P-06-248

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Hydrogeological characterization in bogs, lakes and sea bays

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Kristoffer Rönnback, Aqualog AB

December 2007

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 250, SE-101 24 Stockholm
Tel +46 8 459 84 00

ISSN 1651-4416
SKB P-06-248

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Keywords: Soil, Quaternary deposits, Geological characterization, Geotechnical characterization, Soil tubes, Slug test, Groundwater monitoring well, Hydrogeology, Hydraulic tests, Hydraulic parameters, Transmissivity.

Abstract

The Swedish Nuclear Fuel and Waste Management Company (SKB) carries out site investigations in the Laxemar and Simpevarp area. The main objective of this activity was to obtain information about geology, groundwater levels and -flow, and chemistry in bogs, lakes and sea bays to understand the interactions between surface water and underlying soil aquifers. Another purpose was to increase the knowledge about groundwater discharge areas and to collect sediment samples for determining sedimentation rates.

Drilling and sampling in soil, and installation of groundwater monitoring wells were performed in the area between January and February 2006. At 8 locations soil/rock drilling was performed and at 8 locations soil sampling was performed. Totally 9 groundwater monitoring wells were installed.

The drilling was performed by a track driven drilling rig, GM 65 GTT and the soil sampling was either performed by auger drilling (∅ 82 mm) or by a piston sampler. Air-rotary drilling with a casing driver system (NOEK) was used to check soil depth and to install groundwater monitoring wells.

The soil depth at the boreholes varied between 4.2 and 32.6 m. At most locations, the composition of the soil is peat, gyttja and/or gyttja underlain by sand, clay, silt and till. The composition of the till is mostly sandy.

Slug tests were conducted in all installed wells. The response was generally quick and only for a few wells the recovery period was longer than a few minutes. Therefore, most tests were repeated two or three times, in accordance with the method description for slug tests. The results from the slug tests indicate that the transition between soil and rock generally is very permeable.

Sammanfattning

Svensk Kärnbränslehantering AB (SKB) genomför platsundersökningar i Laxemar och Simpevarpsområdet. Den huvudsakliga målsättningen med denna aktivitet var att erhålla information om geologin, grundvattennivåer och flöden, samt vattnets kemiska sammansättning i mossar, sjöar och havsvikar för att förstå samverkan mellan mossar och jordakvifären. Ett annat syfte var att öka kunskapen om utströmningsområden och att ta sedimentprover för att fastställa sedimentationshastighet.

Jordborrning, jordprovtagning samt installation av grundvattenrör utfördes under januari 2006 – februari 2006. I 8 punkter utfördes jord-bergsondering och i 8 punkter utfördes jordprovtagning. Totalt installerades 9 grundvattenrör för mätning av grundvattennivå. Dessa slugtestades för att karaktärisera jordlagrens hydrauliska egenskaper.

Målet med undersökningen var att erhålla information om jorddjup, jordartssammansättning samt grundvattennivåer inom området. Borrningarna utfördes med en borrbandvagn, GM 65 GTT.

Jordprovtagningen utfördes med skruvprovtagare (∅: 82 mm) eller med kolvprovtagare. Foderrörsborrning (NOEK) användes vid jorddjupsbestämning och vid installation av grundvattenrör. För att säkerställa att bergytan var nådd, borrades det ca 1–3 meter ner i berget. Några grundvattenrör installerades direkt i skruvprovtagningshålen.

Jorddjupen i borrhålen varierade mellan 4,2 och 32,6 m. Jordens sammansättning var i de flesta punkter torv, gyttja och/eller gyttja på sand, lera, silt och morän. Moränen är mestadels sandig.

Slugtesterna visade att återhämtningen var generellt sett snabb och endast ett fåtal brunnar visade återhämtningsförlopp med längre varaktighet än ett par minuter. På grund av detta repeterades de flesta testen två eller tre gånger i enlighet med metodbeskrivningen för slug tester i öppna grundvattenrör. Resultaten från slugtesterna visar att moränen är genomsläpplig och övergången mellan morän och berg generellt sett är mycket permeabel.

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1 Introduction

This document reports the results and primary data evaluation gained by the *drilling and sampling in soil – installation of groundwater monitoring wells in bogs, lakes and bays*, 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 400-06-12 (SKB internal document).

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

The drilling field campaign was carried out by WSP Sweden AB from January to February 2006 following the methodologies described in SKB MD 630.003, SKB MD 600.006, SKB MD 600.004. Data and results were delivered to the SKB site characterization database SICADA.

The aim of the geotechnical drilling campaign is to characterize the Quaternary deposits with respect to stratigraphy and composition. In addition, installation of groundwater monitoring wells for groundwater sampling and monitoring was a key issue. The obtained data is subsequently delivered for purposes of site descriptive modelling.

At 8 locations soil/rock drillings were performed and at 8 locations soil samplings were performed. Totally, 9 groundwater monitoring wells were installed. The locations of the probing points and the installed groundwater monitoring wells are given in Figure 1-1.

All 9 groundwater monitoring wells were slug tested and analysed in two separate field campaigns during March and November 2006. The main objective of slug tests is to characterize the hydraulic properties, such as transmissivity of an aquifer. The principle behind the test is to create a rapid change in the water level and then measure the recovery to initial conditions.

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

Activity Plan	**Number**	**Version**
Sedimentprovtagning och installation av grundvattenrör i mossar, sjöar och havsvikar	AP PS 400-06-12	1.0
Slugtester i grundvattenrör – sjöar, mossar och havsvikar	AP PS 400-06-12 Tillägg till aktivitetsplan	1.0
Method Descriptions	**Number**	**Version**
Metodbeskriving för slugtester I öppna grundvattenrör	SKB MD 325.001	1.0
Metodbeskrivning för jordborrning	SKB MD 630.003	1.0

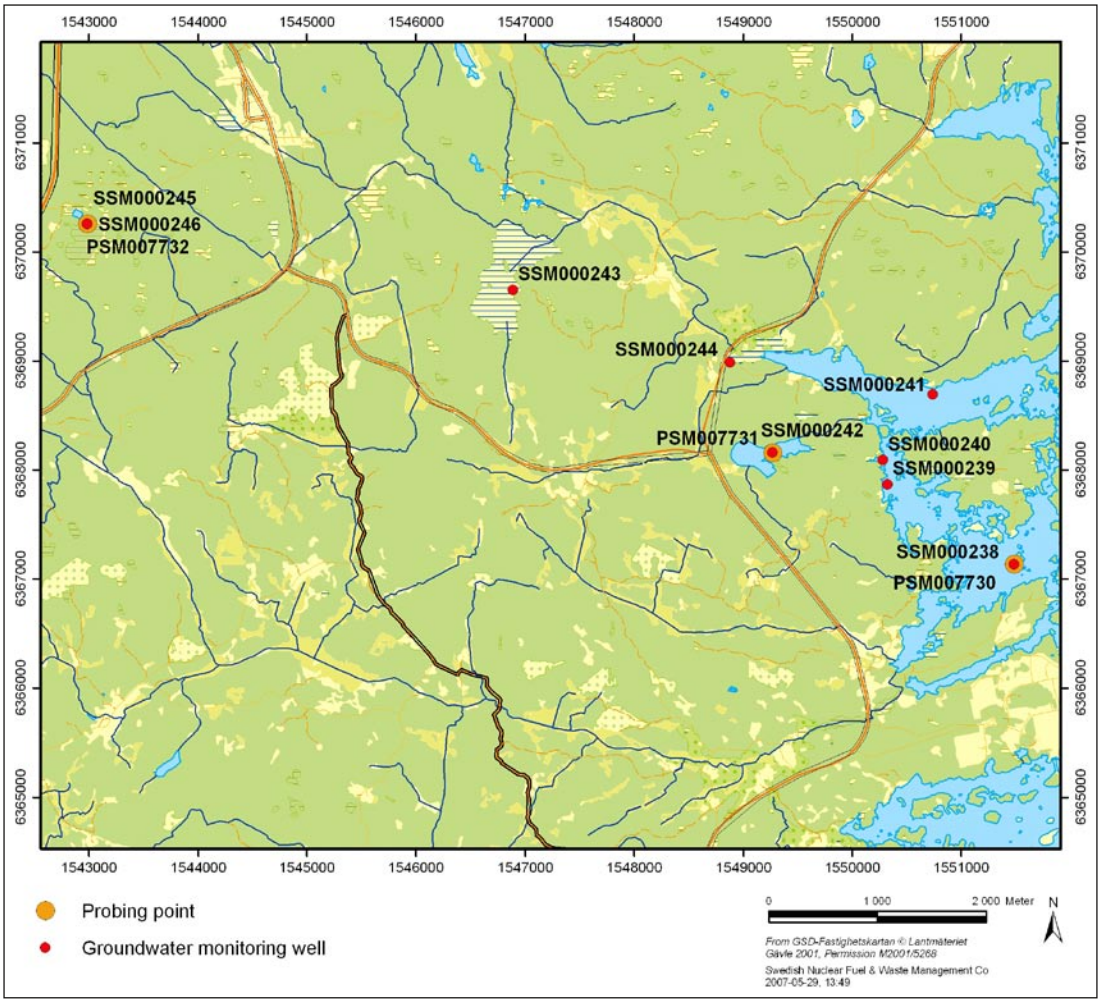


Figure 1-1. *Groundwater monitoring wells and soil probing points in the Laxemar area.*

2 Objectives and scope

The general objective of this study is to characterize bogs, lakes and sea bays with respect to their stratigraphy, groundwater head and groundwater flow.

The specific objectives are to obtain data of sediment thickness, distance to bedrock, stratigraphic units, rate of sedimentation, transmissivity and hydraulic conductivity of the soil in contact with the bedrock, and groundwater head. Another objective is to install wells for monitoring purposes.

To this end an investigation campaign was undertaken, including:

- soil probing,
- soil drilling,
- soil sampling,
- construction of soil wells,
- slug testing.

All installed wells are to be part of the long term monitoring programme, within which groundwater head measurements and water sampling are performed.

3 Drilling equipment

This chapter describes the equipment, instruments, and tools that were used for the tests.

3.1 Drilling and soil sampling

The drilling and soil sampling were performed with a track-driven drilling rig, GM 65 GTT, Figure 3-1. The soil sampling was performed either by auger drilling (∅ = 82 mm) or by a piston sampler. Soil/rock drilling was performed by air-rotary drilling using a casing driver system (NOEK).

Figure 3-1. *GM 65 GTT drilling rig on seawater ice.*

4 Execution of drilling

The drilling work was performed according to SKB's method description SKB MD 630.003 for soil drilling and soil mapping, and according to activity plan AP PS 400-06-012 (SKB internal controlling documents). The work included the following: Preparation and mobilization, drilling and sampling in soil, installation of groundwater monitoring wells, finishing of work, surveying of boreholes, environmental control programme and data handling.

4.1 Mobilization and preparation

Before drilling commenced, service and function control of all equipment was conducted. It was checked that the types of fuel, oil and grease are in accordance with SKB's instruction for chemical products used for drilling works, SKB MD 600.006. Finally, the equipment was cleaned according to SKB's instruction SKB MD 600.004.

Mobilization onto the site included transport, cleaning of all in-hole equipment, preparation of the site, lining up the machine and final control of function. It also included transport of pipes, sand, bentonite, and sampling pots for soil as well as all other necessary equipment.

The drill holes located in lakes or sea bays required special preparations before drilling could commence. The thickness of the ice was checked and drilling was performed only where the ice was at least 0.3 m thick. If the ice was thinner than 0.3 m, it was sprinkled with water and checked again.

4.2 Drilling and sampling in soil

The soil samplings were performed by auger drilling (∅ = 82 mm), by a piston sampler and at one site (PSM007732 Klarebäck bog) with a peat sampler.

When the soil sampling was finished, air-rotary drilling was performed with a casing driver system (NOEK) in the same borehole. To ensure that the bedrock was reached, the drilling continued approximately 0.1–3 metres into the bedrock. In the sea bays, drilling into bedrock was shorter due to the weight of the drilling rig, which caused an increasing weakness of the ice cover. The soil sampling was performed within the activity according to AP PS 400-06-012 and the results are presented in more detail in /15/. The soil samplings were marked with borehole ID followed by serial number (e.g. SSM000244:1) and the characterization of the soil was done in the field. Interpretation of stratigraphical distribution was done separately by a Quaternary geologist and the results are presented in Table 5-1. Notice that the borehole information protocols in Appendix C, which are made by the drilling company, differ somewhat from the determinations by the geologist. All primary results have thereafter been stored in SKB's database SICADA.

4.3 Installation of groundwater monitoring wells

Groundwater monitoring wells were installed inside the drill casing. PEH screens (∅: 63/50 mm, length: 1–2 m, slot: 0.3 mm) and PEH casings (∅: 63/50 mm) were used, Figure 4-1. Filter sand (0.4–0.8 mm) and bentonite clay (Volclay SG40) were filled outside the well while the drill casing was pulled out. There were some problems to fill bentonite clay in the drill casing in wells located in lakes and sea bays due to the great water depths. A PEH cap was installed at the top to prevent debris entering the casing.

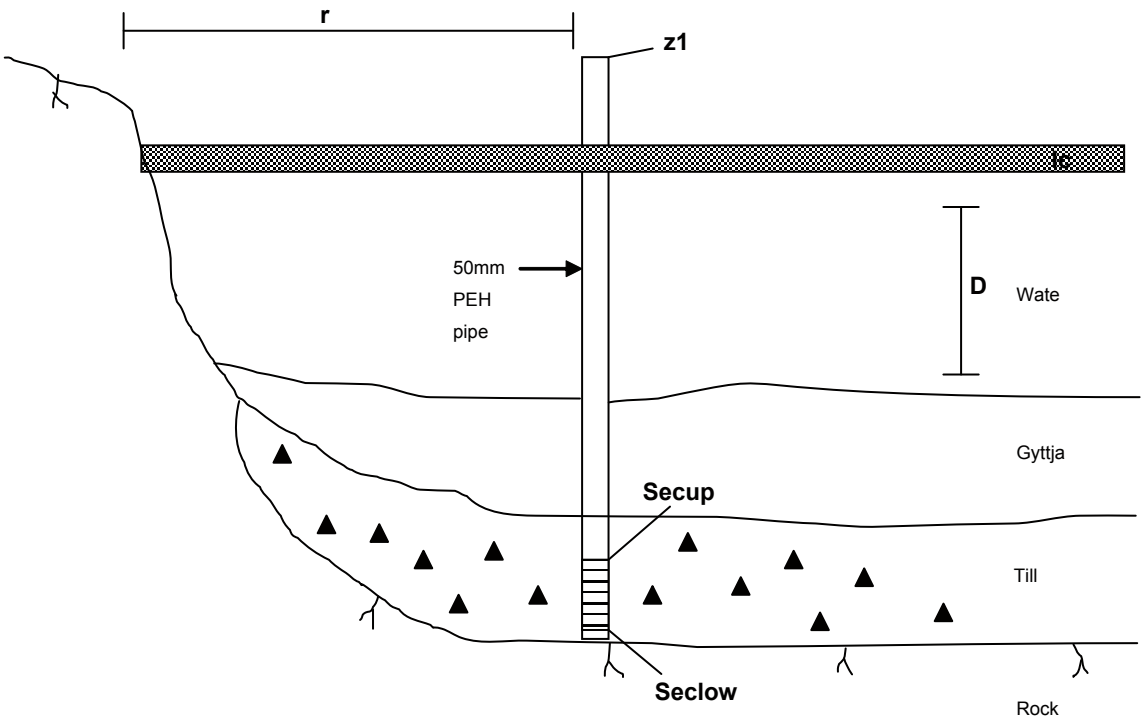


Figure 4-1. *Explanatory sketch of grondwater monitoring well installation.*

After installation, function tests were performed. Water was either pumped out or blown out by air.

The wells SSM000238–SSM000242, installed below surface water, were cut off near the lake or sea bottom. A PEM hose (∅ 40/34 mm) was then connected to the pipe, Figure 4-2 and Figure 4-3. A pressure transducer was installed inside the stand pipe. The pressure gauge was connected with a cable drawn inside the hose to the shore. Except from groundwater level monitoring, according to SKB's hydrochemical programme water samples are taken in the hose using a suction pump. All underwater installation work was performed by the diving company Erlandssons Dyk & Sjötjänst.

4.4 Completion of work

The rig was removed and the site was cleaned.

4.5 Surveying

After finishing the work, all investigation points were temporarily surveyed by precision GPS (X-, and Y-coordinates). After completion of the field work, SKB executed a precision survey for X-, Y- and Z-coordinates using a GPS-RTK instrument according to SKB's Method Instruction SKB MD 110.001. The actual coordinates were stored in the SICADA database in the RT90-RHB70 national reference grid, with an accuracy of 0.020 m in X and Y, and 0.040 m in Z.

