soil type
SSM000224	1E–03[1]	1	1E–03[1]	15.01	2E–02[1]	Not measured! Calculated from standard reference K-values for given soil type
SSM000225	3E–03[1]	1	3E–03[1]	7.99	2E–02[1]	Not measured! Calculated from standard reference K-values for given soil type
SSM000226	6.7E–05	1	6.7E–05	2	1.3E–04	Hvorslev
SSM000227	6.6E–06	1	6.6E–06	0.4	2.6E–06	Bouwer & Rice
SSM000228	1.4E–04	1	1.4E–04	5.73	8.0E–04	Bouwer & Rice
SSM000229	8.0E–05	1	8.0E–05	0.96	7.7E–05	Bouwer & Rice
SSM000230	3.3E–04	1	3.3E–04	0.4	1.3E–04	Bouwer & Rice

[1] The hydraulic conductivity, K and transmissivity, T are estimated. Time period too short to evaluate.

5.5 Summary and discussion

The aquifer properties were evaluated according to the Hvorslev and the Bouwer & Rice methods. The computer program Aquifer Test Version 3.5 was used for the analyses.

Results of the hydraulic conductivity and transmissivity were not possible to evaluate for wells SSM000223, SSM000224 and SSM000225 due to the very fast (1–3 seconds) response duration. After the slug was lowered into the well the water level recovered very fast (1–3 seconds). For these wells the hydraulic conductivity, K have been estimated based on type of soil stratum and from normal values of K /11/.

The results in well SSM000230 are slightly unreliable since the water level recovered quickly (8 seconds).

Sources of uncertainty are: difficulty in predicting the thickness of the aquifer, difficulty in determining whether confined or unconfined conditions prevailed, the heterogeneity of the soil etc.

The values of the transmissivity obtained from the analysis according to the Hvorslev and the Bouwer & Rice methods varied between $2.6 \cdot 10^{-6}$ m²/s and $8.0 \cdot 10^{-4}$ m²/s.

The values of the hydraulic conductivity obtained from the analysis according to the Hvorslev and the Bouwer & Rice methods varied between $6.6 \cdot 10^{-6}$ m/s and $3.3 \cdot 10^{-4}$ m/s.

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Appendix 1

List of generated raw data files and primary data files

Table A1-1. List of generated raw data files and primary data files.

Obs. well	Raw data files: *.mon	Data processing files: *.xls	Primary data files: *.mdb
SSM000222	SSM000222	SSM000222	SKB_Laxemar 2005-11
SSM000223	SSM000223	SSM000223	SKB_Laxemar 2005-11
SSM000224	SSM000224	SSM000224	SKB_Laxemar 2005-11
SSM000225	SSM000225	SSM000225	SKB_Laxemar 2005-11
SSM000226	SSM000226	SSM000226	SKB_Laxemar 2005-11
SSM000227	SSM000227	SSM000227	SKB_Laxemar 2005-11
SSM000228	SSM000228	SSM000228	SKB_Laxemar 2005-11
SSM000229	SSM000229	SSM000229	SKB_Laxemar 2005-11
SSM000230	SSM000230	SSM000230	SKB_Laxemar 2005-11

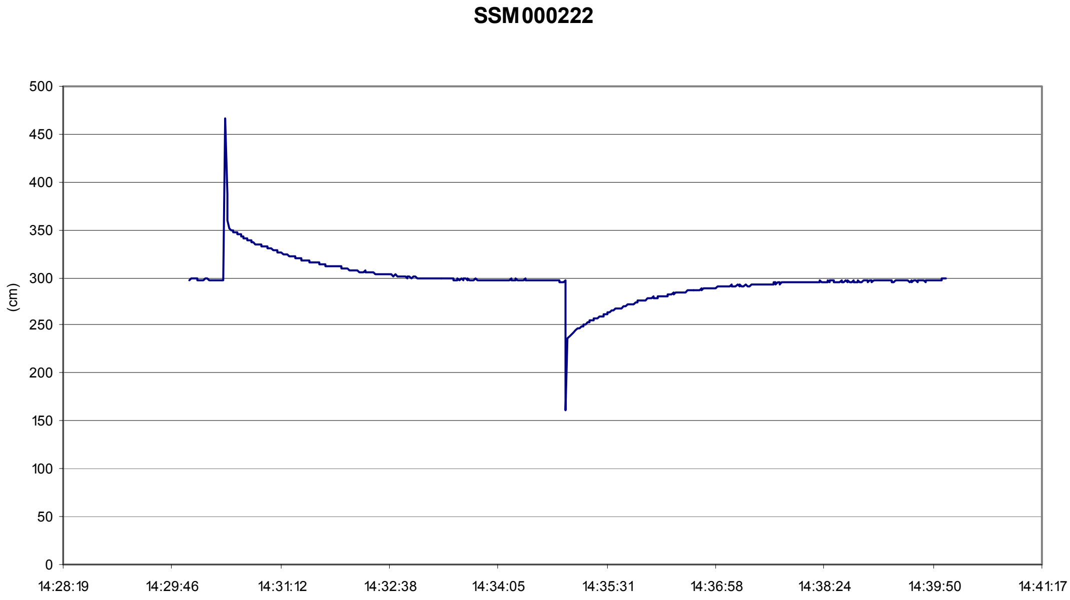
Table A1-2. Evaluated parameters.

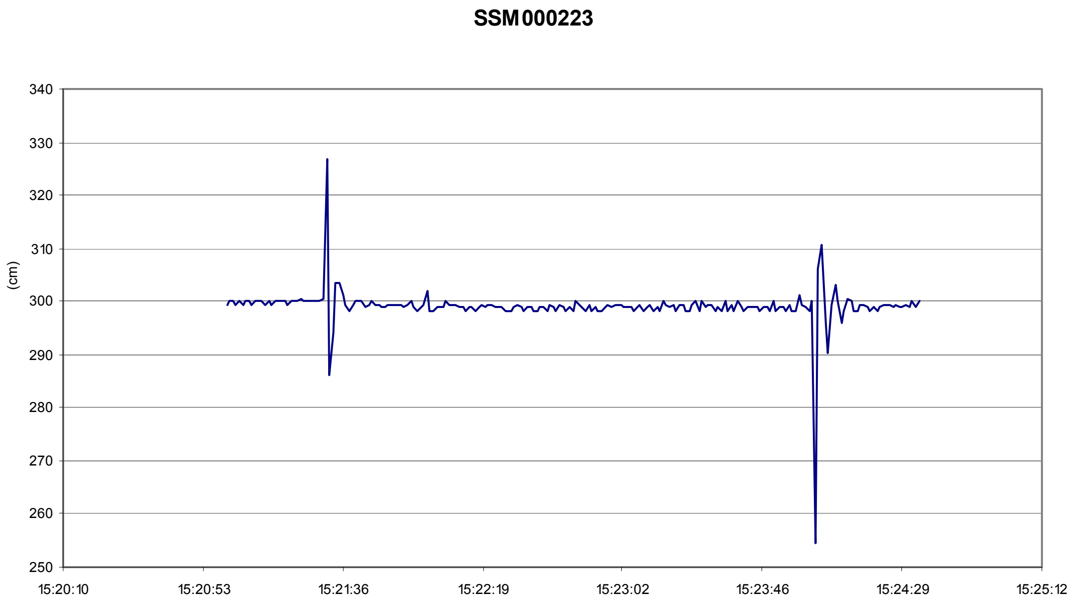
Borehole	Borehole secup[1] (m)	Borehole seclow[1] (m)	Test type (1-6)	Date for test, start YY-MM-DD	Start test hh:mm	tp (s)	h_0 (mwc)	dh_0* (m)	hp (mwc)	B (m)	Screen length (m)	T_s (m^2/s)
SSM000222	4.00	5.00	4	2005-11-02	14:27	194	2.97	0.65	2.97	3.43	1	4.8E–05
SSM000223	6.00	8.00	4	2005-11-02	15:15	2	–	–	–	5.49	2	3.E–04
SSM000224	16.00	17.00	4	2005-11-02	16:04	2	–	–	–	15.01	1	2.E–02
SSM000225	9.00	10.00	4	2005-11-02	16:32	2	–	–	–	7.99	1	2.E–02
SSM000226	4.00	5.00	4	2005-11-03	11:30	42	3.13	0.65	3.15	2	1	1.3E–04
SSM000227	1.00	2.00	4	2005-11-03	12:20	179	1.20	0.76	1.21	0.4	1	2.6E–06
SSM000228	6.00	7.00	4	2005-11-03	09:05	27	3.14	0.65	3.16	5.73	1	8.0E–04
SSM000229	3.00	4.00	4	2005-11-03	09:34	18	1.39	0.76	1.40	0.96	1	7.7E–05
SSM000230	4.00	5.00	4	2005-11-03	10:35	8	1.21	0.76	1.22	0.4	1	1.3E–04

