R-13-20

Meteorological, hydrological and hydrogeological monitoring data from Forsmark – compilation and analysis for the SR-PSU project

SR-PSU Biosphere

Kent Werner, EmpTec

Jeff Norville, Golder Associates AB

Johan Öhman, Geosigma AB

December 2014

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

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Summary

This report presents and analyses meteorological, hydrological and hydrogeological monitoring data from Forsmark collected up to the end of December 2010. The report has been produced in support of the SR-PSU project, which is part of the licence application for the extension of the underground SFR facility. The meteorological dataset comprises data from two local stations, of which one (Storskäret) was decommissioned in 2007, and winter parameters (snow depth and -weight and ice coverage) from five locations. The dataset also includes longer time series (17 years) from surrounding stations operated by SMHI. The surface-water level dataset includes data from six lakes, five ponds and the sea. As of December 2010, groundwater-level monitoring was ongoing in 45 monitoring wells, of which 34 are installed on land and 11 below surface waters. Moreover, data are presented and analysed from four gauging stations installed in streams, including stream discharge and water electrical conductivity. The report also provides a brief overview of hydrogeological monitoring data collected in the upper c 150 m of the rock, including groundwater levels in surface and SFR tunnel boreholes, and groundwater inflow to SFR.

Data screening was performed to attain a groundwater-level dataset representative for the natural, undisturbed system, and linear and multiple regression analyses were used to fill in data gaps in the precipitation and discharge datasets. In terms of relations between meteorological, hydrological and hydrogeological data, no results contradict the results of previous data analyses. However, a previously developed snow accumulation and snow-melt model overestimates the snow water content during part of the 2008/2009 winter season, when the daily average air temperature fluctuates around 0°C. Moreover, new levelling of surface-water level gauges and groundwater-monitoring wells installed in lakes and ponds shows that gauges and wells are displaced vertically during the winter seasons. Even though reference levels have been adjusted as part of the monitoring, actual vertical hydraulic gradients across the bottom of lakes and ponds are associated with some degree of uncertainty.

Sammanfattning

Denna rapport presenterar och analyserar meteorologiska, hydrologiska och hydrogeologiska moniteringsdata från Forsmark, insamlade till och med slutet av december 2010. Rapporten har tagits fram som stöd för SR-PSU-projektet, som är del av tillståndsansökan för en utbyggnad av undermarksanläggningen SFR. Meteorologiska data omfattar två lokala stationer, varav en (Storskäret) lades ner under 2007, samt vinterparametrar (snödjup och -vikt samt istäckning) från fem lokaler. Data omfattar även längre tidsserier (17 år) från omgivande stationer som drivs av SMHI. Ytvattennivådata omfattar sex sjöar, fem gölar och havet. I december 2010 pågick monitering i 45 grundvattenrör, varav 34 är installerade på land och 11 under ytvatten. Data presenteras och analyseras även från fyra vattenföringsstationer i bäckar, inklusive bäckvattenföring och vattnets elektriska konduktivitet. Rapporten ger även en kortfattad översikt över hydrogeologiska moniteringsdata från de övre cirka 150 m av berget, inklusive grundvattennivåer i ytborrhål och tunnelborrhål i SFR, samt inläckage av grundvatten till SFR.

Data sållades för att erhålla en uppsättning grundvattennivådata som representerar ett ostört, naturligt system, och linjär och multipel regressionsanalys användes för att fylla i dataluckor vad gäller nederbörd och vattenföring. Inga resultat i termer av relationer mellan meteorologiska, hydrologiska och hydrogeologiska data motsäger resultaten i tidigare dataanalyser. En tidigare utvecklad modell för snöackumulation och snösmältning överskattar dock snöns vatteninnehåll under en del av vintern 2008/2009, då dygnsmedeltemperaturen fluktuerar kring 0 °C. Nya avvägningar av ytvattenpeglar och grundvattenrör i sjöar och gölar visar att peglar och rör rubbas vintertid. Även om referensnivåerna har justerats inom ramen för moniteringen, är verkliga hydrauliska gradienter tvärs sjöarnas och gölarnas bottnar förknippade med en viss grad av osäkerhet.

Contents

1 Introduction

The final repository for short-lived low and intermediate level radioactive waste, SFR 1, is located in Forsmark in northern Uppland, in the immediate vicinity of the Forsmark nuclear power plant (Figures 1-1 and 1-2). The SFR 1 repository consists of a set of disposal rooms situated in rock at c 60 m depth beneath the sea floor, and is built to receive and after closure serve as a passive repository for the low- and intermediate-level, short-lived radioactive waste. The radioactive waste stored in SFR includes operational waste from Swedish nuclear power plants and from the interim storage facility for spent nuclear fuel, Clab, as well as radioactive waste from other industry, research institutions and medical care. In order to be able to store also decommissioning waste from the Swedish nuclear power plants in SFR, an extension of the repository, referred to as SFR 3, is planned.

As a part of the license application for the extension of SFR, the Swedish Nuclear Fuel and Waste Management Company (SKB) has performed the SR-PSU project. The objective of this project is to assess the long-term radiological safety of the entire future SFR repository, i.e. both the existing SFR 1 and the planned SFR 3. The SR-PSU project is reported in a series of SKB reports, which includes a main report (SKB 2014a) and a set of primary references, e.g. the biosphere synthesis report (SKB 2014b). In addition to these primary references, the safety assessment is based on a large number of background reports (such as the present report) and other references.

The biosphere is a key part of the system considered in a safety assessment of a nuclear waste repository. This is where the main consequences of potential future radionuclide releases from the repository could arise, and hence radionuclide transport and dose calculations are performed within the framework of the biosphere assessment. This report belongs to the biosphere part of the SR-PSU project, SR-PSU Biosphere. SR-PSU Biosphere mainly describes the information needed to calculate effects on humans and the environment in case of a radionuclide release from SFR. The calculated effects are then used to show compliance with regulations related to the future repository performance for time spans up to 100,000 years after closure. Because of the uncertainties associated with the prediction of future development of the site in this time frame, a number of calculation cases are analysed to describe a range of possible site developments. For further details of the biosphere assessment and associated tasks, methodology, organisation and reporting, see SKB (2014b).