For those wells installed in lakes and sea bays, the surveying was done from the ice cover before the pipes were cut off. According to the cut off lengths, new elevation coordinates were calculated

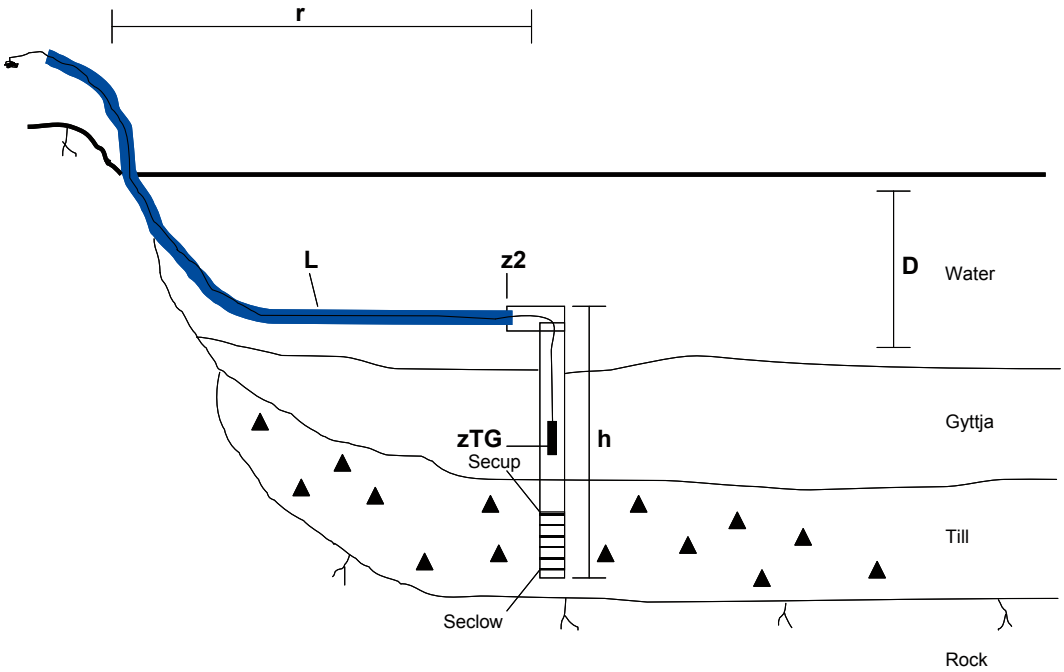


Figure 4-2. *Explanatory sketch of installation below water surface.*

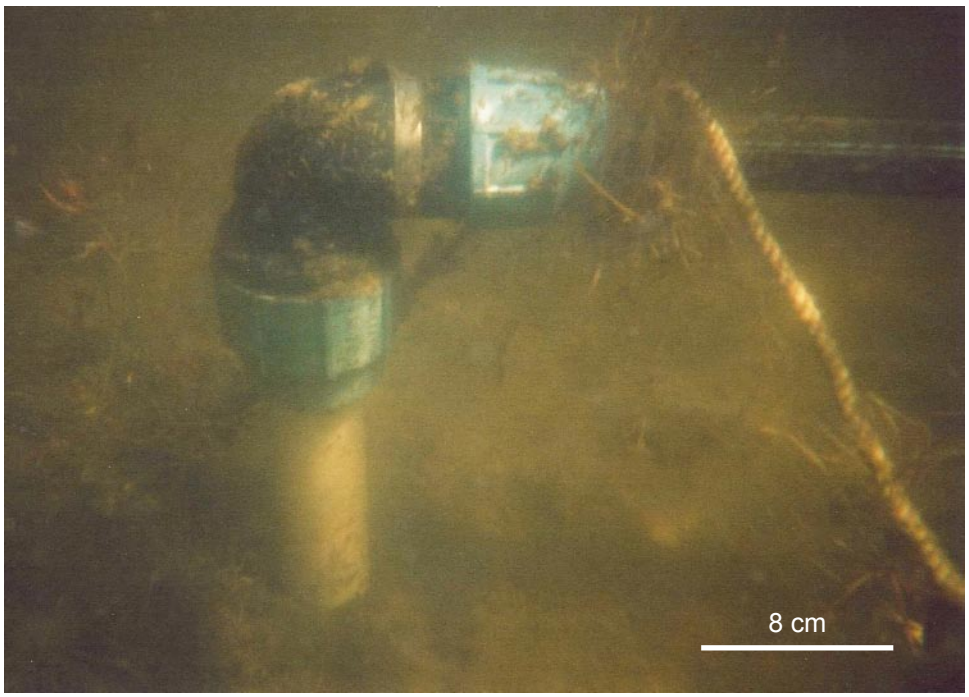


Figure 4-3. *Underwater photograph of soil tube with PEM-hose connected at sea bed.*

and stored in SICADA. Hence, there is minor uncertainty in the Z-coordinates that must be taken in consideration, due to some inclinition of the pipes. The monitoring control points (i.e. the PEM-hoses with the installed monitoring box on-shore) are however surveyed according to the method description. All coordinates are shown in Table 4-1 (groundwater monitoring wells) and Table 5-2 (monitoring control points).

Table 4-1. Coordinates and type for all boreholes.

Borehole	Site	Northing (m) Err 0.020	Easting (m) Err 0.020	Elevation (m.a.s.l.) Err 0.040	Type
SSM000238	Borholmsfjärden (sea bay)	6,367,132.604	1,551,484.944	–3.88 [1]	Soil/rock drilling, groundwater monitoring well
SSM000239	Norrefjärd South (sea bay)	6,367,870.814	1,550,325.426	–1.44 [1]	Soil/rock drilling, soil sampling with auger drilling, groundwater monitoring well
SSM000240	Norrefjärd North (sea bay)	6,368,093.203	1,550,283.159	–1.39 [1]	Soil/rock drilling, soil sampling with auger drilling, groundwater monitoring well
SSM000241	Granholmsfjärden (sea bay)	6,368,694.875	1,550,738.931	–13.66 [1]	Soil/rock drilling, groundwater monitoring well
SSM000242	Lake Frisksjön	6,368,159.636	1,549,267.378	– 0.89 [1]	Soil/rock drilling, groundwater monitoring well
SSM000243	Gäster (bog)	6,369,652.116	1,546,891.728	4.28 [2]	Soil/rock drilling, soil sampling with auger drilling, groundwater monitoring well
SSM000244	Kärrsvik (bog)	6,368,986.441	1,548,877.407	1.911 [2]	Soil/rock drilling, soil sampling with auger drilling, groundwater monitoring well
SSM000245	Klarebäcksmossen (bog)	6,370,254.241	1,542,987.190	27.26 [2]	Soil/rock drilling, soil sampling with auger drilling, groundwater monitoring well
SSM000246	Klarebäcksmossen	6,370,253.556	1,542,985.261	27.58 [2]	Groundwater monitoring well
PSM007730	Borholmsfjärden	6,367,134.000	1,551,482.115	– 4.4 [3]	Soil sampling with piston sampler and sediment sampler, weight sounding
PSM007731	Lake Frisksjön	6,368,159.336	1,549,265.348	– 2.9 [3]	Soil sampling with piston sampler
PSM007732	Klarebäcksmossen	6,370,253.693	1,542,986.347	26.71	Soil sampling with peat sampler

[1] Top of standpipe after the pipe has been cut off at lake or sea bottom.

[2] Top of standpipe.

[3] Sea bottom elevation.

5 Drilling results

5.1 Drilling, soil sampling and installation of groundwater monitoring wells

The location of all boreholes is shown in Figure 1-1 and coordinates and borehole types are listed in Table 4-1. Information about the groundwater monitoring installation system and location of the monitoring control points are presented in Table 5-2 and Figure 5-1.

The stratigraphical interpretations from the drilling sites are presented in Table 5-1. Drawings of all boreholes including sink rate, borehole depth, stratigraphy and groundwater monitoring well design are presented in Appendix C. Photographs of the sites after completion of work are presented in Appendix D.

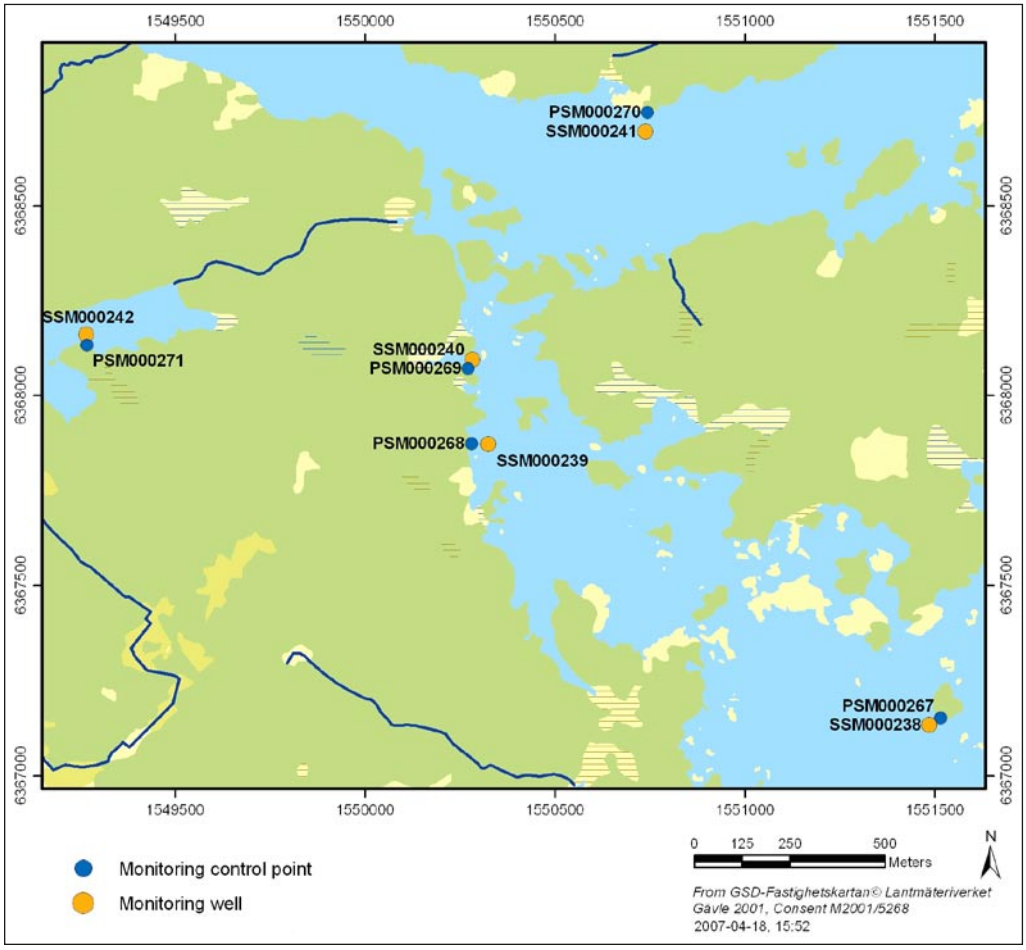


Figure 5.1. *Location of underwater groundwater monitoring installations SSM000238–SSM000242 and monitoring control points PSM000267–PSM000271. All monitoring points are located onshore for easier accessibility. However, it is recommended that PSM000267/SSM000238 (Borholmsfjärden) and PSM000270/SSM000241 (Granholmsfjärden) are visited by boat. Monitoring protection boxes are installed at every control point to avoid rainwater inflow and malfunction of the logger cable connection.*

Table 5-1. Geotechnical drilling soil observations from drilling, sounding and sediment soil sampling.

Site	ID-code	From (m)	To (m)	Layer/Quaternary deposit *	Soil sample	Interval (m)	Sample method
Borholmsfjärden	PSM007730 SSM000238	0.00	4.40	Water			
		4.40	8.40	Gyttja	PSM007730:1	5.00–6.00	Piston sampler
					PSM007730:2	6.00–6.17	
					PSM007730:3	6.17–6.34	
					PSM007730:4	6.34–6.51	
					PSM007730:5	6.50–7.50	
		8.40	9.80	Clay			
		9.80	11.50	Silty till			
		11.50	11.60	Bedrock			
Norrefjärd south	SSM000239	0.00	1.40	Water			
		1.40	3.20	Gyttja	SSM239:1	1.40–3.20	Auger drilling
		3.20	4.20	Silty till			
		4.20	4.40	Bedrock			
Norrefjärd north	SSM000240	0.00	0.80	Water			
		0.80	3.10	Gyttja + plant remains	SSM240:1	0.80–1.50	Auger drilling
					SSM240:2	1.50–1.80	
					SSM240:3	1.80–3.10	
		3.10	3.30	Gravelly sand	SSM240:4	3.10–3.30	Auger drilling
		3.30	3.70	Sandy gravelly clay	SSM240:5	3.30–3.70	Auger drilling
		3.70	5.00	Sandy till			
		5.00	5.40	Bedrock			
Granholmsfjärden	SSM000241	0.0	14.60	Water			
		14.60	21.00	Gyttja			
		21.00	22.00	Clay			
		22.00	22.80	Sand			
		22.80	31.20	Clay			
		31.20	32.60	Sand/Till			
Lake Frisksjön	PSM007731 SSM000242	0.0	2.90	Water			
		2.90	13.00	Gyttja	PSM007731:1	4.00–4.17	Piston sampler
					PSM007731:2	4.17–4.34	
					PSM007731:3	4.34–4.51	
					PSM007731:4	5.00–5.17	
					PSM007731:5	5.17–5.34	
					PSM007731:6	5.34–5.51	
					PSM007731:7	6.00–6.17	
					PSM007731:8	6.17–6.34	
					PSM007731:9	6.34–6.51	
		13.00	17.80	Clay			
		17.80	18.00	Till/Bedrock			

Site	ID-code	From (m)	To (m)	Layer/Quaternary deposit *	Soil sample	Interval (m)	Sample method
Gästern bog	SSM000243	0.0	8.20	Gyttja	SSM243:1	0.00–1.00	Auger drilling
					SSM243:2	1.00–2.00	
					SSM243:3	2.00–3.00	
					SSM243:4	3.00–4.00	
					SSM243:5	4.00–5.00	
					SSM243:6	5.00–6.00	
					SSM243:7	6.00–7.00	
					SSM243:8	7.00–8.20	
		8.20	9.00	Clay gyttja	SSM243:9	8.20–9.00	Auger drilling
		9.00	11.00	Clay	SSM243:10	9.00–10.00	Auger drilling
					SSM243:11		
		11.00	11.40	Sandy till	SSM243:12	11.00–11.40	Auger drilling
		11.40	14.40	Rock			
Kärrsvik	SSM000244	0.00	4.60	Gyttja	SSM244:1	0.00–1.00	Auger drilling
					SSM244:2	1.00–2.00	
					SSM244:3	2.00–3.00	
					SSM244:4	3.00–4.60	
		4.60	5.40	Fine sand	SSM244:5	4.60–5.40	Auger drilling
		5.40	6.60	(Gravelly) sand	SSM244:6	5.40–6.60	Auger drilling
		6.60	9.60	Fine sand	SSM244:7	6.60–7.00	Auger drilling
					SSM244:8	7.00–8.00	
		9.60	11.00	Sandy till	SSM244:9	9.60–10 .80	Auger drilling
		11.00	13.00	Boulder bearing sandy till			
		13.00	16.00	Rock			
Klarebäck bog	PSM007732	0.00	3.50	Peat	PSM007732:1	0.00–1.00	Peat sampler
	SSM000245				PSM007732:2	1.00–1.10	
					PSM007732:3	1.20–2.00	
					PSM007732:4	2.00–3.00	
					PSM007732:5	3.00–4.00	
		3.50	4.10	Gyttja with peat	PSM007732:6	4.00–4.10	Peat sampler
		0.00	3.80	Peat			
		3.80	4.00	Gyttja peat			
		4.00	4.20	Clayey peat	SSM245:1	4.20–4.40	Auger drilling
		4.20	4.40	Sandy till			
		4.40	7.40	Rock			
Klarebäck bog	SSM000246	0.00	3.20	Peat			

* Determined by the Quaternary geologist.

Table 5.2. Groundwater monitoring well information and underwater installation design.

Borehole ID	PEM-hose control point ID[1]	PEM-hose control point Northing (m) Err 0.020	PEM-hose control point Easting (m) Err 0.020	PEM-hose control point elevation (m.a.s.l–) Err 0.030	PEM-hose start inclination (deg)	PEM-hose length (m)	Original standpipe length (m)	Pipe cut off (m)	Present standpipe elevation (m.a.s.l.)	Pressure transducer elevation (m a.s.l.)	Pressure transducer range (mH20)	Water depth (m)
SSM000238	PSM000267	6367151.243	1551514.722	1.564	–62.50	45.3	12.10	4.24	–3.88	–6.38	21.09	4.5
SSM000239	PSM000268	6367872.918	1550280.205	1.614	–88.00	47.1	5.10	2	–1.44	–2.44	21.09	1.4
SSM000240	PSM000269	6368069.594	1550271.739	1.437	–89.00	32.25	6.10	2	–1.39	–3.39	21.09	1
SSM000241	PSM000270	6368745.252	1550744.216	1.472	–74.00	63.85	33.10	14	–13.66	–14.66	70.31	15
SSM000242	PSM000271	6368131.285	1549268.910	3.212	–68.00	36.86	18.10	3	–0.89	–4.89	21.09	3

[1] PEM-hose control point with installed monitoring protection box.