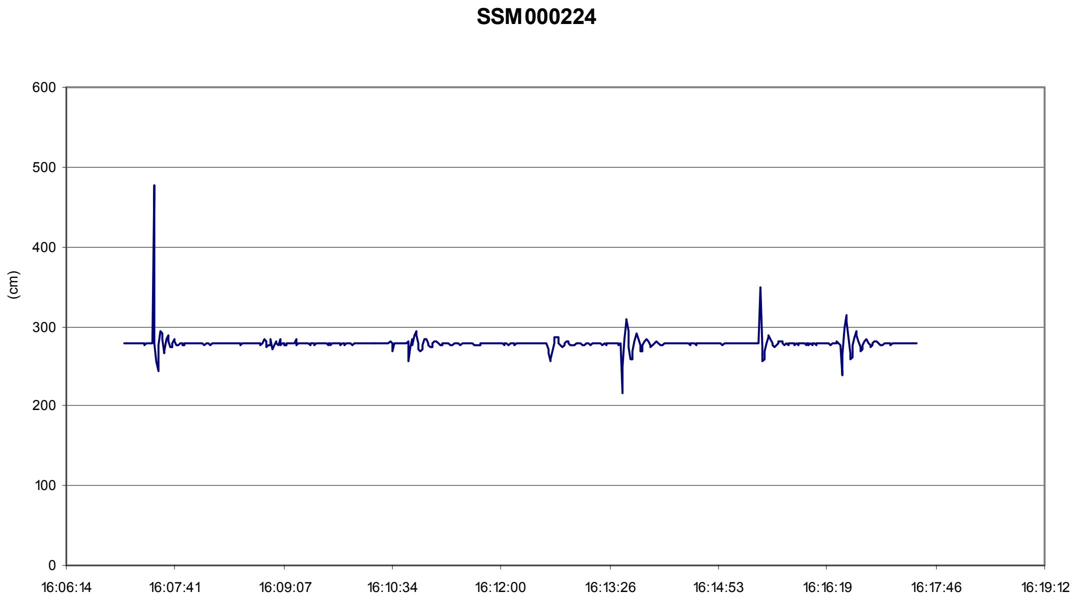
[1] The length is measured from the top of the standpipe.

