R-07-34

Forsmark site investigation

Programme for long-term observations of geosphere and biosphere after completed site investigations

Svensk Kärnbränslehantering AB

June 2007

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1402-3091
SKB Rapport R-07-34

Forsmark site investigation

Programme for long-term observations of geosphere and biosphere after completed site investigations

Svensk Kärnbränslehantering AB

June 2007

Preface

Since the beginning of 2002, Svensk Kärnbränslehantering AB (the Swedish Nuclear Fuel and Waste Management Co) has been conducting site investigations at Forsmark in the municipality of Östhammar and at the Simpevarp-/Laxemar area in the municipality of Oskarshamn for siting of a final repository for spent nuclear fuel. The investigations will be completed during 2007 at both sites, in June 2007 at Forsmark and in December the same year at Oskarshamn. The investigations have resulted in a detailed characterization of the geosphere and biosphere of the two sites, and the site descriptive data are used for modelling geoscientific and ecological conditions and processes.

SKB submitted a programme for the initial site investigations in Forsmark at the end of 2001. Another programme for the completion of the site investigations was presented early in 2005. The investigations that were included in the first programme were completed during 2004, whereas the investigations specified in the latter programme are now in their final stage. During the site investigations, long-term observations, so called monitoring, of certain geoscientific parameters and ecological objects have been initiated in order to obtain time series. The monitoring is planned to continue at least until SKB has given priority to one of the investigated sites in 2009. After that, a decision will be made regarding the scope of continued monitoring. This report describes the programme for subsequent monitoring starting in July, 2007.

The monitoring programme has been elaborated based on the experiences from the site investigations. The main objectives of prolonged monitoring is to establish the undisturbed conditions prevailing at the Forsmark investigation area prior to construction of a potential repository, and to enhance the knowledge about the inherent time dependent variations and dynamics of the geoscientific and ecological systems studied. It will also benefit the production of the environmental impact statement that must accompany the application for permits to site and build a deep repository.

Kaj Ahlbom

Site Manager Forsmark

Abstract

The site investigation at Forsmark will be terminated the last of June, 2007. Hundreds of investigations have been conducted during a period of more than five years. Monitoring of a number of geoscientific parameters and biological objects has been one important part of the site investigation programme. Monitoring is defined as recurrent measurements of the same parameters/objects, so that time series are generated. Long-term monitoring of for example weather parameters, surface water discharge in brooks, and the groundwater head in a large number of boreholes has been conducted during the site investigations. Furthermore, repeated sampling of precipitation, surface water and groundwater in soil and rock for hydrochemical analyses has been carried out, and the groundwater flow in isolated borehole sections has been measured several times. Besides, some biological objects, for example rare bird species, have been invented each year of the site investigation.

The measured parameters and the invented objects are characterized by a certain degree of time dependent variability, which is also site-specific. The aim of the monitoring is primarily to establish the "undisturbed" conditions, the so called "baseline". If a deep repository is sited at Forsmark, many site-specific conditions will change, due to natural causes as well as to the construction works. Knowledge about the undisturbed conditions strengthens the ability to reveal and quantify such changes and to distinguish natural changes from those caused by the human activities.

Another object of monitoring is to, by the study of the variability pattern of the monitored parameters, elevate the knowledge about the underlying, often complex causes governing the variations. In this way the description of site-specific conditions may be more precise and the prospects of modelling important processes are improved.

After completion of the site investigations, a period of about two years will follow, when the investigation results from Forsmark will be further analysed. A long-term safety assessment based on geoscientific and ecological modeling will be made, and the Forsmark site will in this respect and from other aspects be compared with the Laxemar site situated in the municipality of Oskarshamn, which has been investigated simultaneously with the Forsmark site. SKB will then, probably during 2009, give preference to one of the two sites in order to prepare and submit an application under the Environmental Code and the Nuclear Activities Act to localize and build a final repository for spent nuclear fuel at that site. This application must be accompanied by an environmental impact statement, the production of which will profit much from a conscientiously performed monitoring programme.

A continued monitoring programme for the period July 2007–2009 has been decided, and the extent and execution of that programme is presented in this report. This will generate longer time series than have been achieved during the site investigations, which will serve as an improved scientific basis to be used in the site selection process. Broadly speaking, the monitoring programme initiated during the site investigations is suggested to continue after June 2007. However, this programme has been successively expanded during the site investigation period, and some monitoring equipment will not be installed until just before or after completion of the site investigations. Also the recent installations will be included in the continued monitoring programme, which hence, with a few exceptions, will be more extensive than the current programme.

Sammanfattning

Platsundersökningen i Forsmark kommer att avslutas den 30:e juni 2007. Bland de hundratals aktiviteter som bedrivits under de 5½ år som platsundersökningen har pågått ingår monitering av ett antal geovetenskapliga parametrar och biologiska objekt. Med monitering avses upprepade mätningar av samma parametrar/objekt, så att tidsserier skapas. Bl a har långtidsregistrering av väderparametrar, ytavrinning i bäckar samt av grundvattenytans nivå i ett flertal borrhål i jord och berg utförts under platsundersökningen. Vidare har prover tagits regelbundet på nederbörd, ytvatten och grundvatten för hydrokemisk analys, och grundvattenflödet i avgränsade borrhålssektioner har mätts upprepade gånger. Slutligen har ett antal biologiska objekt, bl a skyddsvärda fågelarter, inventerats återkommande under platsundersökningen.

De parametrar som har mätts och de objekt som inventerats inom moniteringsprogrammet karaktäriseras av viss tids- och platsberoende variabilitet. Syftet med monitering är för det första att fastlägga de ”ostörda” förhållandena på platsen. Om ett slutförvar byggs i Forsmark kommer många platsspecifika förhållanden att förändras, både av naturliga orsaker och som en följd av byggnadsverksamheten. Kännedom om de ostörda förhållandena ger en möjlighet att upptäcka och kvantifiera sådana förändringar liksom att skilja mellan naturliga förändringar och sådana som beror av mänsklig verksamhet.

Ett annat syfte med moniteringen är att genom studium av de monitered parametrarnas variationsmönster förbättra kunskapen om bakomliggande, ofta komplexa orsakssamband. Därigenom ökar precisionen vid beskrivningen av de platsspecifika förhållandena och förbättras möjligheterna att modellera viktiga processer.

Efter att platsundersökningen avslutats följer en period av ca två år, då undersökningsresultaten från Forsmark analyseras ytterligare och modellering av de geovetenskapliga och ekologiska förhållandena utförs. Resultaten kommer att ligga till grund för en långsiktig säkerhetsanalys, och Forsmark kommer att ur olika aspekter jämföras med det parallellt undersökta Laxemar-området i Oskarshamns kommun. SKB kommer därefter, sannolikt under 2009, att prioritera en av de två platserna, för vilken en tillståndsansökan enligt miljöbalken och kärntekniklagen för lokalisering och bygge av ett slutförvar för använt kärnbränsle kommer att skrivas. En sådan ansökan måste åtföljas av en miljökonsekvensbeskrivning. Framtagandet av en sådan kommer att underlättas mycket om den kan baseras på ett omsorgsfullt utfört moniteringsprogram.

Det har beslutats att ett fortsatt moniteringsprogram skall genomföras under perioden juli 2007 till 2009, så att längre tidsserier kan erhållas och därmed ett förbättrat vetenskapligt underlag inför valet av plats. Programmet, som presenteras i denna rapport, innebär i stort att de moniteringsaktiviteter som initierats under platsundersökningen fortsätter från och med juli 2007. Emellertid har det under hela platsundersökningen pågått en successiv utbyggnad av moniteringsverksamheten, och viss moniteringsutrustning kommer inte att vara installerad förrän strax innan eller strax efter att platsundersökningen avslutas. Även de nyinstallerade mätpunkterna kommer att ingå i det fortsatta programmet, vilket därmed, med några få undantag, kommer att ha större omfattning än moniteringsprogrammet under platsundersökningen.

Contents

1 Introduction

SKB initiated during 2002 site investigations for a future final repository for spent nuclear fuel in two Swedish municipalities, Östhammar and Oskarshamn. An area south-east of the nuclear power facilities at Forsmark was selected for the site investigations in Östhammar, whereas the site investigations in Oskarshamn have been performed on the peninsula of Simpevarp as well as at the Laxemar area, situated a few kilometres west of Simpevarp, Figure 1-1. The site investigations will be completed in June 2007 at Forsmark and in December 2007 at Oskarshamn.

The overall goal of the site investigations is to obtain the permits required to site and construct the repository at one of the investigated sites. The site investigations must therefore provide the data required for an evaluation of the suitability of the respective investigated sites for a repository. Hence, the material must be comprehensive enough to enable assessment of the long-term safety, the construction related aspects, as well as the impact on the environment and society of the repository.

Figure 1-1. *The Forsmark and Oskarshamn site investigation areas. Black rectangels represent the regional model areas (about 168 km² at Forsmark and 273 km² at Oskarshamn, respectively), whereas the areas inside red borders show the focused investigation areas.*

Data must also be of such structure and quality that comparison of the investigated sites is possible. Based on this, one of the sites will be given priority to by SKB and an application will be submitted under the Environmental Code and the Nuclear Activities Act for locating the repository within the prioritized site.

The site investigations, which have comprised hundreds of investigation activities covering several geoscientific and biological-ecological disciplines, have resulted in a detailed mapping of the geosphere and the biosphere within the investigated areas. Examination of the biosphere, soil layers and the shallow part of the bedrock has been combined with investigations of the deeper parts of the bedrock. The bedrock has been studied down to about 1,000 m vertical depth by drilling and investigation of boreholes, whereas some geophysical methods applied have had an investigation range of several kilometres vertical depth.

The site investigations have been performed in compliance with a number of comprehensive programme documents. Regarding the Forsmark site investigations these documents are:

- a generic site investigation programme /1/,
- a site specific investigation programme for Forsmark relating to the entire site investigation, however with emphasis on the initial part /2/,
- a site specific programme relating to the final part of the site investigation /3/.

The investigations at Oskarshamn have been conducted in accordance with a corresponding set of governing programme documents.

Some of the activities carried out have been singular investigations, whereas other activities have included repeated examinations. For example, a suite of specially selected borehole investigation methods has been applied in every new borehole completed. A special type of repeated measurements of the same parameters is so called monitoring, by which reiterated measurements are performed with a regular time space on a number of geoscientific parameters, and recurrent inventories are made of some biological objects. Monitoring of e.g. meteorological, hydrological, hydrogeological and hydrogeochemical parameters, as well as of some wild animal species, is described in the programme documents referred to above, and hence monitoring activities have been part of the site investigations.

A need for continued monitoring after completion of the site investigations has been identified already in previous SKB reports, e.g. /4/. Such a monitoring programme for Forsmark has recently been stipulated. The objectives, scope and execution of this programme, which is planned to start immediately after completed site investigations, are given in the present report. The monitoring according to this programme is planned to be continued until SKB has prioritized one of the two investigated sites in 2009. After that, new decisions about monitoring will be made, both for the prioritized and the non-prioritized site.

The geological and ecological characteristics of the Forsmark investigation area are exhaustively described in a large number of reports published during the site investigations as well as in the comprehensive site descriptions written /5, 6, 7/. A brief summary of some main characteristics of the site is also given in Chapter 3 in this report.

2 Monitoring during and subsequent to the site investigations – background and objectives

Geoscientific and biological-ecological parameters are characterized by a degree of variability over time. This variability is also site specific. Some time dependent changes, e.g. those caused by mineralogical processes in the rock types prevailing at Forsmark, are extremely slow, whereas other parameters may display rapid and large variations versus time. The latter are mainly inherent in meteorological parameters as well as in ecological, hydrological, hydrogeological or hydrogeochemical parameters measured close to the ground surface. However, there exist for example hydrogeological parameters with significant time dependent variations also at depth.

Many of the observed variations are more or less cyclic. Cyclic processes may display a diurnal character, which for example is mirrored in some meteorological and geohydrological parameters, or show seasonal variations like the majority of meteorological and biological-ecological parameters. However, other, more unpredictable phenomena may also exist, like long-term variations such as climatic trends. The dynamics of geoscientific and biological-ecological systems is often dependent on several, superimposed cyclic and/or acyclic processes. One illustrative example is the groundwater level in soil and bedrock, where variations are generated by e.g. precipitation, plant respiration, and gravitational effects from the moon and the sun. The type of variations created is in this case also depending on site-specific conditions, like the hydraulic transmissivity of the soil layer or bedrock formation in question. Finally, also human activities, like some of the investigations performed during the site investigations, for example pumping or construction works in soil and rock, may have an influence on many geoscientific and biological-ecological parameters.

To interpret and understand the variations with time of different parameters is part of the efforts to establish the "baseline data" of the site, i.e. the data representing "undisturbed" conditions prevailing at the site prior to construction of a repository. The monitoring activities already initiated are therefore an essential part of the site investigations. With early monitoring data as a reference, changes in connection with construction of the repository may be revealed, thereby enabling differentiation between natural changes and variations in time and space caused by human activities.

A second objective of the monitoring is to, by analysis of the variability pattern versus time, elevate the understanding of the processes governing the variations, which will benefit the site description and modelling. This will also contribute to an improved long-term safety assessment of the site.

A third aim of monitoring is to provide a platform for an environmental impact assessment and statement of the Forsmark site, which has to accompany a future application for permits to site and build a deep repository for spent nuclear fuel.

The monitoring programme during the site investigations has yielded time series covering a maximum of about five years. However, monitoring of for instance hydrogeological and hydrogeochemical conditions is depending on access to boreholes and technical installations in those. Because boreholes have been drilled during almost the entire site investigation period, monitoring in the latest completed holes will just have started when the site investigations come to an end, or shortly thereafter. If time series for these shall be obtained at all, it is necessary to continue the monitoring programme for some period after completion of the site investigations. The major part of the monitoring programme presented in this report will therefore continue as before immediately after completion of the site investigations, after which the programme will be successively supplemented with monitoring in the newly installed boreholes. The programme will then be running until SKB has prioritized one of the sites. This will provide time series of approximately two years (if SKB's priority decision is made during 2009) for those boreholes in which monitoring has started very late, and up to seven years for the earliest monitored holes.

To conclude, the scope of the continued programme is based on an evaluation of the previous monitoring. Although modified in some details, and on the whole successively expanded until the summer/early autumn 2007, the programme is by and large a direct continuation of the monitoring activities previously initiated and currently being performed.

After the priority decision, there will follow a period when the authorities are reviewing SKB's application. The duration of this period until a decision can be expected is not known, but may be estimated at about 2–3 years. It is probable that the monitoring programme described in this report will continue also during this period on both the prioritized and the non-prioritized site. However, this will not be finally decided until after SKB has given priority to one of the two sites.

Furthermore, a continued programme for long-term observations and surveillance is also planned to be conducted on the prioritized site during the entire construction- and operation period /4/. This later programme will be designed based on experiences from all previous monitoring and results from modelling the impact of repository construction and operation. Regarding the non-prioritized site, a decision will later be made whether monitoring activities to some extent may continue or are to be terminated.

3 The site

The geological and biological-ecological characteristics of the Forsmark investigation area are exhaustively described in a large number of reports published during the site investigation and in the comprehensive site descriptions written /5, 6, 7/. Also /3/ provides a good representation of the site and of the investigations made, and part of the description below of some main characteristics of the site emerges directly from that report.

3.1 Model areas and boreholes

Figure 3-1 provides an overview of the Forsmark investigation area with environs. After a feasibility study performed prior to the site investigations, SKB designated the area marked in red south-east of the Forsmark Nuclear Power Plant, which is known as the candidate area, as having priority for a site investigation. The blue and green rectangles in the figure show the boundaries defined for the local and regional models that SKB works with when processing data from the site investigation. These models are three-dimensional, and the green rectangle, representing the regional model area, has a vertical extent to 2,200 m from 100 m above the sea level, whereas the blue rectangle, representing the local model area, has a corresponding extent to 1,100 m.

Figur 3-1. *The Forsmark area with environs. The extents of the regional (green) and local (blue) model areas as well as of the candidate area (red) are outlined in the map.*

During the period of more than five years from the start of the site investigations at 2002, a large number of boreholes have been drilled, primarily inside the candidate area but also outside the candidate area border. The boreholes are of three categories:

1) core drilled boreholes, generally with lengths ranging between 100 and 1,000 m,

2) percussion drilled boreholes in bedrock, normally with lengths between about 100 and 300 m, and

3) short boreholes penetrating only the overburden (regolith) resting on the hard bedrock. The major part of the latter boreholes are supplied with groundwater stand-pipes of hard plastic material or metal, which have been driven through part of or the entire soil layer and often a little bit into the bedrock surface.

Figure 3-2 presents the localization of all twelve drill sites for core drilled boreholes at Forsmark, whereas in Figure 3-3 the respective drill sites are displayed in detail. The two figures together show the position of all core drilled boreholes (except a few very short holes drilled for special purposes) and most of the percussion drilled boreholes completed during the site

Figure 3-2. The localization within and close to the Forsmark candidate area of all twelve drill sites for core drilled boreholes. The map also exhibits most of the percussion drilled boreholes completed during the site investigations, in connection to as well as outside these drill sites. Details of the drill sites are given in Figure 3-3.

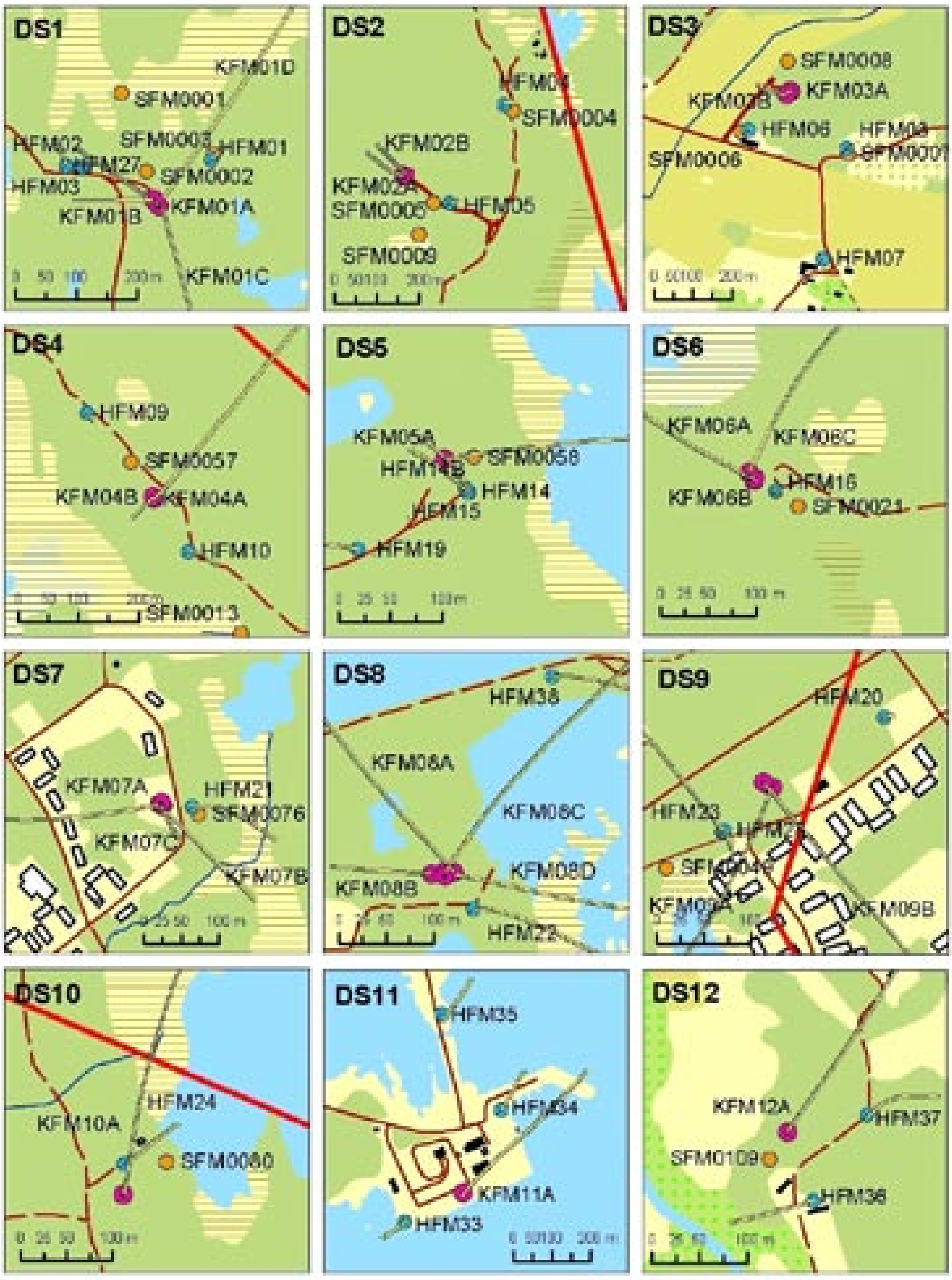


Figure 3-3. Details of the twelve drill sites for core drilled boreholes and the positions of these holes (marked with red circles). A few very short cored holes drilled for special purposes are excluded. Those percussion drilled boreholes (blue circles) and soil boreholes (yellow circles) that are situated at or in the vicinity of the drill sites are also shown.

investigations. In Figure 3-4 the positions of boreholes drilled through the layer of regolith (soil boreholes) are shown. As mentioned above, these boreholes are supplied with a plastic or metal groundwater stand-pipe enabling measurements of the groundwater level and water sampling. In Figure 3-5, finally, the locations of soil boreholes supplied with so called BAT-type filter tips for pore pressure measurements or water sampling are given.