Drilling sites SSM000238–242 are located in relation to major deformation zones at sea bays around the island of Äspö and in Lake Frisksjön, and are characterised as groundwater discharge areas with possible "particle exit points". The drilling sites were however not located in the middle of the major topographical lineaments where the deepest coverage of Quaternary deposits can be expected. Due to the technical complexibility associated with drilling from ice and making the underwater installations, drilling sites were chosen closer to the shore line. This also reduces the pumping time significantly in association with chemical water sampling.

The soil depth at the boreholes located in sea bays varies between 4.2 and 32.6 m. The composition of the soil at most locations is peat and/or gyttja underlain by sand, clay, silt and till. The composition of the till is mostly sandy. However, at SSM000240 the stratigraphy is slightly different, with a gyttja layer underlain by gravelly sand on bedrock.

Drilling sites located in bogs in Kärrsvik (SSM000244) and Gästern (SSM000243) are almost identical and showed a similar stratigraphy to the drilling sites at the sea bays. Wells SSM000245 and SSM000246 (the Klarebäck bog) are located close to each other in a "high-land bog area" (27 m.a.s.l.) and show a 3–4 m thick peat layer at both sites. Lower along the soil profile in SSM000245, a thin layer of clayey gyttja and a sandy till layer was penetrated before the bedrock surface was reached at a depth of 4.4 m.

In order to characterise the chemical composition, the sediment/peat accumulation rate and to facilitate the identification of different soil types, soil sampling was included in the drilling activity. Sediment soil sampling was done in cooperation with another survey (AP PS 400-06-05) and the analysis and results are presented separately in /17/.

Soil sampling using auger drilling was performed at five sites, Norrefjärd South (SSM000239), Norrefjärd North (SSM000240), Gäster (SSM000243), Kärrsvik (SSM000244) and Klarebäcksmossen (SSM000245). All samples were stored in plastic bags marked with sample id-number and depth, after which they were stored in a cooling coinatiner at the Äspö Laboratory.

Sediment samples were collected by a piston sampler at Borholmsfjärden (PSM007730) and in Lake Friskjön (PSM007731). This sampling method included samples down to a depth of 2–2.5 m below the sea or lake bottom. All samples were sliced into 17 cm sections and marked with id-number and depth, for long-time storage at the Äspö Laboratory. A single surface sediment sample was also collected from Borholmsfjärden (PSM007730) using a sediment sampler. In the bog Klarebäcksmossen (PSM007732) a five metre peat core profile with section lengths of 1 m were taken for determination of the peat accumulation rate.

It must be emphasized that the soil type classification done by the Quaternary deposits geologist, which is stored in sicada, differ somewhat from the determination done by the drilling company.

Drawings of all boreholes are presented in Appendix B, and photos of the sites after completion of work are shown in Appendix C.

6 Slug test equipment

The following equipment was used for execution of the slug tests:

6.1 Slug test campaign 1

- Pressure transducer Level Troll 700, In-Situ Inc. range 30 PSI non-vented. Minimum logging rate 0.25 sec.
- Stainless steel 3×0.5 m slugs.
- Water level meter – type Solinst.
- Portable PC.
- Stop watch.
- Tape measure.

6.2 Slug test campaign 2

- Pressure transducer and temperature meter, type DIVER from Van Essen Instruments.
- Portable PC.
- Slugs made from HDPE-pipe (40 mm in diameter and ranging in lengths from 0.5 metres to 3.0 metres), with stainless steel wire (diameter 2.15 mm) and wire stopper.
- Water level meter (type ELWA 50A) and tape measure with a weight designed for measuring the water level in wells.
- Inch measure.
- Cleaning equipment (70% de-naturated alcohol and cotton cloth).

The dimensions for the different parts of the slug test equipment are listed below:

	Slug 0.5 m	Slug 1.0 m	Slug 1.5 m
Total slug length (m)	0.54	1.08	1.53
Slug diameter (mm)	41.5	41.5	41.5
Total volume (L)	0.70	1.43	2.04
Wire thickness (mm)	2.15	2.15	2.15

7 Excecution of slug tests

The tests were performed according to SKB's method description for slug tests, "Slugtester i öppna grundvattenrör" SKB MD 325.001, and the activity plan supplement *"Slugtester i grundvattenrör – sjöar, mossar och havsvikar",* AP PS 400-06-012 (SKB internal documents).

The extent of the first field campaign (March 2006) included the soil wells SSM000238–SSM000242. The tests were performed by Aqualog AB and the analysis and interpretation was done by SWECO VIAK. In the second field campaign (November 2006) soil wells SSM000243–SSM000246 were tested in relation to a separate drilling and soil sampling activity (SKB AP PS 400-06-78 "*Kompletterande jordborrningar och installation av grundvattenrör i kontakten jord-berg*"). The tests were done by Ramböll, and the analysis was done by SWECO VIAK.

7.1 Preparations

Before the tests, all clocks were synchronised to Swedish local time.

The equipment used for logging the water pressure and temperature during the slug tests was calibrated before the testing commenced. To ensure the accuracy of the data logger, the groundwater pressure for undisturbed conditions was logged at two known reference depths and the groundwater level was also measured manually. These data were used as function checks and a good agreement was achieved for all tests.

7.2 Test procedure

The tests in all groundwater monitoring wells located in lakes and sea bays (Field campaign 1) were performed prior to cutting off the pipes. The tests had to be performed before ice breakup. All tests in field campaign 1 were peformed with the same slug volume (0.5 litres).

In each test, the total depth of the well was measured, from the top of standpipe to the bottom of the well, as well as the depth to the undisturbed groundwater level. Subsequently, the slug and wire lengths as well as the logger installation depth were determined. Prior to installation in the well, the equipment was cleaned in accordance with the cleaning instructions described in SKB MD 600.004.

After installation of the logger, the water level was left to stabilise for a short period prior to rapidly sunberging the slug in the well to initiate the falling-head test. The logger sampling frequency was one measurement per second for the full duration of the test. When possible, the water level was also measured manually during the test period.

When the undisturbed water level was recovered, the slug was withdrawn from the well and the rising-head test was conducted according to the procedures described above.

The falling- and rising-head tests were carried out in accordance with the document SKB MD 325.001 (SKB internal controlling document), which is referred to for detailed information on the test procedures.

In SSM000240, a fresh-water ice plug was blocking the standpipe and had to be knocked down prior to the tests. However this had no negative effects on the results as the response time was very short in the well.

Table 7-1 presents a summary of the well details and the main observations during the slug tests.

The nomenclature used in Table 7-1 is explained below. All depths are in metres below top of casing (m b TOC).

ID	borehole name
Secup (m)	depth to top of screen
Seclow (m)	depth to base of screen
Start	start date and time for test series
Stop	stop date and time for test series
Logging interval	measurement time interval in seconds
tp (sec)	total measuring time after start of displacement
h_0 (m)	water level from ToSP prior to initiation of slug test, (* = 1 m extra pipe)
dh_0 (m)	initial displacement
dh_0*/dh_0	deviation of displacement (dh_0* = expected initial displacement, dh_0 = actual initial displacement)
Test type	Fh falling head test/Rh frising head test

Table 7-1.

ID code	Slug test No.	Secup (m)	Seclow (m)	Start (yymmdd hh:mm)	Stop (yymmdd hh:mm)	Logging interval (s)	tp (s)	h_0 (m)	dh_0 (m)	dh_0^*/dh_{0p} (–)	Test type
SSM000238	1	11.00	12.00	060316 11:11	060316 13:27	1		1.21	0.64	–	Fh
SSM000238	1	11.00	12.00	060316 11:11	060316 13:27	1	–	1.21	–0.30	–	Rh
SSM000238	2	11.00	12.00	060316 11:11	060316 13:27	0.5	–	1.21	0.69	–	Fh
SSM000238	2	11.00	12.00	060316 11:11	060316 13:27	0.5	–	1.21	–0.53	–	Rh
SSM000239	1	4.00	5.00	060316 09:30	060316 10:54	1	–	1.97*	0.69	–	Fh
SSM000239	1	4.00	5.00	060316 09:30	060316 10:54	1	–	1.97*	–0.48	–	Rh
SSM000239	2	4.00	5.00	060316 09:30	060316 10:54	0.5	–	1.97*	0.33	–	Fh
SSM000239	2	4.00	5.00	060316 09:30	060316 10:54	0.5	–	1.97*	–0.47	–	Rh
SSM000240	1	5.00	6.00	060316 09:44	060316 10:22	1	–	1.49	0.35	–	Fh
SSM000240	1	5.00	6.00	060316 09:44	060316 10:22	1	–	1.49	–0.47	–	Rh
SSM000240	1	5.00	6.00	060316 09:44	060316 10:22	1	–	1.49	0.78	–	Fh
SSM000240	1	5.00	6.00	060316 09:44	060316 10:22	1	–	1.49	–0.43	–	Rh
SSM000240	2	5.00	6.00	060316 09:44	060316 10:22	0.5	–	1.495	0.51	–	Fh
SSM000240	2	5.00	6.00	060316 09:44	060316 10:22	0.5	–	1.495	–0.46	–	Rh
SSM000240	3	5.00	6.00	060322 10:11	060322 10:11	0.25	–	1.495	–0.22	–	Rh
SSM000240	3	5.00	6.00	060322 10:11	060322 10:11	0.25	–	1.495	–0.48	–	Rh
SSM000240	3	5.00	6.00	060322 10:11	060322 10:11	0.25	–	1.495	0.46	–	Fh
SSM000240	3	5.00	6.00	060322 10:11	060322 10:11	0.25	–	1.495	–0.43	–	Rh
SSM000241	1	32.00	33.00	060315 11:02	060315 15:34	1	–	1.67*	0.87	–	Fh
SSM000241	1	32.00	33.00	060315 11:02	060315 15:34	1	–	1.67*	–0.54	–	Rh
SSM000242	1	17.00	18.00	060316 13:55	060317 08:05	1	–	0.665	0.5	–	Fh
SSM000243	1	11.00	12.00	061117 09:45	061117 11:20	–	301	1.39	0.45	0.80	Fh
SSM000243	1	11.00	12.00	061117 09:45	061117 11:20	–	295	1.39	–0.27	–	Rh
SSM000244		11.00	12.00	061129 14:10	061130 15:21						
SSM000245	1	4.00	5.00	061129 09:40	061129 11:10	–	1,191	0.83	0.12	–	Fh
SSM000245	1	4.00	5.00	061129 09:40	061129 11:10	–	357	0.83	–0.16	2.24	Rh
SSM000246	1	3.00	4.00	061129 11:10	061129 14:15	–	16,765	1.25	0.24	–	Rh

8 Slugtest analyses and interpretations

For most wells the falling- and rising-head tests were repeated three times due to the very rapid response (as outlined in the method description for slug tests). Generally, the data from the first set of tests was used for the analyses, since it showed good agreement with the subsequent test results. If there were any uncertainties related to the data, another set of test data was used for the analyses.

Due to the very rapid response in some wells, it is sometimes difficult to estimate H_0 and t_0 as discussed in /12/. In those cases, the translation method approach has been adopted.

Slug tests in high conductivity formations offer a quite fast and easy way of estimating the formation permeability. Due to limitations in the method, such as the problem of causing an "instantaneous slug introduction" without disturbing or even damaging the logger, especially in very high permeability formations, the results should be used with care. Alternative methods such as grain analyses or pumping tests with longer duration could be used to support the results.

The slug test data have been analysed using the programme Aqtesolv 4.5 /16/. In the following section a brief presentation of the methods used for analysis is given. For further information of the methods please refer to Butler /12/, Kruseman and de Ridder /13/ or User's guide for Aqtesolv /16/.

8.1 SSM000238–SSM000242, SSM000244 – Field campaign 1

The analyses of the slug tests in the groundwater monitoring wells are commented in the following sections; normalized plots are presented below and linear plots are presented in Appendix A.

All tests have been evaluated according to Cooper-Bredehoeft-Papadopulos /10/**,** except SSM000244 which was analysed according to McElwee-Zenner /11/. The former method is developed for estimation of the transmissivity and storativity in fully penetrating wells in confined aquifers, but may be applicable for partly penetrating wells if the formation thickness is replaced by the effective screen length.

Both methods are based on fitting a type curve to a plot of the ratio h_t/h_0 versus time in a lin-log diagram. The McElwee-Zenner method is described in detail in /11, 12/. In the analyses of the slug tests in SSM000239–SSM000242, type curves were fitted visually to the test data in the computer program Aqtesolv /16/.

In some cases, the initial displacement is larger than the theoretical maximum displacement, calculated from the volume of the slug. This phenomenon is assumed to be an effect of a pressure pulse caused as the slug penetrates the water surface. By designating the theoretical value of the initial displacement based on the volume of the slug for a given well diameter, it is possible to compensate for the pressure pulse. The design of the well and the screen is not always ideal, and to ensure the reasonableness of the designated value, the compensated data is plotted and compared to the type curve, and if possible, also to other tests in the well.

SSM000238

Two tests were performed in the well, and the result from the last rising-head test is reported to SICADA. Data from the first test have not been evaluated as the second test is considered to have a higher data quality, see lin-log plot (Figure 8-4).

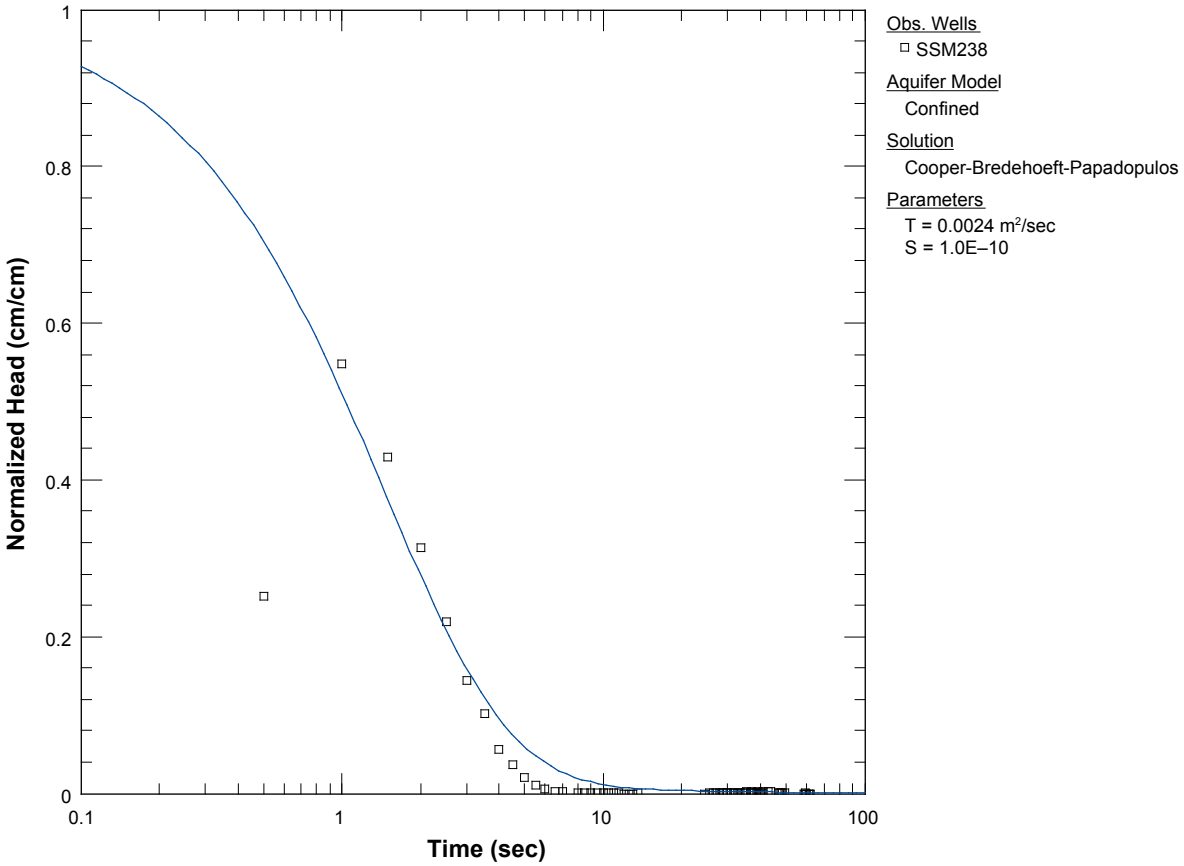


Figure 8-1. *Analysis of rising-head test 2 in SSM000238.*

The tested section is the screen, which is situated between 11.00–12.00 m below Top of Casing (TOC), and the screen length is used for the calculations of the hydraulic conductivity. The natural water level was 1.21 m b ToSP before and after the tests.

SSM000239

The tested section is the screen, situated 4.0–5.0 m below TOC. A 1 m long extra pipe was attached to avoid overflow in the raising-head tests and the undisturbed water level was 1.97 m b ToSP prior to and after the tests. Two tests were performed in the well and the results from the first rising-head test are reported to SICADA.

The test data quality is good and also the fit of the type curves for all tests. However, the data from the first rising-head test is considered to give the most representative value of the hydraulic conductivity at the well screen of SSM000239. The lin-log plot of the first rising-head test is presented in Figure 8-2 below.

SSM000240

The tested section is the screen situated 5.00–6.00 m below TOC. Three tests were performed in the well SSM000240. However, in all falling-head tests the drawdown period is too short to evaluate, and therefore only the rising-head tests are evaluated. The logging time interval was reduced from 1 sec to 0.25 sec due to a fast response time and the undisturbed water level was between 1.49–1.495 m b TOC. The lin-log plot of the third rising-head test in the well is shown in Figure 8-3.