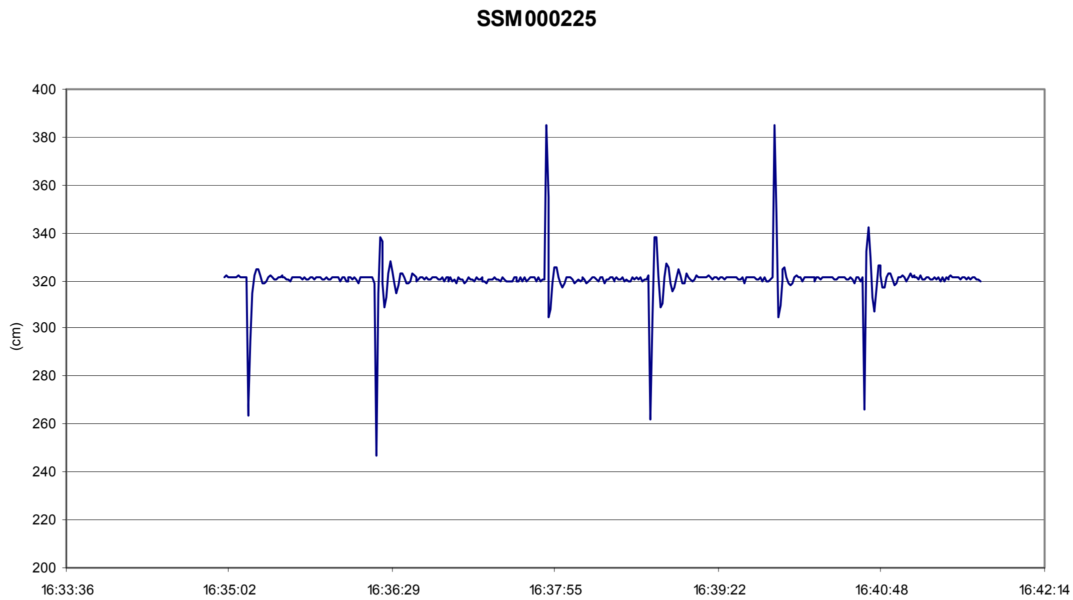
Appendix 2

Plot of primary data for each slug test

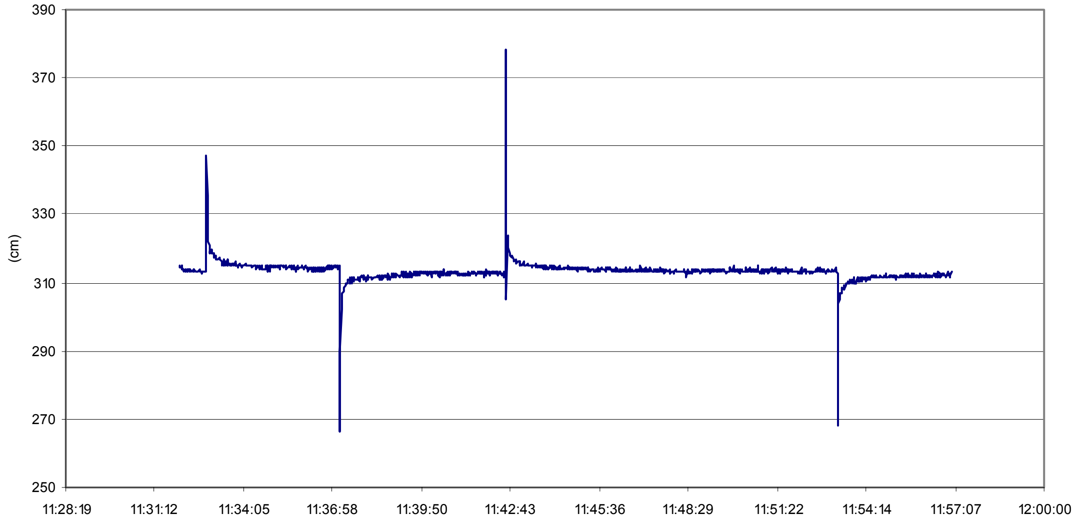




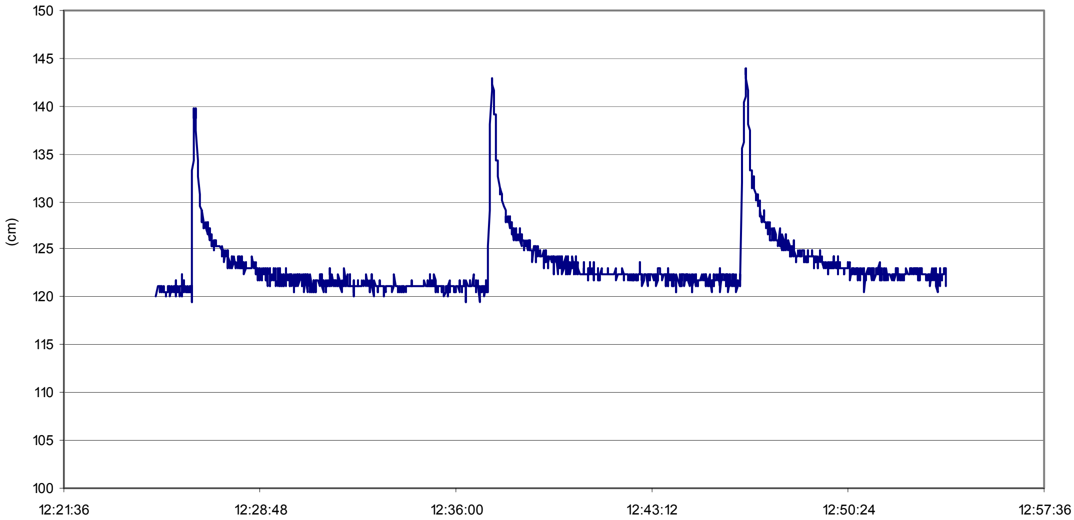

SSM000224
600
500
400
300
200
100
0
(cm)
16:06:14
16:07:41
16:09:07
16:10:34
16:12:00
16:13:26
16:14:53
16:16:19
16:17:46
16:19:12


SSM000225
400
380
360
340
320
300
280
260
240
220
200
(cm)
16:33:36
16:35:02
16:36:29
16:37:55
16:39:22
16:40:48
16:42:14

SSM000226

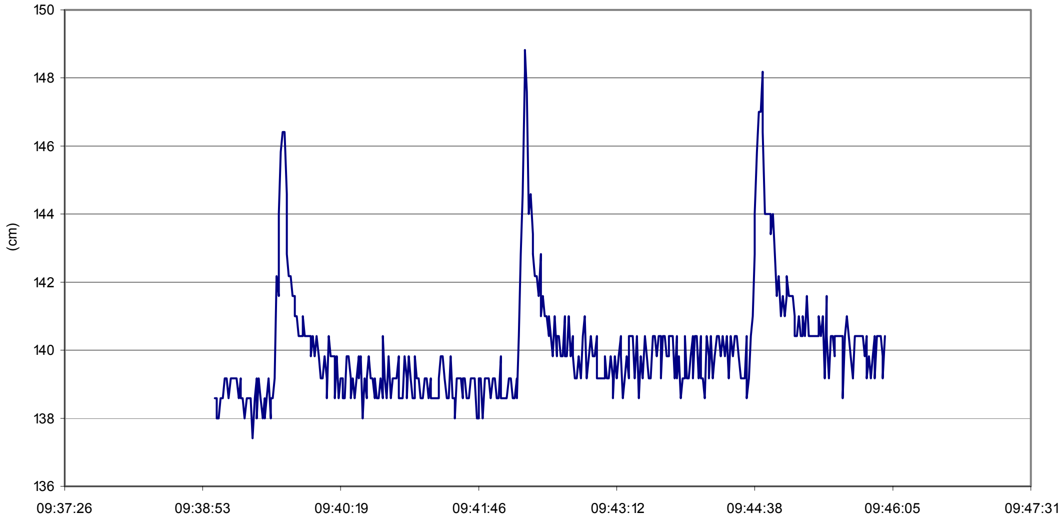


SSM000227

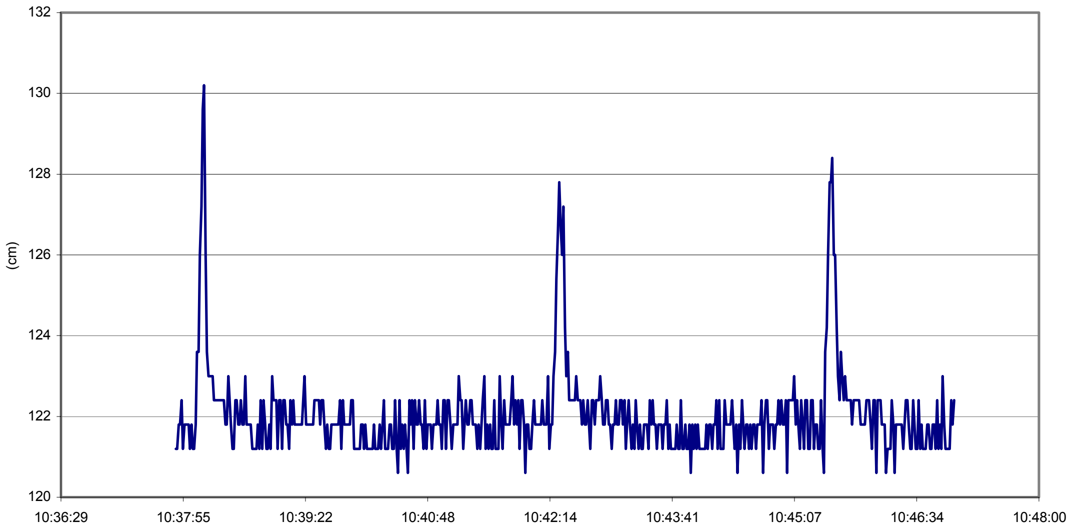


SSM000228

SSM000229



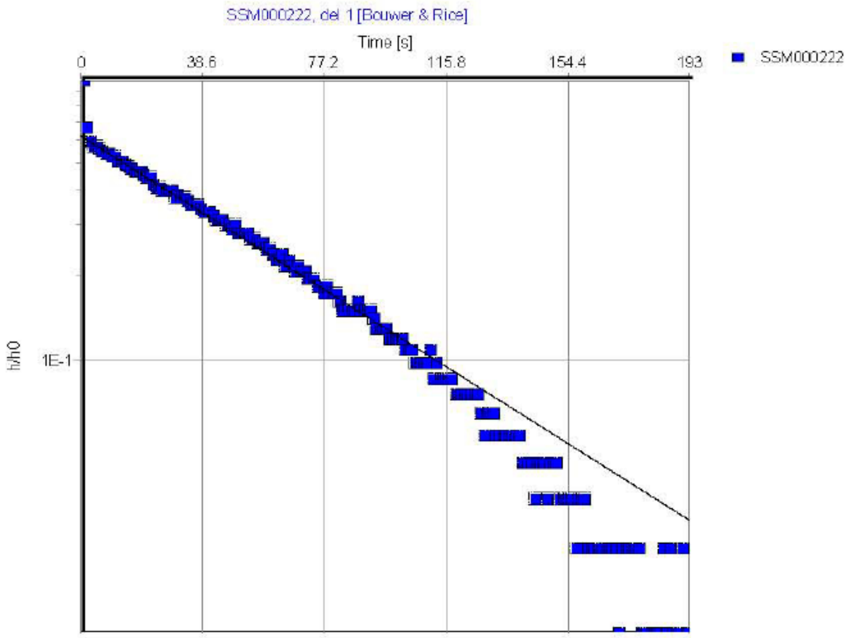
SSM000230



Appendix 3

Normalised slugtest plots

WSP Environmental Slagthuset 211 20 Malmö 040 - 699 62 00	**Slug Test Analysis Report** Project: SKB_Laxemar 2005-11 Number: Client: SKB