In support of the SR-PSU project, this report presents and analyses meteorological, hydrological and hydrogeological monitoring data from Forsmark collected up to the end of December 2010. The primary objective of the report is to provide an overview of the SR-PSU dataset, which extends the datasets available for previous, corresponding analyses (Juston and Johansson 2005, Juston et al. 2007, Johansson and Öhman 2008). For instance, the present dataset is c 3.5 years longer than the dataset available for the SDM-Site project (Johansson and Öhman 2008). Based on the presently available dataset, the report comments on some main observations made in previous, corresponding analyses.

As part of the data analysis, temporally high-resolved data have been transformed to daily averages or sums, non-representative data have been screened out, and gaps in input data required for numerical water-flow modelling have been filled as far as possible. The resulting data have been compiled into an input dataset and a calibration dataset, respectively, available for numerical water-flow modelling within the SR-PSU project, see e.g. the MIKE SHE modelling presented in Werner et al. (2013).

All data used in the report are extracted from SKB's Sicada database. Coordinates are given in the coordinate systems RT 90 2.5 gon V/0:15 (X, Y) and RHB 70 (Z), i.e. vertical (Z) coordinates are expressed in terms of elevation (m) above the RHB 70 datum (0 m elevation).

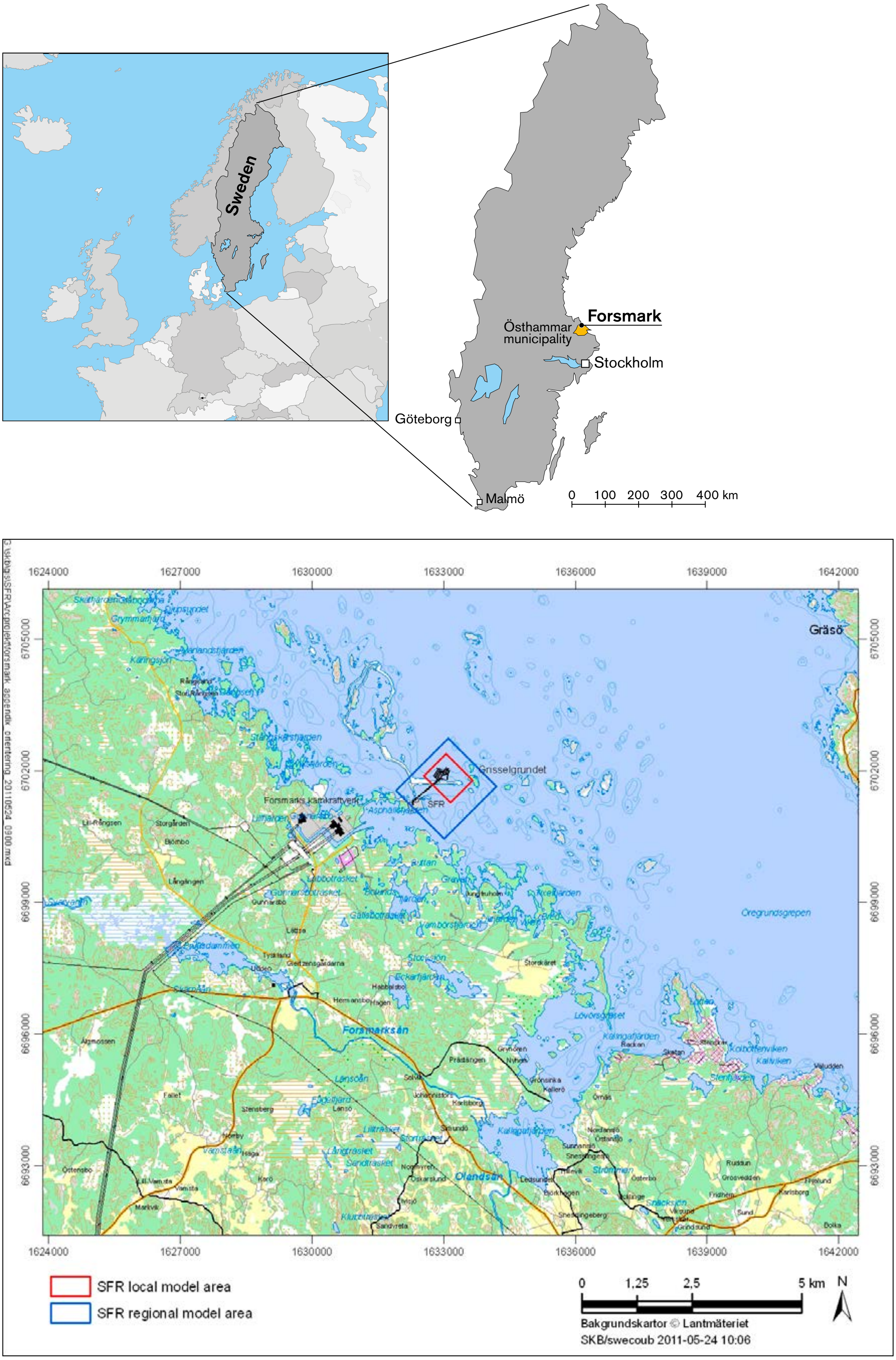


***Figure 1-1.** Location of Forsmark in northern Uppland. The lower map shows the boundaries of the SFR local and regional model areas, and the location of the SFR 1 facility. The local model area (or domain) covers the volume that hosts SFR 1 and SFR 3, whereas the regional model domain places the description of the local domain in a larger context (SKB 2013).*

Figure 1-2. *The surface facilities of SFR 1 in the Forsmark harbour. The subsurface parts of SFR 1 are located beneath the sea floor, approximately 700 m from the surface facilities.*

2 Presentation of data

2.1 Overview of the SR-PSU dataset

This report considers monitoring data gathered up to December 31, 2010, and it presents and evaluates a number of time-series datasets (Table 2-1): Meteorological data, surface-water levels, stream discharges, and groundwater levels in regolith. The report also provides a brief overview of monitoring data on groundwater levels in rock and groundwater inflow to SFR. Except for the groundwater-inflow measurements, which were initiated when the first stage of SFR was taken into operation in 1988, installations of monitoring equipment has been an ongoing process since the start of the Forsmark site investigation (2002) associated with the deep-rock repository for spent nuclear fuel. Table 2-2 provides references to SKB's monitoring reports for the Forsmark site up to the end of year 2010.

The meteorological data of most concern in this study are precipitation (P) and potential evapotranspiration (PET) time series. P was measured at and PET was calculated for two stations (Högmasten and Storskäret) in the study area from May 2003 up to the end of June 2007, at which time the Storskäret station was decommissioned. For comparative purposes, this study also utilises P and PET time-series data from close-by meteorological stations operated by SMHI (the Swedish Meteorological and Hydrological Institute).