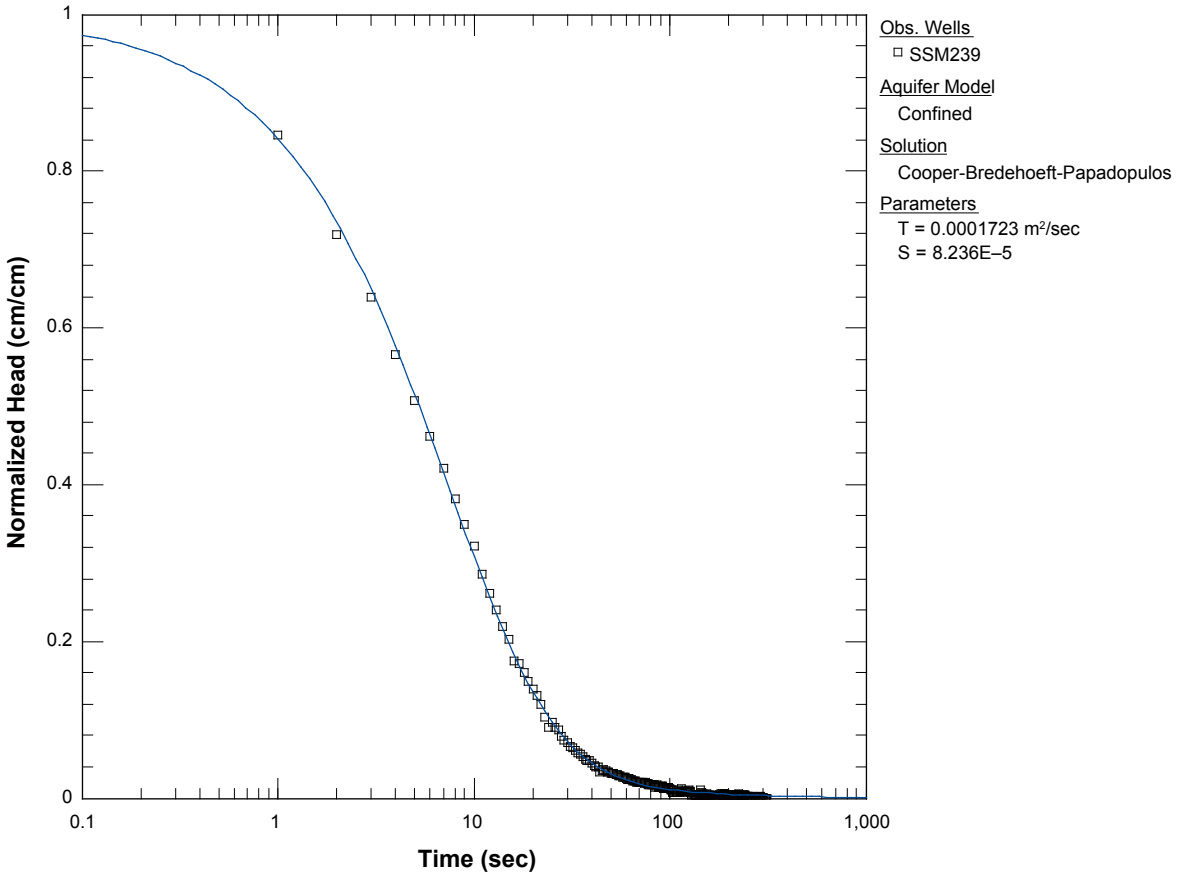


Figure 8-2. *Analysis of rising-head test 1 in SSM000239.*

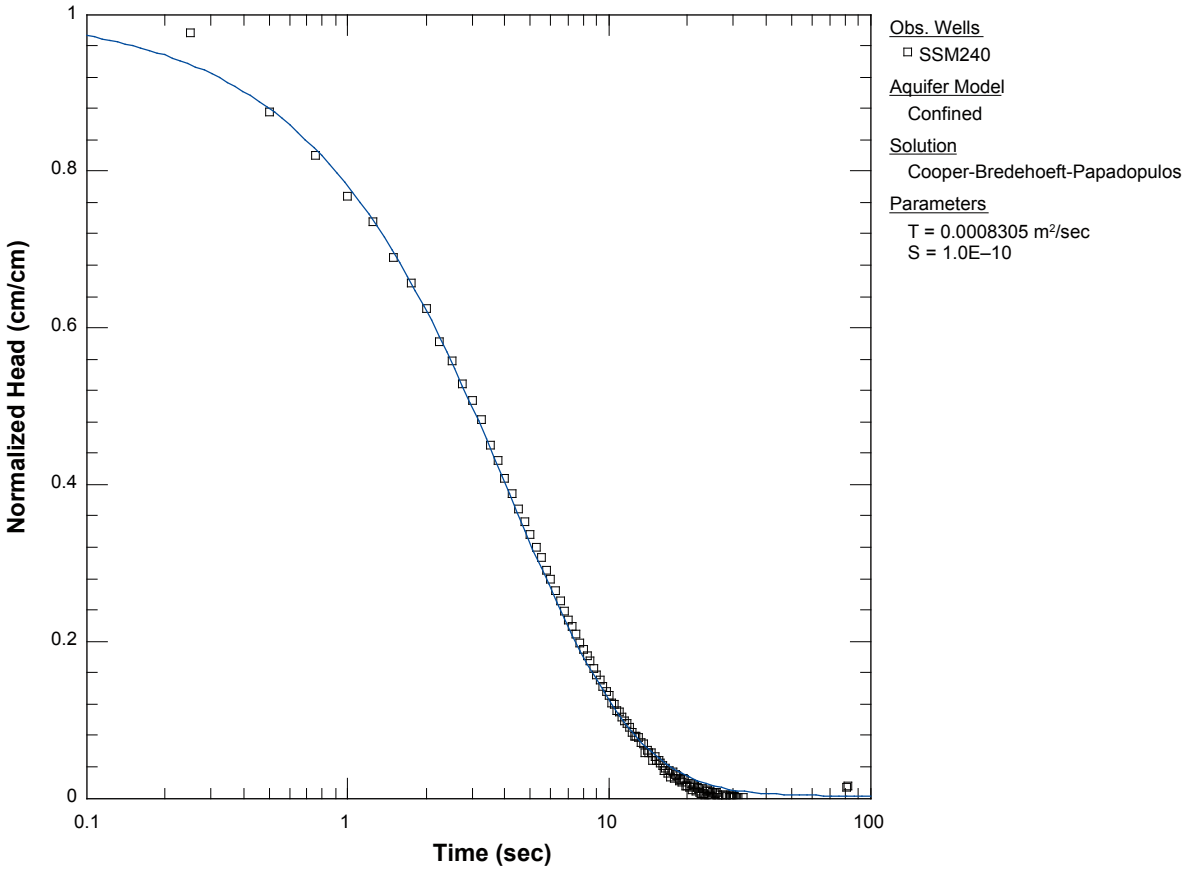


Figure 8-3. *Analysis of rising-head test 3 in SSM000240.*

SSM000241

One test was performed in SSM000241 and the result from the rising-head test is reported to SICADA. The lin-log plot of the analysis is shown in Figure 8-4. The well screen is situated 32.00–33.00 m below TOC and the natural water level was 1.67 m before and after the test, using an 1 m extra pipe.

SSM000242

Only one test was performed in SSM000242, and the result from the falling-head test is reported to SICADA. The screen is situated 17.00–18.00 m below TOC, and the water level was 0.66 m b ToSP prior to test. Since the response was slow, the test had to be prolonged over night to reach complete recovery. However, the data showed that after approximately 2 hours the water level was fully recovered. The lin-log plot of the falling-head test is shown in Figure 8-5.

SSM000244

In the well SSM000244, the water table was oscillating after the introduction or removal of the slug, Figure 8-6. By the method of Cooper-Bredehoeft-Papadopulos /10/, it is not possible to evaluate the tests when such oscillations occur. Hence, the method of McElwee-Zenner /11/ is used instead. The method is developed for evaluation of slug tests with an oscillating response. Such can occur in aquifers with very high conductivity, among other.

The method is used to calculate the hydraulic conductivity based on an estimation of the effective length of the water column, L_e, and the dimensionless damping parameter, C_d, from the test response data. The method and its conceptual model are described in detail in /12/.

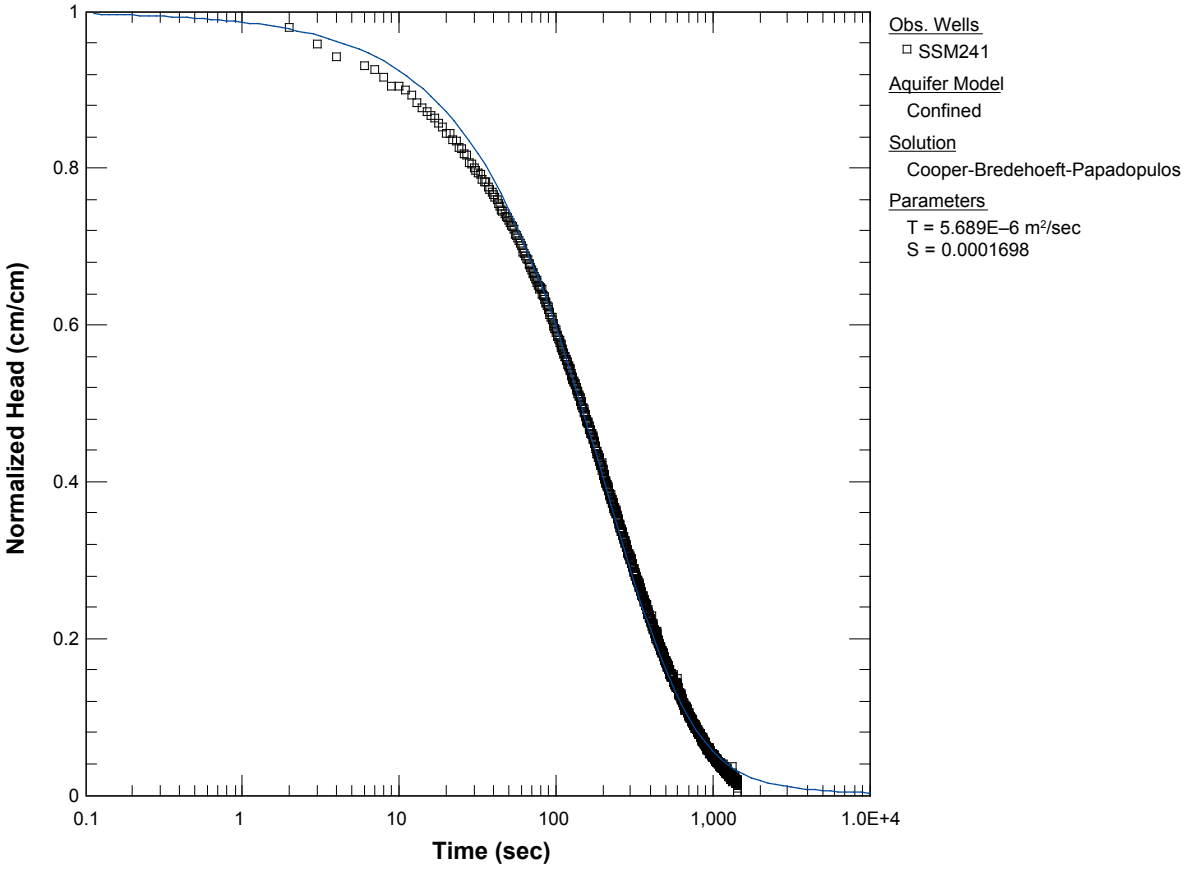


Figure 8-4. *Analysis of rising-head test in SSM000241.*

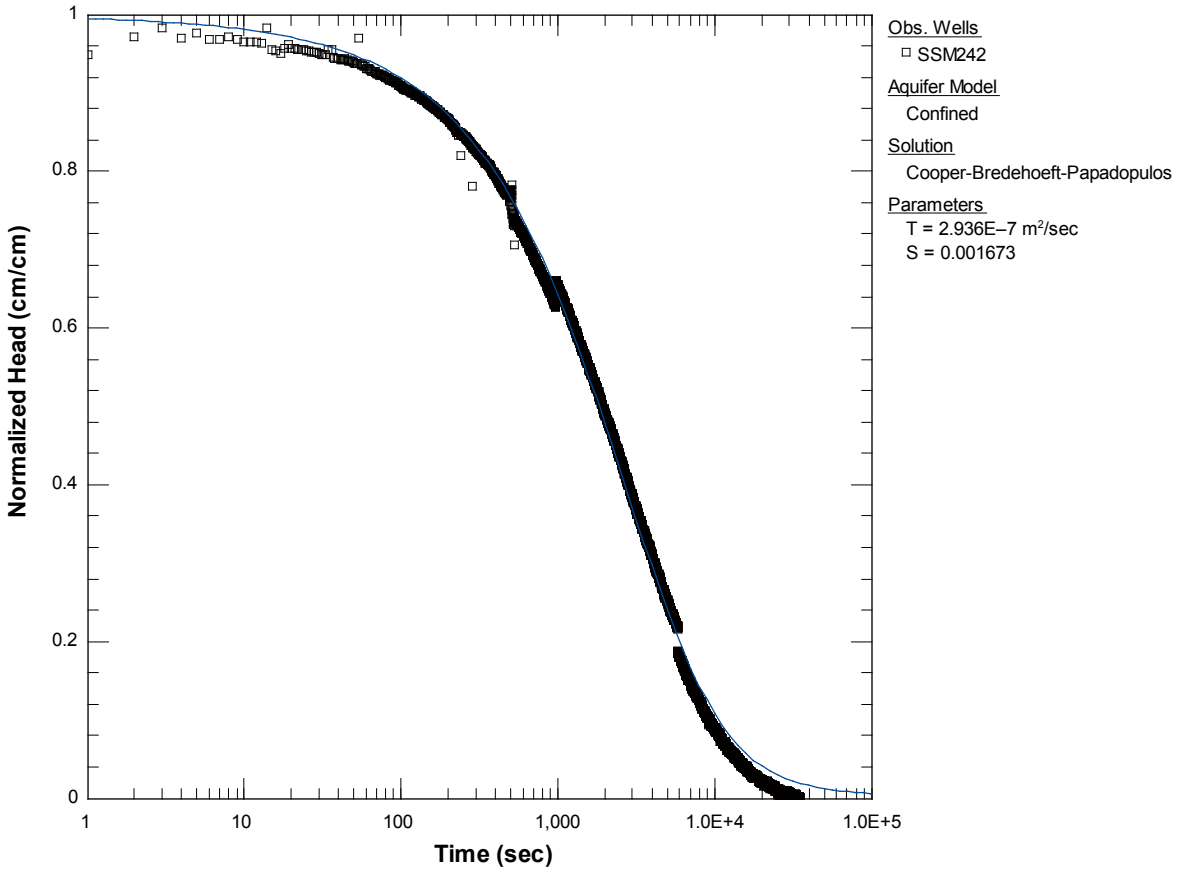


Figure 8-5. *Analysis of falling-head test in SSM000242.*

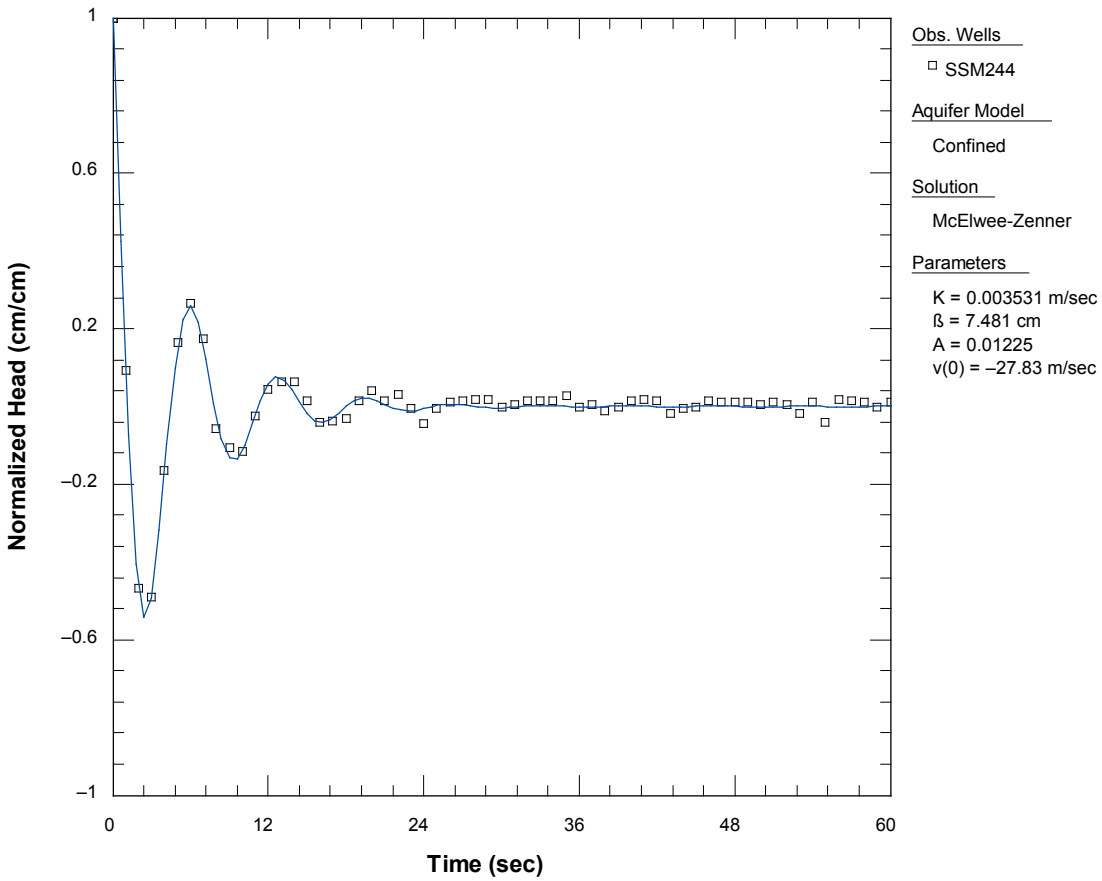


Figure 8-6. *Analysis of slugtest in SSM000244.*

8.2 SSM000243, SSM000245–SSM000246 – Field campaign 2

The following analysis methods are developed for wells that fully penetrate the aquifer. All wells tested during this campaign are partially penetrating wells. In the analyses, the aquifer thickness has been substituted with the effective well screen length, which is set equal to the nominal screen length. A sand filter was installed in all wells and so the effective diameter of the well screen was set equal to the outer diameter of the drill casing, 110 mm.