Slug Test: **SSM000222, del 1**

Analysis Method: **Bouwer & Rice**

Analysis Results: Conductivity: 1.43E-5 [m/s]

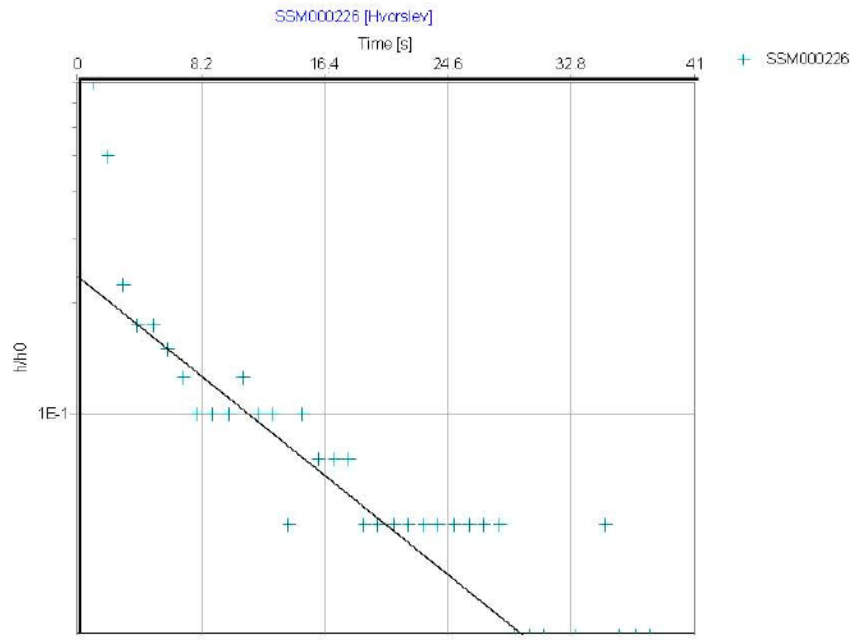
Test parameters:				
	Test Well:	SSM000222	Aquifer Thickness:	3.43 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	1 [m]		
	Boring radius:	0.06 [m]		
	r(eff):	0.037 [m]		

Comments:

Evaluated by: Andreas Sjöberg

Evaluation Date: 2005-11-08

WSP Environmental	Slug Test Analysis Report
Slagthuset	Project: SKB_Laxemar 2005-11
211 20 Malmö	Number:
040 - 699 62 00	Client: SKB



Slug Test: **SSM000226**

Analysis Method: **Hvorslev**

Analysis Results: Conductivity: 6.74E-5 [m/s]

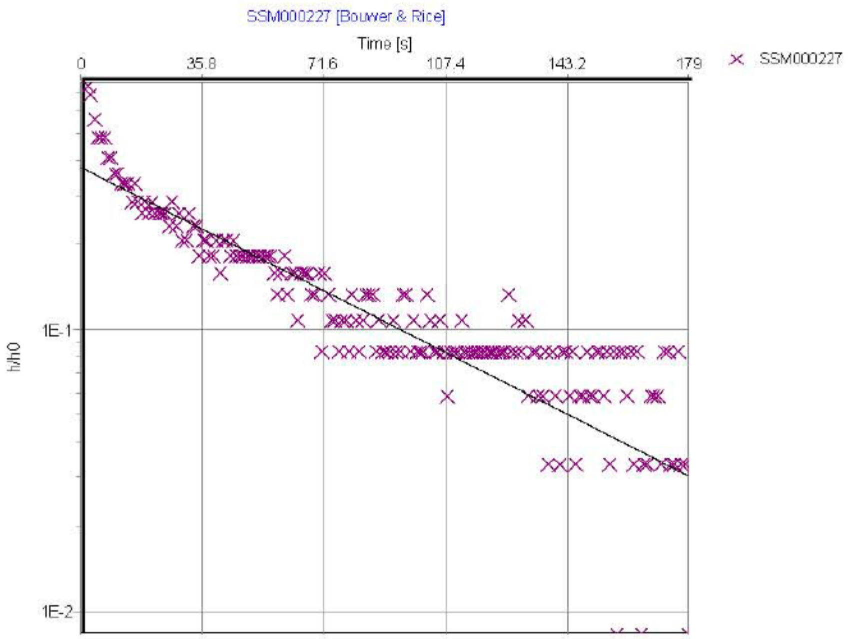
Test parameters:				
	Test Well:	SSM000226	Aquifer Thickness:	2 [m]
	Casing radius:	0.025 [m]		
	Screen length:	1 [m]		
	Boring radius:	0.06 [m]		

Comments:

Evaluated by: Andreas Sjöberg

Evaluation Date: 2005-11-11

WSP Environmental	Slug Test Analysis Report
Slagthuset	Project: SKB_Laxemar 2005-11
211 20 Malmö	Number:
040 - 699 62 00	Client: SKB



Slug Test: **SSM000227, steg 1**

Analysis Method: **Bouwer & Rice**

Analysis Results: Conductivity: 6.56E-6 [m/s]

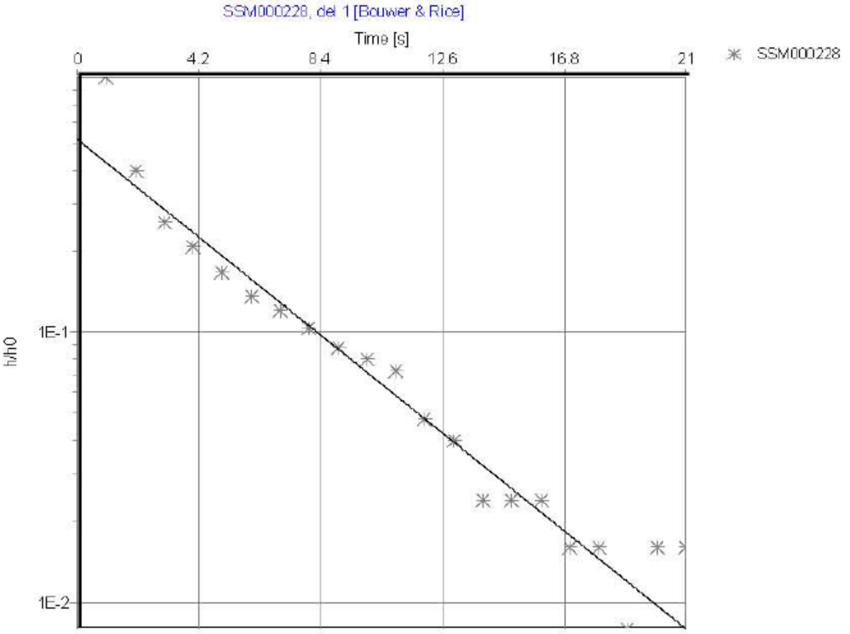
Test parameters:				
	Test Well:	SSM000227	Aquifer Thickness:	0.41 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	1 [m]		
	Boring radius:	0.06 [m]		
	r(eff):	0.037 [m]		

Comments:

Evaluated by:

Evaluation Date: 2005-11-15

WSP Environmental	Slug Test Analysis Report
Slagthuset	Project: SKB_Laxemar 2005-11
211 20 Malmö	Number:
040 - 699 62 00	Client: SKB