Table 2-1. Summary of Sicada deliveries used in the report.

Sicada delivery id	Contents
11_049, 11_049_1, 11_049_2, 11_049_3	Groundwater-level data from percussion-drilled boreholes HFM01–38, Apr. 1, 2007–Dec. 31, 2010. Data from the meteorological stations PFM010700 (Högmasten), PFM010701 (Storskäret), PFM010714 (Films Kyrkby), PFM010725 (Lövsta), PFM010811 (Risinge), PFM010815 (Östhammar), PFM010818 (Söderby-Karlsäng), and PFM010832 (Örskär), Apr. 1, 2007–Dec. 31, 2010. Sea-level data from the gauging stations PFM010038 (SKB) and PFM010039 (SMHI), Apr. 1, 2007–Dec. 31, 2010.
11_070, 11_070_1, 11_070_2	Groundwater-depth data from percussion-drilled boreholes HFM32 and HFM34 (2006), and HFR101 HFR102 and HFR105 (2008). Groundwater-level data from percussion-drilled boreholes HFR102, HFR105 and HFR106 up to Dec. 31, 2010. Groundwater-level data from percussion-drilled boreholes HFM32 and HFM34 up to Dec. 31, 2010 (new levelling, see section 2.5). Groundwater-level data from core-drilled boreholes KFR101, KFR102A, KFR102B, KFR103, KFR104, KFR106 up to Dec. 31, 2010. Pressure data from SFR tunnel boreholes KFR01, KFR02, KFR03, KFR04, KFR05, KFR07A, KFR07B, KFR08, KFR09, KFR13, KFR19, KFR55, KFR56 and KFR105 up to Dec. 31, 2010; corrected for normal air pressure up to 1989 (excl. KFR105), fresh-water pressure 1988–2005 (excl. KFR09 and KFR105), pressure 2006–2010.
11_076	SFR inflow data, Jun. 30, 1988–Dec. 31, 2010.
11_078, 11_078_1	Ice-cover observations from AFM000010 (Lake Eckarfjärden) and AFM000075 (the sea), 2002–2010. Snow data from observation points AFM000071, AFM000072 and AFM001172, 2007–2010. Ground- and surface-water level data from wells/gauges SFM0003, -12, -15, -22, -23, -39, -40, -42, and -64 up to Dec. 31, 2010 (new levelling, see sections 2.3 and 2.4). Ground- and surface-water level data from other wells/gauges, Apr. 1, 2007–Dec. 31, 2010.
11_080, 11_080_1	Data on surface-water levels, surface-water discharges, EC and temperature from surface-discharge gauging stations PFM002667, -2668, -2669 and -5764 up to Dec. 31, 2010. Groundwater-level data from core-drilled boreholes KFM11A and KFR27 up to Dec. 31, 2010.
11_142	Air-temperature data from PFM010700 (Högmasten); daily mean, max. and min. May, 12, 2003–Mar. 31, 2007; half-hour data Apr. 1, 2007–Dec. 31, 2010.
12_003, 12_003_1	EC data from PFM002292 (Lake Bolundsfjärden) up to Dec. 31, 2009 (no data for 2010, see Johansson and Juston 2011b).
12_030	Groundwater-level data from percussion-drilled borehole HFR101 up to Dec. 31, 2010.
12_040	Coordinates for all measurement points of the Sicada deliveries listed above.

Table 2-2. Available meteorological, hydrological and near-surface hydrogeological monitoring data, with references to corresponding monitoring reports.

Meteorological data	References
Regional data (incl. long-term averages)	Lindell et al. (2000), Larsson-McCann et al. (2002).
Forsmark data	
Precipitation, air temperature, global radiation, potential evapotranspiration, wind speed and -direction, humidity, air pressure.	Wern and Jones (2006, 2007a, b, 2008), Andersson and Jones (2009, 2010, 2011).
Snow depth, ground frost and ice cover.	Aquilonius and Karlsson (2003), Heneryd (2004, 2005, 2006, 2007), Nyberg and Wass (2008b, 2009b, 2010), Wass (2011).
Hydrological data	**References**
Regional stream-discharge data (incl. long-term averages)	Lindell et al. (2000), Larsson-McCann et al. (2002).
Forsmark data	
Manual stream-discharge measurements.	Nilsson et al. (2003, 2010), Nilsson and Borgiel (2004, 2005, 2007, 2008), Johansson (2005a), Qvarfordt et al. (2008), Berg et al. (2009), SKBdoc 1334707.
Automatic stream-discharge measurements.	Johansson and Juston (2007, 2009, 2011a, b).
Surface-water level measurements in the sea, lakes and ponds.	Nyberg et al. (2004), Nyberg and Wass (2005, 2006, 2007, 2008a, 2009a), SKBdoc 1319765.
Hydrogeological Forsmark data	**References**
Groundwater levels in regolith and rock.	Nyberg et al. (2004), Nyberg and Wass (2005, 2006, 2007, 2008a, 2009a), SKBdoc 1319765.

Surface-water levels are measured at one location in the sea (one previous level gauge was destroyed by ice in November 2005), in six lakes (Bolundsfjärden, Eckarfjärden, Fiskarfjärden, Norra Bassängen, Gällsboträsket, and Tjärnpussen) and in five relatively small ponds (one is a manual gauge). One previous surface-water level gauge in Lake Lillfjärden was destroyed by ice in December 2006. Surface-water levels are measured at four gauging stations in four streams; measured water levels are converted to discharges using station-specific level-discharge relationships. The first discharge-gauging station became operational in April 2004, and the other three were taken into operation some eight months later in December 2004.

As of December 2010, groundwater levels are automatically registered in 45 groundwater monitoring wells in regolith. These include 11 wells installed in till below surface waters (lakes and ponds). The first measurements started in May 2003, which is the first month of the time series presented and analysed in this report. Most groundwater-level time series from these wells were interrupted for one or more time intervals.