The response in the wells (SSM00243, 245 and 246) were analysed with three applicable method, described below.

Cooper et al. method
The Cooper et al. method /10/ was originally developed to estimate the transmissivity in a confined aquifer and for fully penetrating wells. The Cooper analysis is recommended as the primary analysis method in SKB MD 325.001. The analysed response curves are shown in Figure 8-7 and 8-8 respectively.

Hvorslev method
The Hvorslev method /12/ is designed to estimate the hydraulic conductivity in a confined aquifer. The method is based on the assumption that the plot of the normalised response data versus time is linear. Due to the effects of elastic storage in the aquifer, the data often shows a concave upward curvature. For the analyses, the emphasis for the curve fitting is the early-time data. The analysed response curves in soil well SSM000246 is shown in Figure 8-9.

Bouwer and Rice method
The Bouwer Rice method /17/ is based on the Thiem equation and is valid for steady-state flow in unconfined or leaky aquifers of infinite extent. Wells are assumed to be fully or partially penetrating.

Derived transmissivities from these tests are compiled in Table 9-1.

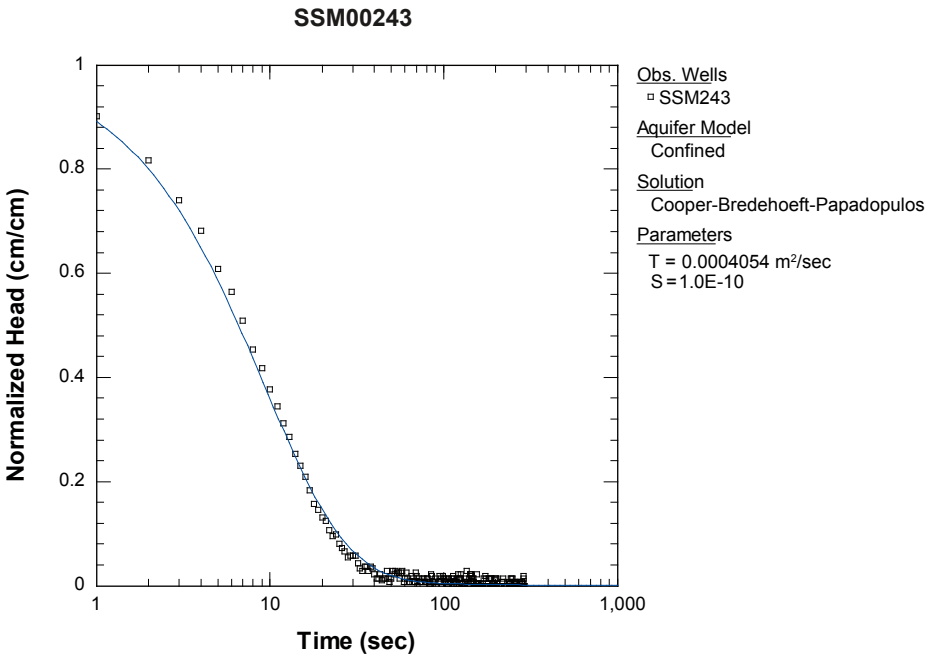


Figure 8-7. *Analysis of slugtest in SSM000243.*

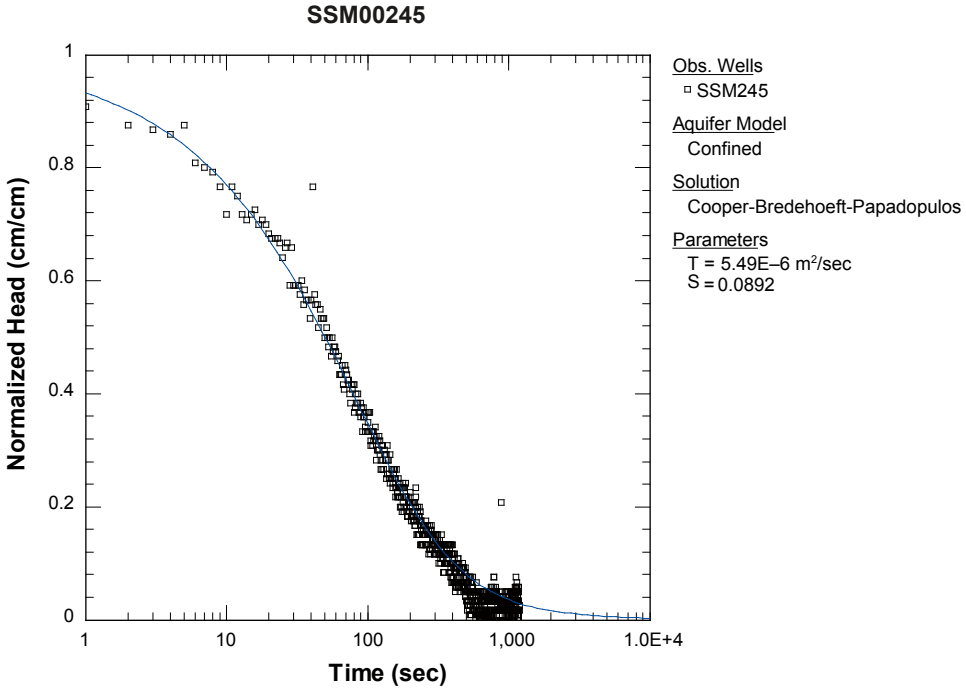


Figure 8-8. *Analysis of slugtest in SSM000245.*

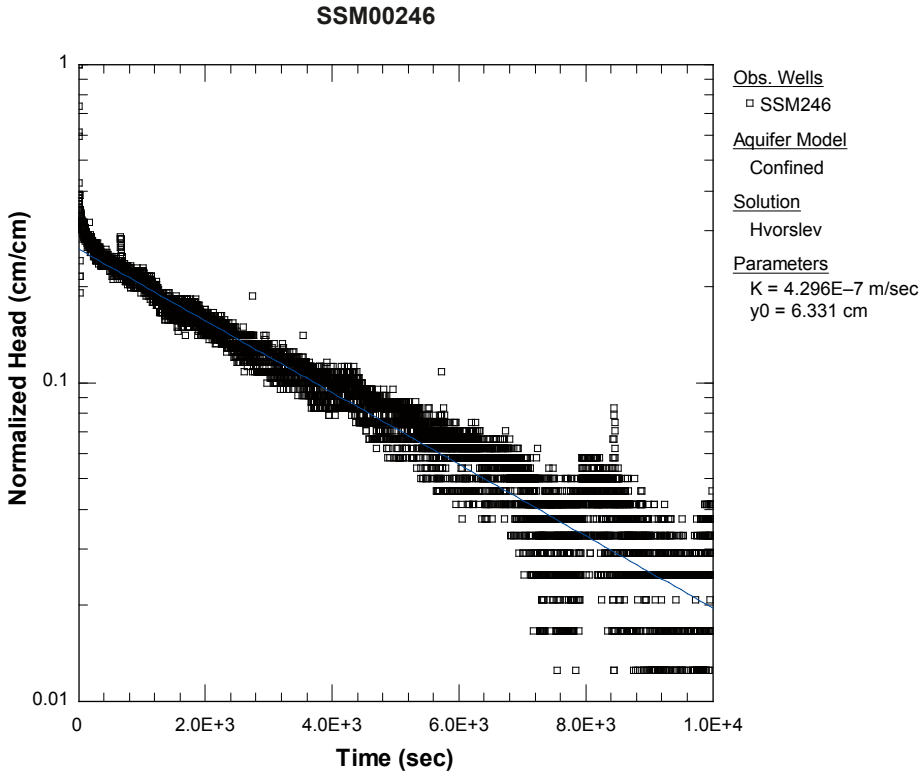


Figure 8-9. *Analysis of slugtest in SSM000246.*

9 Hydrogeological results

9.1 Slug test campaign 1

The evaluated parameters are presented in Table 9-1. Some of the calculations give a very low estimation of the storage coefficient, S. However, as slug tests only involve a small volume around the tested well screen, the S-values are neither presented in this report nor reported to the SICADA data base. Linear plots of the tests are shown in Appendix A.

The measurements in SSM000238 showed a very fast recovery. As a result, the logging time interval had to be reduced to 0.5 second. In three of the tests, the observed oscillations are indications of very high hydraulic conductivity of the aquifer.

SSM000239 had recovery periods of about 200 seconds with vertical displacements from 0.38 to 0.50 m. The data were evaluated from the first rising-head test.

SSM000240 was also showed a very fast recovery, which was impossible to measure with the manual water level meter. The logging time interval was therefore set to 0.25 seconds and the tests showed displacements of approximately 0.50 m.

In SSM000241, only one complete test was carried out due to the slow response (recovery time 19 minutes).

In SSM00242, the time for recovery was even longer, and the measurements were continued over night. Only one falling-head test was carried out, with 100% recovery after 4 hours and 15 minutes.

Note that the displacement in SMM000241 was 0.57 m in both tests (falling and rising head), and 0.47 m in SSM000242 (falling head).

SSM000244 showed oscillations with an amplitude of 0.45 m, and the pulse lasted for about 60 seconds in all three tests.

9.2 Slug test campaign 2

The local topography, geotechnical conditions, groundwater levels and results from slug test campaign 2 are presented in Table 9-1. Graphs showing linear plots of the slug test results are presented in Appendix A. The original data are stored in SICADA, and is traceable by the activity plan number. The data in the data base will be used for further interpretation.

SSM00243 showed a recovery period of 90 seconds.

The response in SSM00244 was fast and after 15–30 seconds the water level was recovered. The water oscillated during the test, and the data were evaluated separately (see results from Slug test campaign 1).

The recovery time for SSM00245 was about 8 minutes. The nearby observation well SSM00246 indicated a very slow recovery, and after more than 2 hours 45% of the recovery still remained. The screen is installed between 4.1–5.1 m b ToC in SSM00245 (total depth is 5.1 m) and between 3.0–4.0 m in SSM00246 (total depth is 4.1 m) . Table 9-1 presents the evaluated parameters for the slug tests in all areas.

Table 9-1. Evaluated parameters from slug tests in groundwater monitoring wells during field campaign 1 and 2. Boldfaced values are considered most representative i.e. best choice.

	Falling head test		Rising head test	
Observation well	**Test no.**	**T (m^2/s)**	**Test no.**	**T (m^2/s)**
METHOD: *Cooper et al.*				
SSM000238	–	–	2	**2.4×10^{-3}**
SSM000239	–	–	1	**1.7×10^{-4}**
SSM000240	–	–	3	**8.3×10^{-4}**
SSM000241	–	–	1	**5.7×10^{-6}**
SSM000242	1	**2.9×10^{-7}**	–	–
SSM000243	1	2.8×10^{-4}	1	**4.1×10^{-4}**
SSM000245	1	**5.5×10^{-6}**	1	1.1×10^{-5}
SSM000246	1	–	1	1.7×10^{-7}
METHOD: *Hvorslev*				
SSM000243	1	1.1×10^{-4}	1	1.3×10^{-4}
SSM000245	1	9.2×10^{-6}	1	2.0×10^{-5}
SSM000246	1	**4.3×10^{-7}**	1	8.3×10^{-8}
METHOD: *Bouwer Rice*				
SSM000243	1	7.6×10^{-5}	1	1.1×10^{-4}
SSM000245	1	5.3×10^{-6}	1	1.0×10^{-5}
SSM000246	1	2.2×10^{-7}	1	4.4×10^{-8}
METHOD: *McElwee-Zenner*				
SSM000244	1	3.5×10^{-3}		

9.3 Environmental programme

Checklists according to SKB's environmental routines were signed by the Activity Leader and filed in SKB's archive.

9.4 Data handling

Records for the following items: Activities, cleaning of equipment, installation of groundwater monitoring wells and pore pressure devices, and discrepancy reports have been collected by the Activity Leader for quality control and storage.

10 References

/1/ **SKB 2001a.** Site investigations: Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB. (In Swedish).

/2/ **SKB 2001b.** Geoveteskapligt program för platsundersökning vid Simpevarp. SKB R-01-44, Svensk Kärnbränslehantering AB. (In Swedish).

/3/ **SKB 2002.** Execution programme for the initial site investigations at Simpevarp. SKB P-02-06, Svensk Kärnbränslehantering AB. (In Swedish).

/4/ **SKB 2004.** Oskarshamn site investigation. Drilling and sampling in soil- Installation of groundwater monitoring wells. SKB P-04-121, Svensk Kärnbränslehantering AB.

/5/ **SKB 2004.** Oskarshamn site investigation. Slug tests in groundwater monitoring wells in soil in the Simpevarp area. SKB P-04-122, Svensk Kärnbränslehantering AB.

/6/ **SKB 2004.** Oskarshamn site investigation. Drilling and sampling in soil- Installation of groundwater monitoring wells in the Laxemar area. SKB P-04-317, Svensk Kärnbränslehantering AB.

/7/ **SKB 2004.** Oskarshamn site investigation. Slug tests in groundwater monitoring wells in soil in the Laxemar area. SKB P-04-318, Svensk Kärnbränslehantering AB.

/8/ **SKB 2004.** Oskarshamn site investigation. Drilling and sampling in soil- Installation of groundwater monitoring wells in the Laxemar area. SKB P-04-317, Svensk Kärnbränslehantering AB

/9/ **SKB 2006.** Oskarshamn site investigation. Slug tests in groundwater monitoring wells SSM000222–SSM000230 in soil in the Laxemar area. SKB P-06-149, Svensk Kärnbränslehantering AB

/10/ **Cooper H H, Bredehoeft J D, Papadopulos S S, 1967.** Response of a finite-diameter well to an instantaneous charge of water. Water Resources Research, vol. 3, no. 1, pp. 263–269.

/11/ **McElwee C D, Zenner M, 1993.** Unified analysis of slug tests including nonlinearities, inertial effects and turbulence. Kansas Geological Survey, Open File Report 93–45.

/12/ **Butler J J Jr, 1998.** The design performance and analysis of slug tests. Lewis Publishers, USA.

/13/ **Kruseman G P, de Ridder N A, 1990.** Analysis and evaluation of pumping test data. International Institute for Land Reclamation and Improvement, IRLI publication 47. Wageningen, the Netherlands.

/14/ **Waterloo Hydrogeologic Inc, 2002.** User's guide for Aquifer Test, Waterloo Hydrogeologic Inc., Waterloo, Ont. Canada.

/15/ **Sternbeck J, Land M, Nilsson Ö, 2006.** 210Pb and 14C dating of sediments and peat. Accumulation rates of carbon, nitrogen and phosphorus. Oskarshamn and Forsmark site investigations. SKB P-06-301, Svensk Kärnbränslehantering AB.

/16/ **Hydrosolve Inc.** User's guide to Aqtesolv for Windows soft. Rston, VA, USA.