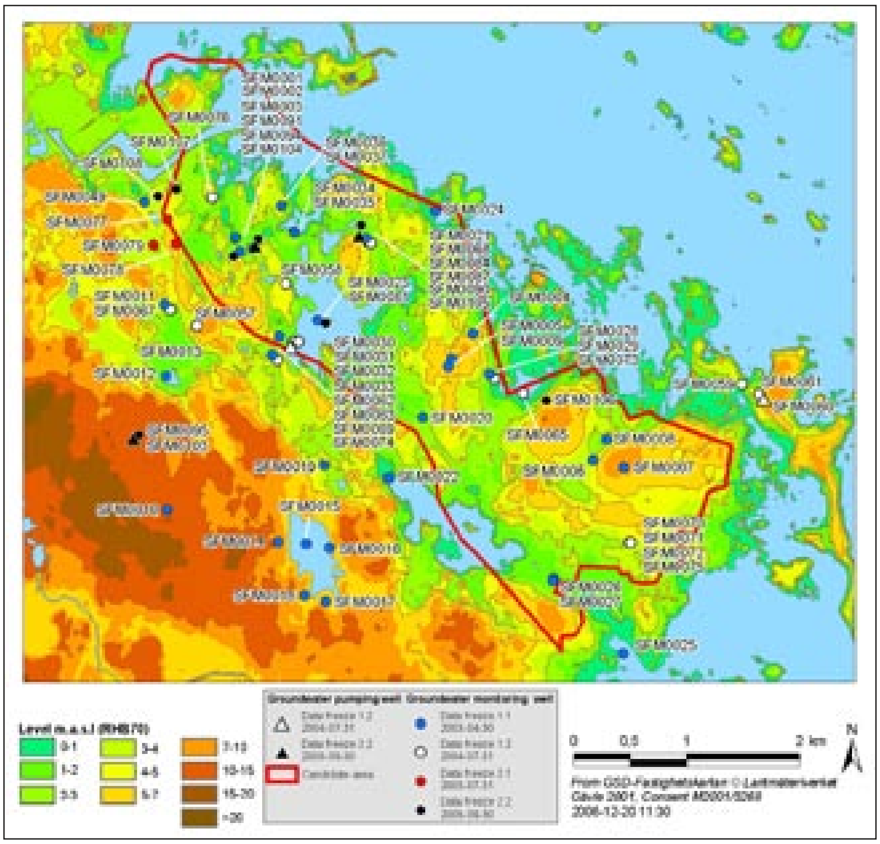


Figure 3-4. *Elevation map with existing soil boreholes supplied with groundwater stand-pipes.*

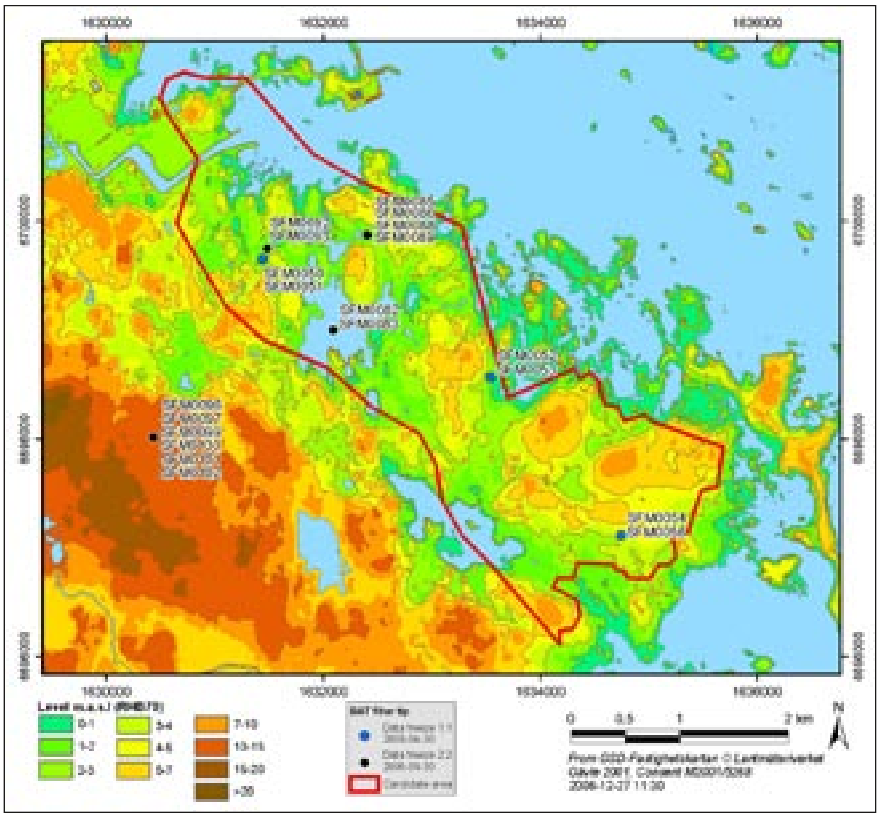


Figure 3-5. *Elevation map with existing soil boreholes supplied with groundwater stand-pipes with BAT-type filter tips.*

3.2 Geological conditions

Figure 3-6 shows a three-dimensional geological model of the hard rock part of the investigation area. The crystalline bedrock in the Forsmark area is part of an elongated rock block, a so called tectonic lens, which extends from the nuclear power plant to beyond Öregrund to the south-east. To the north-east and south-west, the area is bounded by regional zones with deformed bedrock, the so called Singö- respectively Forsmark deformation zones (not shown in Figure 3-6). These types of relatively well-preserved, more or less lenticular blocks between bands of deformed bedrock prevail at several locations in the region, as well as in other regions with a similar geological history. Their origin can be traced to deformation processes that acted while the rock was still subject to high pressures and temperatures. The result was wide zones that run in long bands, where the rock has been deformed in a ductile manner and formed banded and folded structures. More distinct zones of fractured rock are often superimposed, which is a result of brittle deformation at later stages when the rock had solidified. Deformations and movements have, naturally enough, had a tendency to become concentrated to bands where they were once initiated, since the bedrock there is weakened. The intervening rock has therefore remained relatively unaffected.

The rock types in the candidate area itself are relatively uniform and are dominated by metamorphosed granite (metagranite). Other granitoid variants, like tonalite, are found both to the south-east and the north-west. Basic rocks such as diorite and gabbro, as well as metavolcanic rocks, are common south-west of the candidate area. The metavolcanic rocks contain accumulations of ore minerals, particularly the iron mineral magnetite.

Although the investigation site is situated close to the coast, most of the bedrock is till-covered, see Figure 3-7. However, some bare outcrops lie scattered throughout the area. Smaller parts of the till-covered areas also have overlying regolith such as glacial and postglacial clay, gyttja and peat. The till, which in some places can be very thick (10–15 m), is composed of several beds with varying grain size distribution. The till is generally very calcareous.

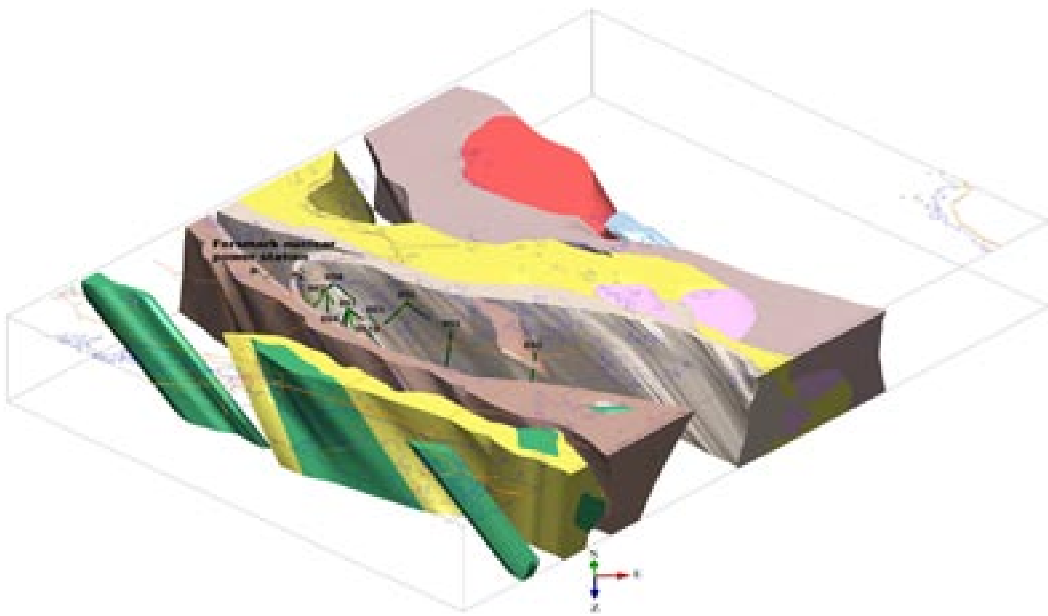


Figure 3-6. *Bedrock geological model of the Forsmark area (model version 2.2). The rock domain in which the repository is planned to be sited is in the model marked as the central empty space. This domain is characterized by low-deformed homogeneous metagranite. Other granitoid variants, which often have been subject to a higher degree of ductile and brittle deformation (e.g. the domains with brownish and lilac colours) exist outside this domain. Green colour represents basic rocks and yellow colour metavolcanic rocks. Drill sites and many of the core drilled boreholes in the repository domain are also shown in the figure as well as the Forsmark nuclear power plant.*

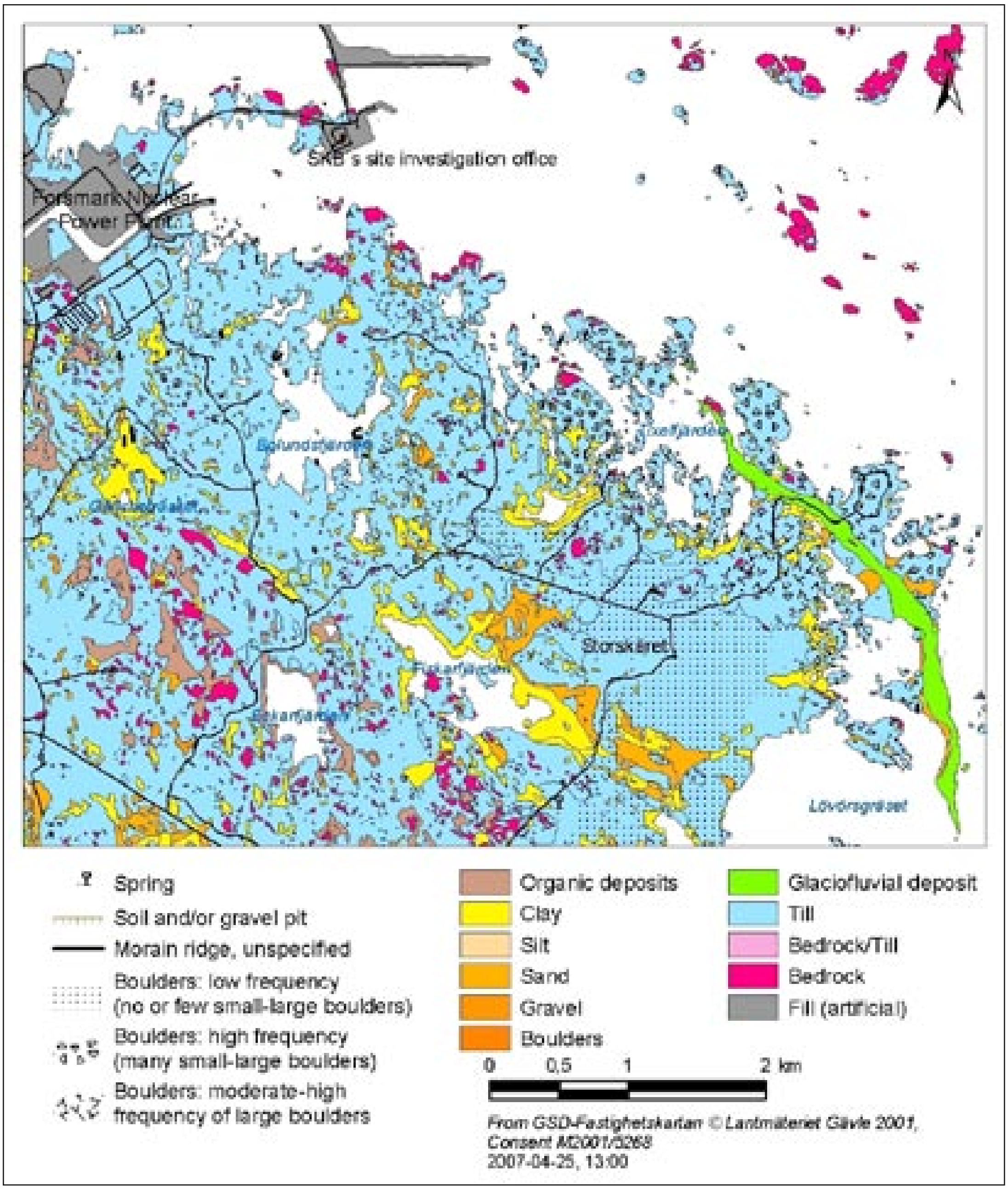


Figure 3-7. Simplified version of Quaternary geological map of the Forsmark area.

3.3 Meteorological and hydrological conditions

SKB started measurements of meteorological parameters during the spring 2003. Figure 3-8 shows the accumulated, corrected precipitation for the three years 2004, 2005 and 2006, which has amounted to 504, 592 and 529 mm respectively. This can be compared with the normal precipitation for the period 1961–1990 according to SMHI, which is 559 mm.

Other measured parameters are wind speed, atmospheric pressure, wind direction, global radiation and humidity. Also snow and frost depths have been measured since the winter 2002/2003.

Stream discharge measurements in brooks have been performed since spring 2003. The diagram in Figure 3-9 demonstrates an example of the discharge pattern during the two years 2005 and 2006 from the largest catchment area, at the Bolundsbäcken brook inflow into Lake Bolundsfärden (5.6 km^2). The flow pattern differs relatively much between the two years.

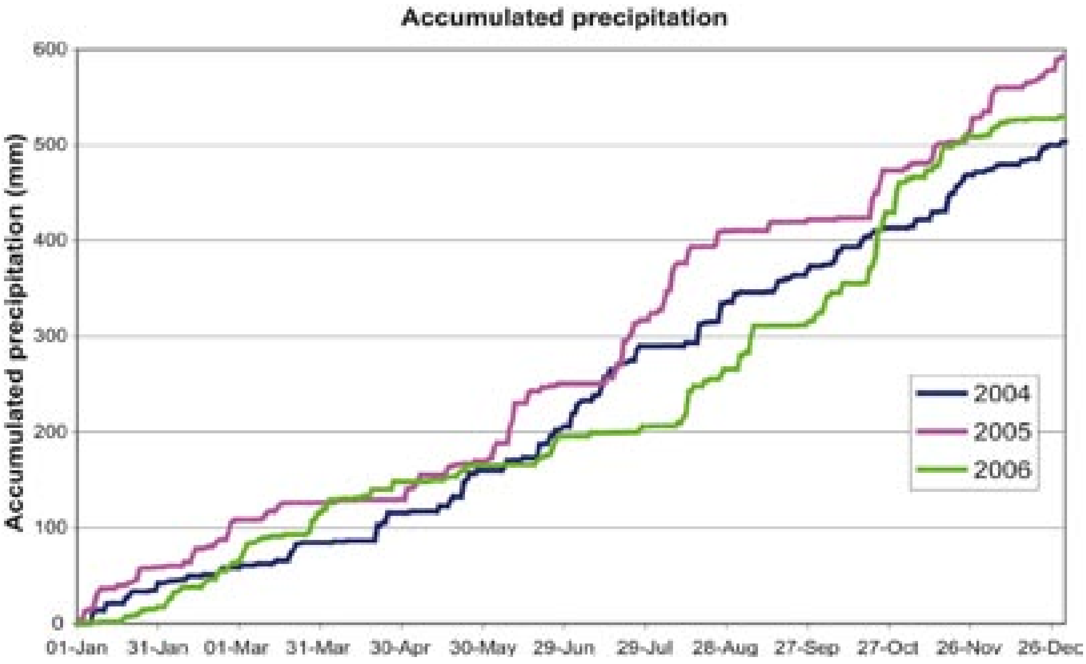


Figure 3-8. Accumulated precipitation in Forsmark for the three years 2004, 2005 and 2006.

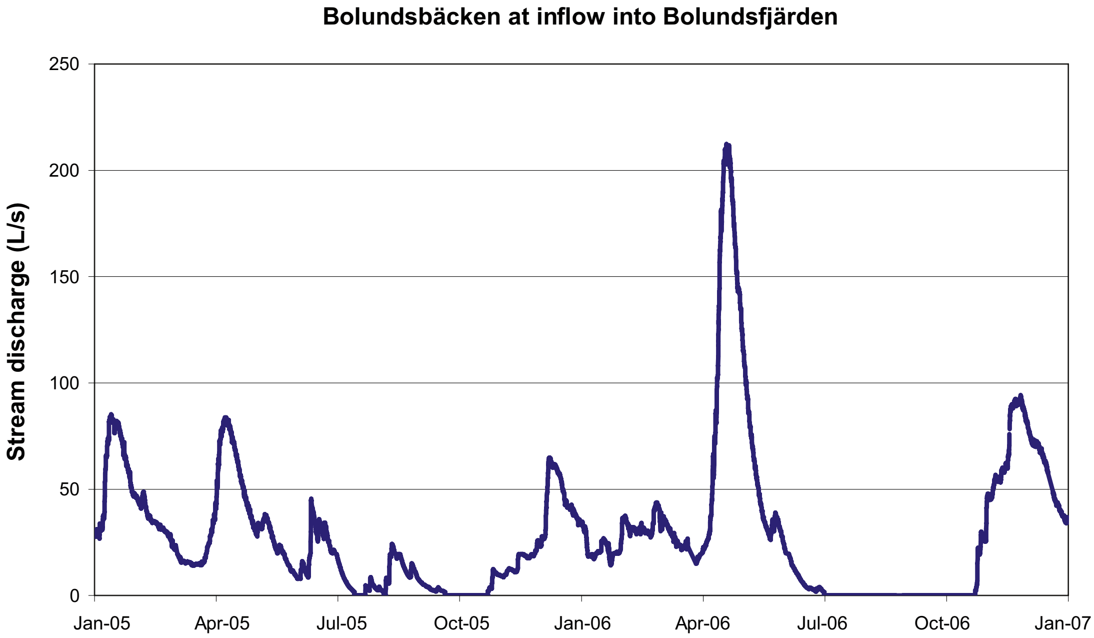


Figure 3-9. Discharge into the Lake Bolundsfärden from the Bolundsbäcken brook.

During spring and autumn 2006 the discharge was high with a very dry summer in between, whereas the discharge showed smaller variations and a more even distribution over the year during 2005.

3.4 Hydrogeological conditions

The hydrogeological investigations performed so far in the candidate area have revealed some clearly distinctive features as regards the fracture situation and water flow in the bedrock. Figure 3-10 exemplifies this with data from the first, deep, almost vertical cored borehole. The average fracture frequency in the shallow part of the bedrock (down to a depth of about 300 m) is normal for Swedish crystalline bedrock. Sections with distinct, usually gently-dipping, highly conductive fractures are encountered down to a depth of about 200–300 m. This pattern seems, on the whole, to exist throughout the tectonic lens.

At greater depths, below 200–300 m, the bedrock in the candidate area is distinguished by a low fracture frequency and low hydraulic conductivity. At and beyond repository depth

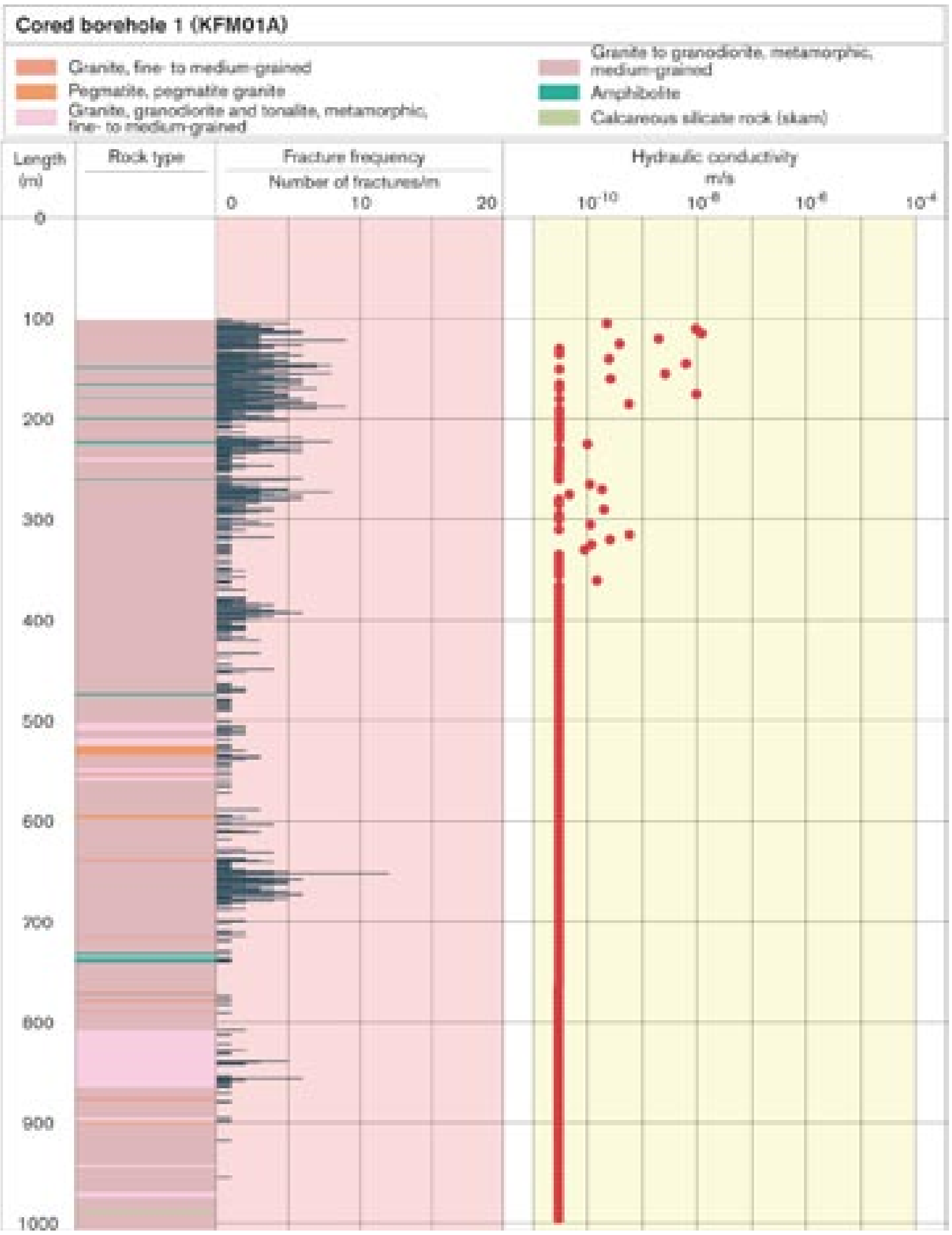
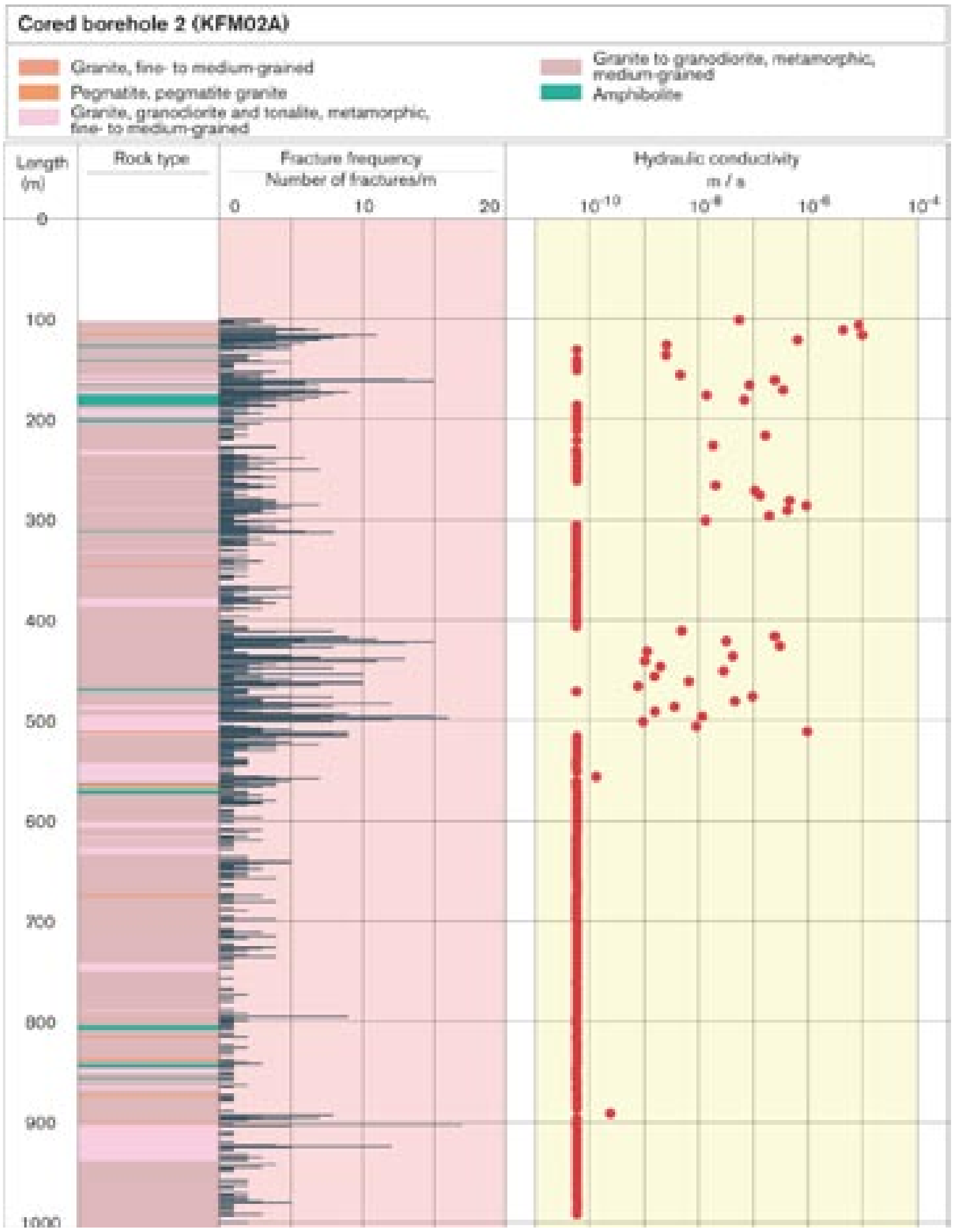