The number of percussion-drilled boreholes in the rock increased steadily during the studied period. As of December 2010, there was ongoing monitoring in 41 percussion-drilled boreholes (including 3 at the SFR facility) and 20 (mostly short) core-drilled boreholes at SFR. Of these 20 core-drilled boreholes, 8 are drilled from the surface and 12 are drilled from tunnels in SFR. Most of these wells were sectioned with between 1–3 packers. It should be noted that, due to considerable differences in groundwater salinity and thereby in density with depth, groundwater levels measured in boreholes in the rock should be regarded as so called point-water heads, unless stated otherwise (for details, see Juston et al. 2007, Johansson 2008, Johansson and Öhman 2008).

2.2 Meteorological data

2.2.1 Paremeters and measurements locations

Figure 2-1 shows the locations of SKB's local meteorological stations (Högmasten and Storskäret) and surrounding meteorological stations operated by SMHI. Monitoring at the Högmasten (PFM-010700) and Storskäret (PFM010701) stations was initiated on May 12, 2003. The Storskäret station was decommissioned on July 1, 2007. Moreover, meteorological data are delivered annually to SKB for a number of surrounding SMHI stations, including Films Kyrkby (PFM010714), Lövsta (PFM010725), Risinge (PFM010811), Östhammar (PFM010815), Söderby-Karlsäng (PFM010818) and Örskär (PFM010832). The Högmasten station is located in the area of the planned surface facilities for the final repository for spent nuclear fuel. At some stage, this station will therefore be decommissioned. A new meteorological station, PFM006281 (Labbomasten), was established at drill site 1 (KFM01A and -B) in 2012 and taken into operation in 2013.

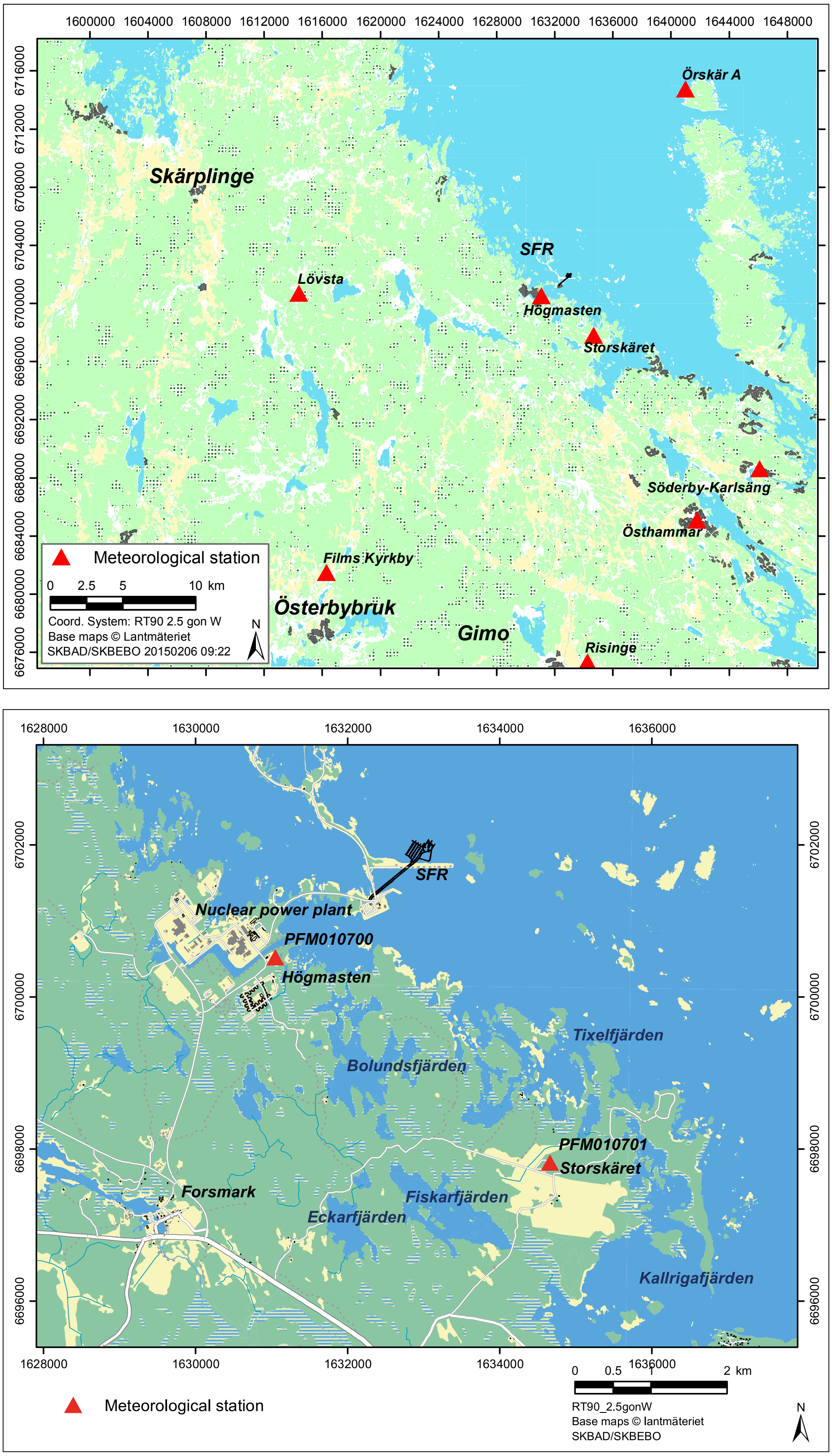


Figure 2-1. *Upper figure: Locations of SKB's local meteorological stations Högmasten and Storskäret (the latter decommissioned in 2007), and surrounding stations operated by SMHI. Lower figure: Detailed map showing the locations of SKB's stations.*

Table 2-3. Summary of SMHI meteorological data available in the end of 2010.

ID	Location	Start date (YYYY-MM-DD)	Stop date (YYYY-MM-DD), this report
PFM010714	Films Kyrkby	1963-01-01	2010-12-31
PFM010725	Lövsta	1961-01-01	2010-12-31
PFM010811	Risinge	2001-01-01	2010-12-31
PFM010815	Östhammar	1994-01-01	2010-12-31
PFM010818	Söderby-Karlsäng	2003-12-01	2010-12-31
PFM010832	Örskär	1961-01-01	2010-12-31

SKB's meteorological measurements comprise precipitation, air temperature, air pressure (only measured at Högmasten), wind speed and wind direction, air humidity, and global radiation (only measured at Högmasten). Wind speed and wind direction are measured at 10 m above the ground surface, whereas all other parameters are measured at 2 m above the ground surface. All precipitation data presented in this report are corrected for various types of measurement losses (the measured precipitation is lower than the actual, corrected precipitation). The potential evapotranspiration (PET) is calculated by SMHI, using the so-called Penman equation, and delivered to SKB. For details regarding instruments, recording intervals, data handling, and methodology for precipitation corrections and PET calculations, the reader is referred to Johansson and Öhman (2008) and references therein.