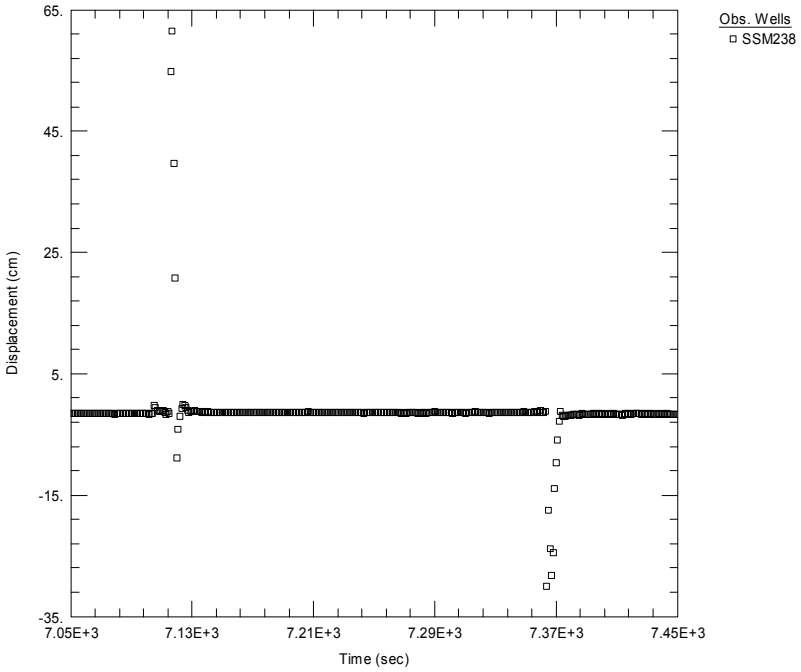
/17/ **Bouwer H, Rice R C, 1976.** A slug tests for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. *Water Resources Research*, 12(3), pp. 423–428.

Appendix A

Linear plots

SSM000238

Test 1:



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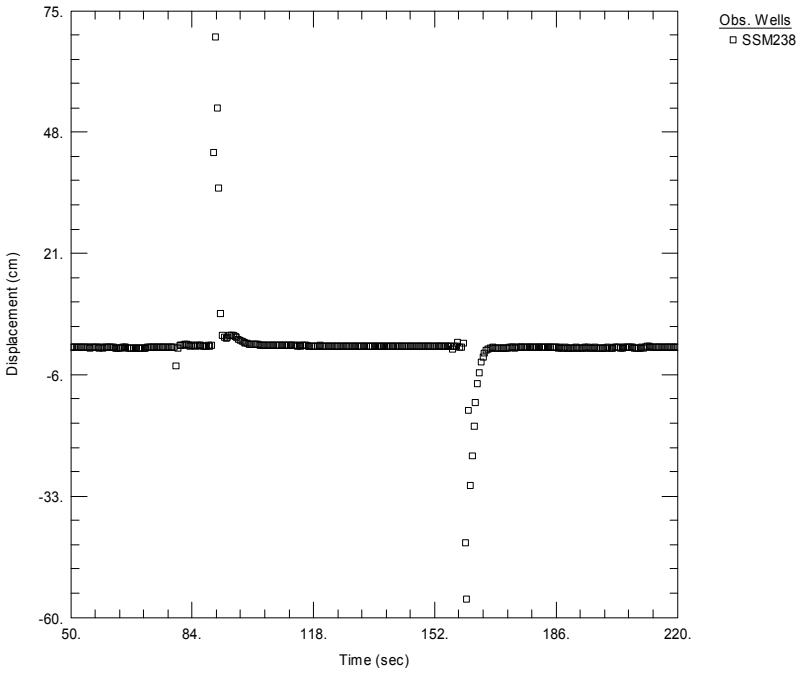
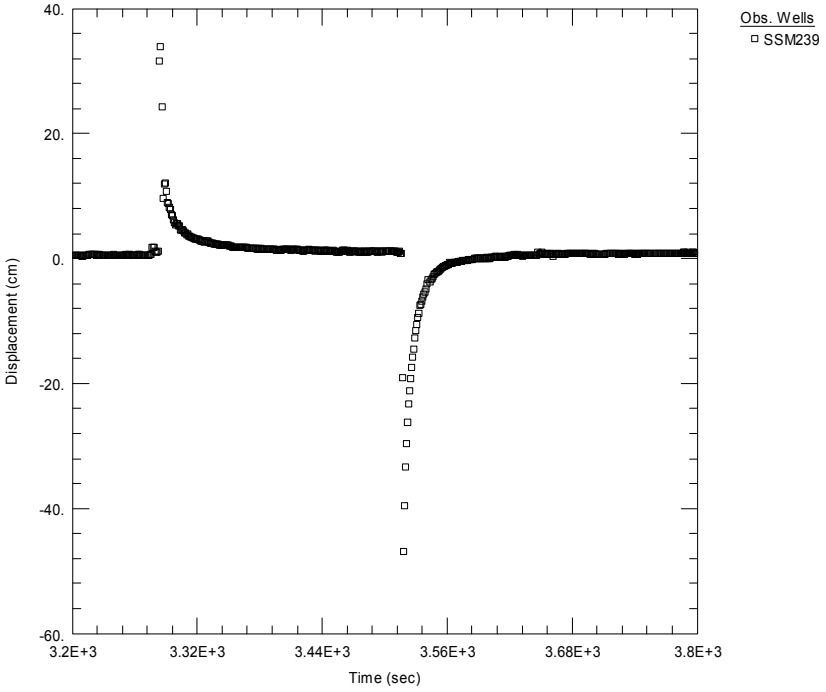


SSM000239

Test 1:



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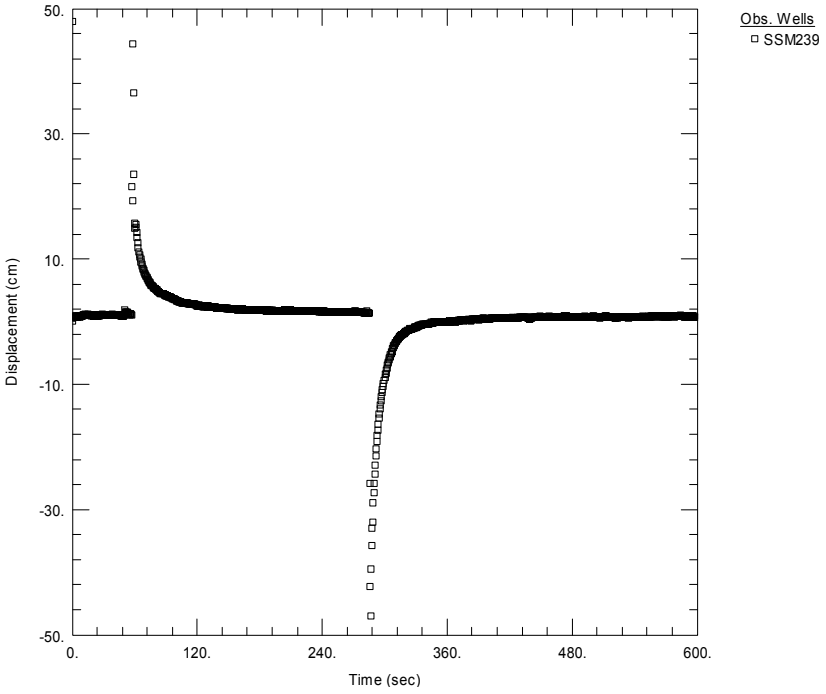
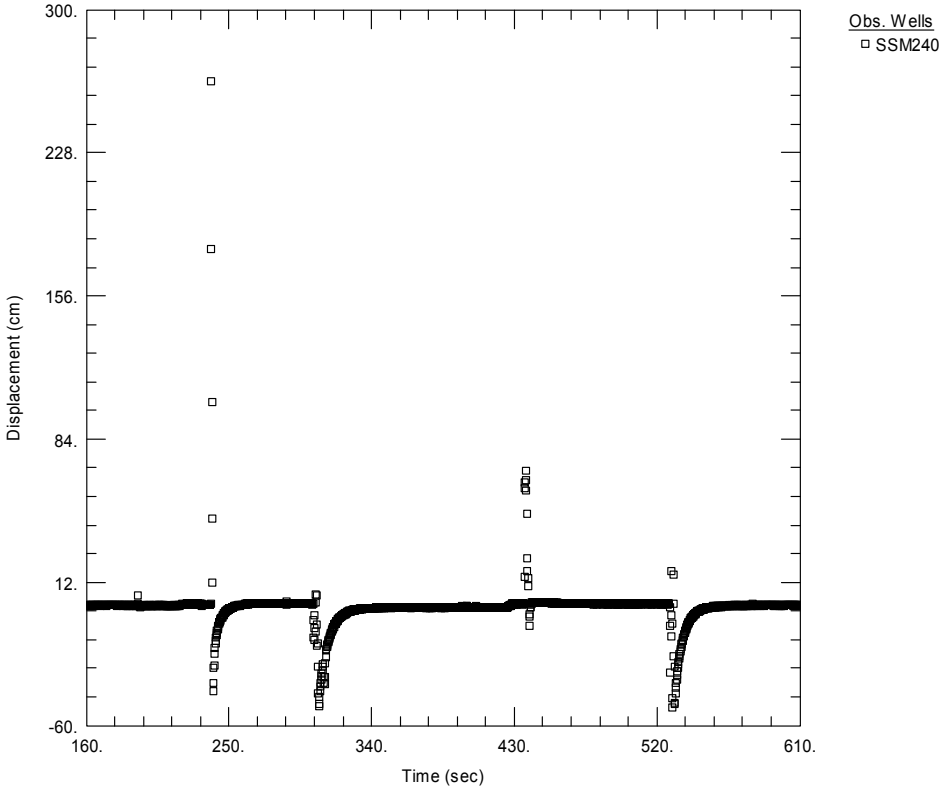


SSM000240



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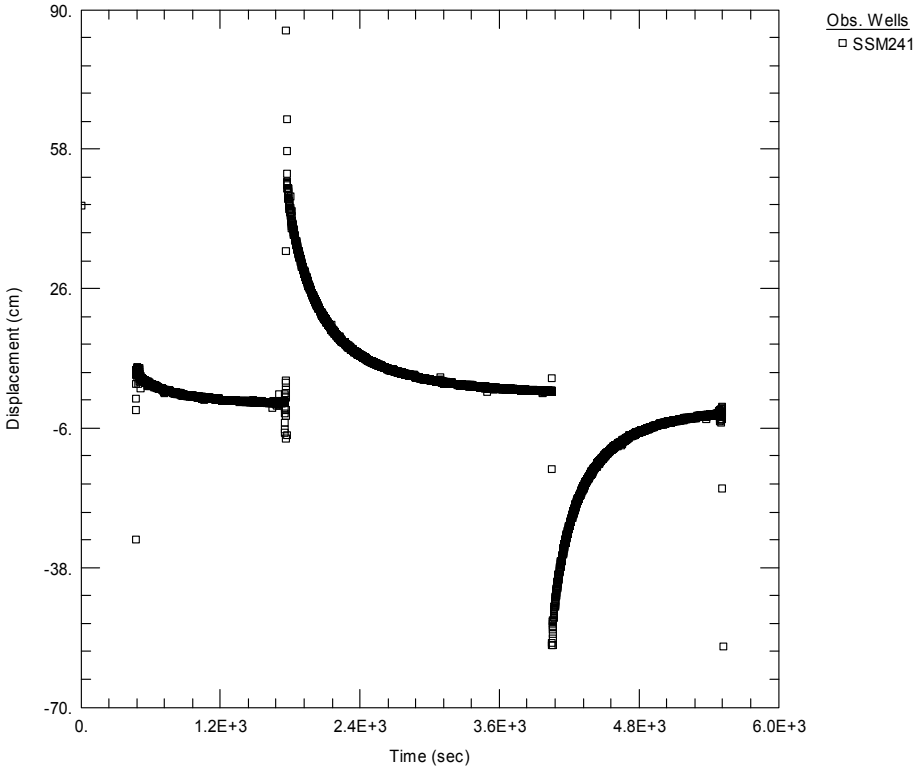

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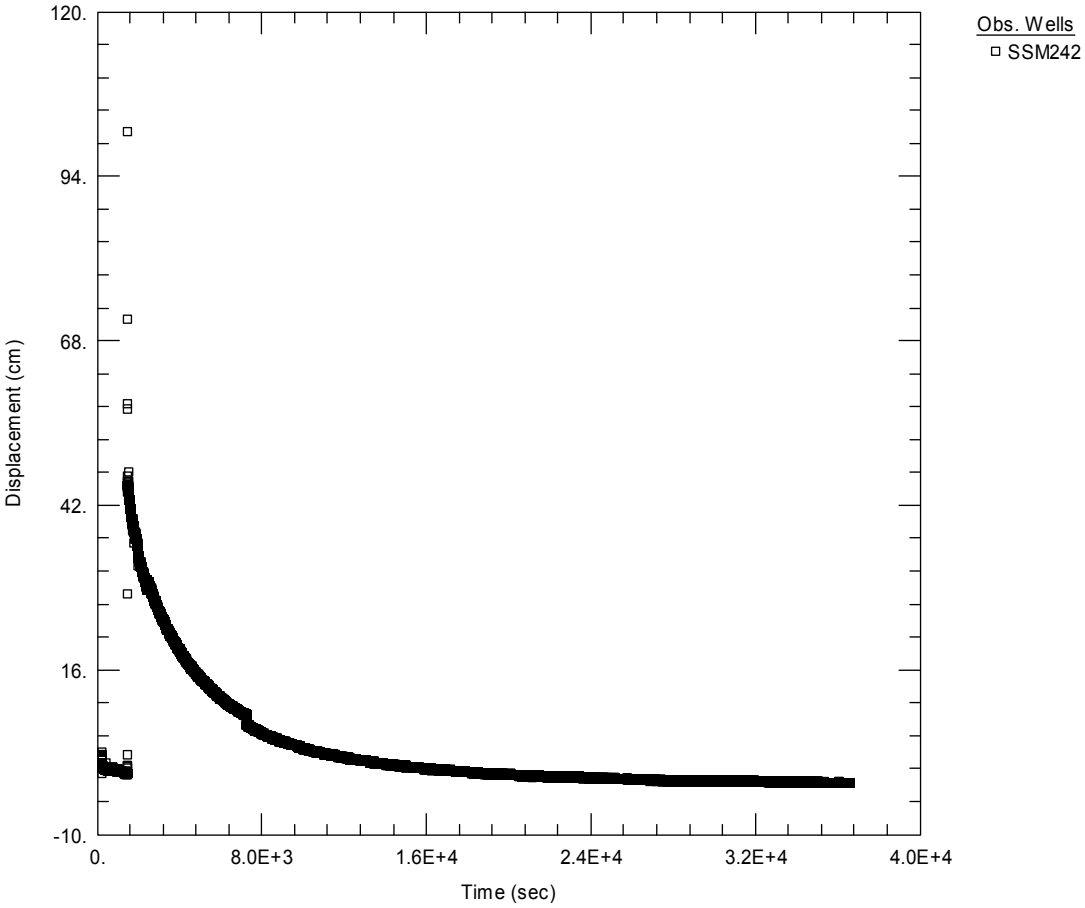