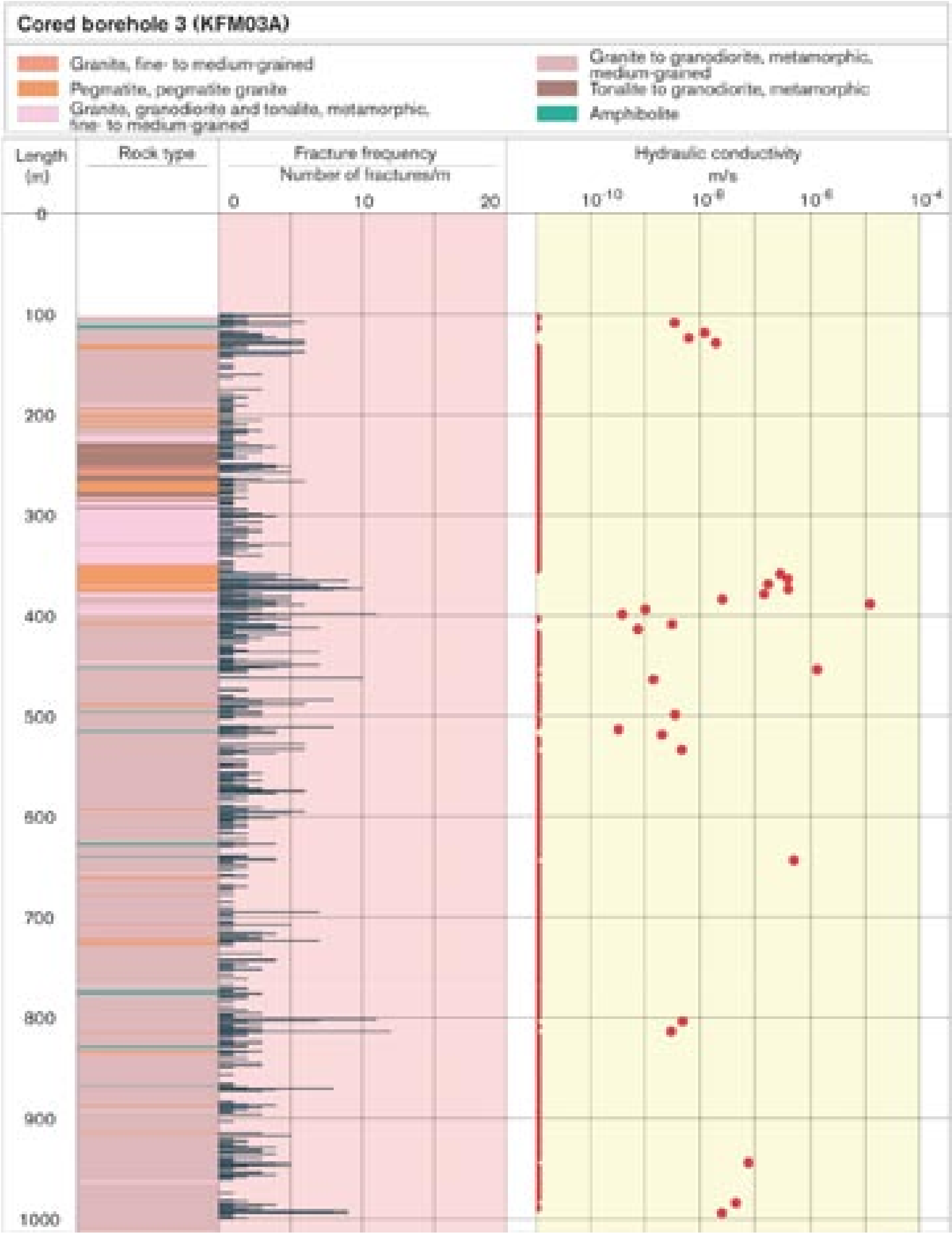
Figure 3-10. Cored borehole KFM01A. Metamorphosed granite (metagranite) dominates. The fracture frequency is normal to about 300 m. Below, it is very low with the exception of two sections. From about 360 m to the bottom of the borehole, the hydraulic conductivity is at or below the measurement limit. (Data from borehole section 0–100 m are not displayed in this diagram because this part of the hole is percussion drilled.)

(400–500 m), borehole sections of several hundred metres have been observed where the hydraulic conductivity is at, or below, the measurement limit. However, exceptions from this pattern occur. Especially the south-eastern part of the candidate area displays a different character, where a suite of distinct, gently dipping zones, however with moderately increased hydraulic conductivity, intersect the bedrock also at depth, see Figures 3-11 and 3-12.

As regards the hydrogeological conditions of the Quaternary deposits in Forsmark, which are dominated by till, field- and laboratory tests have revealed relatively large differences in hydraulic conductivity due to variations in the grain size distribution. Often the most superficial parts



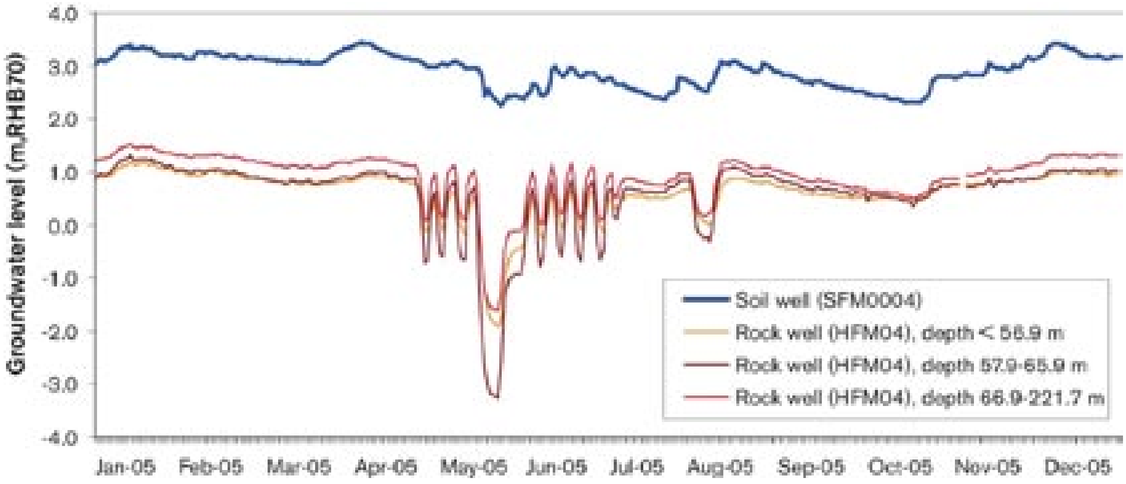
Figur 3-11. *Cored borehole KFM02A. This borehole, which is situated in the middle of the candidate area, shows similarities with KFM01A regarding lithological conditions, fracture frequency and hydraulic conductivity, except from the increased fracture frequency and hydraulic conductivity between about 420–530 m. This is due to the fact that a gently dipping fracture zone (ZFMA2) intersects the borehole at the upper part of this interval and a horizontal fracture zone (ZFMF1) at the lower part. The fracture zone ZFMA2 has an inclination of about 20° (from the horizontal plane) towards south-east and intersects the ground surface approximately along a straight line between drill sites DS1 and DS6 (see Figure 3-2). (See comment in Figure 3-10 regarding section 0–100 m.)*



Figur 3-12. *Cored borehole KFM03A is situated in the south-eastern part of the candidate area. The metamorphic granite (metagranite) dominates also in this borehole, although the presence of tonalite, pegmatite and fine-grained granite is higher than in KFM01A and KFM02A. The fracture frequency is low to about 370 m. Between 370 and 400 m it is increased, indicating that the borehole intersects one or several fracture zones. Below this depth the fracture frequency is again low, except within a few short sections which also display increased hydraulic conductivity. These sections correspond to a suite of sub-parallel, gently dipping fracture zones. (See comment in Figure 3-10 regarding section 0–100 m.)*

of the till, which have been exposed to wave washing, are about 100 times as conductive as the till further down. However, sometimes an increased conductivity is observed also at the bottom layer of the till, which is resting directly on the bedrock. Clay, gyttja and other fine-grained soil types, which are found especially within wetland areas, generally display low hydraulic conductivity values.

An interesting observation is that the groundwater levels in the Quaternary deposits at many places in the investigation area are much higher than in the rock. Figure 3-13 shows that the groundwater level in the two closely situated soil and rock wells (SFM0004 and HFM04) differ by about two metres.



Figur 3-13. *Groundwater levels in Quaternary deposits and rock in two nearby boreholes at Forsmark.*

The groundwater levels in soil and rock exhibit co-variations that indicate some hydraulic contact between these aquifers, however with a limited discharge from soil to rock. The lower groundwater level in the rock compared to in the soil could possibly be explained by a rapid diversion of groundwater to the recipient (the Baltic Sea) via superficial, near-horizontal and very high-conductive fractures.

The hydraulic gradients in the Forsmark investigation area are generally low, in Quaternary deposits as well as in the rock, due to the flat topography.

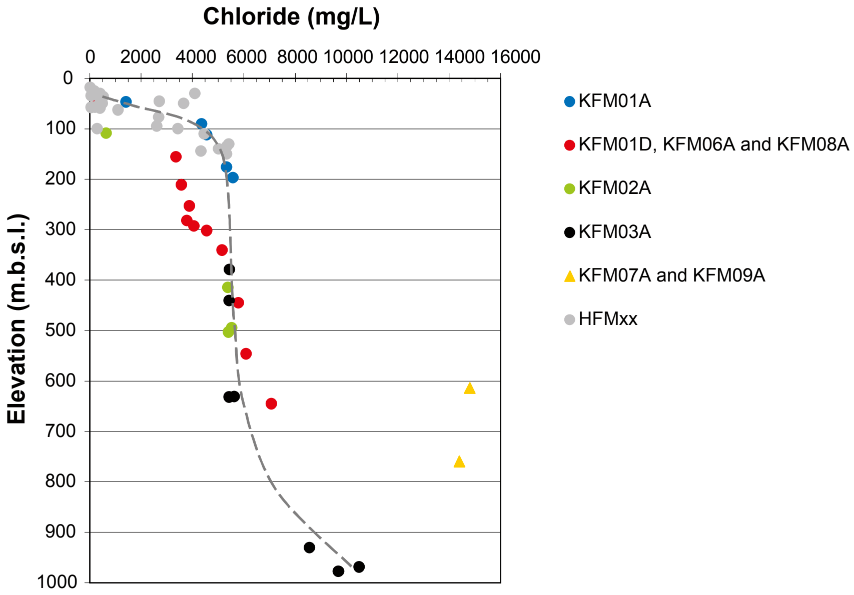
3.5 Hydrogeochemical conditions

The groundwater in the soil layers at Forsmark is generally distinguished by high pH-values and high concentrations of major components, especially calcium and bicarbonate. Groundwater sampled from groundwater pipes situated in low-lying discharge areas contains a strong contribution of marine water with increased levels of chloride, bromide, sodium and magnesium. Pipes located in recharge areas, which are situated at higher levels in the terrain, provide a groundwater clearly influenced by the calcareous till, which elevates the concentrations of calcium, bicarbonate and strontium.

Concerning groundwater in the rock, the salinity usually is enhanced with depth. Close to the coast the saline water is nearer the ground surface than inland, and in the investigation area at Forsmark the salinity increases rapidly versus depth. Already at about 100–150 m the chloride concentration is higher than in the sea off Forsmark.

Groundwater is always a mixture of waters of different origins and its composition is the endpoint of a long evolution. High salinity in the rock groundwater at Forsmark is usually due to the presence of remains of water from the Littorina Sea or even more saline water from deep rock layers (so called brine water). Owing to the flat topography at Forsmark, the hydraulic driving force is low, which means that it takes a long time for old groundwater to be flushed out from the aquifer.

The rock groundwaters in Forsmark are mixtures of waters of mainly four different origins; 1) meteoric water, 2) Littorina seawater, 3) glacial meltwater, and 4) deep saline groundwater (brine). The groundwater composition in water samples from different boreholes and depths is to a high degree related to the different structural-geological units identified at Forsmark. The diagram in Figure 3-14 displays chloride concentrations with depth from several boreholes within the investigation area. At first, the chloride concentration increases rapidly versus depth but is then levelling out within the depth interval 150–640 m. At greater depths the salinity is

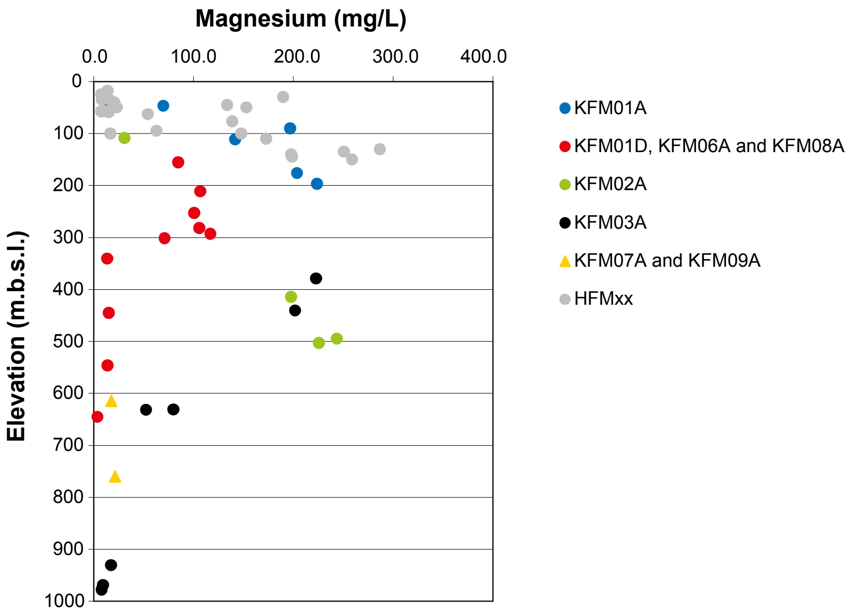


Figur 3-14. *Chloride concentration versus vertical depth. Data representing conditions above and adjacent to the major, gently dipping deformation zones ZFMA2 and ZFMF1 as well as from the south-eastern part of the candidate area are joined by a dashed grey line. The boreholes labelled with red colour (KFM01D, KFM06A and KFM08A) are those situated in the low-fractured rock unit encountered below and north-west of deformation zones ZFMA2 and ZFMF1.*

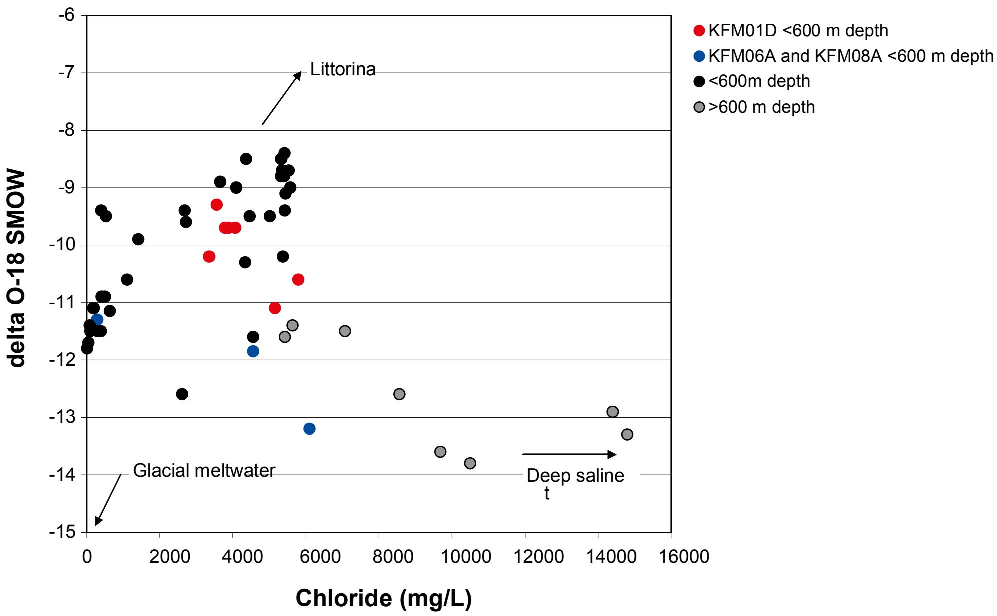
again elevated. However, the chloride concentration trend is different in groundwater associated with the low-permeable bedrock of very low fracture frequency below and north-west of the major deformation zones ZFMA2 and ZFMF1 (in Figure 3-14 corresponding to the boreholes symbolised by red in filled circles) compared to the rest of the groundwater samples mainly representing several gently dipping deformation zones including ZFMA2 and ZFMF1 and adjacent bedrock affected by these zones.

Zone ZFMA2 reaches the ground surface approximately along a straight line between drill sites DS1 and DS6, see Figure 3-2. However, the low-fractured rock encountered below this zone continues towards north-west, and for example boreholes KFM06A, KFM01D and KFM08A are at depth penetrating this rock unit. The most saline groundwaters (chloride exceeding 14,000 mg/L) in Forsmark are observed at depth in boreholes KFM07A and KFM09A. The sampled borehole sections in these boreholes represent deformation zones adjacent to strongly foliated bedrock at the north-western and south-western margin of and outside the low-fractured rock constituting the target volume.

The diagram in Figure 3-15 displays magnesium concentrations versus depth. High magnesium and sulphate concentrations as well as a low bromide to chloride ratio indicate a marine origin of the water. As shown by the magnesium diagram, increased concentrations of magnesium, representing groundwater of clear Littorina seawater origin, is observed between approximately 100 m and 600 m depth in deformation zones and in bedrock adjacent to ZFMA2 and ZFMF1 in boreholes KFM01A, KFM02A and KFM03A (blue, green and black circles). A less pronounced Littorina signature is observed down to about 300 m depth in the bedrock below and north-west of zones ZFMA2 and ZFMF1 but is absent below this depth (boreholes KFM01D, KFM06A and KFM08A, red circles). Also isotope quotients may be used to separate groundwaters of different origins as shown in the diagram in Figure 3-16.



Figur 3-15. Magnesium concentration versus vertical depth.



***Figur 3-16.** $\delta^{18}O$ ‰ SMOW versus chloride concentration. The three boreholes with less pronounced marine (or non-marine) signatures at relatively shallow depths (KFM01D, KFM06A and KFM08A) indicated by red and blue colours are mainly those situated in the low-fractured rock unit encountered below and north-west of the deformation zones ZFMA2 and ZFMF1.*

3.6 Nature and culture

The Forsmark area is flat and low-lying. As recently as during the early Middle Ages, the region lay beneath the sea, after which the process of land uplift led to the formation of islands in what is now a coastal area. The landscape of today contains many small shallow lakes and bays. The rate of land uplift is about 6 mm per annum, and the water areas are in different stages of being pinched off from the sea. This process of evolution from sea to land also leads to a rapid succession of different biotopes, which is interesting from an ecological perspective.

Productive coniferous forest dominates in the higher parts of the area, except at the far south-east, where the landscape opens up into fields, meadows and deciduous glades (Figure 3-17). The arable land is here to a large part consisting of boulder clay.

Due to the combination of open water, wetlands and woodlands, the bird life is diverse and numerous (Figure 3-18). The flora is also rich. The calcareous soils provide good conditions for many calcium-dependent species (Figure 3-19).

The high natural merits entail that the Forsmark area is of national interest for nature conservation, among others for its ornithological values. The Kallriga reserve, south-east of the candidate area, has been set aside to preserve these values and has the status of a Natura 2000 site.

Figure 3-17. *Meadow land at Storskäret, south-eastern part of the Forsmark candidate area.*

Figure 3-18. *Due to the combination of open water, wetlands and woodlands, the bird life is rich.*

Figur 3-19. *Lady's slipper occurs on calcareous soils in the woodlands and pasturelands of Forsmark.*

4 Programme for long-term observations after completion of the site investigations

4.1 Quality assurance and environmental impact

The monitoring programme after completed site investigations at Forsmark is presented in this chapter. Although the programme is primarily described under the headings for the respective disciplines, several monitoring activities will be coordinated during sampling/measurements performed in the field.

The monitoring shall be performed according to the SKB system for quality assurance. This implies that each activity must be conducted in compliance with an approved Activity Plan (AP) and appropriate SKB Method Documents (MD), when applicable. Field activities shall, apart from laws, regulations and ordinances, follow SKB's existing procedures. Furthermore, data shall be treated and delivered to SKB and reports written according to SKB routines.

Contractors engaged by SKB for performance of activities must issue a quality plan for each assignment and carry out and document internal quality controls. With fieldwork, it is of outmost importance that activities are carried out with satisfactory safety as regards humans and environment. The Contractor must therefore in his quality plan include a risk assessment regarding safety, security, health and environment. The experiences so far from performance of the monitoring activities are that the risks regarding humans are small, and that the environmental impact is very limited.

4.2 Reference areas

The understanding of geoscientific and biological-ecological processes studied by creating time series within a specific site, may be improved if results from this site can be compared with monitoring data from other sites, especially if data are acquired during roughly the same period of time at the different sites. The site or sites which provide(s) comparative data may be called "reference area(s)". SKB performs monitoring of several parameters both at Forsmark and Oskarshamn. Most of the monitored parameters are identical, and therefore these two areas may, in many respects, serve as reference areas for each other, although comparative analyses have not yet been initiated. Information about which parameters are monitored both at Forsmark and Oskarshamn are given below, together with some examples of "external"reference areas:

- *Geological monitoring by GPS-measurements*, see Section 4.3, has been performed also at the Oskarshamn site investigation, however only during 2002. The results are presented in /8/, and data are available in the SKB database Sicada. The GPS-measurements at Forsmark are related to the Swepos network stations at Lovö, Uppsala and Mårtsbo, that are defined by the Swedish Land Survey as stations with stable fundaments.
- *Monitoring of ground electrical currents,* Section 4.4, is performed also at the Oskarshamn site investigation, by the same method, and the monitoring will continue during the period 2008–09.
- *Meteorological monitoring,* cf Section 4.5, has been carried out at the Oskarshamn site investigation during approximately the same period as at Forsmark, following roughly the same principles and using the same type of equipment at both sites. Data from the two sites are accessible in Sicada and in several primary data reports. Furthermore, meteorological data (especially precipitation) have during the site investigations been compared with corresponding data from nearby meteorological stations managed by SMHI (The Swedish Meteorological and Hydrological Institute). Meteorological monitoring at Oskarshamn will,

like at Forsmark, continue during 2008–09. Meteorological data from SMHI from nearby weather stations (as well as from more distant stations) will also in the future be available for comparison.