Winter parameters, in the form of snow depth, snow weight and lake- and sea-bay ice coverage, are measured and observed at five locations (Figure 2-2). The water content of snow is calculated by weighing snow samples at every snow-depth measurement. Snow depth and ice-cover observations were initiated during the 2002/2003 winter season, whereas snow water-content measurements started during the following winter season. Johansson and Öhman (2008) summarise the results of ground-frost depth measurements, which started during the 2003/2004 winter season and were discontinued after the 2005/2006 winter season.

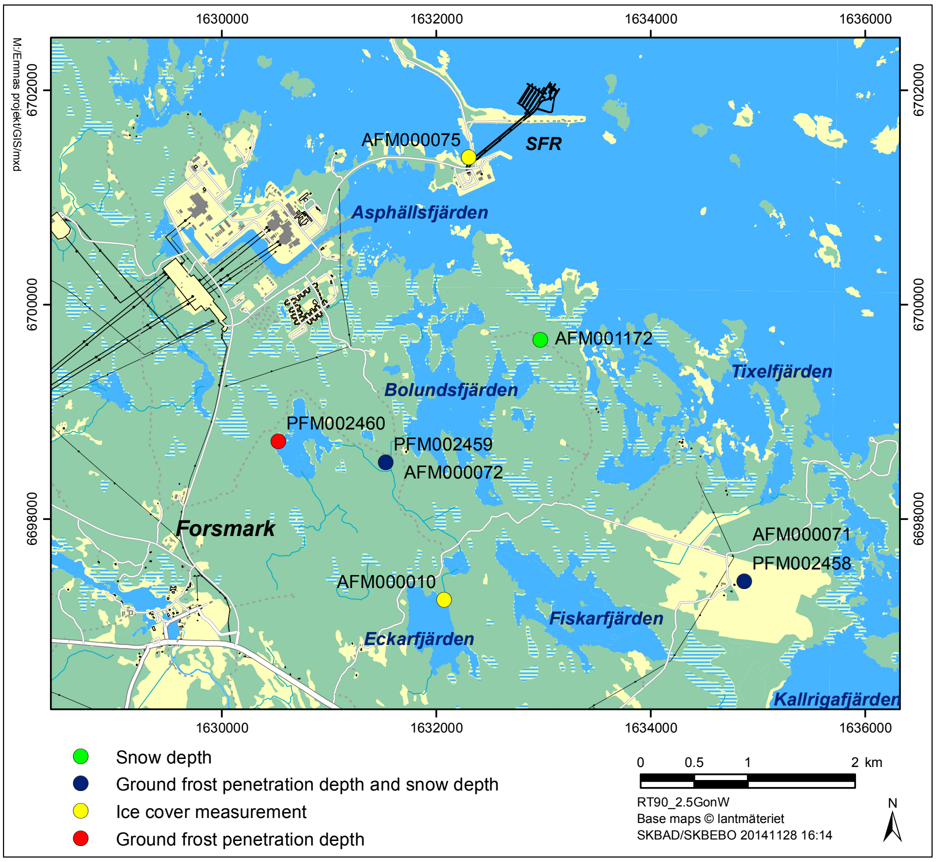


Figure 2-2. Locations of monitoring points for winter parameters. Ground-frost depth measurements were discontinued after the 2005/2006 winter season.

2.2.2 Precipitation and potential evapotranspiration

Figure 2-3 is based on 17 years (1994–2010) of precipitation data from the three SMHI stations at Lövsta, Östhammar and Örskär (cf. Figure 2-1). The figure also includes data from the SMHI station Söderby-Karlsäng, established in December 2003. For this 17-year period, the average annual precipitation at Lövsta, located c 15 km west of Forsmark, was 711 mm, which can be compared to only 511 mm at Örskär (a small island approximately 15 km northeast of Forsmark). These data show that there is a strong eastward precipitation gradient across the Forsmark area, with larger precipitation at the inland stations. The upper plot of Figure 2-4 shows the total annual precipitation at the same stations during the period 2003–2010 and the average of the 17-year dataset 1994–2010.

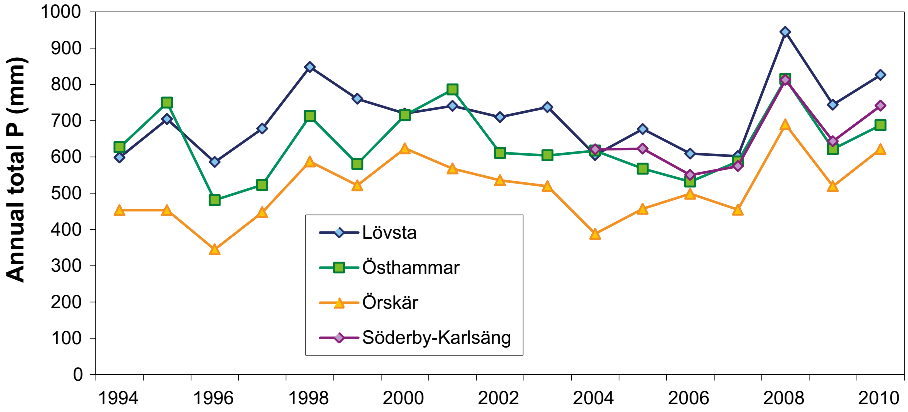


Figure 2-3. *Annual precipitation (P) at four SMHI stations for the period 1994–2010. At the station Söderby-Karlsäng measurements commenced on December 1, 2003. Note that Örskär data are missing for November 1995, whereas Östhammar data are missing for November 2006.*