Slug Test: **SSM000228, del 1**

Analysis Method: **Bouwer & Rice**

Analysis Results: Conductivity: 1.42E-4 [m/s]

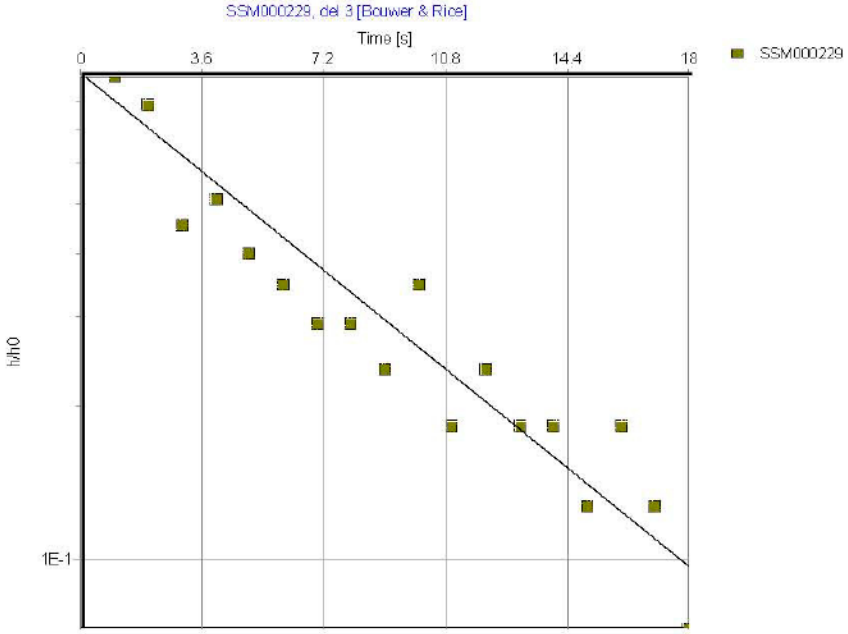
Test parameters:				
	Test Well:	SSM000228	Aquifer Thickness:	5.73 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	1 [m]		
	Boring radius:	0.06 [m]		
	r(eff):	0.037 [m]		

Comments:

Evaluated by: Andreas Sjöberg

Evaluation Date: 2005-11-14

WSP Environmental	Slug Test Analysis Report
Slagthuset	Project: SKB_Laxemar 2005-11
211 20 Malmö	Number:
040 - 699 62 00	Client: SKB



Slug Test: **SSM000229, del 3**

Analysis Method: **Bouwer & Rice**

Analysis Results: Conductivity: 7.97E-5 [m/s]

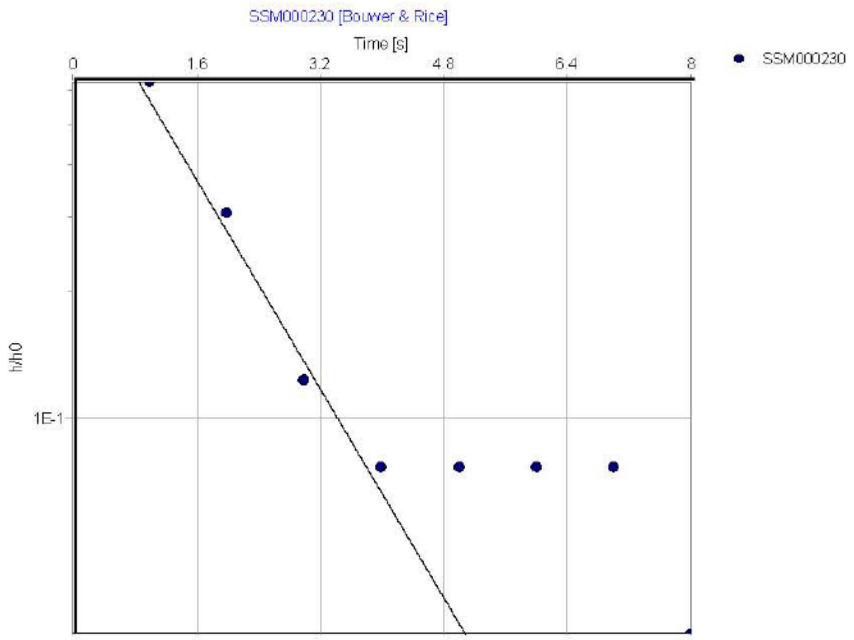
Test parameters:				
	Test Well:	SSM000229	Aquifer Thickness:	0.97 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	1 [m]		
	Boring radius:	0.06 [m]		
	r(eff):	0.037 [m]		

Comments:

Evaluated by:

Evaluation Date: 2005-11-15

WSP Environmental	Slug Test Analysis Report
Slagthuset	Project: SKB_Laxemar 2005-11
211 20 Malmö	Number:
040 - 699 62 00	Client: SKB



Slug Test: **SSM000230**

Analysis Method: **Bouwer & Rice**

Analysis Results:			Conductivity:	3.33E-4 [m/s]
Test parameters:	Test Well:	SSM000230	Aquifer Thickness:	0.41 [m]
	Casing radius:	0.025 [m]	Gravel Pack Porosity (%)	25
	Screen length:	1 [m]		
	Boring radius:	0.06 [m]		
	r(eff):	0.037 [m]		

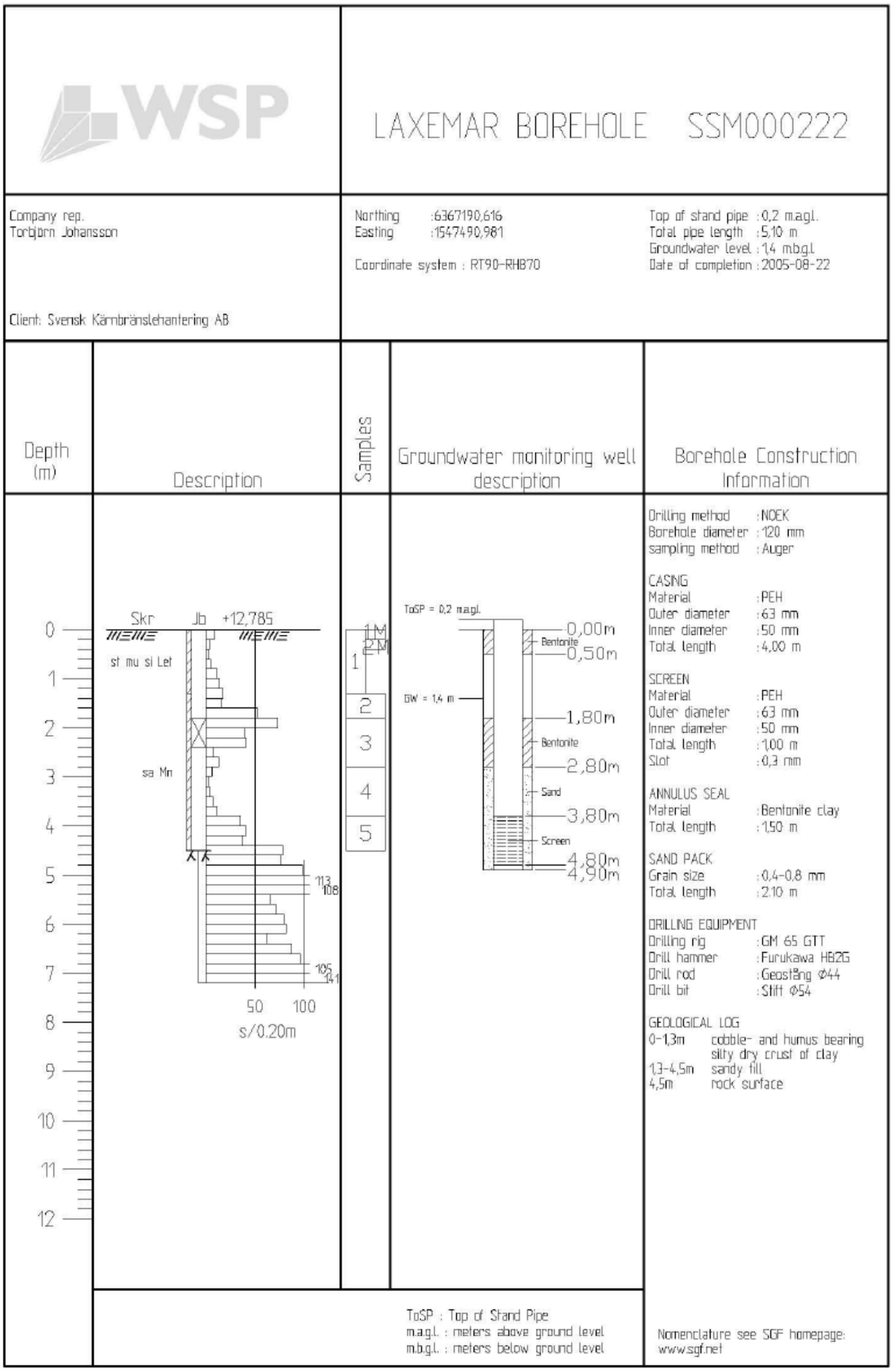
Comments:

Evaluated by:

Evaluation Date: 2005-11-15

Appendix 4

Soil well construction loggs



LAXEMAR BOREHOLE SSM000223

Company rep.
Torbjörn Johansson

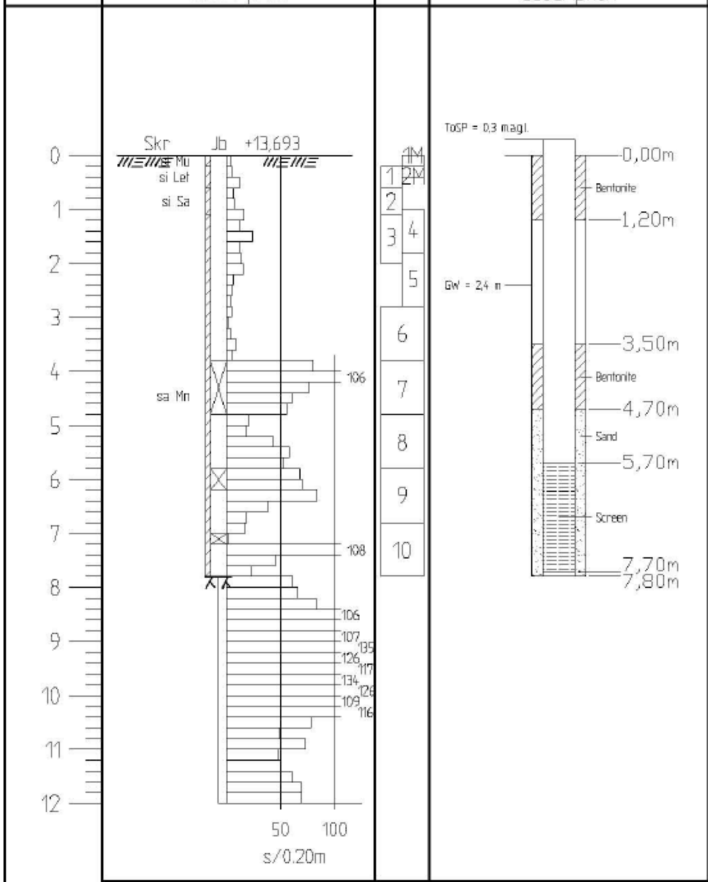
Client: Svensk Kärnbränslehantering AB

Northing :6367171,742
Easting :1547513,653

Coordinate system : RT90-RHB70

Top of stand pipe : 0,30 m.a.g.l.
Total pipe length : 8,10 m
Groundwater level : 2,4 m.b.g.l.
Date of completion : 2005-08-24

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 6,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 2,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 2.40 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 3,10 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Φ44
Drill bit : Stift Φ54

GEOLOGICAL LOG
0-0,2m silty topsoil
0,2-0,6m silty dry crust of clay
0,6-1,1m silty sand
1,1-7,8m sandy till
7,8m rock surface

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

LAXEMAR BOREHOLE SSM000224

WSP

Company rep.
Torbjörn Johansson

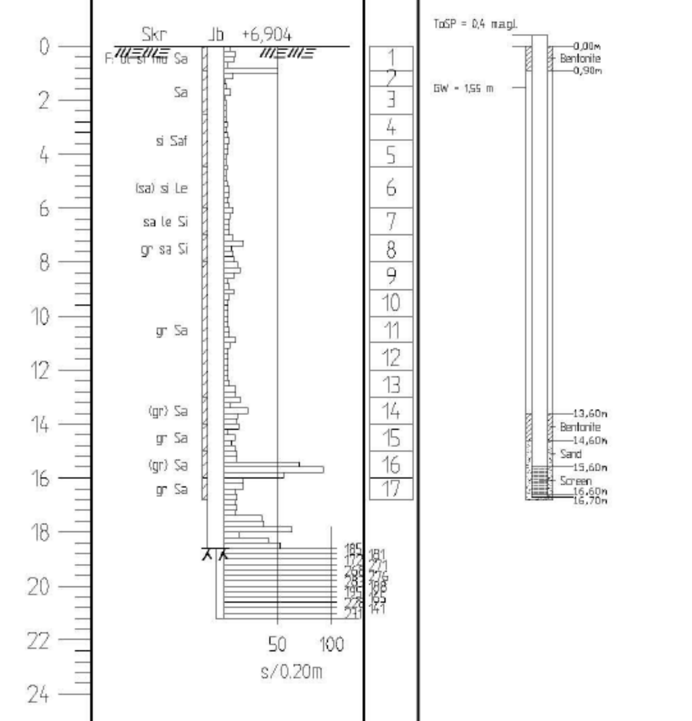
Client: Svensk Kärnbränslehantering AB

Northing :6368091,688
Easting :1548666,979

Coordinate system : RT90-RHB70

Top of stand pipe : 0,40 m.a.g.l.
Total pipe length : 17,10 m
Groundwater level : 1,55 m.b.g.l.
Date of completion : 2005-09-06

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 16,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 1,90 m

SAND PACK
Grain size : 0,4–0,8 mm
Total length : 2,20 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Ø44
Drill bit : Stift Ø54

GEOLOGICAL LOG
0–0,9m Fill: boulder-, cobble- and humus-bearing sand
0,9–2,5m sand
2,5–4,5m silty fine sand
4,5–6,0m somewhat sandy silty clay
6,0–7,0m sandy clayey silt
7,0–8,0m gravelly sandy silt
8,0–13,0m gravelly sand
13,0–14,0m somewhat gravelly sand
14,0–15,0m gravelly sand
15,0–16,0m somewhat gravelly sand
16,0–16,8m gravelly sand
18,6m rock surface