- *Measurements of snow depth and observations of ice cover*, Section 4.6, which has been conducted during the same period and in the same way at the site investigation in Oskarshamn, are performed in compliance with methods developed and applied by SMHI. Data from both sites are accessible in Sicada and in several primary data reports. Future snow and ice data from Oskarshamn and SMHI will serve as data sets suitable for comparison with Forsmark data.
- *Hydrological monitoring (surface water levels in lakes and in the Baltic Sea and discharge data from brooks including flow rate, EC and temperature),* Section 4.7, has been performed during approximately the same period and in the same way at the Oskarshamn site investigation. Discharge data from catchment areas close to and far from Forsmark are also available from SMHI. Future Oskarshamn and SMHI data will be a resource for comparison with Forsmark data.
- *Groundwater level monitoring in Quaternary deposits,* see Section 4.8, is carried out at the Oskarshamn site investigation according to the same methods and data collection principles as at Forsmark, and the Oskarshamn monitoring will continue just like at Forsmark. Another source for data comparison is the groundwater observation net managed by the Geological Survey of Sweden (SGU).
- *Groundwater level monitoring in bedrock,* Section 4.9, at the Oskarshamn site investigation uses the same methods and data handling principles as are applied at Forsmark, and the Oskarshamn monitoring will continue just like at Forsmark. Also for this type of monitoring the groundwater observation net managed by SGU as well as data from the SGU Well Archives are and will in the future constitute a source for comparison with Forsmark data.
- *Hydrochemical monitoring in surface waters (precipitation, Baltic Sea, lakes and brooks),* Section 4.10, is performed at the Oskarshamn site investigation using the same methods and data collection principles as at Forsmark, and the Oskarshamn monitoring will continue like at Forsmark. Forsmark will from July 2007 initiate sampling of precipitation at a reference site in Västergötland, close to lake Vänern, in order to compare primarily the contents of tritium between Forsmark, situated close to a nuclear power plant, with the contents in precipitation at a site far from such facilities. Otherwise, for this type of monitoring it may be difficult to find reference areas in Sweden, where sampling and analysis of surface waters is performed as systematically as is done at SKB's sites at Forsmark and Oskarshamn. However, such investigations are to some extent performed by SGU, universities and other research institutes as well as by consulting agencies etc.
- *Hydrochemical groundwater monitoring,* Section 4.10, at the Oskarshamn site investigation is performed by applying the same methods and data handling principles as at Forsmark, and the Oskarshamn monitoring will be continued in the near future like it will be at Forsmark. For this type of monitoring also the groundwater observation net managed by SGU as well as data from the SGU Well Archives may serve as material for comparison. Some data may also be available from universities, consulting agencies etc.
- *Groundwater flow monitoring,* see Section 4.11, is an activity characterised by a high degree of specialization, which is probably not performed anywhere else in Sweden than at the SKB site investigations. However, also in this case Forsmark data can be compared with Oskarshamn data, since monitoring has been performed, and will during the period 2007–2009, be carried out at both sites.
- *Ecological monitoring,* see Section 4.12, at Forsmark has during the site investigations focused on *birds and elks,* and monitoring of these objects will continue 2007–09. Monitoring of birds is performed in the same way at the Oskarshamn site investigation, which then may serve as a reference area. Regarding one of the monitored species, the white-tailed eagle, *Haliaeetus albicilla,* comparison is also made with two reference areas, one north of, and the other south of Forsmark.

As concerns monitoring of elk *(Alces alces),* results from the Forsmark area have been and will in the future be compared with results from the reference area Saxmarken in Hållnäs, some tens of kilometres north of Forsmark.

4.3 Geological monitoring

4.3.1 GPS-monitoring – Background

A GPS monitoring project is currently being performed at the Forsmark site investigation. The objective of the monitoring is to identify possible movements in the bedrock within and outside the Forsmark candidate area. Seven thermally and physically stable measurement stations for GPS monitoring were built at Forsmark during the autumn 2005. The stations were established within a 10-kilometres radius in three areas of different geological characteristics: 1) north-east of the Singö zone (two stations), 2) within the candidate area (three stations), and 3) south-west of the Forsmark deformation zone (two stations). The locations of the stations are shown in Figure 4-1 and the coordinates are listed in Table 4-1.

The stations consist of a stainless steel rod fixed in the bedrock, upon which the GPS antenna mounts. Each station is dedicated a GPS equipment to be used only at that station. The measurement set comprises a GPS receiver collecting raw GPS data and a choke ring antenna linked to the receiver using a coaxial cable. The receivers and antennas are dual frequency high precision geodetic grade.

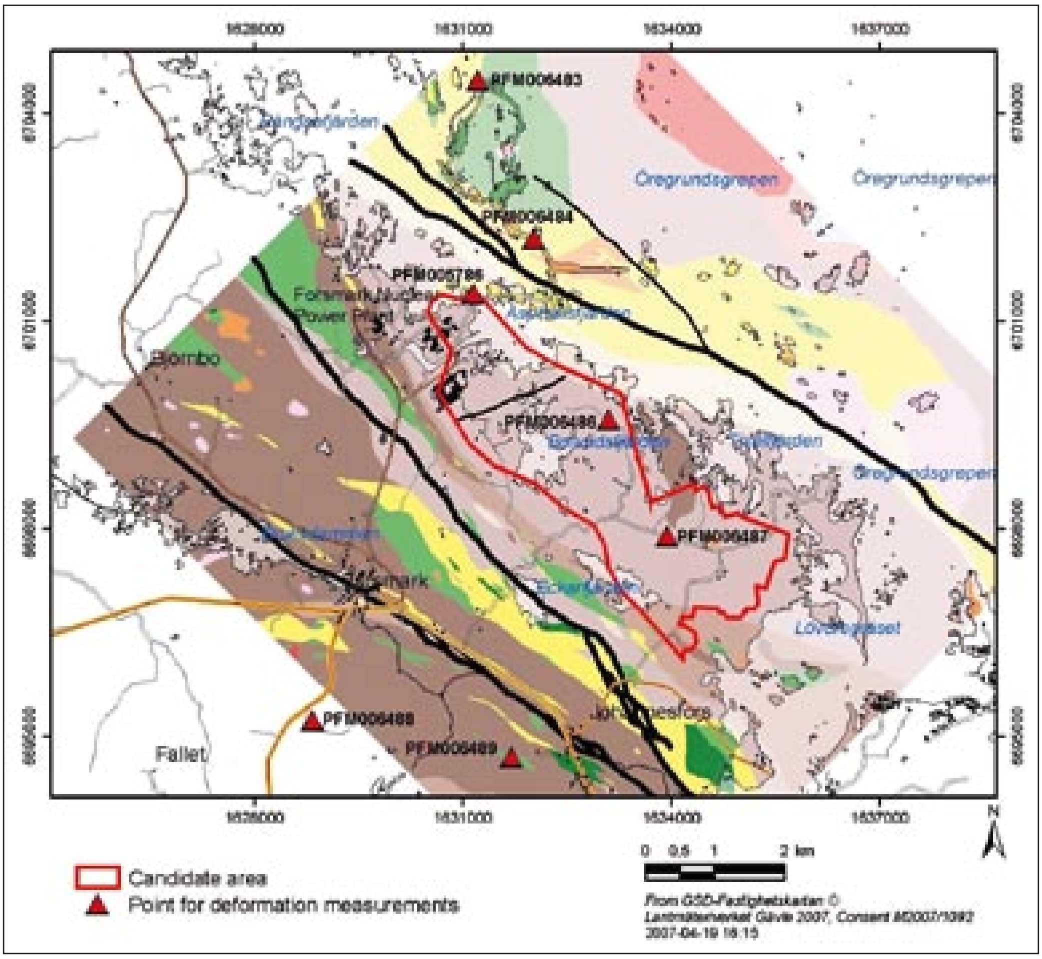


Figure 4-1. *Location of GPS stations.*

Table 4-1. The seven GPS stations (coordinates in RT 90 2.5 gon W 0:-15; RHB70).

Point ID	Northing	Easting	Elevation
PFM006483	6704470.217	1631225.109	2.796
PFM006484	6702177.301	1632030.643	1.684
PFM006486	6699575.573	1633108.248	3.404
PFM006487	6697890.033	1633952.532	5.984
PFM006488	6695230.051	1628847.471	15.704
PFM006489	6694703.665	1631709.252	7.943
PFM005786	6701390.643	1631157.590	1.606

During each measurement campaign the GPS receiver saves a reading every second for the duration of the five days campaign. The antennas remain mounted on the stations during the entire project (3 years), whereas all other equipment is in place at the stations only during the campaigns. The measurements will also be related to the Swepos network stations at Lovö, Uppsala and Mårtsbo, that are defined by the Swedish Land Survey as stations with stable fundaments. There will be fifteen campaigns in total, and until June 2007, eight sessions have been conducted and stored in Sicada. Results from 2005 and 2006 are presented in /9/.

4.3.2 GPS-monitoring – Programme

Field performance

The current programme is already decided to run a year and a half after the termination of the site investigations, i.e. until the turn of the year 2008/2009. During 2007–2008 three and four campaigns, respectively, will be conducted. Thereafter the results should be evaluated and a decision be made whether the programme shall be prolonged or not.

Data handling and processing

Data are stored in Sicada after each measurement campaign.

Documentation

The GPS-monitoring is documented in one P-report per annum written by the Contractor. The P-reports should be in the format specified by SKB. In the reports all measurements should be documented and nonconformities compared with the programme specified.

4.3.3 Seismic monitoring – Background

According to an agreement with SKB, the Department of Earth Sciences at the Uppsala University, has during the last years carried out observations of seismic activity in Sweden within the programme of the Swedish National Seismic Network (SNSN). The university has also constructed several new observation stations. The goal is to complement the existing regional seismic network to establish a local seismic network that also permits registration of small earthquakes in order to obtain relatively long time series and thereby gain a better understanding of the causes of seismic events in the site investigation areas.

The SNSN network consists today of 59 stations, see Figure 4-2, of which two stations are located close to the Forsmark candidate area, at drill site 4 (see Figure 3-2) and at the island of Gräsö (see Figure 3-1).

Fundamental information about the seismic events, including origin time, hypocenter location and information about the source parameters are given after every three months /10/.

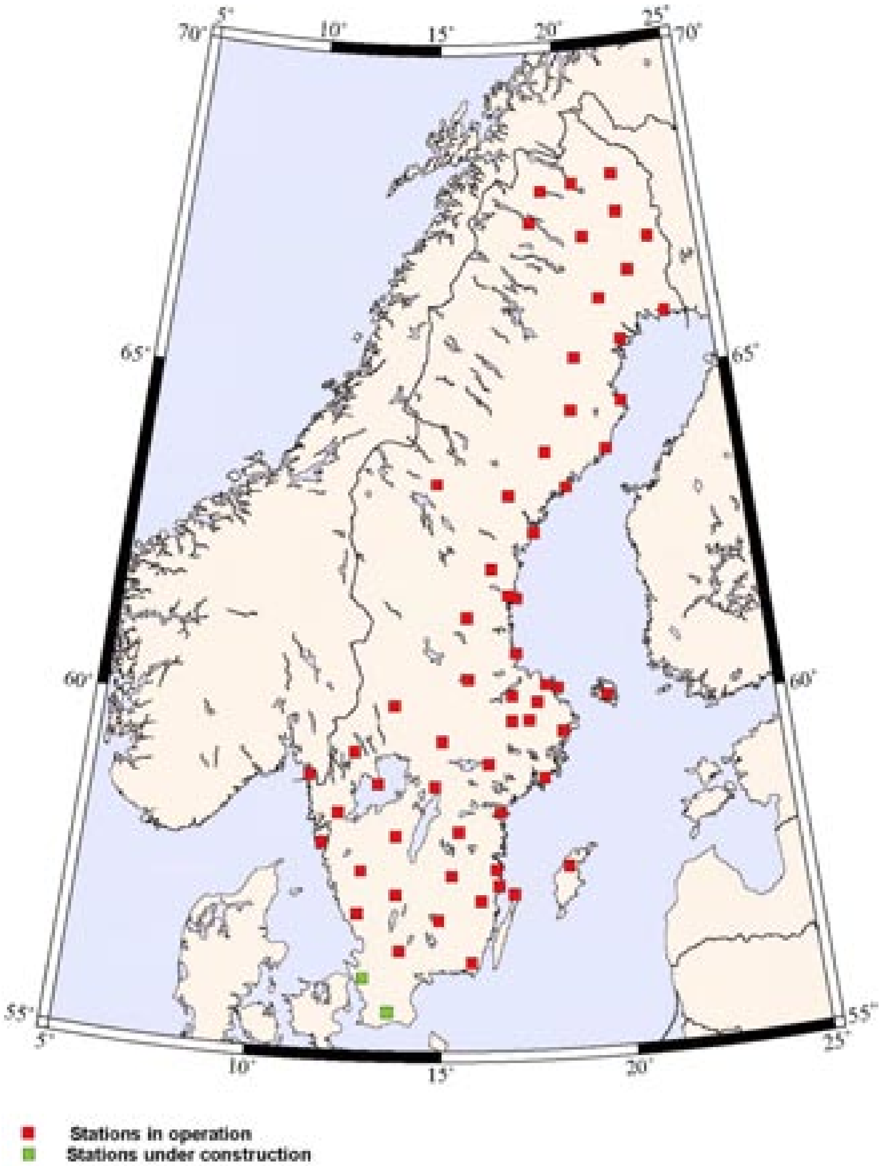


Figure 4-2. *The present Swedish National Seismic Network.*

The sensitivity of the network allows for complete recording of all earthquakes down to a magnitude of lower than 0.5 within the network and down to magnitude 0.0 near SKB's investigation sites at Forsmark and Oskarshamn.

The seismic monitoring is managed by the PU department at SKB, i.e. not by the site investigation managements at Forsmark and Oskarshamn, respectively. However, data handling and reporting are following approximately the same routines as applied at the site investigations at Forsmark and Oskarshamn. Data, which are stored in Sicada, are also reported quarterly to SKB in P-reports.

4.3.4 Seismic monitoring – Programme

According to current plans, the SNSN monitoring programme will continue until 2011. The same routines as today for data handling and reporting will be applied.

4.4 Monitoring of ground electrical currents

4.4.1 Background

In conjunction with borehole investigations and ground geophysical measurements, externally generated electrical fields have been demonstrated to occur in the ground within the investigation area. A DC-field is generated by the monopolar high voltage electrical cable between Sweden and Finland (the so called Fennoskan cable) and exerts an influence on the investigation area from the ground surface to depths of several hundred metres. Also an AC-field has been observed in the north-western part of the candidate area extending from the ground surface to about 300 m vertical depth. This field probably emerges from the electrical installations in connection with the nuclear power plant.The static (DC) electrical field has since the summer 2006 been measured in north-south and east-west directions by two pairs of electrodes situated at drill site 1 (DS1), see Figures 3-2 and 3-3. The electrodes in each pair are located 100 m apart, and the electric field is measured as the potential difference between the electrodes. The electrodes are solid-state non-polarizable Pb-PbCl, and have proved to be stable and with very little intrinsic noise /11/. Measurements are registered once per minute by the data logger, and data are stored by the HMS system (Hydro Monitoring System) /12/, but the activity has not been documented in any other way.

4.4.2 Monitoring programme

Field performance

The current monitoring programme will be prolonged until the priority decision is made by SKB in 2009. The measurements will be conducted in the same way as so far. However, if the equipment would fail, a decision will be made at that point whether it is worthwhile repairing it, or if the monitoring should be ended.

Data handling and processing

Data will primarily be stored by SKB personnel in the HMS-system for later transfer to Sicada.

Documentation

A P-report will be written presenting results from the monitoring during the site investigations as well as from the period July 2007–2009. The P-report should be in the format specified by SKB. In the report all measurements should be documented and presented in graphs and nonconformities compared with the programme specified.

4.5 Meteorological monitoring

4.5.1 Background

Two meteorological stations were established for the site investigation in May 2003 (Figure 4-3).

The coordinates of the two stations are shown in Table 4-2 and the parameters measured are listed in Table 4-3.

The wind was measured at 10 m above ground level, the other parameters at 2 m.

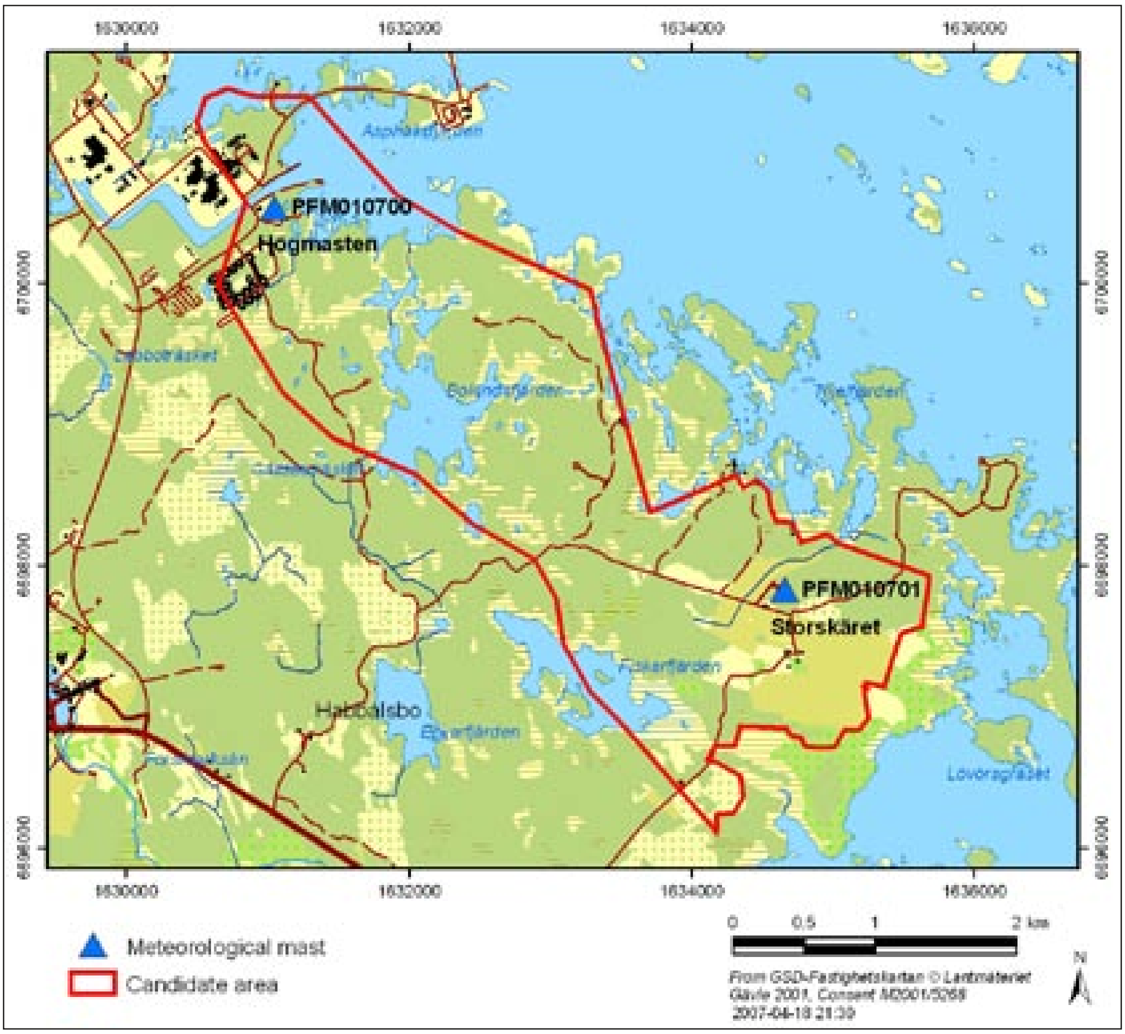


Figure 4-3. Locations of the two meteorological stations established at Forsmark in May 2003, Högmasten (PFM010700) and Storskäret (PFM010701).

Table 4-2. SKB's meteorological stations (coordinates in RT 90 2.5 gon W 0:-15).

Identity	X	Y	Type	Name
PFM010700	6700525	1631046	Meteorological station	Högmasten (Forsmark)
PFM010701	6697827	1634659	Meteorological station	Storskäret

Table 4-3. Equipment used for collection of meteorological data at the meteorological stations.

Parameters	Equipment
Precipitation	Geonor T200 complete with pedestal and wind shield
Air temperature	Pt100 sensor with radiation shield and ventilated Young 41004
Barometric pressure (only at Högmasten)	PTB200
Wind speed and direction	RM Young Wind monitor
Air humidity	Rotronic HygroClip MP 100H
Global radiation (only at Högmasten)	Kipp & Zonen CM21 with warming and fan

Data are collected every half-hour. The different parameters are valid for the following time periods:

- Precipitation: Accumulated sum of precipitation every 30 min. The 30-min precipitation value is the difference between two adjacent accumulated precipitation sums.
- Temperature: 30-minutes mean of one-second values.
- Barometric pressure: 30-minutes mean of one-second values.
- Wind speed and wind direction: The latest 10-minutes mean value for the actual 30 minutes. Hence, for the 10:00 data the measurement is from 09:51 to 10:00.
- Relative humidity: 30-minutes mean of one-second values.
- Global radiation: 30-minutes mean of one-second values.

The planned monitoring programme, including data handling, processing and documentation, starting from July 1, 2007, is described below.

4.5.2 Monitoring programme

Field performance

The two meteorological stations, which have been running since 2003, will be operated as described in Section 4.5.1 until June 30, 2007. The meteorological data from the two stations have shown very similar values, with the exception of precipitation, for which minor local variations occur. Since precipitation values for the station "Högmasten" are representative for the catchment area that includes the potential repository, and because the small differences in data between the two stations have little or no consequence for modelling, continued monitoring of the station "Storskäret" is considered not needed, and this station (PFM010701) will therefore be closed down on July 1, 2007, whereas the registrations at Högmasten (PFM010700) will be operated as before, with the same monitoring parameters and the same recording intervals.

Data handling and processing

Unchecked data should be transferred to SKB's HMS database /12/ every four hours via FTP (File Transfer Protocol). The data logger at the station has internal memory to secure the data in case of communication disturbances.

Every week a primary check for missing and incorrect values is to be performed, and every 3-months quality assured data shall be delivered to SKB's HMS database for transfer by SKB to final storage in SKB's Sicada database. All quality checks should be documented in SKB's HMS-adjusted dairy.

In connection with the delivery of the quality assured data, corrected precipitation (according to Alexandersson, 2005, /13/) and potential evapotranspiration (from the Penman equation as described in detail by Eriksson, 1981, /14/) should be calculated and delivered to HMS for later storage in Sicada.

Documentation

Every three months, in connection with the delivery of quality assured data, a so called PIR-report shall be written, in which all quality checks are described, as well as the changes on raw data that these checks resulted in. HMS-adjusted diaries shall be delivered at the same time.

A P-report should be delivered annually in February (referring to Jan–Dec the previous year) according to the format specified by SKB. The P-report shall include all measurements and calculations, documented and presented in graphs of daily and monthly values. Annual means and sums should be calculated as well. The annual reports shall also include data from nearby SMHI stations, delivered in digital form in SKB's Excel table format. Nonconformities compared with the monitoring programme must be specified.

The first P-report should include the whole year of 2007.

4.6 Snow depth/water contents and ice cover/ice break-up monitoring

4.6.1 Background

During the site investigation, snow depth/water contents and ice cover/ice break-up have been measured at the stations shown in Figure 4-4. The measurements have been performed weekly during the winter season. The coordinates of the snow depth/water contents stations are given in Table 4-4. The planned monitoring programme, including data handling, processing and documentation, starting from the winter season of 2007/2008, is described below.

Figure 4-4. Locations of the snow depth/water contents measurement stations and the ice cover/ice break-up observation points.

Table 4-4. ID-code numbers and coordinates of the snow depth/water contents stations (coordinate system: RT 90 2.5 gon W 0:-15).