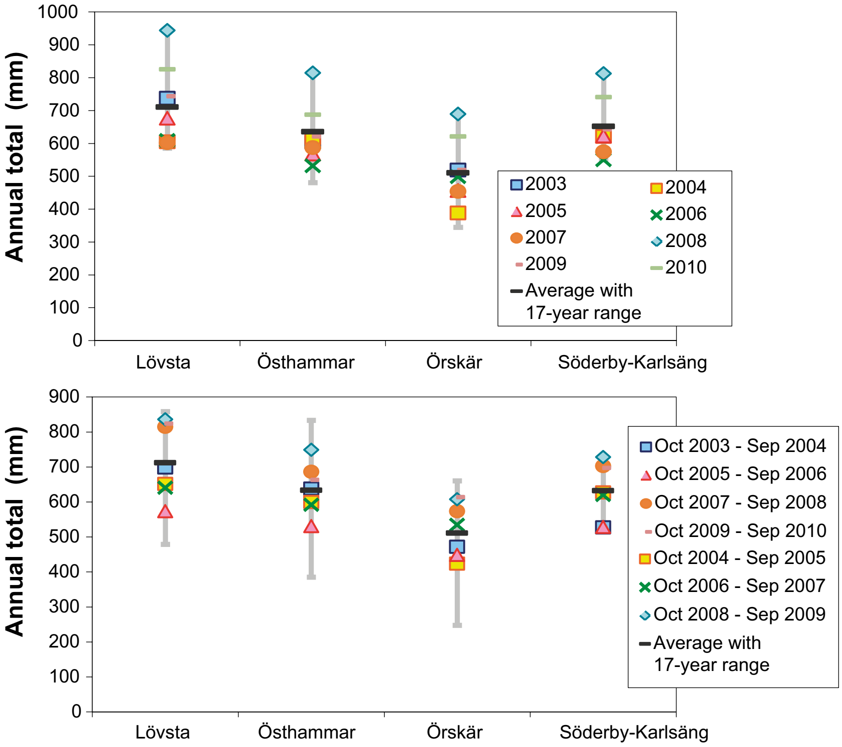


Figure 2-4. *Upper plot: Total annual precipitation at four SMHI stations during the period 2003–2010, and annual average precipitation for the period 17-year 1994–2010. Bottom: Total annual precipitation for one-year periods (October–September) and annual average precipitation for the 17-year period October 1993–September 2010. Note that Örskär data are missing for November 1995, and that Östhammar data are missing for November 2006.*

In the lower plot, data are shown for one-year periods during the period October 2003–September 2010 and the annual average precipitation for the period October 1993–September 2010.

Figure 2-5 shows daily precipitation at the Högmasten station during the period May 14, 2003–December 31, 2010, and the Storskäret station up to the end of June 2007. According to Johansson and Öhman (2008), there was a strong correlation between Högmasten and Storskäret in terms of daily precipitation, particularly during non-summer months.

As indicated in Figure 2-5, the dataset has periods of missing data. As no systematic analyses of data-filling methods has yet been performed, regression analyses were tentatively used to fill in data gaps of the current dataset using data from the SMHI stations Lövsta, Örskär and Söderby-Karlsäng. Specifically, for the Storskäret station, daily precipitation is estimated using the expression $P_{\text{Storskäret}} = P_{\text{Lövsta}} \cdot 0.399063444 + P_{\text{Örskär}} \cdot 0.60889543 + P_{\text{Söderby-Karlsäng}} \cdot 0.050353037$. The corresponding expression for the Högmasten station is $P_{\text{Högmasten}} = P_{\text{Lövsta}} \cdot 0.207778941 + P_{\text{Örskär}} \cdot 0.519060016 + P_{\text{Söderby-Karlsäng}} \cdot 0.269721755$.

Figure 2-6 shows monthly total precipitation at the Högmasten and Storskäret stations and four SMHI stations for the period June 2003–December 2010. For the Högmasten and Storskäret stations, missing data days are filled using regression analysis. As can be seen in these plots, the stations demonstrate similar seasonal patterns, with Örskär typically having the lowest precipitation on a monthly basis.

Figure 2-7 shows the total annual precipitation at Högmasten, Storskäret (up to the end of June 2007) and four SMHI-stations for the period 2004–2010. As mentioned above, missing data for the SKB stations are filled by regression analysis. Moreover, in this figure missing Östhammar data (November 2006) are also filled by regression analysis, using data from the Lövsta, Örskär and Söderby-Karlsäng stations. Specifically, for the Östhammar station, missing monthly precipitation is estimated using the expression $P_{\text{Östhammar}} = P_{\text{Lövsta}} \cdot 0.13294 + P_{\text{Örskär}} \cdot 0.0627744 + P_{\text{Söderby-Karlsäng}} \cdot 0.819357$.

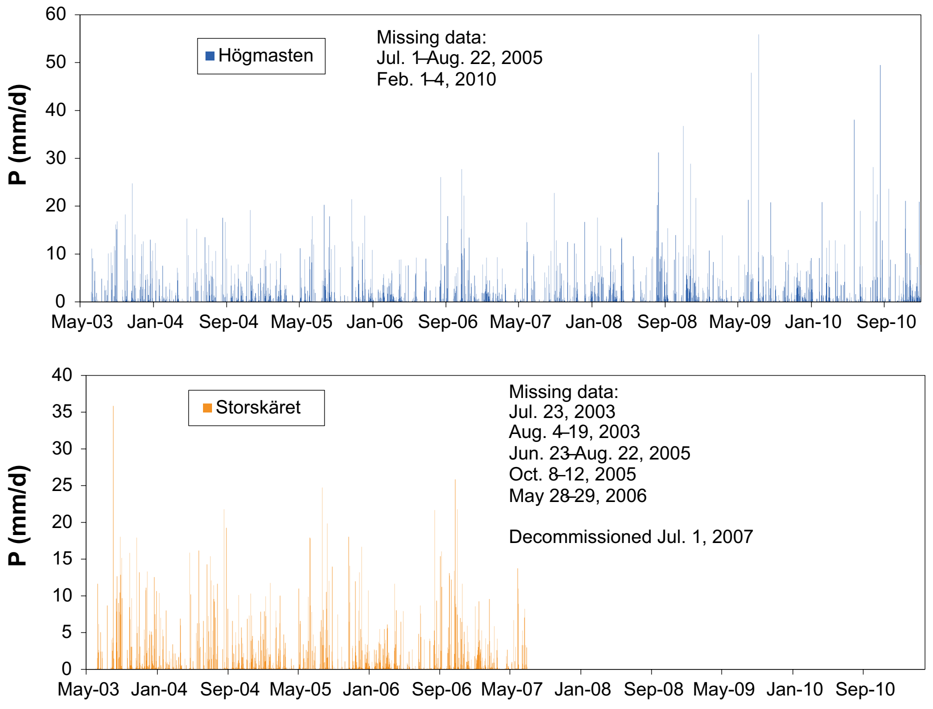


***Figure 2-5.** Daily precipitation at the Högmasten station (upper plot) and the Storskäret station (lower plot) during the period May 14, 2003–December 31, 2010. Data gaps are filled by regression analysis using data from the surrounding SMHI stations Lövsta, Örskär and Söderby-Karlsäng.*