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

LAXEMAR BOREHOLE SSM000225

Company rep.
Torbjörn Johansson

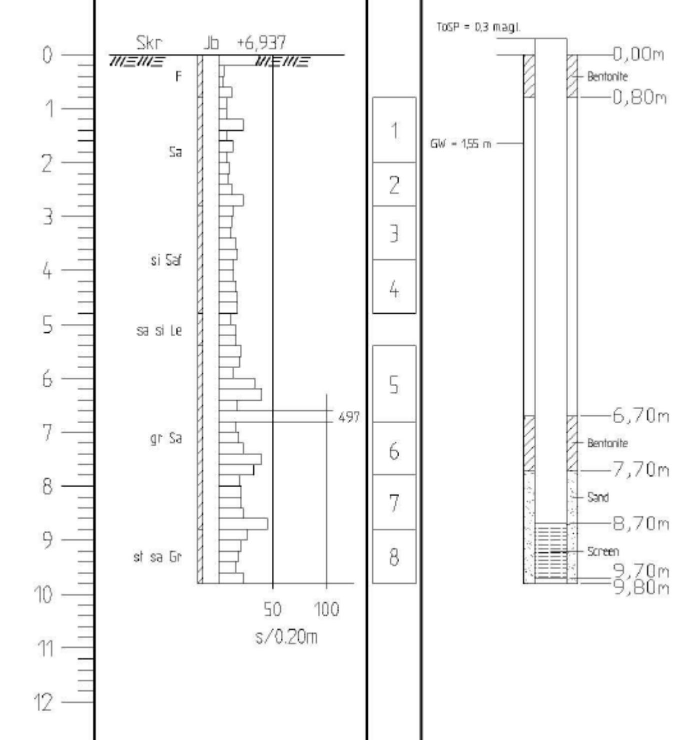
Client: Svensk Kärnbränslehantering AB

Northing :6368092,167
Easting :1548669,442

Coordinate system : RT90-RHB70

Top of stand pipe : 0,3 m.a.g.l.
Total pipe length : 10,10 m
Groundwater level : 1,55 m.b.g.l.
Date of completion : 2005-09-06

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 9,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 1,80 m

SAND PACK
Grain size : 0,4–0,8 mm
Total length : 2,10 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Φ44
Drill bit : Stift Φ54

GEOLOGICAL LOG
0–0,8m Fill
0,8–2,8m sand
2,8–4,8m silty fine sand
4,8–5,4m sandy silty clay
5,4–8,8m gravelly sand
8,8–9,8m cobble-bearing sandy gravel

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

LAXEMAR BOREHOLE SSM000226

Company rep.
Torbjörn Johansson

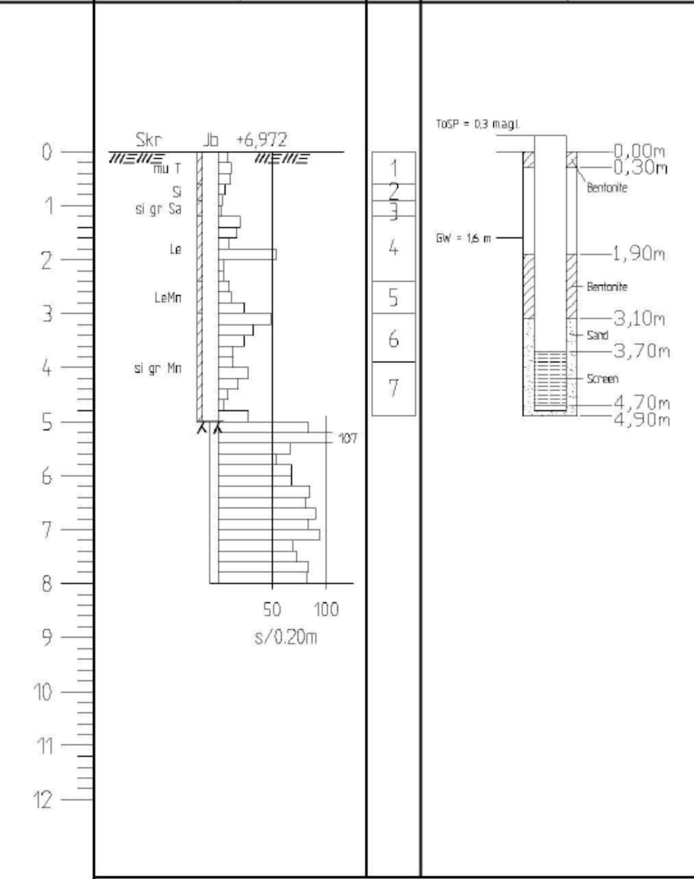
Client: Svensk Kärnbränslehantering AB

Northing :6367696,292
Easting :1549790,186

Coordinate system : RT90-RHB70

Top of stand pipe :0,3 m.a.g.l.
Total pipe length :5,10 m
Groundwater level :1,6 m.b.g.l.
Date of completion :2005-09-14

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method :NOEK
Borehole diameter :120 mm
sampling method :Auger

CASING
Material :PEH
Outer diameter :63 mm
Inner diameter :50 mm
Total length :4,00 m

SCREEN
Material :PEH
Outer diameter :63 mm
Inner diameter :50 mm
Total length :1,00 m
Slot :0,3 mm

ANNULUS SEAL
Material :Bentonite clay
Total length :1,50 m

SAND PACK
Grain size :0,4-0,8 mm
Total length :1,80 m

DRILLING EQUIPMENT
Drilling rig :GM 65 GTT
Drill hammer :Furukawa HB2G
Drill rod :Geostång Ø44
Drill bit :Stift Ø54

GEOLOGICAL LOG
0-0,6 m humus-bearing peat
0,6-0,9m silt
0,9-1,2m silty gravelly sand
1,2-2,4m clay
2,4-3,0m clay till
3,0-5,0m silty gravelly till
5,0m rock surface

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

LAXEMAR BOREHOLE SSM000227

Company rep.
Torbjörn Johansson

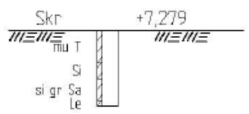
Client: Svensk Kärnbränslehantering AB

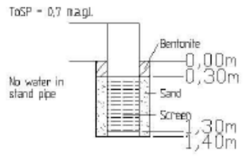
Northing :6367693,239
Easting :1549787,713

Coordinate system : RT90-RHB70

Top of stand pipe : 0,7 m.a.g.l.
Total pipe length : 2,10 m
Groundwater level : -
Date of completion : 2005-09-14

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information
0–12	Skr +7,279; mu T; Si; si gr Sa; Le	1	ToSP = 0,7 m.a.g.l.; Bentonite 0,00m – 0,30m; Sand; Screen 1,30m – 1,40m; No water in stand pipe	see below





Drilling method : Auger
Borehole diameter : 82 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 0,30m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,10 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Ø44
Drill bit : Stift Ø54

GEOLOGICAL LOG
0-0,6m humus-bearing peat
0,6-0,9m silt
0,9-1,3m silty gravelly sand
1,3-1,4m clay