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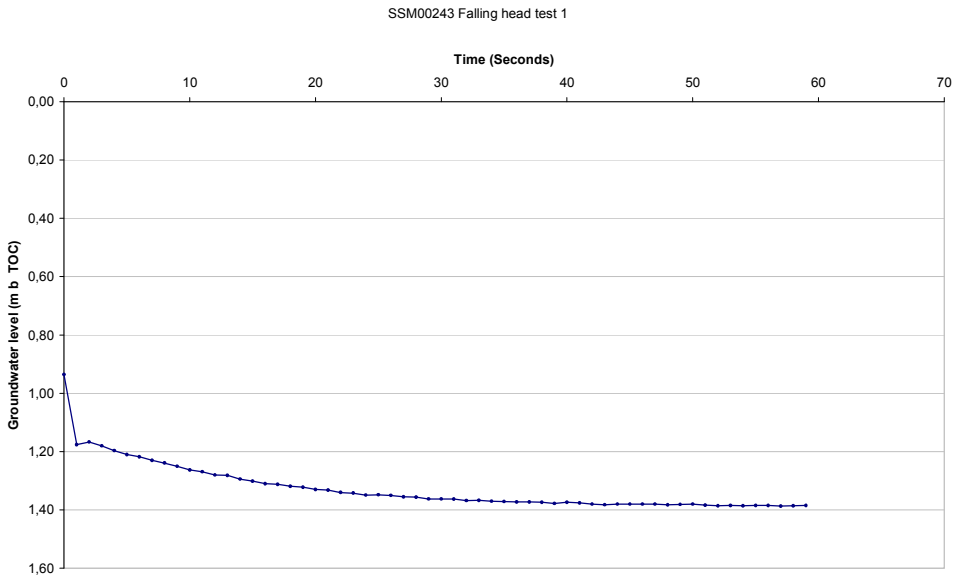
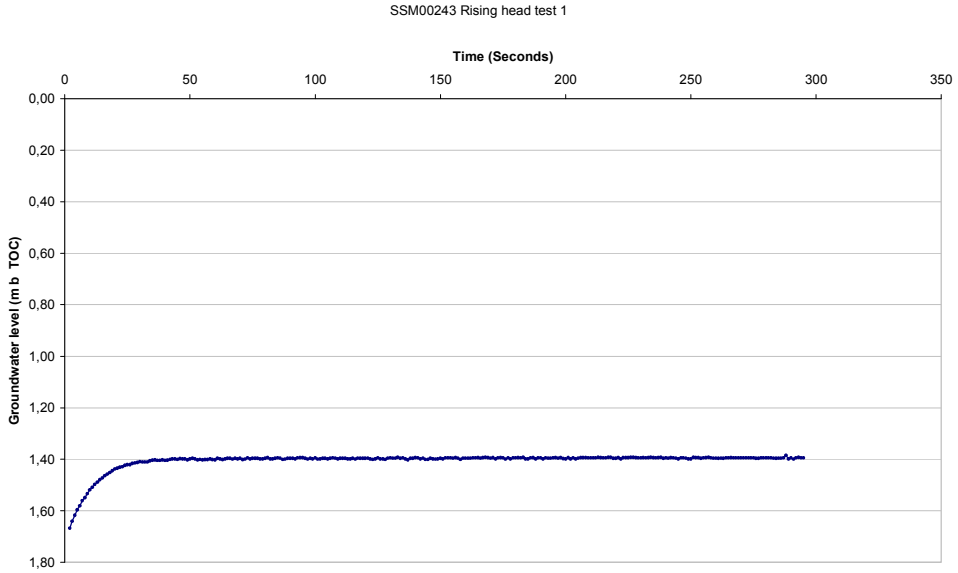
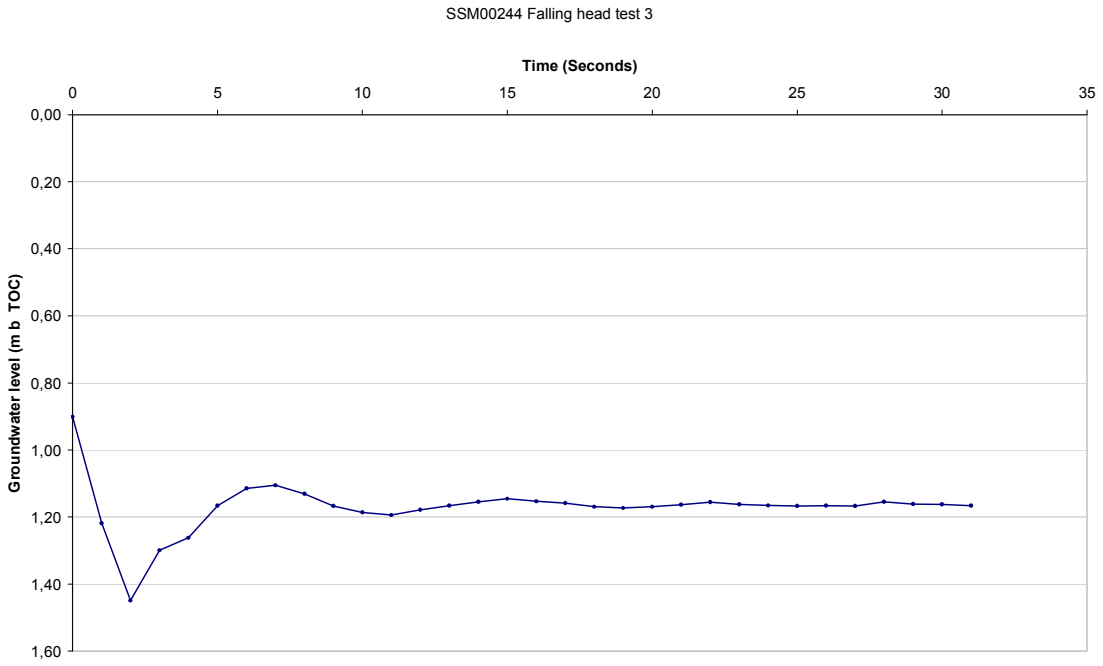
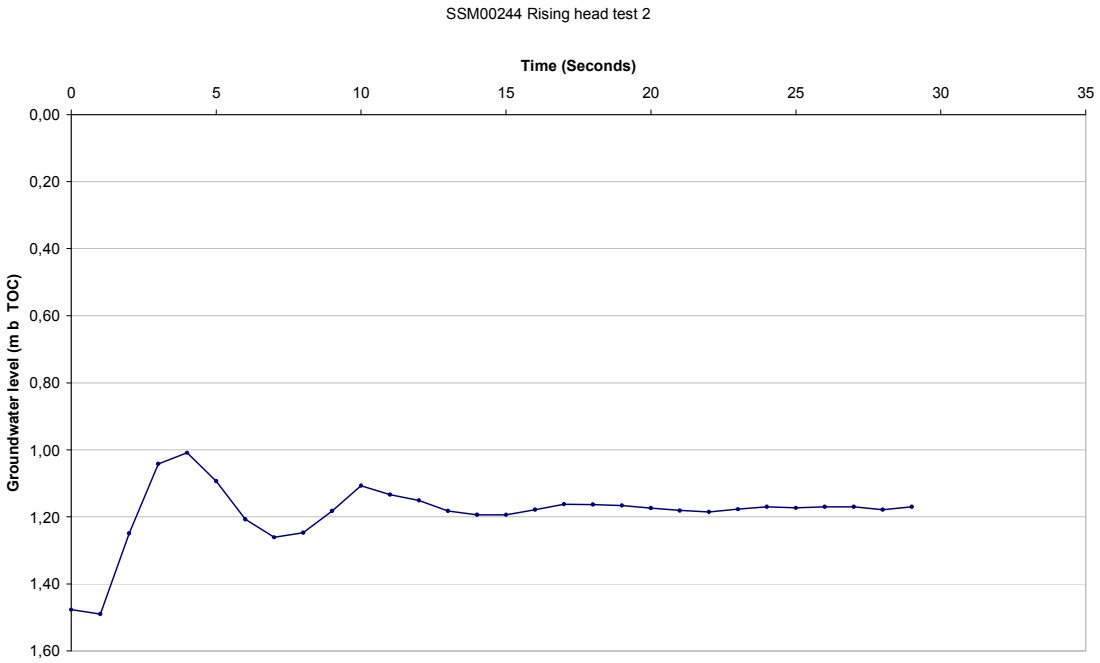


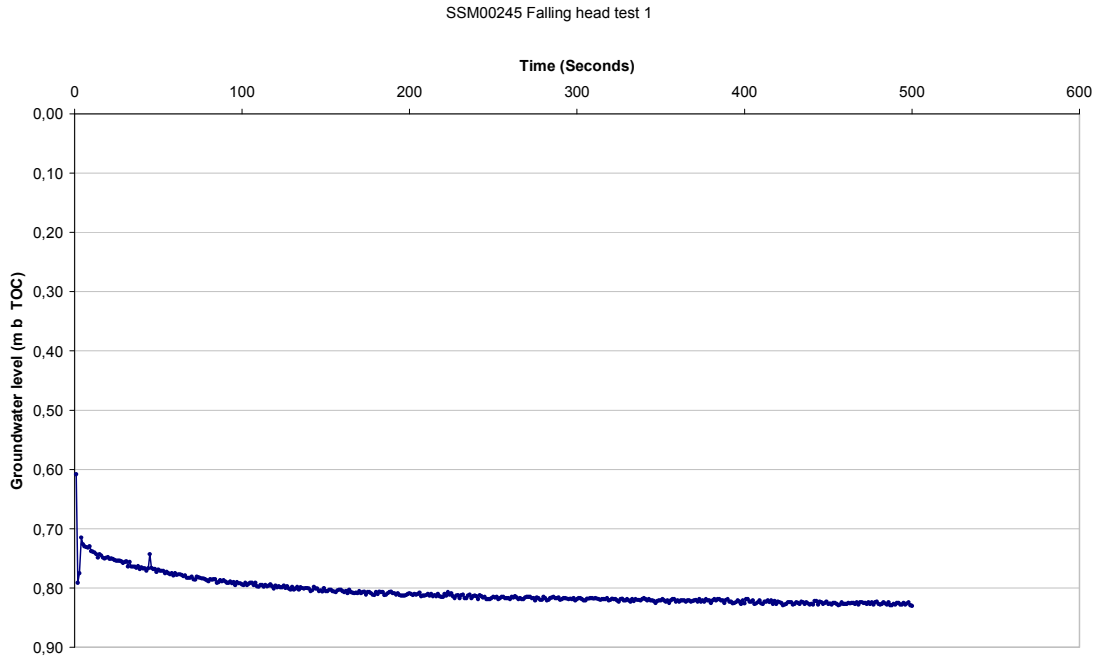

SSM00243 Rising head test 1
Time (Seconds)
0
50
100
150
200
250
300
350
0,00
0,20
0,40
0,60
0,80
1,00
1,20
1,40
1,60
1,80
Groundwater level (m b TOC)

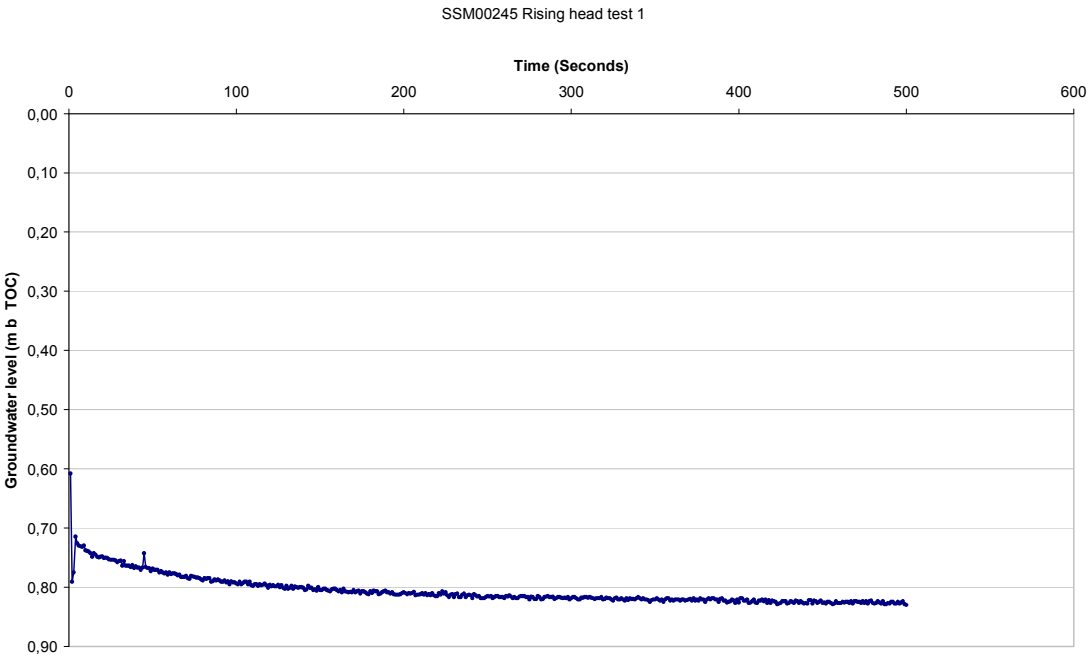
SSM000244


SSM00244 Falling head test 3
Time (Seconds)
0
5
10
15
20
25
30
35
0,00
0,20
0,40
0,60
0,80
1,00
1,20
1,40
1,60
Groundwater level (m b TOC)

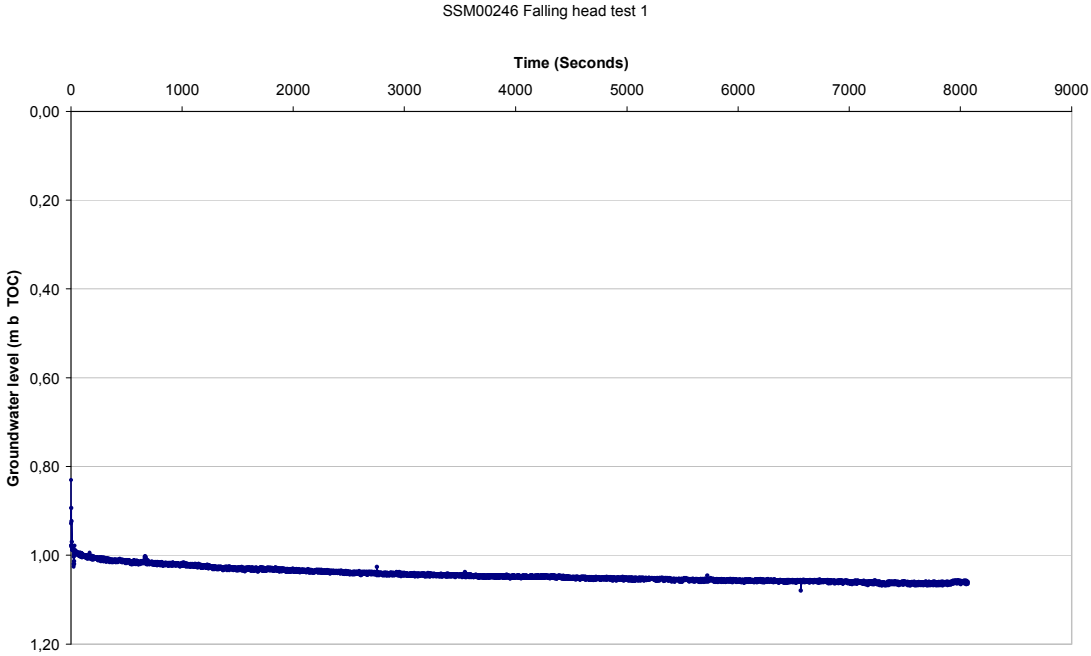

SSM00244 Rising head test 2
Time (Seconds)
0
5
10
15
20
25
30
35
0,00
0,20
0,40
0,60
0,80
1,00
1,20
1,40
1,60
Groundwater level (m b TOC)

SSM000245


SSM00245 Falling head test 1
Time (Seconds)
0
100
200
300
400
500
600
0,00
0,10
0,20
0,30
0,40
0,50
0,60
0,70
0,80
0,90
Groundwater level (m b TOC)


SSM00245 Rising head test 1
Time (Seconds)
0
100
200
300
400
500
600
0,00
0,10
0,20
0,30
0,40
0,50
0,60
0,70
0,80
0,90
Groundwater level (m b TOC)

SSM000246


SSM00246 Falling head test 1
Time (Seconds)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0,00
0,20
0,40
0,60
0,80
1,00
1,20
Groundwater level (m b TOC)

Well construction and lithological logs

BOREHOLE SSM000238

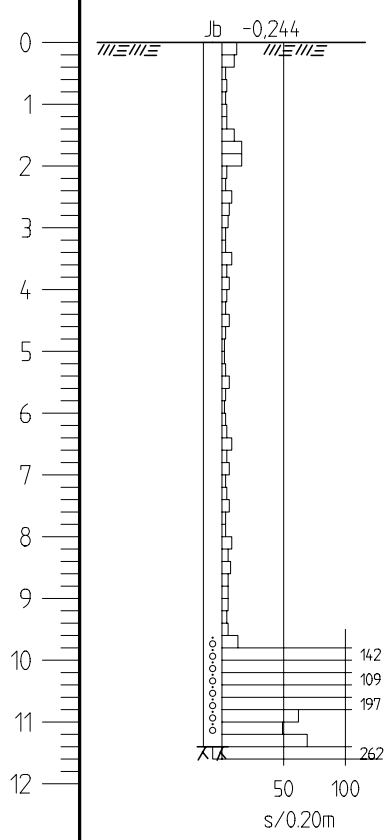
Company rep.
Torbjörn Johansson

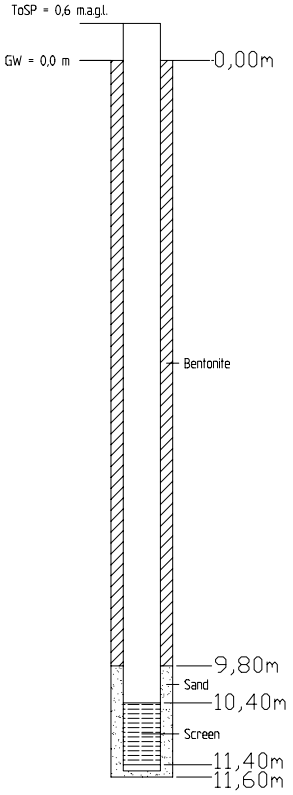
Client: Svensk Kärnbränslehantering AB

Northing :6367132,604
Easting :1551484,944

Coordinate system : RT90-RHB70

Top of stand pipe :0,6 m.a.g.l.
Total pipe length :12,10 m
Groundwater level :0,0 m.b.g.l.
Date of completion :2006-02-21





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 : 11,00 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 : 9,80 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 Φ44
Drill bit : Stift Φ54

GEOLOGICAL LOG
0-4,4m Water
4,4-8,4m dy
8,4-9,8m clay
9,8-11,5 silty till
11,5m 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

BOREHOLE SSM000239

Company rep.
Torbjörn Johansson

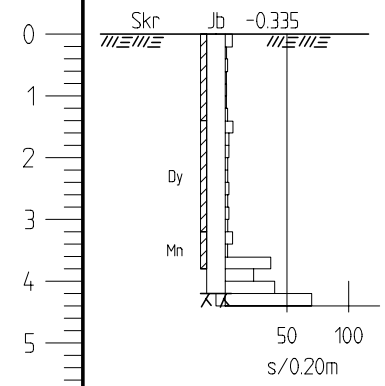
Client: Svensk Kärnbränslehantering AB

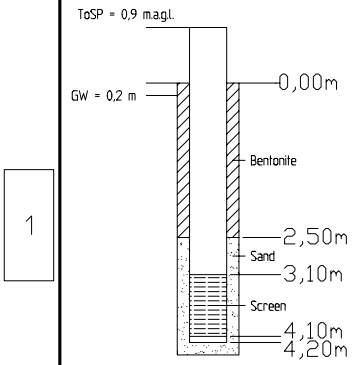
Northing :6367870,814
Easting :1550325,426