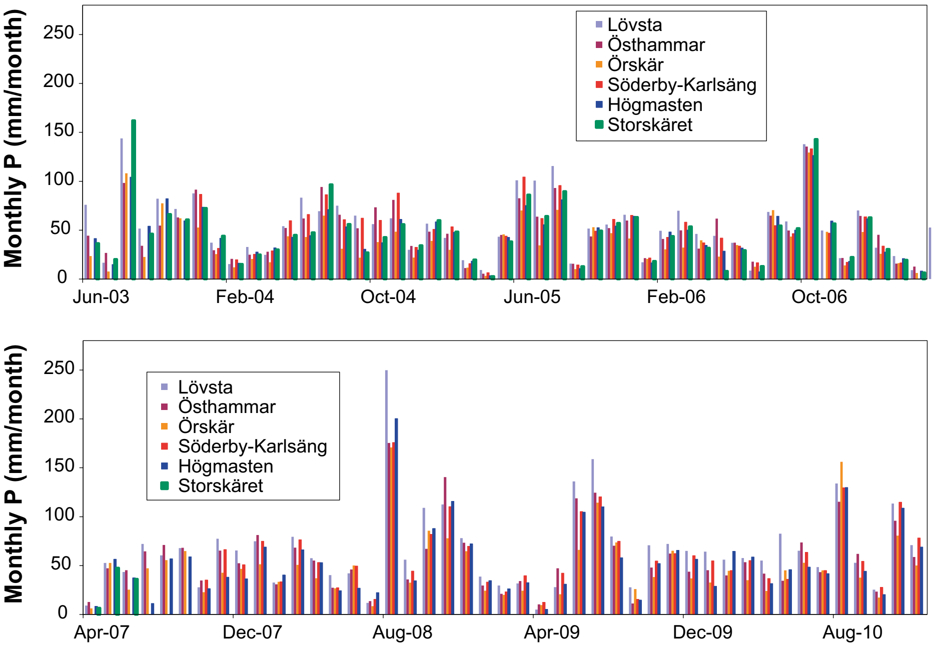


Figure 2-6. *Monthly total precipitation at Högmasten, Storskäret and four SMHI stations for the period June 2003–March 2007 (upper plot) and April 2007–December 2010 (lower plot). Missing Högmasten and Storskäret data are filled using regression analysis. Note that Östhammar data are missing for November 2006.*

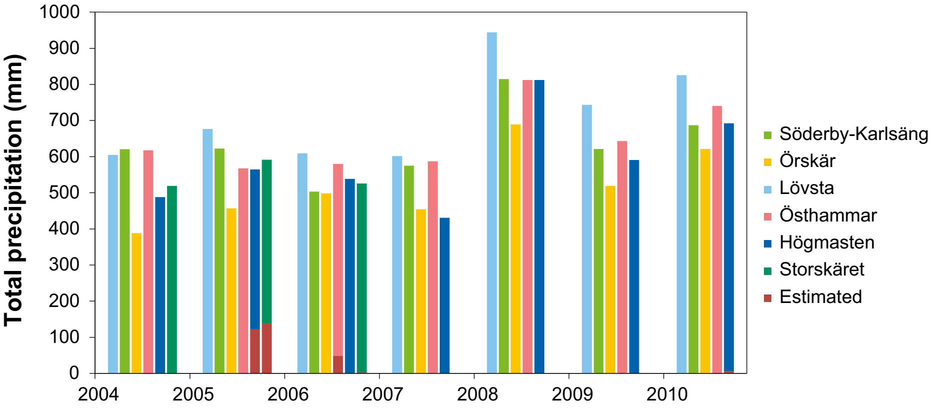


Figure 2-7. *Annual total precipitation at Högmasten, Storskäret and four SMHI stations for the period 2004–2010. The Storskäret station was decommissioned July 1, 2007. For this station, the annual total precipitation 2007 is therefore set to zero in the figure.*

Table 2-4 presents annual average and annual total precipitation for the Högmasten station for ten different time periods, including the individual years 2004–2010. For the three long time periods the annual average precipitation is c 585–590 mm, which is above the estimated annual average (559 mm) for the current reference normal period 1961–1990 (Johansson 2008). For the individual years 2004–2010, the annual total precipitation is in the interval 440–812 mm. Figure 2-8 shows monthly precipitation at Forsmark for the period 2004–2010 (average of Högmasten and Storskäret up to the end of June 2007, Högmasten thereafter). Table 2-4 and Figure 2-8 indicate that the period 2007–2010 is characterised by more precipitation compared to the period 2004–2006. Specifically, for the period 2007–2010 the average monthly and annual precipitation were 54 and 632 mm, respectively, whereas the corresponding averages were 45 and 538 mm for the period 2004–2006.

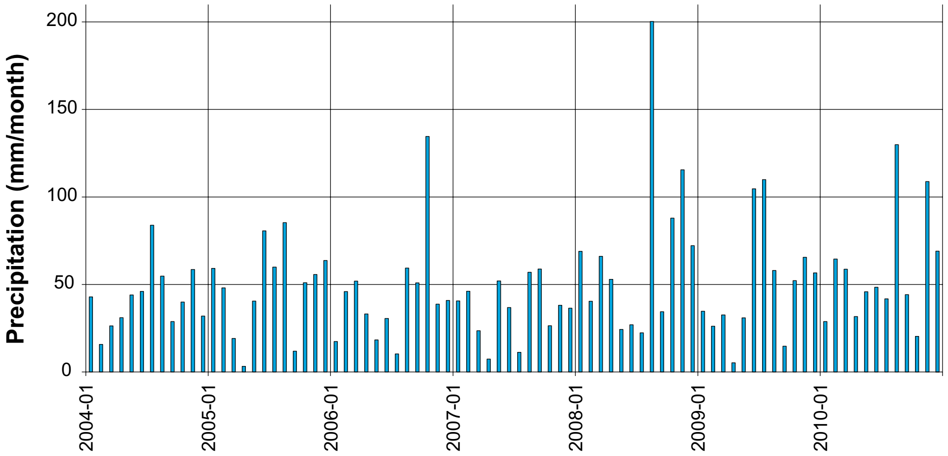


Figure 2-8. Monthly precipitation (average of Högmasten and Storskäret up to the end of June 2007, Högmasten thereafter) for the period 2004–2010.