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

LAXEMAR BOREHOLE SSM000228

Company rep.
Torbjörn Johansson

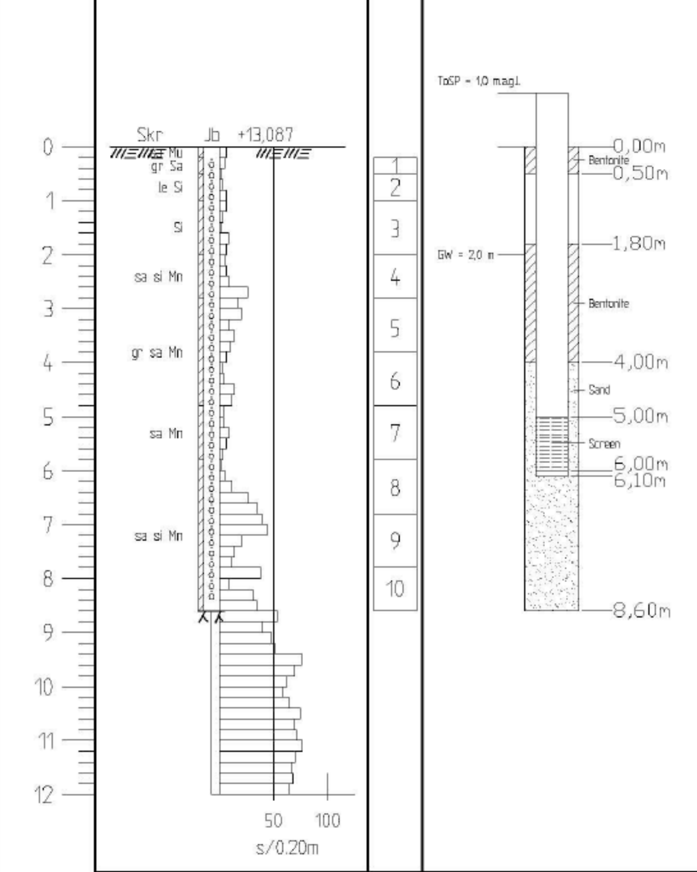
Client: Svensk Kärnbränslehantering AB

Northing :6366503,701
Easting :1548718,363

Coordinate system : RT90-RHB70

Top of stand pipe : 1,0 m.a.g.l.
Total pipe length : 7,10 m
Groundwater level : 2,0 m.b.g.l.
Date of completion : 2005-09-19

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 6,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 2,70 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 4,60 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Ø44
Drill bit : Stift Ø54

GEOLOGICAL LOG
0-0,2m sandy topsoil
0,2-0,5m gravelly sand
0,5-1,0m clayey silt
1,0-2,0m silt
2,0-2,8m sandy silty till
2,8-4,8m gravelly sandy till
4,8-5,8m sandy till
5,8-8,6m sandy silty till
8,6m rock surface

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

LAXEMAR BOREHOLE SSM000229

Company rep.
Torbjörn Johansson

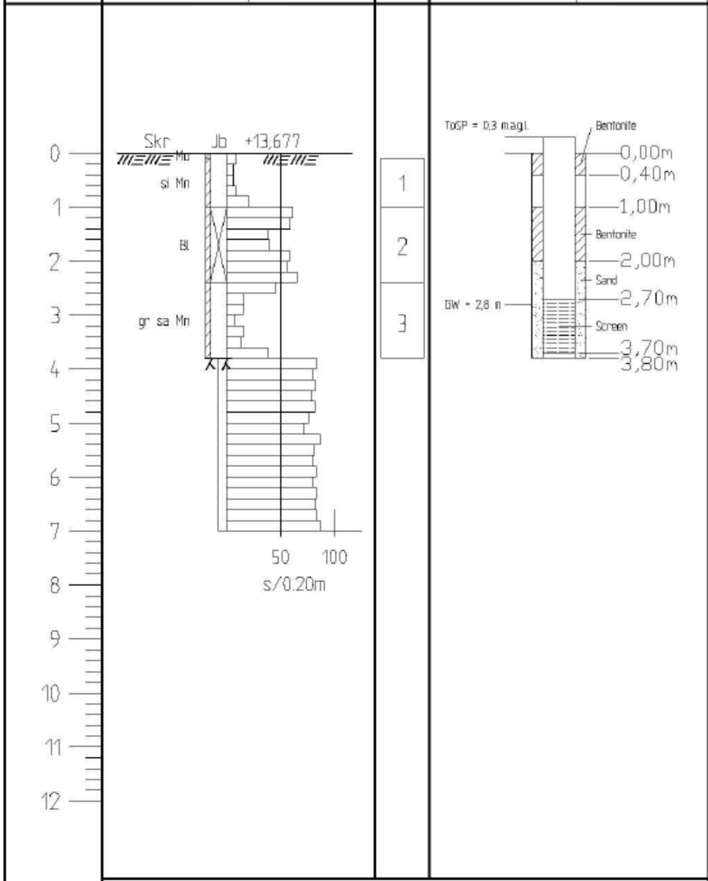
Client: Svensk Kärnbränslehantering AB

Northing :6366475,650
Easting :1548721,342

Coordinate system : RT90-RHB70

Top of stand pipe : 0,3 m.a.g.l.
Total pipe length : 4,10 m
Groundwater level : 2,8 m.b.g.l.
Date of completion : 2005-09-20

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 3,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 1,40 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,80 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Ø44
Drill bit : Stift Ø54

GEOLOGICAL LOG
0-0,1m topsoil
0,1-1,0m silty till
1,0-2,4m boulders
2,4-3,8m gravelly sandy fill
3,8m rock surface

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

LAXEMAR BOREHOLE SSM000230

Company rep.
Torbjörn Johansson

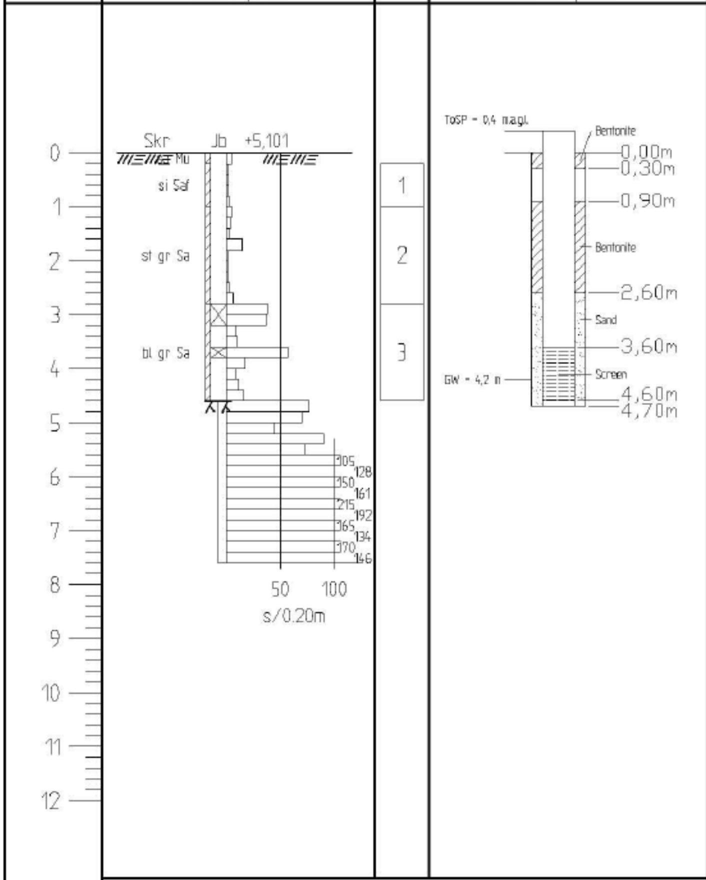
Client: Svensk Kärnbränslehantering AB

Northing :6366219,918
Easting :1550069,106

Coordinate system : RT90-RHB70

Top of stand pipe : 0,4 m.a.g.l.
Total pipe length : 5,10 m
Groundwater level : 4,2 m.b.g.l.
Date of completion : 2005-09-21

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 4,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 2,00 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 2,10 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Ø44
Drill bit : Stift Ø54

GEOLOGICAL LOG
0-0,2m sandy topsoil
0,2-1,0m silty fine sand
1,0-2,8m cobble-bearing gravelly sand
2,8-4,6m boulder-bearing gravelly sand
4,6m rock surface

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