Parameter	ID-code	X	Y	Type of location
Snow				
Depth and water contents	AFM000071			Open field
	1	6697419	1634872	
	2	6697413	1634869	
	3	6697412	1634874	
	4	6697416	1634877	
Depth and water contents	AFM000072			Forest glade
	1	6698528	1631524	
	2	6698524	1631527	
	3	6698529	1631527	
	4	6698534	1631523	
Depth and water contents	AFM001172			Forest glade
	1	6699475	1633157	
	2	6699468	1633157	
	3	6699473	1633160	
	4	6699480	1633160	
Ice cover	AFM000010	6697230	1632050	Lake
	AFM000075	6701371	1632303	Sea bay

4.6.2 Monitoring programme

Field performance

The monitoring programme performed during the site investigation, as described in Section 4.6.1, will continue without any changes.

Data handling and processing

After every weekly measurements, data should be delivered to SKB in digital form in SKB's Excel table format for storage in Sicada.

Documentation

A P-report for the passed winter season should be delivered annually in May according to the format specified by SKB. In the report all measurements and calculations shall be documented and presented in graphs and tables, and nonconformities compared with the programme specified.

4.7 Hydrological monitoring

4.7.1 Background

During the site investigation, surface water levels have been measured at two locations in the Baltic Sea and in six lakes. At one of the sea locations (in Kallrigafjärden) and in one of the lakes (Lillfjärden) the measurement stations were destroyed by ice lifting and have not been replaced. The locations of the remaining six stations are shown in Figure 4-5, and the coordinates of the stations are listed in Table 4-5. Surface water levels are recorded every two hours and all gauges, with exception of PFM010038, are linked to HMS via GSM.

Figure 4-5. Locations of the surface water level gauging stations.

Table 4-5. Surface water level gauges included in the monitoring programme (coordinate system: RT 90 2.5 gon W 0:-15, RHB 70).

Borehole	X	Y	Z	Type
PFM010038*	6701375.07	1632560.63	2.55	The Baltic, Forsmark Harbour
SFM0039	6699867.01	1631751.42	1.40	Norra Bassängen
SFM0040	6698983.16	1632063.77	1.57	Bolundsfjärden
SFM0041	6697010.49	1631963.34	5.93	Eckarfjärden
SFM0042	6697598.02	1632696.42	1.53	Fiskarfjärden
SFM0064	6698491.57	1630718.38	2.80	Gällsboträsket

*Re-named from SFM0038.

Surface discharge, water electrical conductivity (EC) and water temperature are monitored at four locations, and at one station only EC is measured. The locations of the gauging stations and their catchment areas are shown in Figure 4-6, and the stations are listed in Table 4-6. A photo of the discharge gauging station PFM002667 is shown in Figure 4-7. With exception of discharge gauging station PFM002668, the monitoring is performed in one small and one large flume at all stations. The small flume is used for discharges up to 20 L/s and the large flume for discharges > 20 L/s.

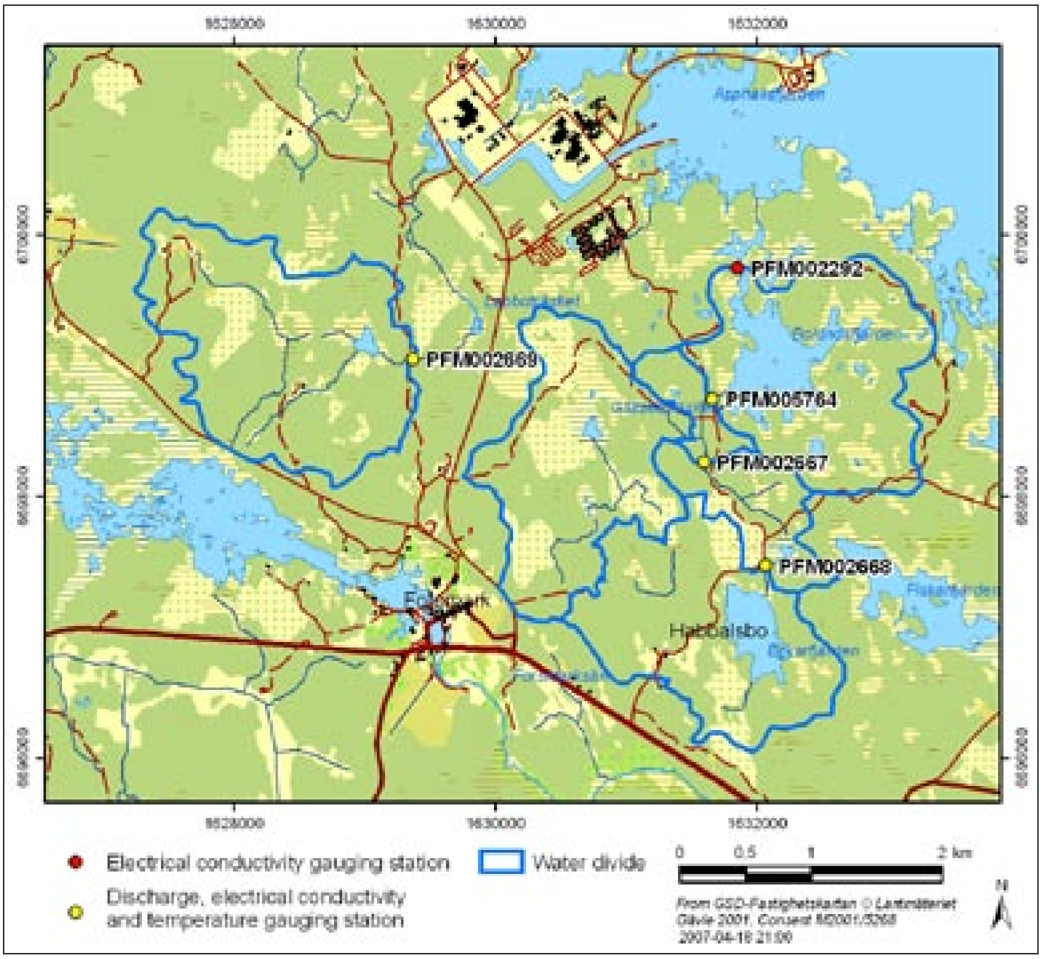


Figure 4-6. Locations of the surface water discharge gauging stations and the EC gauging station.

Figure 4-7. Discharge station PFM002667 with the large flume in the foreground, the small flume upstream in the background, and the service module to the left. The tube in the middle of the brook between the flumes is screened and used for installation of devices for measurement of electrical conductivity and temperature.

Table 4-6. Summary of surface water discharge gauging stations with associated catchment areas. All gauges are linked to HMS via GSM.

Gauging station	Catchment area (km^2)	Catchment id no.	Measured parameters
PFM005764	5.59	AFM001267	Level, discharge, EC and temp.
PFM002667	3.01	AFM001268	Level, discharge, EC and temp.
PFM002668	2.28	AFM001269	Level, discharge, EC and temp.
PFM002669	2.83	AFM001270	Level, discharge, EC and temp.
PFM002292	8.00	AFM000050	EC

Surface water levels are recorded in both flumes every 15 minutes. Also EC and temperature are recorded every 15 minutes. The water depths in the upstream end of the flumes are measured manually by a ruler at least once a month for calibration of the automatic recordings.

Exact positions of the flumes and equations for calculation of the discharge are given in Appendix 1.

The planned monitoring programme, including data handling, processing and documentation, starting from July 1, 2007, is described below.

4.7.2 Monitoring programme

Field performance

The monitoring programme carried out during the site investigation, as described in Section 4.7.1, will continue without any changes.

Data handling and processing

The level, EC, and temperature data are, and will in the continued programme, be automatically transferred to HMS. Manual soundings of the water depths in the flumes should be performed monthly. Every three months the data shall be quality checked, and if necessary the automatic recordings be adjusted based on the manual soundings. After the quality check, data shall be transferred to SKB's Sicada database.

For the calculation of discharge, the level data from the discharge gauging stations are imported from the Sicada database. An additional data screening is performed including comparisons of the results from the small and large flumes as well as between the different gauging stations. If necessary, data considered as likely erroneous should be excluded in the discharge calculations. After calculation, discharge data should be delivered to Sicada. Level data excluded in the calculations are specified as "Comments" in Sicada. The discharge calculations are performed by SKB.

Documentation

The surface water level monitoring from the Baltic Sea and the lakes should be documented in PIR-reports every three months and in annual P-reports (Jan–Dec) together with all groundwater levels from monitoring in Quaternary deposits and bedrock, see Sections 4.8 and 4.9. In the PIR-reports all quality checks should be described as well as the changes on raw data that these checks resulted in. The PIR-reports should be in the format specified by SKB. All measurements shall be documented and presented in graphs, and nonconformities compared with the programme are to be specified.

Separate annual P-reports (Jan–Dec) should be written for the surface water discharge gauging stations including water level, discharge, EC, and temperature measurements. The P-reports should be in the format specified by SKB. All measurements shall be documented and presented in graphs and nonconformities compared with the programme specified.

4.8 Groundwater level monitoring in Quaternary deposits

Hydrogeological monitoring serves as a basis for describing groundwater levels as well as flow distribution and variations with time of these parameters in the Quaternary deposits and in the rock mass. The natural groundwater level variations prior to a possible future construction of a deep repository are measured, but the monitoring equipment is also used to register pressure responses during single-hole pumping tests and interference tests. At a later stage, the monitoring system may also be used to measure pressure responses during tunnelling for the deep repository at the prioritized site. This section presents groundwater monitoring in the Quaternary deposits, i.e. in the soil layers, by the use of monitoring equipment installed in boreholes penetrating the soil layer and supplied with screened groundwater stand-pipes.

The monitoring equipment for boreholes in till and sand consists of a pressure transducer connected to a data logger, which may be linked to the HMS-system either via GSM or be a stand-alone unit. Boreholes driven into very low-transmissive deposits like clay are instead supplied with a so called BAT-type filter tip used for pore pressure measurements. So far, the latter measurements have been manually operated.

Groundwater level monitoring in the rock mass in percussion- and core-drilled boreholes is presented in Section 4.9.

4.8.1 Background

At present (June, 2007) groundwater levels are monitored in 43 wells in Quaternary deposits. The locations of the monitoring wells are shown in Figure 4-8 and the wells are listed in Appendix 2.

Groundwater levels are recorded every two hours. 18 of the 43 monitoring wells are linked to HMS via GSM, whereas the others have stand-alone loggers.

Since spring 2006 pore pressure is measured in seven BAT-type filter tips. The locations of the filter tips are shown in Figure 4-9 and the filter tips are listed together with the groundwater monitoring wells in Appendix 2. A drawing of a BAT-type filter tip is displayed in Figure 4-10. The seven BAT-type filter tips for pore pressure measurements belong, together with seven BAT-type filter tips for groundwater sampling, see Section 4.10, to the special GBIZ investigation (Geosphere Biosphere Interface Zone, a special programme designed to investigate the properties of this potentially important interface). The filter tips for pore pressure measurements and those for hydrochemical sampling are situated two by two quite close to each other.

Until the end of June 2007, manual pore pressure measurements will be performed once per month, whereas hydrochemical sampling in the nearby BAT-type filter tips is made only once per three months (Section 4.10).

Below, the planned monitoring programme, including data handling, processing and documentation, starting from July 1, 2007, is described.

Figure 4-8. *Locations of groundwater monitoring wells in Quaternary deposits (wells monitored in June 2007).*

Figure 4-9. Locations of the BAT-type filter tips included in the monitoring programme of pore pressure.

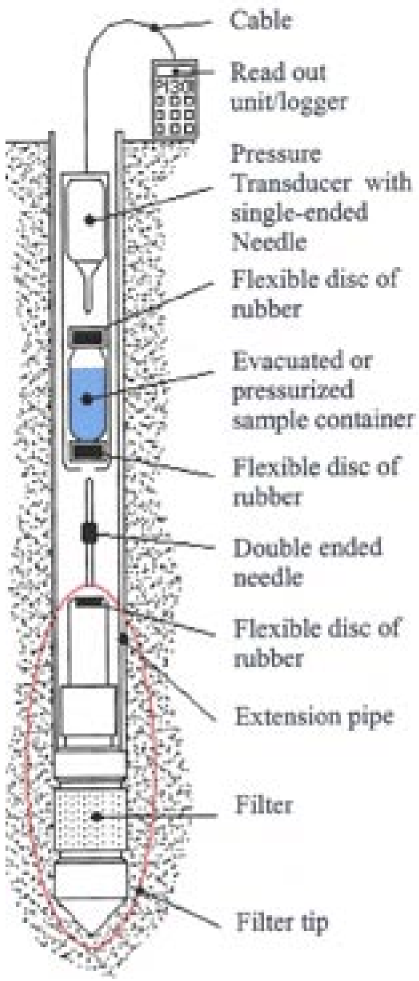


Figure 4-10. *GeoN BAT-type permeameter equipment.*

4.8.2 Monitoring programme

Field performance

The present monitoring programme for groundwater levels in Quaternary deposits, as specified above, should be continued without any changes.

In the case a monitoring equipment breaks down, it shall be replaced, if it does not belong to the low-priority monitoring wells listed in Table 4-7. The principles for classifying a monitoring well as low-prioritized are described in Section 4.9.2. Monitoring equipment from the low-priority wells may be used to replace malfunctioning equipment in other wells in the order listed in Table 4-7. SKB's Activity Leader must be contacted if malfunctioning equipment needs to be replaced.

Table 4-7. Low-priority groundwater monitoring wells. Malfunctioning equipment from these wells needs not be replaced and well-functioning equipment should be used to replace failing equipment in other groundwater monitoring wells in Quaternary deposits. For the latter purpose the equipment should be used in ascending order.

Order for replacement station	Well Id.
1	SFM0065
2	SFM0017
3	SFM0006
4	SFM0008

From July 2007, the manual pore pressure measurements in the seven BAT-type filter tips shown in Figure 4-9 should be carried out monthly until June 2008. SKB will then make an evaluation of the collected data and decide whether to terminate the measurements or to continue. If the measurements are to be continued, installation of automatic recording devices will be considered.

Data handling and processing

The groundwater levels from the monitoring wells are at present, and will in the future be, automatically transferred to SKB's HMS database. Manual sounding of the levels should be performed monthly. Every three months the data shall be quality checked, and if necessary the automatic recordings are adjusted based on the manual soundings. After the quality check, data shall be transferred to SKB's Sicada database.

The results of the manual pore pressure measurements should be delivered to SKB in digital form in SKB's Excel table format after every measurement for storage in Sicada.

Documentation

The groundwater levels should be documented in PIR-reports every three months and in annual P-reports (Jan–Dec) together with surface water levels in the Baltic Sea and in monitored lakes, see Section 4.7.2, as well as all groundwater levels from the monitoring in the bedrock wells, see Section 4.9. All quality checks are described in the PIR-reports together with the changes on raw data that these checks resulted in. The P-reports should be in the format specified by SKB, and all measurements shall be documented and presented in graphs, and nonconformities compared with the programme shall be specified.

In connection with the evaluation of the pore pressure measurements in June 2008, a report documenting all measurements performed so far will be written by SKB, in compliance with SKB's P-report format. All measurements and calculations should be documented in the report and presented in graphs and tables, and nonconformities compared with the programme shall be specified.

4.9 Groundwater level monitoring in bedrock

As mentioned in Section 4.8, hydrogeological monitoring is a platform for describing groundwater levels (from which the groundwater head may be calculated) and thereby, indirectly, flow distribution and flow variations with time in the soil layers and in the underlying crystalline bedrock. This section presents groundwater level monitoring in bedrock by the use of monitoring equipment installed in percussion drilled and core drilled boreholes.

4.9.1 Background

Monitoring may be performed in an open borehole supplied with a pressure transducer and a logger. However, deep boreholes in crystalline rock penetrate fractures at different levels in the rock mass, and an open borehole constitutes a short-circuited connection between these fracture systems. In order to permit groundwater level monitoring of fractures at different depths, borehole equipment which serves to isolate the respective fracture systems from each other has to be installed, thereby preventing an uncontrolled mixing of groundwater from different levels, possibly with different hydraulic head and hydrochemical composition.

The preparations made to enable monitoring in isolated sections in deep core drilled or percussion drilled boreholes at SKB's investigation sites involve sectioning off the boreholes by means of a single packer or a straddle packer system with hydraulically expandable rubber packers, so that the groundwater level can be measured in each section, see Figure 4-11. With the SKB pressure monitoring system, the diameter in Ø 76 mm cored boreholes is large enough to permit

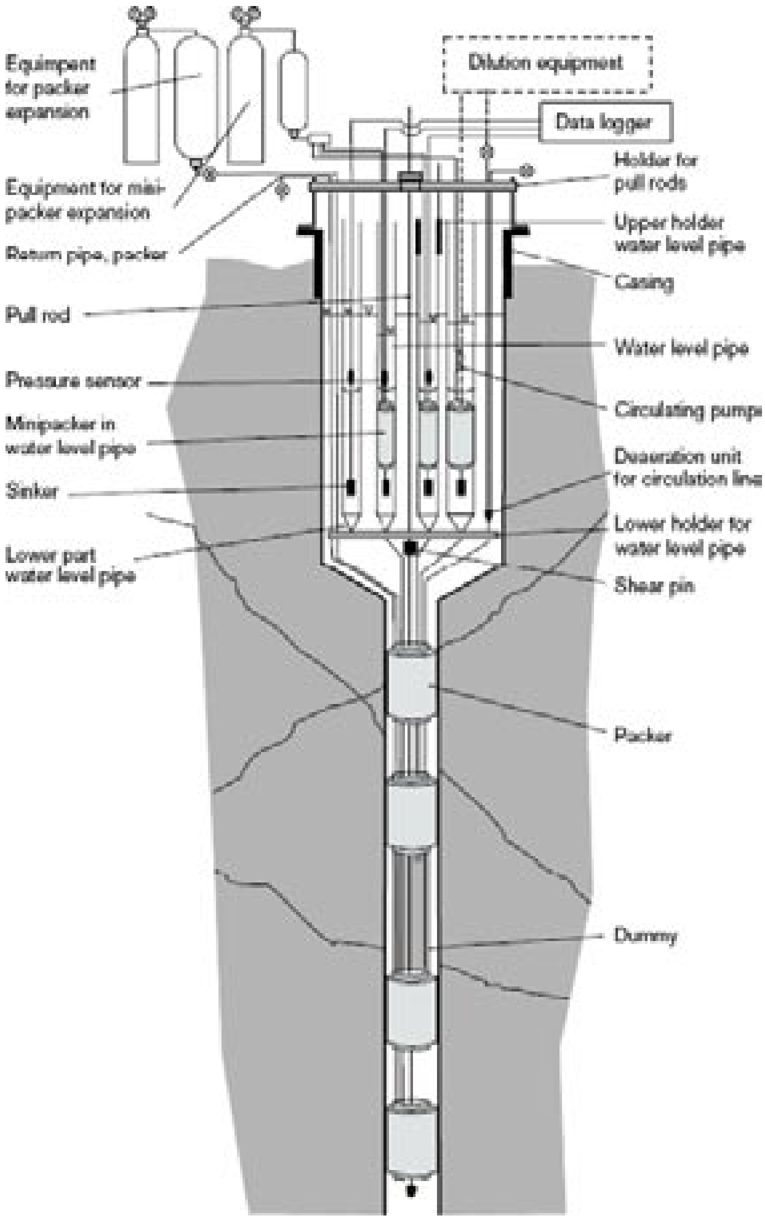


Figure 4-11. *Principle of the SKB system for monitoring of groundwater levels in sectioned boreholes.*

isolation of up to ten sections for pressure monitoring, but the number of sections in boreholes with only a few hydraulically conductive fractures and fracture zones may be considerably less. A thin plastic tubing connects each borehole section with another tubing of larger diameter in the upper part of the borehole, which in most cored boreholes at Forsmark is enlarged to Ø 200 mm to provide more space for *in-the-hole* equipment (so called telescopic boreholes). Mini-packers installed in the larger tubings ensure rapid responses when pressure changes occur in the respective borehole sections. A pressure sensor above the mini-packer registers the groundwater pressure in each section, and the pressure is converted to groundwater level. Data are stored in the previously mentioned HMS system. Figure 4-12 shows on-going installation of monitoring equipment in a core drilled borehole.

Two out of the ten pressure sections can be supplied with equipment for groundwater sampling (cf Section 4.10) and/or circulation of the groundwater in the section (cf Section 4.11). This is done by connecting two extra hoses and installing a portable pump (Figure 4-11). One of the hoses opens at the bottom of the section and the other at the top. With the water circulation equipment the flow through the packed-off section may be determined by adding a tracer and measuring its dilution with time. The circulation sections also provide tracer injection points or sampling points to be used in cross-hole tracer tests. After completed installations, the borehole collar housing is provided by a container, which serves to protect the above ground equipment from wind and weather as well as from sabotage and other kinds of damage, see Figure 4-13.

Figure 4-12. *Installation of equipment for groundwater level monitoring in a core drilled borehole.*

Figure 4-13. *Interior of container used as borehole collar shelter after installation of groundwater level monitoring equipment in a core drilled borehole of telescopic type.*

In percussion boreholes, which at Forsmark have a diameter of 140 mm, the SKB monitoring system permits the use of up to three packers, which means that groundwater pressure (re-calculated to levels) can be measured in four sections, one of which can also be a equipped to function as a circulation section. The pressure registration and data storage follow the same principles as for core drilled boreholes. The housing used for percussion drilled boreholes is shown in Figure 4-14.

Figure 4-15 presents the positions of all cored boreholes drilled during the site investigations (except a number of very short boreholes drilled for special purposes). The displayed holes are all included, or are planned to be included, in the monitoring programme. Figure 4-16 shows a corresponding map for all monitored percussion boreholes, which comprise all boreholes except HFM06 and two holes drilled for special objectives. (Regarding priority classes in the figures, see Section 4.9.2).

Installation of monitoring equipment has been successively carried out as new boreholes have been produced during the site investigation. The last installations will not be completed until shortly after the end of the site investigations. Table 4-8 presents the boreholes included in the current monitoring programme (June 2007) as well as those intended to be supplied with monitoring equipment just before or shortly after July 2007. The table includes the same

Figure 4-14. *Interior of two housings used as borehole collar shelters after installation of groundwater level monitoring equipment in percussion drilled boreholes.*

boreholes as those displayed on the maps in Figures 4-15 and 4-16, i.e. all cored and nearly all percussion boreholes (HFM06 not monitored) drilled during the site investigations, except the above mentioned boreholes drilled for special purposes. Figure 4-17 presents a graph showing the period during which the individual boreholes have been monitored during the site investigations.

When the installation work is completed, all cored boreholes and most (about 2/3) of the percussion boreholes will be supplied with single packer or straddle packer installations. About 1/3 of the percussion drilled boreholes will only be supplied with a pressure sensor and a logger, i.e. each borehole will be monitored as one single borehole section covering the entire borehole length.

4.9.2 Monitoring programme

Field performance

The groundwater level monitoring programme for the post site investigation period July 2007 to 2009 is to be performed in all core- and percussion drilled boreholes currently being monitored. Furthermore, monitoring equipment will be installed in a number of boreholes during the summer and early autumn 2007, and also these recently drilled boreholes will be included in the monitoring programme, totally 62 boreholes and 223 borehole sections, see Table 4-8. However, the boreholes are classified in priority categories. Figure 4-15 shows a map with the core drilled boreholes grouped into two priority classes, whereas Figure 4-16 displays a corresponding map for the percussion drilled boreholes with a subdivision into five categories.

Figure 4-15. Map showing all 25 cored drilled boreholes within the Forsmark site investigation area which are already included in the current monitoring programme or will be included prior to or just after completion of the site investigations.