Coordinate system : RT90-RHB70

Top of stand pipe :0,9 m.a.g.l.
Total pipe length :5,10 m
Groundwater level :0,2 m.b.g.l.
Date of completion :2006-02-22

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





1

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 : 2,30 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,90 m

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

GEOLOGICAL LOG
0-1,4m Water
1,4-3,2m dy
3,2-3,8m till
4,2m 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

BOREHOLE SSM000240

Company rep.
Torbjörn Johansson

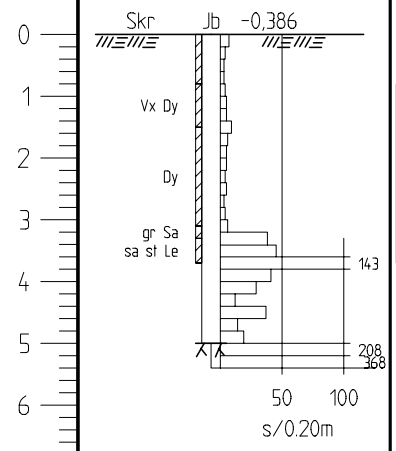
Client: Svensk Kärnbränslehantering AB

Northing :6368093,203
Easting :1550283,159

Coordinate system : RT90-RHB70

Top of stand pipe :1,0 m.a.g.l.
Total pipe length :6,10 m
Groundwater level :0,0 m.b.g.l.
Date of completion :2006-02-23

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 : 3,50 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,90 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 Water
0,8-1,5m plant remains and dy
1,5-3,1m dy
3,1-3,3m gravelly sand
3,3-3,7m sandy cobble-bearing clay
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

BOREHOLE SSM000241

Company rep.
Torbjörn Johansson

Client: Svensk Kärnbränslehantering AB

Northing :6368694,875
Easting :1550738,931

Coordinate system : RT90-RHB70

Top of stand pipe :0,5 m.a.g.l.
Total pipe length :33,10 m
Groundwater level :0,0 m.b.g.l.
Date of completion :2006-02-15

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information
0 3 6 9 12 15 18 21 24 27 30 33 36	Jb -0.160		ToSP = 0,5 m.a.g.l GW = 0,0 m 0,00m Bentonite Sand 31,0m 31,50m 32,50m Screen	Drilling method : NOEK Borehole diameter : 120 mm sampling method : Auger CASING Material : PEH Outer diameter : 63 mm Inner diameter : 50 mm Total length : 32,00 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 : 31,0 m SAND PACK Grain size : 0,4-0,8 mm Total length : 1,60 m DRILLING EQUIPMENT Drilling rig : GM 65 GTT Drill hammer : Furukawa HB2G Drill rod : Geostång Φ44 Drill bit : Stift Φ54 GEOLOGICAL LOG 0-14,6m Water 14,6-21,0 dy 21,0-22,0m clay 22,0-22,8m sand 22,8-31,2m clay 31,2-32,6m sand / till

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

BOREHOLE SSM000242

Company rep.
Torbjörn Johansson

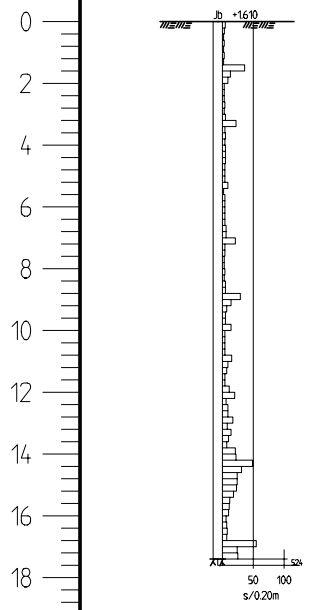
Client: Svensk Kärnbränslehantering AB

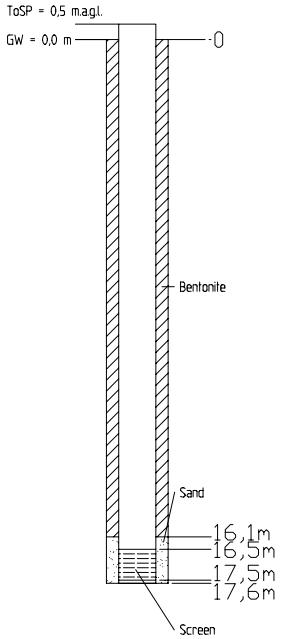
Northing :6368159,636
Easting :1549267,378

Coordinate system : RT90-RHB70

Top of stand pipe : 0,5 m.a.g.l.
Total pipe length : 18,10 m
Groundwater level : 0,0 m.b.g.l.
Date of completion : 2006-02-07

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





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

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 17,00 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 : 16,10 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,50 m

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

GEOLOGICAL LOG
0-2,9m Water
2,9-4,5m dy
4,5-13,0m gyttja
13,0-16,8m clay
16,8-17,4m till
17,4m 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

BOREHOLE SSM000243

Company rep.
Torbjörn Johansson

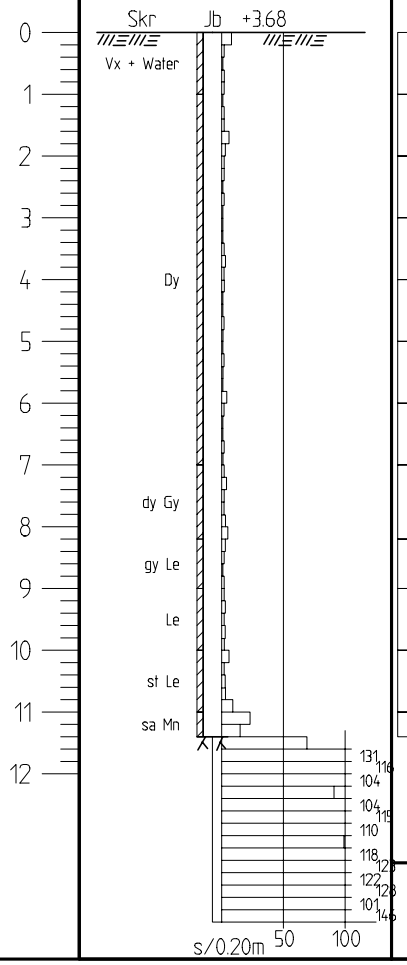
Client: Svensk Kärnbränslehantering AB

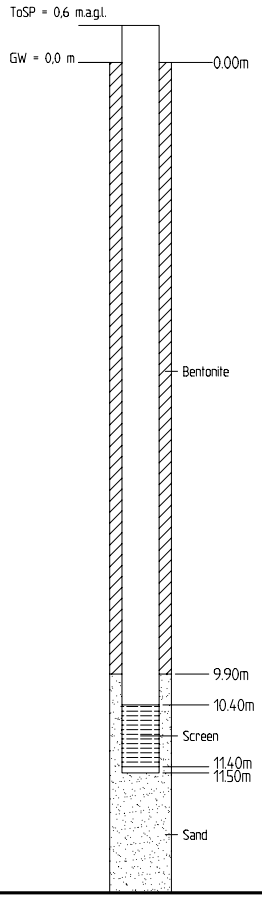
Northing :6369652,116
Easting :1546891,728

Coordinate system : RT90-RHB70

Top of stand pipe :0,6 m.a.g.l.
Total pipe length :12,10 m
Groundwater level :0,0 m.b.g.l.
Date of completion :2006-02-13

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





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

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

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 11,00 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 : 9,90 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 4,50 m

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

GEOLOGICAL LOG

0-1,0m	Water + plant remains
1,0-7,0m	dy
7,0-8,2m	dy-bearing gyttja
8,2-9,0m	gyttja-bearing clay
9,0-10,0m	clay
10,0-11,0m	cobble-bearing clay
11,0-11,4m	sandy till
11,4m	rock surface

Nomenclature see SGF homepage:
www.sgf.net

BOREHOLE SSM000244

Company rep.
Torbjörn Johansson

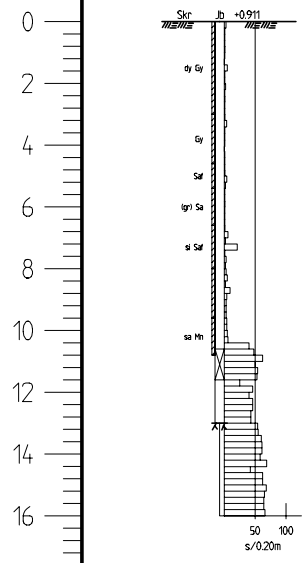
Client: Svensk Kärnbränslehantering AB

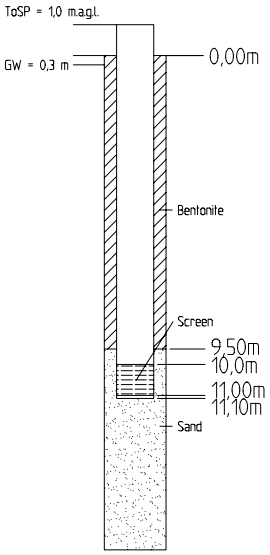
Northing :6368986,441
Easting :1548877,407

Coordinate system : RT90-RHB70

Top of stand pipe : 1,0 m.a.g.l.
Total pipe length : 12,10 m
Groundwater level : 0,3 m.b.g.l.
Date of completion : 2006-02-28

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 : 11,00 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 : 9,50 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 6,00 m

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

GEOLOGICAL LOG

0-3,0m	dy-bearing gyttja
3,0-4,6m	dy
4,6-5,4m	fine sand
5,4-6,6m	somewhat gravelly sand
6,6-8,0m	silty fine sand
9,6-10,8m	sandy till
11,0-13,0m	bouder-bearing sandy till
13,0m	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

BOREHOLE SSM000245

Company rep.
Torbjörn Johansson

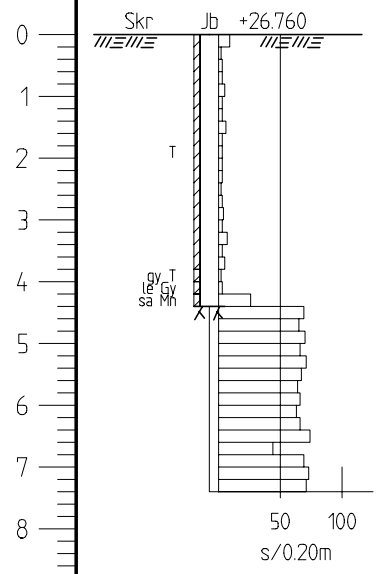
Client: Svensk Kärnbränslehantering AB

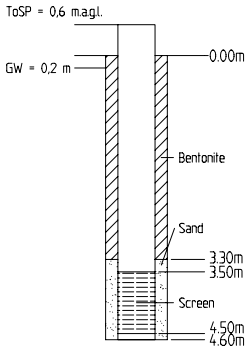
Northing :6370254,241
Easting :1542987,190

Coordinate system : RT90-RHB70

Top of stand pipe :0,5 m.a.g.l.
Total pipe length :5,10 m
Groundwater level :0,2 m.b.g.l.
Date of completion :2006-02-02

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 : 3,30 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,30 m

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

GEOLOGICAL LOG
0-3,8m Peat
3,8-4,0m gyttja-bearing peat
4,0-4,2m clayey gyttja
4,2-4,4m sandy till
4,4m 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

BOREHOLE SSM000246

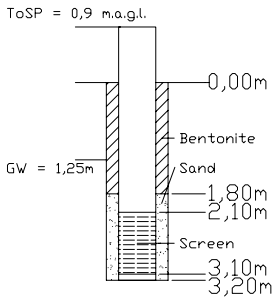
Company rep.
Torbjörn Johansson

Client: Svensk Kärnbränslehantering AB

Northing :6370253,556
Easting :1542985,261

Coordinate system : RT90-RHB70

Top of stand pipe :0,9 m.a.g.l.
Total pipe length :4,10 m
Groundwater level :1,25 m.b.g.l.
Date of completion :2006-02-02

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information
0 1 2 3 4 5 6 7 8 9 10 11 12	Ground level = +26,680 Drilling data see PSM007732			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 : 1,80 m SAND PACK Grain size : 0,4-0,8 mm Total length : 1,40 m DRILLING EQUIPMENT Drilling rig : GM 65 GTT Drill hammer : Furukawa HB2G Drill rod : Geostång Φ44 Drill bit : Stift Φ54 GEOLOGICAL LOG 0-3,2m Peat

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

BOREHOLE PSM007730

Company rep.
Torbjörn Johansson

Client: Svensk Kärnbränslehantering AB

Northing :6367130
Easting :1551484

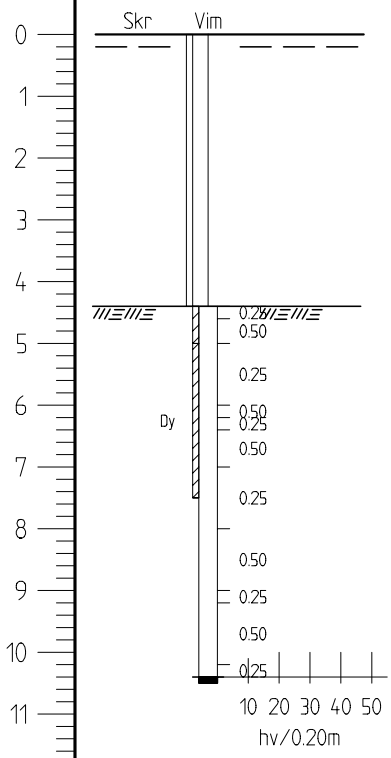
Coordinate system : RT90-RHB70

Date of completion: 2006-02-21

Depth (m)

Description

Samples



GEOLOGICAL LOG

0-4,4m	Water
4,4-8,4m	dy
8,4-9,8m	clay
9,8-11,5m	silty till

Nomenclature see SGF homepage:
www.sgf.net

BOREHOLE PSM007731

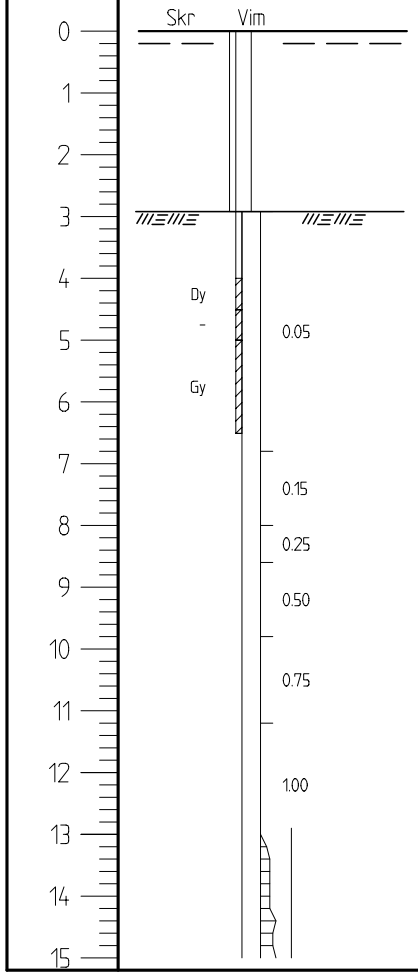
Company rep.
Torbjörn Johansson

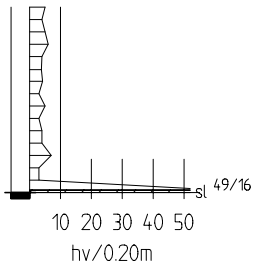
Client: Svensk Kärnbränslehantering AB

Northing :6368157
Easting :1549269

Coordinate system : RT90-RHB70

Date of completion: 2006-02-06





GEOLOGICAL LOG

0-2,9m	Water
2,9-4,5m	dy
4,5-13,0m	gyttja
13,0-17,8m	clay
17,8-18,0m	till

Nomenclature see SGF homepage:
www.sgf.net

BOREHOLE PSM007732

Company rep.
Torbjörn Johansson

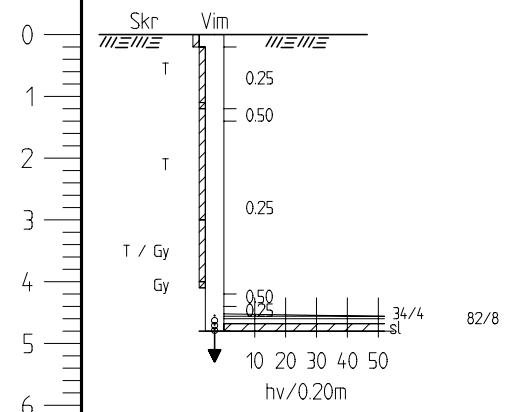
Client: Svensk Kärnbränslehantering AB

Northing :6370253
Easting :1542987

Coordinate system : RT90-RHB70

Date of completion: 2006-02-02

Depth (m)	Description	Samples



GEOLOGICAL LOG

0-3,0m	Peat
3,0-4,0m	peat / gyttja
4,0-4,1m	gyttja

Nomenclature see SGF homepage:
www.sgf.net

Appendix C

Photos of the borehole sites after completion of work

Borehole SSM000238

Borehole SSM000239

Borehole SSM000240

Borehole SSM000241

Borehole SSM000242

Borehole SSM000243

Borehole SSM000244

Borehole SSM000245 (nearest) and SSM000246