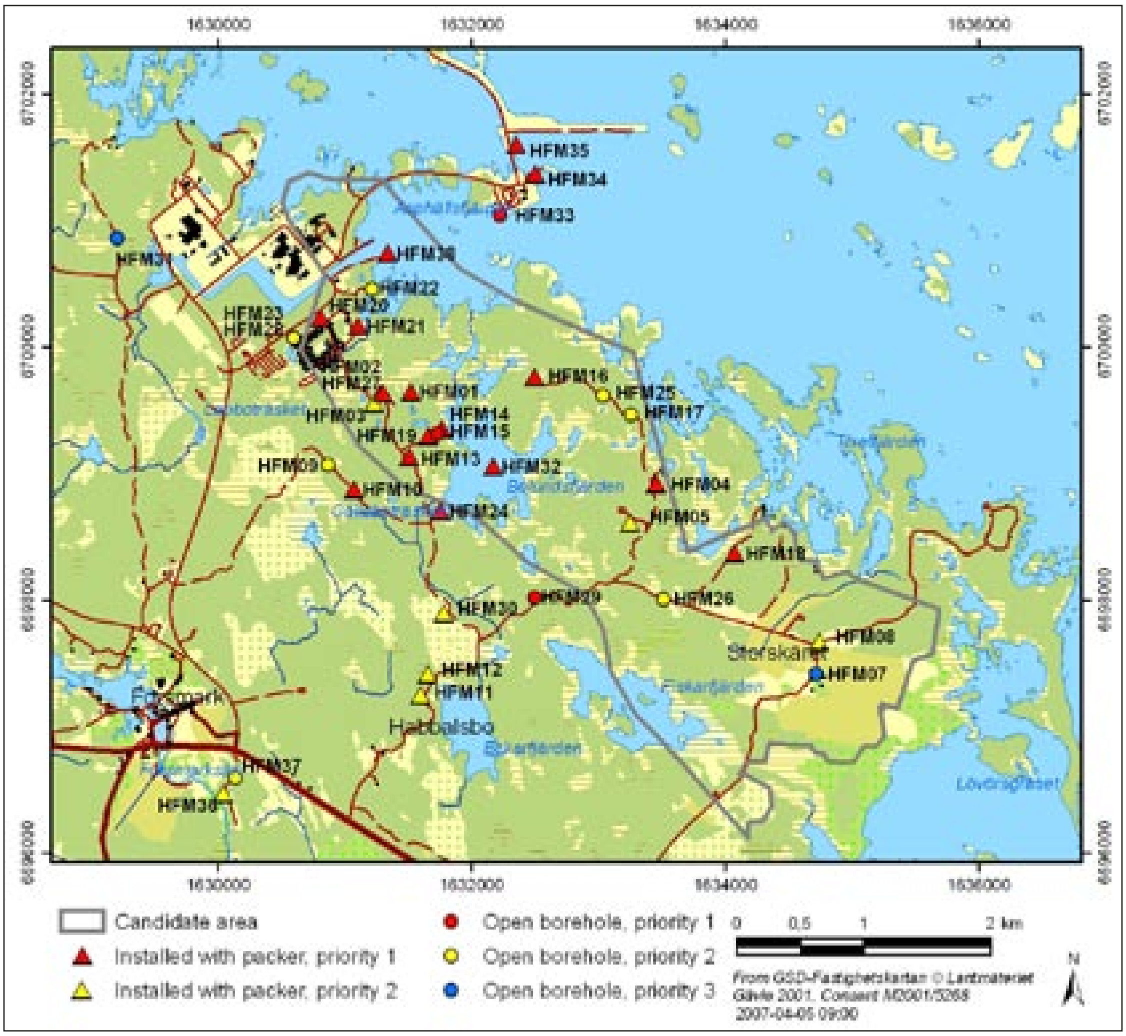


Figure 4-16. Map showing all 37 percussion drilled boreholes within the Forsmark site investigation area included in the current monitoring programme. The only percussion boreholes excluded from monitoring are HFM06 and two boreholes drilled for special purposes.

Table 4-8. Core- and percussion drilled boreholes currently monitored as well as those intended to be supplied with monitoring equipment prior to or shortly after completion of the site investigations in June 2007. The latter are labelled with grey colour. For all boreholes currently monitored, the number and type of monitored borehole sections are presented. Circulations sections enable monitoring of the groundwater level and the groundwater flow and also permit groundwater sampling. In Appendix 3 the monitored sections are presented as regards position in the borehole (borehole length).

Borehole, core drilled (K) percussion drilled (H)	Coordinates (coordinate system: RT 90 2.5 gon W 0:-15, RHB 70) Northing	Easting	Number of monitored sections; Pressure monitoring (p), Circulation section (c)
KFM01A	6699530	1631397	6 p 1 p, c
KFM01B	6699539	1631388	3 p
KFM01C	6699524	1631404	3 p
KFM01D	6699542	1631405	5 p 2 p, c
KFM02A	6698713	1633183	6 p 2 p, c

KFM02B	6698719	1633186	5 p 2 p, c
KFM03A	6697852	1634631	6 p 2 p, c
KFM03B	6697844	1634619	2 p
KFM04A	6698922	1630979	6 p 1 p, c
KFM05A	6699345	1631711	5 p 1 p, c
KFM06A	6699733	1632443	6 p 2 p, c
KFM06B	6699732	1632446	3 p
KFM06C	6699741	1632437	8 p 2 p, c
KFM07A	6700127	1631032	5 p 1 p, c
KFM07B	6700124	1631037	3 p
KFM07C	6700126	1631034	4 p
KFM08A	6700494	1631197	7 p 2 p, c
KFM08B	6700493	1631173	3 p
KFM08C	6700496	1631188	5 p
KFM08D	6700492	1631199	5 p 2 p, c
KFM09A	6700115	1630647	3 p
KFM09B	6700120	1630639	3 p
KFM010A	6698629	1631716	4 p 1 p, c
KFM011A	6701104	1632367	5 p 2 p, c
KFM012A	6696577	1630052	4 p 1 p, c
HFM01	6699605	1631485	2 p 1 p, c
HFM02	6699593	1631269	2 p 1 p, c
HFM03	6699593	1631273	2 p
HFM04	6698879	1633421	2 p 1 p, c
HFM05	6698647	1633290	2 p
HFM07	6697416	1634716	1 p (open borehole)
HFM08	6697703	1634778	2 p
HFM09	6699065	1630869	1 p (open borehole)
HFM10	6698835	1631037	2 p
HFM11	6697283	1631636	2 p
HFM12	6697446	1631696	2 p
HFM13	6699094	1631474	2 p 1 p, c
HFM14	6699313	1631735	1 p (open borehole)
HFM15	6699312	1631733	1 p 1 p, c
HFM16	6699721	1632466	2 p 1 p, c
HFM17	6699462	1633261	1 p (open borehole)
HFM18	6698327	1634037	3 p

HFM19	6699258	1631627	2 p 1 p, c
HFM20	6700187	1630777	4 p
HFM21	6700126	1631074	4 p
HFM22	6700456	1631218	1 p (open borehole)
HFM23	6700068	1630595	1 p (open borehole)
HFM24	6698662	1631720	3 p
HFM25	6699616	1633039	1 p (open borehole)
HFM26	6698009	1633516	1 p (open borehole)
HFM27	6699595	1631246	3 p 1 p, c
HFM28	6700069	1630597	1 p (open borehole)
HFM29	6698019	1632503	1 p (open borehole)
HFM30	6697932	1631820	4 p
HFM31	6700860	1629207	1 p (open borehole)
HFM32	6699015	1632137	3 p 1 p, c
HFM33	6701043	1632223	1 p (open borehole)
HFM34	6701325	1632470	3 p
HFM35	6701556	1632321	4 p
HFM36	6696504	1630082	3 p
HFM37	6696592	1630137	1 p (open borehole)
HFM38	6700701	1631302	3 p

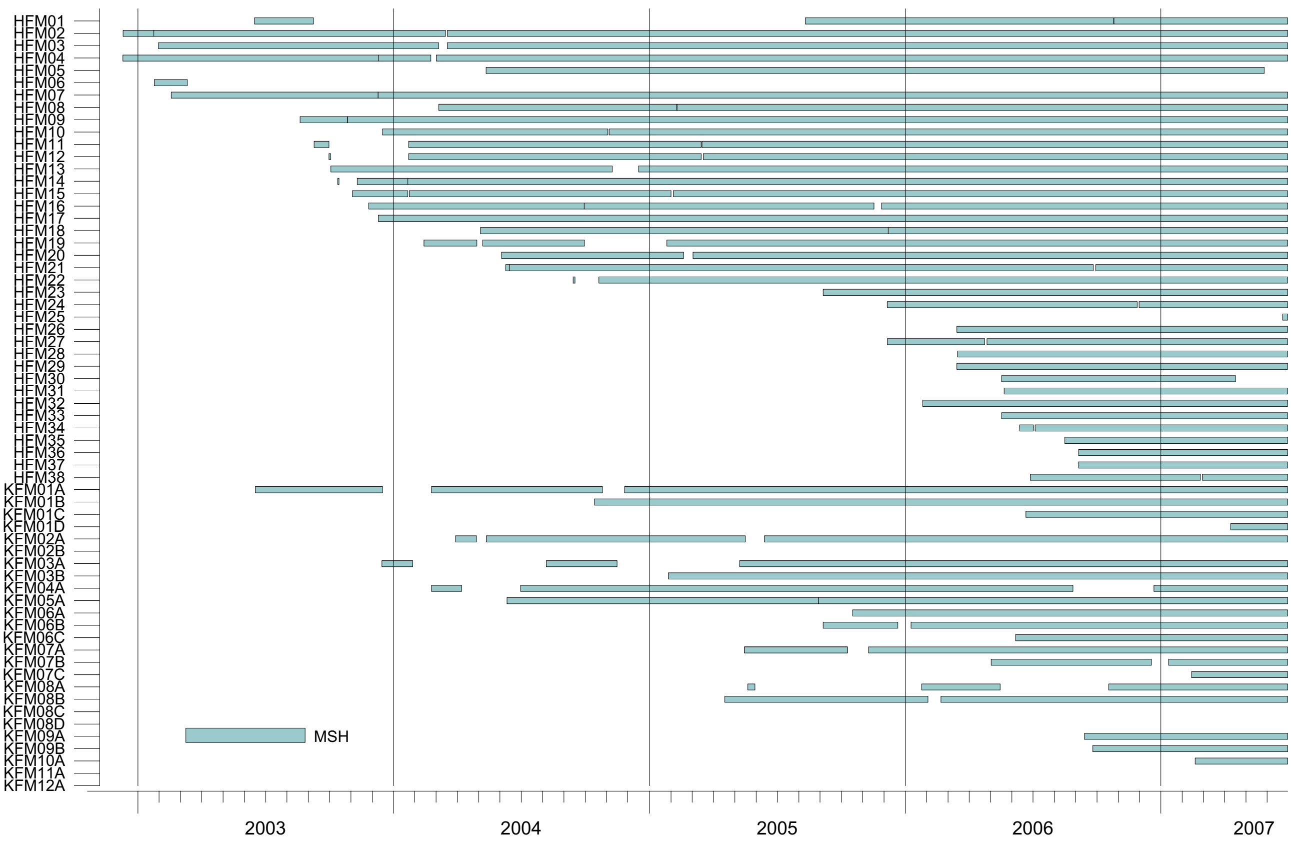


Figure 4-17. Graph showing the periods during which groundwater level monitoring has been on-going during the site investigations.

The priority classification, which has been established on the basis of the experiences from the monitoring carried out so far (for example regarding which monitored boreholes that are most critical during interference tests as well as during non-disturbed conditions), aims at providing guidance in decision-making when equipment fails, about how urgent it is to repair the equipment and how large repair/re-installation costs that can be accepted, seen in relation to the scientific importance of that specific borehole. "Priority 1" indicates a borehole of the highest priority, which should be repaired, if broken, within a time period of a few days up to two weeks. "Priority 2" also indicates that equipment should be repaired, but allowing a longer delay (two weeks up to a month).

Boreholes labelled "Priority 3" (only percussion drilled boreholes) can be dismissed from the monitoring programme if the equipment fails. The equipment in these boreholes can also be used as spare parts for boreholes with a higher priority. The monitoring programme will carry on with the same intensity as during the site investigation. Groundwater levels (measured as pressure) will normally be monitored at the same interval as currently, which also includes "event logging", i.e. besides saving logged values at every two hours, values are saved also if the groundwater level changes more than 0.1 m between these occasions, see Table 4-9. The data sampling interval may though be changed for certain periods of time if needed, e.g. during complementary investigations, if any.

A correlation evaluation is performed after about one year of undisturbed data acquisition, to establish if any of the boreholes can be excluded in the programme. The strategy should then be to exclude boreholes which are obviously monitoring the same feature, thereby generating data sets with a high correlation.

Data handling and processing

The groundwater levels from both core- and percussion drilled boreholes will be automatically transferred on-line to SKB's HMS database. Manual level measurements should be performed monthly for calibration. Every three months the data are quality checked and, if necessary, the automatic recordings are adjusted based on the manual soundings. After the quality check, data shall be transferred to SKB's database Sicada four times a year.

Documentation

The groundwater levels should be documented in PIR-reports every three months and in annual P-reports. In the PIR-reports all quality checks shall be described as well as the changes on raw data that these checks resulted in. The P-reports, which also include results from monitoring of surface water levels in the Baltic Sea and in some lakes, see Section 4.7.2, as well as groundwater levels in Quaternary deposits, see Section 4.8.2, should be in the format specified by SKB, and all measurements shall be documented and presented in graphs, and nonconformities compared with the programme specified.

Table 4-9. Monitoring programme for hydrogeological pressure measurements.

Boreholes	Data sampling interval	Pressure difference criterium for extra data sampling	Interval of manual level measurements (for calibration use)	Rinse pumping of pressure transmitting hoses
Cored borehole, KFMxxx	2 h	0.1 m	1 month	1–2 year(s)
Percussion borehole, HFMxx	2 h	0.1 m	1 month	1–2 year(s)

4.10 Hydrochemical monitoring

4.10.1 Background

The hydrochemical monitoring programme includes sampling as well as field- and laboratory analyses of water samples collected from precipitation, surface waters, near surface groundwaters including private wells, and groundwaters from percussion- and core drilled boreholes. The sampling objects constitute two categories: water above bedrock and within bedrock. The first category of monitoring also includes determination of parameters for the surface ecosystem monitoring programme (see Section 4.12). The surface water monitoring has therefore been coordinated between the two programmes. The sampling locations, sampling frequency, and analytical protocol are described under two headings for waters above and within bedrock, respectively, in the following text. As the investigation procedure is very much the same, independently of type of sampling object, the monitoring field programme, analytical work, data delivery and reporting are described together for the different objects, in the same sections of this report.

Water above the bedrock

Water above the bedrock includes precipitation, surface waters and near surface groundwaters.

Samples from precipitation have been collected and analysed since the autumn 2002 as part of the site investigations. The performance and results have been documented in /15/.

From the start of the site investigation, comprehensive chemical investigation campaigns for surface waters and near surface waters (from soil pipes, some supplied with a BAT-type filter tip) were conducted for two years /16, 17, 18/. This was followed by less extensive long-term monitoring programmes regarding surface waters and near surface waters (including three private wells), that were initiated as parts of the site investigations in July 2004 and July 2005, respectively /19, 20, 21/.

The sampling objects and the sampling frequencies for the long-term monitoring (after the two initial years) are listed in Table 4-10, and the extent of the analytical protocol is given in Table 4-11. Besides sampling, the fieldwork includes measurements of chemical and physical parameters in the field (Table 4-11). These measurements are performed in a depth profile for each sea and lake location (at 0.5 m, 1.0 m, 2.0 m etc). The measurements in streams are conducted at one depth only, and near surface groundwaters are pumped through a simple measurement cell, where the measurements take place.

The position of precipitation collectors as well as sampling locations for surface waters are presented in Figure 4-18, whereas Figure 4-19 is a photo showing surface water sampling. The locations of the soil pipes, BAT-pipes and private wells (near surface groundwaters) are given in Figure 4-20. Twelve of the soil pipes (seven of them equipped with BAT-type filter tips) belong to the special GBIZ investigation, cf Section 4.8.1. As shown in Table 4-10, only one BAT-type filter tip, no. SFM0051, does not belong to the GBIZ programme. Figure 4-21 is a photo showing sampling of shallow groundwater in soil pipes.

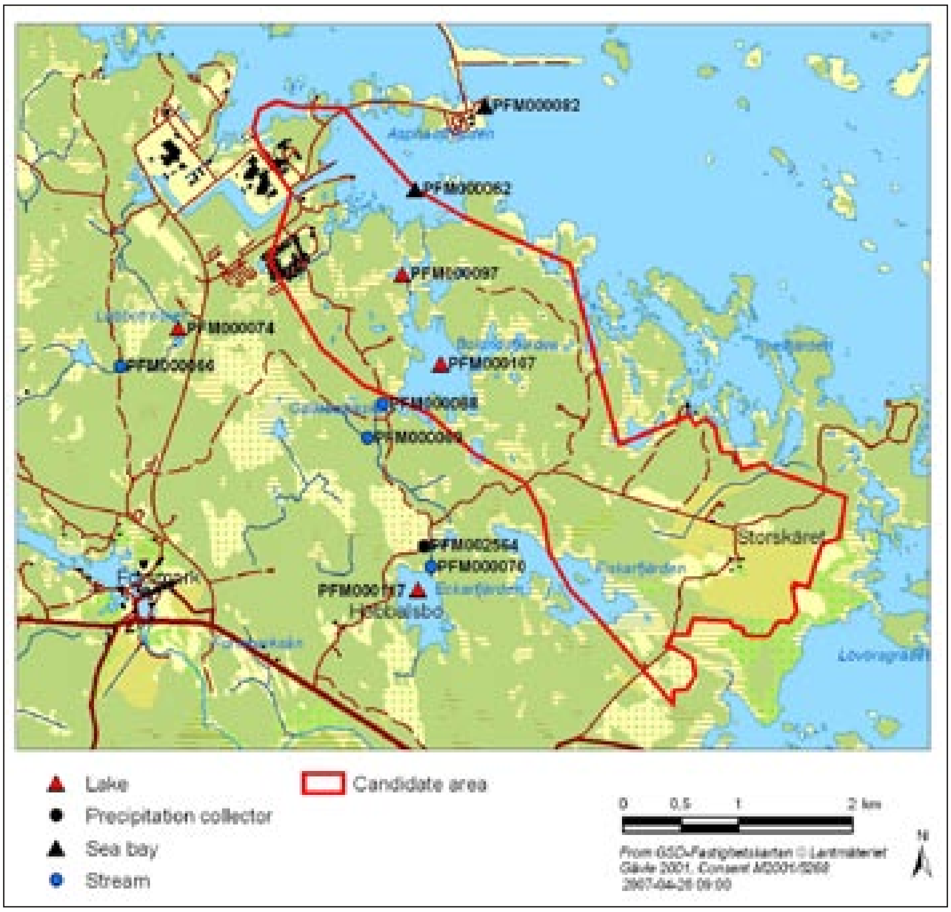


Figure 4-18. Positions of precipitation collector as well as sampling points for surface waters. Point PFM102269, at Lake Biotestsjön about 3 km north of PFM000082, which is sampled only for tritium determinations, is not included in the map.

Figure 4-19. Surface water sampling at Forsmark.

Figure 4-20. Locations of soil pipes, pipes supplied with BAT-type filter tips, and private wells. Objects belonging to the GEBIZ-programme (see explanation in Table 4-10) are shown as red and purple in filled triangles and circles, respectively.

Figure 4-21. Sampling of shallow groundwater in soil pipes driven into sediments below the surface water table in a wetland at Forsmark.

Table 4-10. Sampling objects and sampling frequency for precipitation, surface waters and near surface groundwaters (Id-codes, coordinates, comments and sampling occasions per year).

Sampling objects	Coordinate system: RT 90 2.5 gon W 0:-15)	Comments	Sampling occasions/year
Precipitation			
PFM002564	1632002, 6697501	Will continue at least until June 2008	6
Lakes			
PFM000074	1629854, 6699393	Labboträsket	12
PFM000097*	1631814, 6699868	Norra bassängen	12
PFM000107	1632065, 6699031	Bolundsfjärden	12
PFM000117	1631946, 6697118	Eckarfjärden	12
Sea bays			
PFM000062	1631921, 6700605	SV Forslingens grund	12
PFM000082	1632528, 6701336	Alternative to PFM000062	
PFM102269	1631405, 6704412	Lake Biotestsjön, Only tritium	12
Streams			
PFM000066	1629343, 6699064	Öster Gunnarsboträsket	12
PFM000068	1631641, 6698735	Kungsträsket	12
PFM000069	1631510, 6698440	Bolundsskogen	12
PFM000070	1632061, 6697319	Norr Eckarfjärden	12
Near surface groundwaters			
SFM0001	1631335, 6699713	Borrplats 1 (BP1)	4
SFM0023**	1632064, 6698983	Pipe in sediment (Bolundsfjärden)	4 (not Fe, Mn etc)
SFM0032	1631726, 6698838	Doublet pipe for chemistry	4
SFM0037	1631744, 6699992	Doublet pipe for chemistry	4
SFM0049	1630533, 6700028	Doublet pipe for chemistry	4
SFM0051	1631488, 6699600	BAT-type filter tip, DS1	4
SFM0081**	1632093, 6698999	GEBIZ, (until April 2008)	4 (not Fe, Mn etc)
SFM0084**	1632406, 6699868	GEBIZ, (until April 2008)	4 (not Fe, Mn etc)
SFM0087	1632406, 6699868	GEBIZ, (until April 2008)	4
SFM0091**	1631490, 6699745	GEBIZ, (until April 2008)	4 (not Fe, Mn etc)
SFM0095	1630437, 6698015	GEBIZ, (until April 2008)	4
SFM0083	1632093, 6699000	GEBIZ, BAT-type filter tip, (until April 2008)	4
SFM0086***	1632406, 6699869	GEBIZ, BAT-type filter tip, (until April 2008)	4
SFM0089***	1632406, 6699868	GEBIZ, BAT-type filter tip, (until April 2008)	4
SFM0093***	1631490, 6699745	GEBIZ, BAT-type filter tip, (until April 2008)	4
SFM0097***	1630438, 6698015	GEBIZ, BAT-type filter tip, (until April 2008)	4
SFM0100***	1630437, 6698015	GEBIZ, BAT-type filter tip, (until April 2008)	4
SFM0102	1630438, 6698015	GEBIZ, BAT-type filter tip, (until April 2008)	4
Private wells			
PFM000001	1634709, 6697373		1
PFM000009	1634724, 6698227		1
PFM006382	1634249, 6698691		1

* Only sonde measurements.
** Pipe made of iron (not stainless steel).
*** Sampling is difficult, very time consuming, and of limited scientific value. Object may be omitted.
**** GEBIZ = Geosphere Biosphere Interface Zone.

Table 4-11. Extent of laboratory analyses and field measurements of water sampled above the bedrock.

Extent of analyses Constituents and measured variables	Determinations/year Precipit.	Lakes	Sea bays	Streams	N. surf. gw	Priv. wells
Major constituents (Na, K, Ca, Mg, HCO_3, Cl, SO_4, SO_4_S, Si, Br, F, Li, Sr, pH_lab, EC_lab)	6	12	12	12	4	–
Surface water supplements (NO_3, NO_2+NO_3, PO_4, NH_4, colour*, TOC, DOC, POC*, PON* , POP*, Chlorofphyll a och c*, pheopigment*, Tot-N, Tot-P, SiO_4, suspended matter*)	–	12	12	12	4	–
Field measurements 1 (pH, ORP, EC, water temperature, dissolved oxygen)	–	12	12	12	4	–
Field measurements 2 (turbidity, chlorophyll, light)*	–	12	12	–	–	–
Fe, Mn, HS-, Environmental metals (Al, Zn, Ba, Cr, Mo, PB, Cd, Hg, Co, V, Cu, Ni, P, As) (excluded for SFM0023, SFM0081, SFM0084 and SFM0091)	–	4	4	–	2	–
Trace metals (La, Ce, Pr, Nd, Sm. Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, SC, In, Th, Rb, Zr, Sb, Cs, Tl, Y, Hf, U) (excluded for SFM0023, SFM0081, SFM0084 and SFM0091)	–	1	1	–	2	–
Isotopes 1 (^{3}H, δ^2H, δ^{18}O)	6	4	4	–	4	–
Isotopes 2 (δ^{37}Cl, δ^{13}C, ^{14}C (pmC), ^{10}B/^{11}B, ^{87}Sr/^{86}Sr, δ^{34}S, ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn)	–	1	1	–	1	–
Drinking water quality (E-coli, hardness etc)	–	–	–	–	–	1

*Only in surface waters.

Water within the bedrock

Water within the bedrock includes groundwater in percussion- and core drilled boreholes.

A monitoring programme for groundwater from percussion boreholes and core drilled boreholes has been running since 2005 as part of the site investigations, and the performance and results are documented in two P-reports /22, 23/. The monitored boreholes, see Figure 4-22, are equipped with straddle packers in order to isolate different borehole sections for long-term pressure monitoring, see Section 4.9.1. Some of these sections are so called circulation sections designed also for tracer tests, water sampling, and groundwater flow measurements (cf Sections 4.9.1 and 4.11). The boreholes and circulation sections included in the monitoring programme as well as their hydraulic transmissivities are listed in Table 4-12. See also Appendix 3.

The sampling is performed twice a year according to SKB class 5 and class 3 (see definition in /1/), respectively. The analytical protocol, which also includes field measurements of pH, EC, and water temperature, is given in Table 4-13. The field measurements are performed using separate field pH-meters and field EC-meters, see Figure 4-23.

Figure 4-22. Locations of percussion- (blue) and core drilled boreholes (red) included in the hydrochemical monitoring programme.

Figure 4-23. During the field measurements of pH, temperature and conductivity, water from the borehole is led through a measurement cell consisting of three plastic bottles.

Table 4-12. Boreholes and borehole sections currently included in the hydrochemical monitoring programme for percussion- and core drilled boreholes as well as boreholes and borehole sections planned to be supplied with monitoring equipment for groundwater sampling prior to or shortly after completion of the site investigations in June 2007. The latter are labelled with grey colour. Also the hydraulic transmissivity for each section is presented.

Bh section	Section (borehole length, m)	Transmissivity [m²/s]
KFM01A:5	109–130	1.0 E–7*
KFM01D:2	429–438	8.0 E–7*
KFM01D:4	311–321	2.0 E–7*
KFM02A:3	490–518	2.1 E–6*
KFM02A:5	411–442	2.5 E–6*
KFM02B:2	491–506	3.0 E–5*
KFM02B:4	410–431	2.0 E–5*
KFM03A:1	969.5–994.5	5.5 E–7*
KFM03A:4	633.5–650	2.4 E–6*
KFM04A:4	230–245	2.0 E–5*
KFM05A:4	254–272	1.4 E–8*
KFM06A:3	738–748	1.2 E–7*
KFM06A:5:	341–362	3.5 E–6*
KFM06C:3	647–666	5.3 E–8*
KFM06C:5	531–540	1.1 E–6*
KFM07A:2	962–972	5.0 E–7*
KFM08A:2	684–694	1.0 E–6*
KFM08A:6	265–280	1.0 E–6*
KFM08D:2	825–835	2.0 E–8*
KFM08D:4	660–680	2.0 E–7*
KFM10A:2	430–440	3.0 E–5*
KFM11A:2	690–710	1.0 E–6*
KFM11A:4	446–456	6.0 E–7*
KFM12A:x	270–280	1.0 E–6*
HFM01:2	33.5–45.5	4.0 E–5**
HFM02:2	38–48	5.9 E–4**
HFM04:2	58–66	7.9 E–5**
HFM13:1	159–173	2.9 E–4**
HFM15:1	85–95	1.0 E–4**
HFM16:2	54–67	3.5 E–4**
HFM19:1	168–182	2.7 E–4**
HFM21:3	22–32	4.0 E–5**
HFM27:2	46–58	4.0 E–5**
HFM32:3	26–31	2.3 E–4**

* From PSS (Pipe String System) and PFL (Posiva Flow Log) measurements.

** From HTHB (HydroTester HammarBorrhål) measurements.

Table 4-13. Extent of laboratory analyses and field measurements of water in the bedrock.

Class	Constituent/parameter	Laboratory
3, 5	pH_field, EC_field, temp	Field measurement
3, 5	pH_lab, EC_lab, 25 ºC	MFL*
3, 5	HCO_3 (alkalinity)	MFL*
3, 5	Uranine (KFM-boreholes)	MFL*
3, 5	Cl^-, SO_4^{2-}, Br^-, F^-	Äspö
3, 5	Na, K, Ca, Mg, SO_4, S, Si, Li, Sr	External
3, 5	δ^2H, $\delta^{18}O$, ^3H	External
5	Fe(+II), Fe(tot)	MFL
5	HS^-	Äspö
5	NH_4	MFL
5	NH_4, NO_2, NO_3, NO_2+NO_3, PO_4	External
5	DOC, TOC	External
5	Br, I	External
5	Fe, Mn, Trace metals (Al, Zn, Ba, Cr, Mo, PB, Cd, Hg, Co, V, Cu, Ni, P, As, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, SC, In, Th, Rb, Zr, Sb, Cs, Tl, Y, Hf and U)	External
5	Isotopes 2 ($\delta^{37}Cl$, $\delta^{13}C$, ^{14}C (pmC), $^{10}B/^{11}B$, $^{87}Sr/^{86}Sr$, $\delta^{34}S$, ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn)	External

* MFL = Mobile Field Laboratory.

4.10.2 Monitoring programme

Field performance

Sampling and analyses of precipitation will be included in the monitoring programme after the site investigations for at least one more year (to June 2008) using a new collector for rain and snow, see Figure 4-24, otherwise according to the programme described in Section 4.10.1. After that an evaluation will be made, which leads up to a decision whether the monitoring shall be further continued or terminated.

The performance and extent of sampling and analyses of surface waters and near surface waters (from soil pipes, some supplied with a BAT-type filter tip, and private wells) in the monitoring phase after June 2007 is planned to continue unchanged from the programme that has been applied during 2004, 2005, and 2006. However, twelve of the soil pipes (seven of them equipped with BAT-type filter tips) belong to the special GBIZ investigation that was included in the current programme as late as 2006. Sampling in these boreholes will continue until April 2008, after which SKB will evaluate the collected data and decide if the measurements shall continue or be terminated. If they are completed, sampling point no. SFM0051 will be the only remaining BAT-type filter tip for which the hydrochemical monitoring continues.

Regarding monitoring in percussion- and core drilled boreholes, the sampling methods and extent of analyses will remain unchanged in the coming monitoring phase after June 2007. However, the number of isolated borehole sections to be sampled will increase when all borehole installations are completed, cf Chapter 2, Section 4.9.2 and Table 4-12. One of SKB's mobile field laboratories, see Figure 4-25, is to be used for analyses.

The execution of the monitoring programme involves the sub-operations listed in Table 4-14 and encompasses both field work and laboratory work. It is necessary that the laboratory personnel is approved according to the accreditation by Swedac.

Figure 4-24. *Sample collectors for precipitation (PFM002564), to the left for rain and to the right for snow. The construction prevents evaporation.*

Figure 4-25. *Indoor picture from the SKB mobile field laboratory. The laboratory is mainly used for time critical analyses (pH, EC, alkalinity, Fe(tot), Fe(+II) and ammonium) and for certain treatment/preservation of water samples.*

Table 4-14. Hydrochemical monitoring programme for groundwater sampled in percussion- and core drilled boreholes. Sub-operations and distribution of work.

Sub-operation	Field staff	Field staff or laboratory personnel	Laboratory personnel
Preparation and packing of sample bottles, filters etc		X	
Calibration of sonde or field pH-meter and field EC-meter	X		
Clean-up pumping in order to exchange the water in the system 3 to 5 times (soil pipes and borehole sections)	X		
Sampling (including possible filtering and conservation according to method descriptions)	X		
Field measurements (multi-parameter sonde or field pH-meter and field EC-meter)	X		
Package and sending of samples to consulted laboratories		X	
Storage of archive samples in freeze container		X	
Analyses of Fe(+II) and Fe(tot), alkalinity, lab-pH, lab-EC and NH_4 in mobile field laboratory			X
Contact with consulted laboratories			X
Data deliveries, see text below	X	X	
Data storage, see text below			X*
Reporting, see text below	X		

* Only analytical results.

Data handling and processing

Analytical results from the field laboratory and from external laboratories are transferred to Sicada by the person responsible for the mobile field laboratory, whereas results from the Äspö chemical laboratory are transferred by SKB personnel at the latter laboratory.

Documentation

The sampling and analyses of 1) precipitation, 2) surface waters, 3) near surface groundwaters including groundwater from private wells and 4) groundwater sampled from percussion- and core drilled boreholes are documented yearly in four free-standing parts that are compiled to one P-report before printing. The P-report should be in the format specified by SKB. All measurements shall be documented, and nonconformities compared with the programme specified.

4.11 Groundwater flow

4.11.1 Background

The monitoring programme for groundwater flow in boreholes is closely linked to the programme for groundwater sampling in core- and percussion drilled boreholes. The two activities include the same borehole sections and partly the same equipment is used. Shortly after the end of the site investigation 34 borehole sections in 25 boreholes will be equipped for groundwater flow measurements, see Figure 4-26, Table 4-15, and Appendix 3.

Measurements within the current monitoring programme, using the tracer dilution technique, have been performed once a year since November 2005, cf Table 4-15. A few borehole sections have also been measured in connection with hydraulic interference tests during the summers 2005 and 2006.

Table 4-15. Currently monitored borehole sections with respect to groundwater flow as well as boreholes and borehole sections planned to be supplied with monitoring equipment for groundwater flow measurements (circulation sections) prior to or shortly after completion of the site investigations (labelled with grey colour). The measured transmissivity value in each section as well as results from flow measurements performed so far are also shown.

Borehole:sec	Depth (m)	T (m^2/s)	Jun–Jul 2005 /24/ (ml/min)	Nov–Dec 2005 /25/ (ml/min)	Jun–Jul 2006 /26/ (ml/min)	Nov 2006 /27/ (ml/min)
KFM01A:5	109–130	1.0 E–7*	0.3	–	–	0.1
KFM01D:2	429–438	8.0 E–7*	–	–	–	–
KFM01D:4	311–321	2.0 E–7*	–	–	–	–
KFM02A:3	490–518	2.1 E–6*	–	2.1	2.0	0.8
KFM02A:5	411–442	2.5 E–6*	–	1.0	0.5	0.4
KFM02B:2	491–506	3.0 E–5*	–	–	–	–
KFM02B:4	410–431	2.0 E–5*	–	–	–	–
KFM03A:1	969.5–994.5	5.5 E–7*	–	1.7	–	–
KFM03A:4	633.5–650	2.4 E–6*	–	0.5	–	0.5
KFM04A:4	230–245	2.0 E–5*	–	–	–	–
KFM05A:4	254–272	1.4 E–8*	–	0.5	1.5	1.4
KFM06A:3	738–748	1.2 E–7*	–	0.3	0.8	0.6
KFM06A:5	341–362	3.5 E–6*	–	0.5	0.4	0.6
KFM06C:3	647–666	5.3 E–8*	–	–	–	0.4
KFM06C:5	531–540	1.1 E–6*	–	–	–	0.3
KFM07A:2	962–972	5.0 E–7*	–	–	–	–
KFM08A:2	684–694	1.0 E–6*	–	–	–	–
KFM08A:6	265–280	1.0 E–6*	–	–	–	–
KFM08D:2	825–835	2.0 E–8*	–	–	–	–
KFM08D:4	660–680	2.0 E–7*	–	–	–	–
KFM10A:2	430–440	3.0 E–5*	–	–	–	–
KFM11A:2	690–710	1.0 E–6*	–	–	–	–
KFM11A:4	446–456	6.0 E–7*	–	–	–	–
KFM12A:X	270–280	1.0 E–6*	–	–	–	–
HFM01:2	33.5–45.5	4.0 E–5*	–	–	–	–
HFM02:2	38–48	5.9 E–4**	80	38	21	8.9–38
HFM04:2	58–66	7.9 E–5**	–	2.2	–	10.4
HFM13:1	159–173	2.9 E–4**	–	24	8.3	4.3
HFM15:1	85–95	1.0 E–4**	1.0	0.8	1.4	5.2
HFM16:2	54–67	3.5 E–4**	–	–	–	1.6–6.6
HFM19:1	168–182	2.7 E–4**	–	9.7	6.2	3.4
HFM21:3	22–32	4.0 E–5**	–	–	–	–
HFM27:2	46–58	4.0 E–5**	–	–	–	0.4
HFM32:3	26–31	2.3 E–4**	–	–	3.7	0.5

* From PSS (Pipe String System) and PFL (Posiva Flow Log) measurements.

** From HTHB (HydroTester HammarBorrhål) measurements.

Figure 4-26. Forsmark investigation area with boreholes used for monitoring of groundwater flow.

4.11.2 Monitoring programme after PLU

Field performance

The monitored borehole sections shown in Table 4-15 will be included in the planned monitoring programme after the site investigations, which accordingly will encompass 34 sections.

The plan is to continue with the same measurement frequency, i.e. one measurement per year, and at the same time of the year (late autumn). Table 4-15 shows some results from measurements performed twice per year. However, this is due to special circumstances, when "extra" flow measurements (during non-pumped circumstances) have been performed in conjunction with interference tests. The second half of the year 2007 will be the first occasion when all 34 sections are included. Some boreholes or borehole sections may later be excluded if the measurements show only very small variations. Problems with the borehole installations may also discard sections if they are considered to be of less interest.

Data handling and processing

Data and measurement protocols should be delivered immediately after each field campaigne to SKB in digital form in SKB's Excel table format for storage, together with processed data, in Sicada.

Documentation

The results should be documented annually in an SKB P-report. The report, which shall be in the format specified by SKB, is to be delivered in February and shall include all measurements and calculations performed as well as nonconformities compared with the programme specified. If monitored sections are discarded, the motives for this should be accounted for in the report. An example of a complete documentation is given in /25/.

4.12 Ecology

4.12.1 Background

The surface ecosystem monitoring programme currently performed in the site investigations includes three different activities:

- yearly inventories of sensitive bird species,
- yearly acquisition of data regarding elk demography and reproduction in cooperation with local hunters,
- recurrent sampling, laboratory and field analyses of surface waters.

The two first monitoring activities are further described in the text below, whereas the monitoring of surface waters is performed in coordination with the hydrochemical monitoring programme and is described in Section 4.10.

The three investigations all comprise parameters which vary over time, and therefore long time series of site specific data are valuable. The parameters registered may also be sensitive to nearby environmental changes such as construction and operation of a repository for radioactive waste. For all three investigations, monitoring programmes have already been in operation during the site investigation.

Monitoring of sensitive bird species

Monitoring of bird species has been performed in the Forsmark area from the start of the site investigation in 2002 /28, 29, 30, 31, 32/. Since 2003 special attention has been paid to sensitive and listed species within the regional model area (see map in Figure 4-27).

The activity comprises an inventory of occurrence and breeding success of a number of selected bird species (all listed according to Swedish or EU authorities). The first priority is to follow up already known territories and, if resources are available, efforts are made to find other territories. The selected species are listed in Table 4-16. The investigation follows the breeding season and starts in spring each year. The field work is completed during late summer.

Monitoring of elk (Alces alces) demography and reproduction in cooperation with local hunters

Acquisition of data from elk in the Forsmark area regarding demography and reproduction has been performed in cooperation with local hunters since the hunting season 2002/2003 /33, 34/. During the last years SKB has also contributed with some resources for the data sampling in an area north of Forsmark, Saxmarken in Hållnäs, which is considered as a reference area concerning mammals. This has provided access to a data set which includes a somewhat longer time series (since 1999) than the data set from Forsmark.

Figure 4-27. Monitoring of selected bird species is performed in the regional model area (black rectangle) in the map.

Table 4-16. Bird species included in the monitoring programme.

English name	Swedish name	Latin name	Listing*
Black-throated Diver	Storlom	*Gavia artica*	(EU)
Honey Buzzard	Bivråk	*Pernis apivorus*	(Sw, EU)
Osprey	Fiskgjuse	*Pandion haliaetus*	(EU)
White-tailed eagle	Havsörn	*Haliaeetus albicilla*	(Sw, EU)
Ural owl	Slaguggla	*Strix uralensis*	(EU)
Lesser spotted woodpecker	Mindre hackspett	*Dendrocopus minor*	(Sw)
Wryneck	Göktyta	*Jynx torquila*	(Sw)
Red-backed shrike	Törnskata	*Lanius collurio*	(Sw, EU)
Black grouse	Orre	*Tetrao tetrix*	(EU)
Capercaillie	Tjäder	*Tetrao urogallus*	(EU)
Hazelhen	Järpe	*Bonasia bonasia*	(EU)

* EU = listed according to European Commission Birds Directive, Sw = listed according to the Swedish Redlist.

The hunters gather different kinds of information about observed and shot individuals of elk. This is reported on a website (www.jaktwebb.se). After hunting, jaws and uteruses from the shot elk individuals are frozen and later sent to a company for analysis in order to estimate age and reproductivity, and from these data estimates of the demography and reproductivity of the local elk population are made.

The activity follows the hunting season and starts in September each year. The observations of alive animals and acquisition of anatomical samples from shot individuals are performed during hunting, which for elk commences in September and ends in January the next year. When the hunting is over, the company mentioned collects the samples of jaws and uteruses, which are then analysed.

Monitoring of surface waters

See Section 4.10.

4.12.2 Monitoring programme

Field performance

Monitoring of sensitive bird species will continue after the site investigations with the same frequency and by applying the same methodology. A repeated line and point observation study of the bird fauna within the regional model area is performed during 2007 and will be presented in the bird monitoring report for that year.

Monitoring of elk demography and reproduction will after the site investigations be performed in the same way as during the site investigations.

Surface water monitoring, see Section 4.10.

Data handling and processing

As concerns *monitoring of sensitive bird species*, data shall be delivered to SKB during December. The data delivery includes paper protocols as well as two Excel files. One contains a list of all field observations and the other processed information about breeding success (a file which is extended for each year). All this material contains data for which there are access restrictions, and data are therefore not saved in Sicada. The breeding success data are incorporated in SKB's GIS database, also in this case with restrictions on the availability of data. The complete data delivery is sent to SKB Oskarshamn and is stored in a special archive.

Data from *monitoring of elk data* should be delivered to SKB in April each year and shall include a raw data file as well as the processed data (both Excel files) for storage in Sicada.

Regarding data from *monitoring of surface water*, see Section 4.10.

Documentation

The activity *monitoring of sensitive bird species* shall be documented in a P-report delivered to SKB in December, presenting the investigation and the results according to earlier reports /31, 32/.

Documentation of *monitoring of elk demography and reproduction* shall be made in two reports (one for Forsmark and one for Saxmarken), in Swedish. These reports, which are written by the company making the analyses, shall be delivered to the local hunters (via SKB). The P-reports shall be in the format specified by SKB and present performance and results as well as nonconformities compared with the programme specified.

For documentation of *monitoring of surface water*, see Section 4.10.

5 Future changes of the scope of the monitoring programme

After completion of the site investigations in June 2007, a new project will start at Forsmark which will administrate the monitoring programme and some other activities during the period until SKB during 2009 has decided which site that shall be prioritized. The scope of the monitoring programme at the beginning of this new project is presented in this report. However, the extent and performance may be changed with time. This may be due mainly to three reasons:

1) monitoring equipment may be malfunctioning,
2) supplementary investigations may be initiated, which, for example if new boreholes are drilled, may entail expansion of the monitoring programme, and
3) changes of the monitoring programme may be motivated by scientific considerations not linked to supplementary investigations. These possible situations are discussed below.

5.1 Consequenses for the monitoring programme if monitoring equipment is malfunctioning

If a component in the monitoring equipment fails, irrespective of what kind of equipment, fault-tracing will be initiated as soon as possible after the error is observed. When the malfunctioning component is localized, a decision is made whether it is worthwhile mending or exchanging the component, or if that part of the monitoring shall be terminated. This issue is prepared by the Activity Leader managing the monitoring activity in question, who should consult the Project Manager for SKB Site modelling, whereafter the decision is made by the Forsmark Project Manager. The decision and the motives for it shall be properly documented.

Concerning hydrogeological monitoring, the priority lists in Sections 4.8 and 4.9 should serve as guidance in the decision-making regarding equipment for groundwater head monitoring in Quaternary deposits and in bedrock. Because hydrochemical monitoring and, concerning monitoring in bedrock, groundwater flow monitoring for many boreholes are linked to this equipment, these disciplines may be involved in the decision process. The Activity Leader for groundwater level monitoring in Quaternary deposits and in bedrock, respectively, will prepare the issue, if relevant after consultation with the Activity Leaders for hydrochemistry and groundwater flow measurements, and after taking advice from the Project Manager for SKB Site modelling. The Forsmark Project Manager makes the decision, which shall be carefully documented including motives for the decision.

5.2 Consequenses for the monitoring programme in case of supplementary investigations

After completion of the site investigations in June 2007, analysis of the investigation results will continue. The extended and deepened analyses of the site investigation results may possibly reveal some gaps and imperfections in the data material, and hence demands may be called for supplementary investigations. The extent of supplementary data needed is not known in advance. However, if supplementary investigations will be performed, they should preferably be held together in one single field campaign, in which as many activities as possible are carried out simultaneously, all in order to limit this extra investigation time as much as possible.

However, if such investigations take place, they may have some implications on the monitoring programme. The monitoring of natural trends might temporarily be disturbed, for example if a new borehole is drilled, whereby pumping activities may cause a drawdown, which possibly may influence monitoring in nearby situated boreholes. Supplementary investigations may also entail a change in the scope of the monitoring programme. An obvious example is that if one or several new boreholes are drilled, they might be included in the monitoring programme. A decision to do so will be made by the Forsmark Project Manager after preparation of the issue by the Activity Leader concerned and after consulting SKB's Site modelling Project Manager. The decision will be documented, including the motives for expansion of the monitoring programme.

5.3 Other scientific reasons for changing the monitoring programme

The continued analysis of site investigation data including monitoring data may motivate changes in the scope and/or performance of the monitoring programme, which was also mentioned in Section 4.9. If a need for expansion of the monitoring programme is demonstrated, the decision-making should then be according to Section 5.2.

The analysis of monitoring data may, however, also lead to a decision to reduce the monitoring programme, for example if several objects turn out to monitor the same feature, so that data are closely correlated. The Project Manager may then, after the Activity Leader concerned has prepared the issue, and after taking advise from SKB's Site modelling Project Manager, decide that one or several monitoring objects may be excluded from the programme. Also in this case the decision shall be documented, including motivation for reducing the monitoring programme.

6 References

/1/ **SKB, 2001.** Platsundersökningar. Undersökningsmetoder och generellt genomförande-program. SKB R-01-10, Svensk Kärnbränslehantering AB. (In Swedish).

/2/ **SKB, 2001.** Program för platsundersökning vid Forsmark. SKB R-01-42, Svensk Kärnbränslehantering AB. (In Swedish).

/3/ **SKB, 2005.** Programme for further investigations of geosphere and biosphere. SKB R-05-14, Svensk Kärnbränslehantering AB.

/4/ **Bäckblom G, Almén K-E, 2004.** Monitoring during the stepwise implementation of the Swedish deep repository for spent fuel. SKB R-04-13, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2004.** Preliminary site description Forsmark area – version 1.1. SKB R-04-15, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2005.** Preliminary site description Forsmark area – version 1.2. SKB R-05-18, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2006.** Site description modelling Forsmark stage 2.1. Feedback for completion of the site investigations including input from safety assessment and repository engineering. SKB R-06-38, Svensk Kärnbränslehantering AB.

/8/ **Sjöberg LE, Pan M, Asenjo E, 2002.** An analysis of the Äspö crustal motion-monitoring network observed by GPS in 2000, 2001 and 2002. SKB R-02-33, Svensk Kärnbränslehantering AB.

/9/ **Gustafson L, Ljungberg A, 2007.** GPS deformation measurements in Forsmark. Annual report 2006. SKB P-07-089, Svensk Kärnbränslehantering AB.

/10/ **Bödvarsson, R, 2007.** Swedish National Seismic Network (SNSN). A short report on recorded earthquakes during the first quarter of the year 2007. SKB P-07-82, Svensk Kärnbränslehantering AB.

/11/ **Petiau G, Dupis A, 1980.** Noise temperature coefficient and long-time stability of electrodes for telluric observations. Geophysical Prospecting 28 (5), pp. 792–804.

/12/ **Almén K-E, Stenberg L, 2005.** Äspö Hard Rock Laboratory. Characterization methods and instruments. SKB TR-05-11, Svensk Kärnbränslehantering AB.

/13/ **Alexandersson H, 2005.** Enkel bedömning av nederbördsförluster på fyra automat-stationer. SMHI PM for SKB. (In Swedish).

/14/ **Eriksson B, 1981.** Den ”potentiella” evapotranspirationen i Sverige. SMHI, RMK 28. (In Swedish).

/15/ **Nilsson D, 2005.** Forsmark site investigation. Sampling and analysis of precipitation, years 2002 to 2005. SKB P-05-143, Svensk Kärnbränslehantering AB.

/16/ **Nilsson A-C, Karlsson S, Borgiel M, 2003.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, March 2002 to March 2003. SKB P-03-27, Svensk Kärnbränslehantering AB.

/17/ **Nilsson A-C, Borgiel M, 2004.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, March 2003 to March 2004. SKB P-04-146, Svensk Kärnbränslehantering AB.

/18/ **Nilsson A-C, Borgiel M, 2005.** Forsmark site investigation. Sampling and analyses of near surface groundwaters. Results from sampling of shallow soil monitoring wells, BAT pipes, a natural spring and private wells, May 2003–April 2005. SKB P-05-171, Svensk Kärnbränslehantering AB.

/19/ **Nilsson A-C, Borgiel M, 2005.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, March 2004–June 2005. SKB P-05-274, Svensk Kärnbränslehantering AB.

/20/ **Nilsson A-C, Borgiel M, 2007.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, July 2005–June 2006. SKB P-07-95, Svensk Kärnbränslehantering AB.

/21/ **Berg C, Nilsson A-C, Borgiel M, 2006.** Forsmark site investigation. Hydrochemical monitoring of near surface groundwaters. Results from sampling of five shallow soil monitoring wells, one BAT pipe and three private wells, July 2005–April 2006. SKB P-06-304, Svensk Kärnbränslehantering AB.

/22/ **Berg C, Nilsson A-C, 2006.** Forsmark site investigation. Hydrochemical monitoring of percussion- and core drilled boreholes. Results from water sampling and analyses during 2005. SKB P-06-57, Svensk Kärnbränslehantering AB.

/23/ **Berg C, Nilsson A-C, 2007.** Forsmark site investigation. Hydrochemical monitoring of percussion- and core drilled boreholes. Results from water sampling and analyses during 2006. SKB P-07-47, Svensk Kärnbränslehantering AB.

/24/ **Wass E, Andersson P, 2006.** Forsmark site investigation. Groundwater flow measurements and tracer tests at drill site 1. SKB P-06-125, Svensk Kärnbränslehantering AB.

/25/ **Wass E, 2006.** Forsmark site investigation. Groundwater flow measurements in permanently installed boreholes. Test campaign no. 1, 2005. SKB P-06-59, Svensk Kärnbränslehantering AB.

/26/ **Lindquist A, Wass E, 2006.** Forsmark site investigation. Groundwater flow measurements in conjunction with the interference test with pumping in HFM14. SKB P-06-188, Svensk Kärnbränslehantering AB.

/27/ **Wass E, 2007.** Forsmark site investigation. Groundwater flow measurements in permanently installed boreholes. Test campaign no. 2, 2006. SKB P-07-50, Svensk Kärnbränslehantering AB. (In prep.).

/28/ **Green M, 2003.** Fågelundersökningar inom SKB:s platsundersökningar 2002. Forsmark. SKB P-03-10, Svensk Kärnbränslehantering AB. (In Swedish).

/29/ **Green M, 2004.** Bird monitoring in Forsmark 2002–2003. Forsmark site investigation. SKB P-04-30, Svensk Kärnbränslehantering AB.

/30/ **Green M, 2005.** Bird monitoring in Forsmark 2002–2004. Forsmark site investigation. SKB P-05-73, Svensk Kärnbränslehantering AB.

/31/ **Green M, 2006.** Bird monitoring in Forsmark 2005. Forsmark site investigation. SKB P-06-46, Svensk Kärnbränslehantering AB.

/32/ **Green M, 2007.** Bird monitoring in Forsmark 2006. Forsmark site investigation. SKB P-07-02, Svensk Kärnbränslehantering AB.

/33/ **Cederlund G, Lemel J, Wallin K, 2006.** Älgstammens ålderssammansättning och reproduktion i Forsmark. Forsmark site investigation. SKB P-06-219, Svensk Kärnbränslehantering AB. (In Swedish).

/34/ **Cederlund G, Lemel J, Wallin K, 2006.** Älgstammens ålderssammansättning och reproduktion i Saxmarken – Hållnäs. Forsmark site investigation. SKB P-06-218, Svensk Kärnbränslehantering AB. (In Swedish).

Appendix 1

Coordinates for the surface water discharge gauging stations and equations for the calculation of discharge

Table A1-1. Coordinates for the discharge gauging long-throated flumes (Northing and Easting, RT 90 2.5 gon W 0:-15, elevation RHB70).

Id	Northing	Easting	Elevation
PFM005764 Nov 27, 2003–Oct 1, 2004			
Small flume (QFM1:1)			
Obs. tube, top of casing	6698745.4	1631660.9	2.190
Flume bottom, upstream edge	6698747.3	1631659.1	0.903
Flume bottom, downstream edge	6698748.1	1631660.2	0.895
Large flume (QFM1:2)			
Obs. tube, top of casing	6698751.8	1631667.2	2.117
Flume bottom, upstream edge	6698753.0	1631666.0	0.895
Flume bottom, downstream edge	6698754.9	1631668.1	0.885
PFM005764 Oct 5, 2004 –			
Small flume (QFM1:1)			
Obs. tube, top of casing	6698745.4	1631660.9	2.190
Flume bottom, upstream edge	6698747.3	1631659.1	0.903
Flume bottom, downstream edge	6698748.1	1631660.2	0.895
Large flume (QFM1:2)			
Obs. tube, top of casing	6698751.8	1631667.2	2.117
Flume bottom, upstream edge	6698753.0	1631666.0	0.895
Flume bottom, downstream edge	6698754.9	1631668.1	0.885
PFM002667			
Small flume (QFM2:1)			
Obs. tube, top of casing	6698263.0	1631595.5	2.679
Flume bottom, upstream edge	6698264.1	1631593.5	1.502
Flume bottom, downstream edge	6698265.0	1631594.0	1.501
Large flume (QFM2:2)			
Obs. tube, top of casing	6698270.2	1631598.4	2.721
Flume bottom, upstream edge	6698271.0	1631596.5	1.511
Flume bottom, downstream edge	6698274.6	1631598.7	1.505
PFM002668 (QFM3)			
Obs. tube, top of casing	6697474.9	1632066.9	5.482
Flume bottom, upstream edge	6697475.5	1632065.7	4.287
Flume bottom, downstream edge	6697476.7	1632067.5	4.280
QFM4 PFM002669			
Small flume (QFM4:1)			
Obs. tube, top of casing	6699047.4	1629371.7	6.994
Flume bottom, upstream edge	6699046.6	1629371.2	5.852
Flume bottom, downstream edge	6699046.4	1629372.5	5.849
Large flume (QFM4:2)			
Obs. tube, top of casing	6699045.9	1629379.9	6.901
Flume bottom, upstream edge	6699043.9	1629379.1	5.843
Flume bottom, downstream edge	6699041.8	1629382.7	5.855

Table A1-2. Discharge equations for the long-throated flumes and recommended discharge interval.

Id	Discharge eq. (Q = discharge /L/s/, h = water depth /m/)	Recommended interval (L/s)
PFM005764 Nov 27, 2003–Oct 1, 2004		
Small flume (QFM1:1)	$Q = 864.9 \times h^{2.576}$	0–20
Large flume (QFM1:2)*	$Q = 1{,}175 \times h^{2.15}$	20–70
PFM005764 Oct 5, 2004 –		
Small flume (QFM1:1	$Q = 864.9 \times h^{2.576}$	0–20
Large flume (QFM1:2)	$Q = 2{,}298 \times (h+0.03459)^{2.339}$	20–1,400
PFM002667		
Small flume (QFM2:1)	$Q = 864.9 \times h^{2.576}$	0–20
Large flume (QFM2:2)	$Q = 2{,}001.5 \times (h+0.02660)^{2.561}$	20–500
PFM002668 (QFM3)		
	$Q = 979.1 \times (h)^{2.574}$	0–250
QFM4 PFM002669		
Small flume (QFM4:1)	$Q = 864.9 \times h^{2.576}$	0–20
Large flume (QFM4:2)	$Q = 1{,}117.6 \times (h+0.02727)^{2.604}$	20–920

*Equation obtained from calibration measurements April 13–May 24, 2004. Critical value was not reached and calculated discharge may therefore be influenced by downstream conditions. Obtained values should be considered as indicative and be used with caution.

Appendix 2

Coordinates for groundwater monitoring wells and BAT-type filter tips in Quaternary deposits

Table A2-1. Coordinates for groundwater monitoring wells and BAT-type filter tips in Quaternary deposits (Northing and Easting, RT 90 2.5 gon W 0:-15, elevation RHB70).

Borehole	X	Y	Z (top of casing)	Type of well and logger connection
SFM0001	6699713.31	1631335.44	1.10	Groundwater monitoring well, stand-alone logger
SFM0003	6699614.59	1631487.30	1.94	Groundwater monitoring well, stand-alone logger
SFM0004	6698865.76	1633441.21	4.14	Groundwater monitoring well, stand-alone logger
SFM0005	6698647.55	1633252.18	6.80	Groundwater monitoring well, stand-alone logger
SFM0006	6697747.16	1634501.93	6.29	Groundwater monitoring well, stand-alone logger
SFM0008	6697930.56	1634622.99	3.77	Groundwater monitoring well, stand-alone logger
SFM0010	6697313.87	1630734.94	13.54	Groundwater monitoring well, linked to HMS via GSM
SFM0011	6699117.11	1630711.39	2.65	Groundwater monitoring well, linked to HMS via GSM
SFM0012	6698492.25	1630719.10	2.85	Groundwater monitoring well, linked to HMS via GSM
SFM0013	6698698.54	1631122.63	1.98	Groundwater monitoring well, linked to HMS via GSM
SFM0014	6697027.00	1631715.50	6.61	Groundwater monitoring well, stand-alone logger
SFM0015	6697009.79	1631964.04	5.77	Groundwater monitoring well, linked to HMS via GSM
SFM0017	6696504.81	1632138.16	6.69	Groundwater monitoring well, linked to HMS via GSM
SFM0019	6697700.72	1632118.35	4.77	Groundwater monitoring well, stand-alone logger
SFM0021	6699706.35	1632492.99	1.97	Groundwater monitoring well, stand-alone logger
SFM0022	6697597.55	1632697.18	1.49	Groundwater monitoring well, linked to HMS via GSM
SFM0023	6698982.51	1632064.42	1.06	Groundwater monitoring well, linked to HMS via GSM
SFM0025	6696039.39	1634774.05	0.86	Groundwater monitoring well, linked to HMS via GSM
SFM0026	6696702.65	1634151.84	1.59	Groundwater monitoring well, stand-alone logger
SFM0028	6698507.93	1633588.91	1.07	Groundwater monitoring well, linked to HMS via GSM
SFM0030	6698678.20	1631662.72	2.79	Groundwater monitoring well, stand-alone logger
SFM0033	6698839.01	1631728.18	1.69	Groundwater monitoring well, stand-alone logger
SFM0034	6699757.49	1631858.50	1.58	Groundwater monitoring well, linked to HMS via GSM
SFM0036	6699991.99	1631746.07	1.51	Groundwater monitoring well, linked to HMS via GSM
SFM0049	6700027.55	1630533.057	4.03	Groundwater monitoring well, stand-alone logger
SFM0057	6698979.93	1630949.38	4.82	Groundwater monitoring well, stand-alone logger
SFM0058	6699349.27	1631739.76	3.55	Groundwater monitoring well, stand-alone logger
SFM0061	6698376.67	1635923.81	5.40	Groundwater monitoring well, stand-alone logger
SFM0062	6698838.72	1631807.99	1.18	Groundwater monitoring well, stand-alone logger
SFM0065	6698380.94	1633841.58	0.97	Groundwater monitoring well, linked to HMS via GSM
SFM0077	6699920.65	1630389.40	5.02	Groundwater monitoring well, stand-alone logger
SFM0078	6699703.70	1630764.94	5.24	Groundwater monitoring well, stand-alone logger
SFM0079	6699690.55	1630567.90	4.20	Groundwater monitoring well, stand-alone logger
SFM0080	6698658.52	1631719.10	4.36	Groundwater monitoring well, stand-alone logger
SFM0081	6698999.91	1632093.49	1.31	Groundwater monitoring well, linked to HMS via GSM
SFM0082	6699000.14	1632093.97	1.39	BAT-type filter tip for determination of pore pressure, no logger
SFM0084	6699868.49	1632405.99	1.23	Groundwater monitoring well, linked to HMS via GSM
SFM0085	6699868.91	1632405.79	1.67	BAT-type filter tip for determination of pore pressure, no logger

Borehole	X	Y	Z (top of casing)	Type of well and logger connection
SFM0087	6699868.14	1632406.37	1.31	Groundwater monitoring well, linked to HMS via GSM
SFM0088	6699868.15	1632405.59	1.10	BAT-type filter tip for determination of pore pressure, no logger
SFM0091	6699745.57	1631490.63	1.41	Groundwater monitoring well, linked to HMS via GSM
SFM0092	6699746.06	1631490.71	1.41	BAT-type filter tip for determination of pore pressure, no logger
SFM0095	6698017.75	1630437.62	12.10	Groundwater monitoring well, linked to HMS via GSM
SFM0096	6698014.59	1630436.94	11.64	BAT-type filter tip for determination of pore pressure, no logger
SFM0099	6698014.14	1630437.49	11.56	BAT-type filter tip for determination of pore pressure, no logger
SFM0101	6698014.51	1630437.85	12.04	BAT-type filter tip for determination of pore pressure, no logger
SFM0104	6699591.79	1631275.36	3.55	Groundwater monitoring well, stand-alone logger
SFM0105	6699710.16	1632464.60	3.62	Groundwater monitoring well, stand-alone logger
SFM0106	6698321.31	1634043.40	4.69	Groundwater monitoring well, stand-alone logger
SFM0107	6700187.42	1630769.19	3.15	Groundwater monitoring well, stand-alone logger

Appendix 3

Boreholes included in the hydrogeological monitoring programme in bedrock

Table A3-1. Boreholes and borehole sections included in the hydrogeological monitoring programme in bedrock. Boreholes planned to be supplied with monitoring equipment just prior to or immediately after completion of the site investigations are labelled in grey. Coordinates are also presented in the table. The borehole lengths are rounded to the nearest metre.

Borehole	Coordintes (RT90) Northing	Easting	Section number	Section, pressure (p), circulation (c)
KFM01A	6699530	1631397	6	0–108, p
			5	109–130, p, c
			4	131–204, p
			3	205–373 p
			2	374–430, p
			1	431–1,001, p
KFM01B	6699539	1631388	3	0–100, p
			2	101–141, p
			1	142–500, p
KFM01C	6699524	1631404	3	0–58, p
			2	59–237, p
			1	238–450, p
KFM01D	6699542	1631405	7	0–153, p
			6	154–252, p
			5	253–310, p
			4	311–321, p, c
			3	322–428, p
			2	429–438, p, c
			1	439–800, p
KFM02A	6698713	1633183	8	0–132, p
			7	133–240, p
			6	241–410, p
			5	411–442, p, c
			4	443–489, p
			3	490–518, p, c
			2	519–888, p
			1	889–1,002, p
KFM02B	6698719	1633186	7	0–130
			6	131–245, P
			5	246–409, p
			4	410–431, p, c
			3	432–490, p
			2	491–506, p, c
			1	507–570, p
KFM03A	6697852	1634631	8	0–350.5, p
			7	351.5–401.5, p
			6	402.5–471.5, p
			5	472.5–632.5, p
			4	633.5–650, p, c

Borehole	Coordintes (RT90) Northing	Easting	Section number	Section, pressure (p), circulation (c)
			3	651–819.5, p
			2	820.5–968.5, p
			1	969.5–994.5, p, c
KFM03B	6697844	1634619	2	0–51, p
			1	52–102, p
KFM04A	6698922	1630979	7	0–163, p
			6	164–185, p
			5	186–229, p
			4	230–245, p, c
			3	246–390, p
			2	391–495, p
			1	496–1,001, p
KFM05A	6699345	1631711	6	0–114, p
			5	115–253, p
			4	254–272, p, c
			3	273–489, p
			2	490–698, p
			1	699–1,002, p
KFM06A	6699733	1632443	8	0–150, p
			7	151–246, p
			6	247–340, p
			5	341–362, p, c
			4	363–737, p
			3	738–748, p, c
			2	749–826, p
			1	827–1,001, p
KFM06B	6699732	1632446	3	0–26, p
			2	27–50, p
			1	51–100, p
KFM06C	6699741	1632437	10	0–186, p
			9	187–280, p
			8	281–350, p
			7	351–401, p
			6	402–530, p
			5	531–540, p, c
			4	541–646, p
			3	647–666, p, c
			2	667–872, p
			1	873–1,001, p
KFM07A	6700127	1631032	6	0–148, p
			5	149–190, p
			4	191–225, p
			3	226–961, p
			2	962–972, p, c
			1	973–1,001, p
KFM07B	6700124	1631037	3	0–74, p
			2	75–202, p
			1	203–300, p
KFM07C	6700126	1631034	4	0–110, p
			3	111–160, p
			2	161–301, p
			1	302–500, p

Borehole	Coordintes (RT90) Northing	Easting	Section number	Section, pressure (p), circulation (c)
KFM08A	6700494	1631197	9	0–161, p
			8	162–215, p
			7	216–264, p
			6	265–280, p, c
			5	281–473, p
			4	474–503, p
			3	504–683, p
			2	684–694, p, c
			1	695–1,001 p
KFM08B	6700493	1631173	3	0–70, p
			2	71–112, p
			1	113–200, p
KFM08C	6700496	1631188	9	0–161, p
			8	162–215, p
			7	216–264, p
			6	265–280, p, c
			5	281–473, p
			4	474–503, p
			3	504–683, p
			2	684–694, p, c
			1	695–1,001, p
KFM08D	6700492	1631199	7	0–160, p
			6	161–330, p
			5	331–659, p
			4	660–680, p, c
			3	681–824, p
			2	825–835, p, c
			1	836–950, p
KFM09A	6700115	1630647	3	0–300 p
			2	301–550 p
			1	551–800 p
KFM09B	6700120	1630639	3	0–200 p
			2	201–450 p
			1	451–616 p
KFM010A	6698629	1631716	5	0–152, p
			4	153–352, p
			3	353–429, p
			2	430–440, p, c
			1	441–500, p
KFM011A	6701104	1632367	7	0–130, p
			6	131–360, p
			5	361–445, p
			4	446–456, p, c
			3	457–689, p
			2	690–710, p, c
			1	711–850, p
KFM012A	6696577	1630052	5	0–165, p
			4	166–269, p
			3	270–280, p, c
			2	281–490, p
			1	491–601 p

Borehole	Coordintes (RT90) Northing	Easting	Section number	Section, pressure (p), circulation (c)
HFM01	6699605	1631485	3	0–32.5, p
			2	33.5–45.5, p, c
			1	46.5–200, p
HFM02	6699593	1631269	3	0–37, p
			2	38–48, p, c
			1	49–100, p
HFM03	6699593	1631273	2	0–18, p
			1	19–26, p
HFM04	6698879	1633421	3	0–57, p
			2	58–66, p, c
			1	67–222, p
HFM05	6698647	1633290	2	0–138, p
			1	139–200, p
HFM07	6697416	1634716	1	p (open borehole)
HFM08	6697703	1634778	2	0–116, p
			1	117–143, p
HFM09	6699065	1630869	1	p (open borehole)
HFM10	6698835	1631037	2	0–99, p
			1	100–150, p
HFM11	6697283	1631636	2	0–53 p
			1	54–182, p
HFM12	6697446	1631696	2	0–56.5 p
			1	57.5–210, p
HFM13	6699094	1631474	3	0–100, p
			2	101–158, p
			1	159–173, p, c
			Blind	174–176
HFM14	6699313	1631735	1	p (open borehole)
HFM15	6699312	1631733	2	0–84, p
			1	85–95, p, c
			Blind	96–100
HFM16	6699721	1632466	3	0–53, p
			2	54–67, p, c
			1	68–132, p
HFM17	6699462	1633261	1	p (open borehole)
HFM18	6698327	1634037	3	0–27, p
			2	28–41, p
			1	42–180, p
HFM19	6699258	1631627	3	0–103, p
			2	104–167, p
			1	168–182, p, c
			Blind	183–185
HFM20	6700187	1630777	4	0–48, p
			3	49–100, p
			2	101–130, p
			1	131–301, p
HFM21	6700126	1631074	4	0–21, p
			3	22–32, p, c
			2	33–106, p
			1	107–202, p
HFM22	6700456	1631218	1	p (open borehole)

Borehole	Coordintes (RT90) Northing	Easting	Section number	Section, pressure (p), circulation (c)
HFM23	6700068	1630595	1	p (open borehole)
HFM24	6698662	1631720	3	0–35, p
			2	36–65, p
			1	66–151, p
HFM25	6699616	1633039	1	p (open borehole)
HFM26	6698009	1633516	1	p (open borehole)
HFM27	6699595	1631246	4	0–24, p
			3	25–45, p
			2	46–58, p, c
			1	59–128, p
HFM28	6700069	1630597	1	p (open borehole)
HFM29	6698019	1632503	1	p (open borehole)
HFM30	6697932	1631820	4	0–60, p
			3	61–73, p
			2	74–176, p
			1	177–201, p
HFM31	6700860	1629207	1	p (open borehole)
HFM32	6699015	1632137	4	0–25, p
			3	26–31, p, c
			2	32–97, p
			1	98–203, p
HFM33	6701043	1632223	1	p (open borehole)
HFM34	6701325	1632470	3	0–21, p
			2	22–90, p
			1	91–201, p
HFM35	6701556	1632321	4	0–33, p
			3	34–150, p
			2	151–181, p
			1	182–201, p
HFM36	6696504	1630082	3	0–45, p
			2	46–68, p
			1	69–152, p
HFM37	6696592	1630137	1	p (open borehole)
HFM38	6700701	1631302	3	0–23, p
			2	24–41, p
			1	42–201, p