Table 2-4. Annual average and annual total precipitation at the Högmasten station for different time periods. Missing periods are estimated using regression analysis.

Time period	Annual average corrected precipitation (mm)
Jan. 2004–Dec. 2010	589
Oct. 2003–Sep. 2010	591
Jun. 2003–May 2010	584
2004	488
2005	564
2006	535
2007	440
2008	812
2009	591
2010	692

Table 2-5 gives the annual average potential evapotranspiration (PET) for ten different time periods (cf. Table 2-4), whereas Figure 2-9 plots daily sums and rolling annual sums (from May 2004) for the period May 2003–December 2010. For the three long time periods, irrespective of period the annual average PET sum is c 510 mm, whereas the annual PET sum is in the interval 463–539 mm for the individual years 2004–2010. During the period May 12, 2003–December 31, 2010, the average and maximum daily PET sums are 1.4 and 7.2 mm, respectively (negative daily PET sums are set to zero). As shown in Figure 2-10, the average monthly PET sum for the period June 2003–December 2010 varies between 110–120 mm per month in June–July, and 1–3 mm per month in January–February and November–December.

Table 2-5. Calculated potential evapotranspiration (PET) at the Högmasten station for different time periods. Negative daily PET sums are set to zero.

Time period	PET (mm)
Jan. 2004–Dec. 2010	509
Oct. 2003–Sep. 2010	508
Jun. 2003–May 2010	513
2004	509
2005	526
2006	539
2007	524
2008	508
2009	492
2010	463

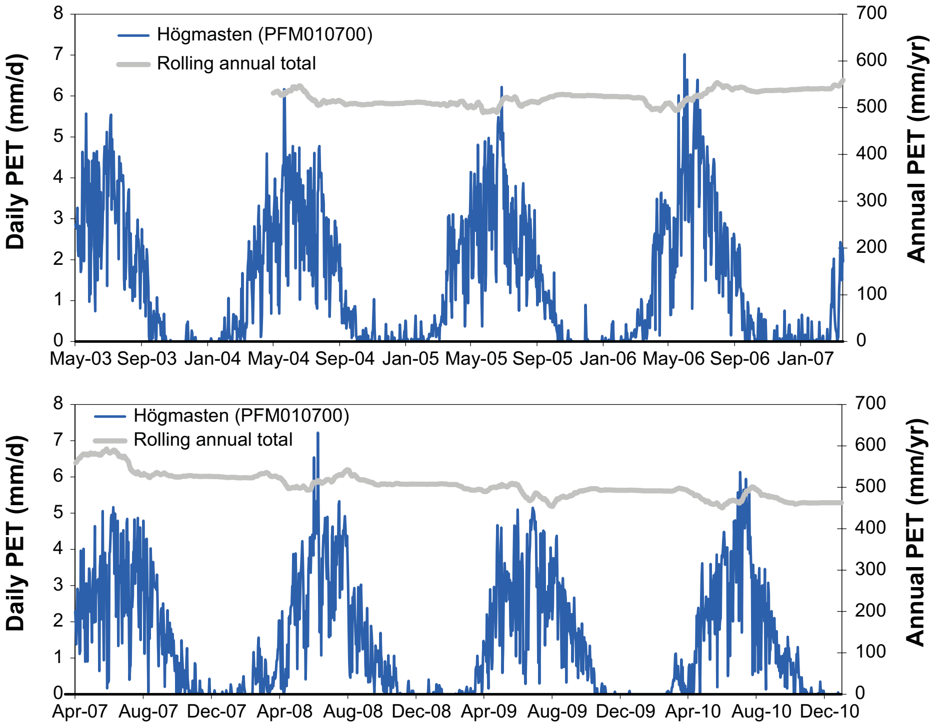


Figure 2-9. *Daily sums and rolling annual sum of calculated PET for the Högmasten station. Negative daily PET sums are set to zero.*

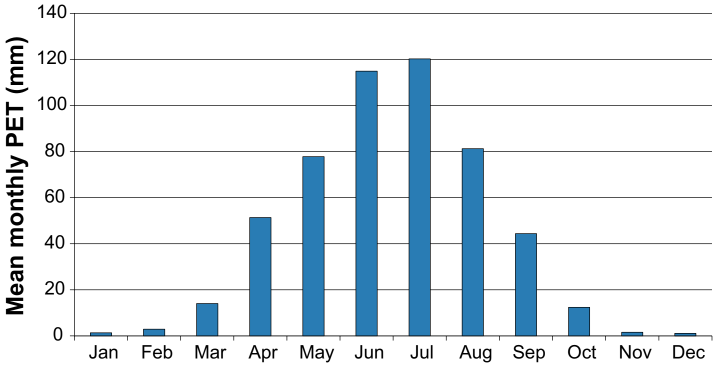


Figure 2-10. *Average monthly PET at the Högmasten station for the period June 2003–December 2010. Negative daily PET sums are set to zero.*

2.2.3 Winter parameters

Snow-depth measurements were initiated during the 2002/2003 winter season (Aquilonius and Karlsson 2003), whereas snow-weight measurements were initiated during the subsequent 2003/2004 winter season (Heneryd 2004, 2005, 2006, 2007, Nyberg and Wass 2008b, 2009b, 2010, Wass 2011). The winter-time measurements are done at three locations, representing open land (AFM000071 at Storskäret) and forest (AFM000072 at Lake Bolundsfjärden, and from the 2003/2004 winter season also AFM001172 at Jungfruholm), see Figure 2-2. At each location, snow depth and snow weight are measured at six points, of which the average snow weight is used to calculate the average snow water content (Figure 2-11).

Table 2-6 summarises maximum snow depths and maximum snow water contents during the 2002/2003–2010/2011 winter seasons. Data up to the 2006/2007 winter season have been taken from Aquilonius and Karlsson (2003) and Heneryd (2004, 2005, 2006, 2007), whereas data from the 2007/2008–2010/2011 winter seasons were included in the Sicada delivery 11_078 (Table 2-1). Note that seasonal maxima of snow depth and snow water content do not always occur on the same dates.

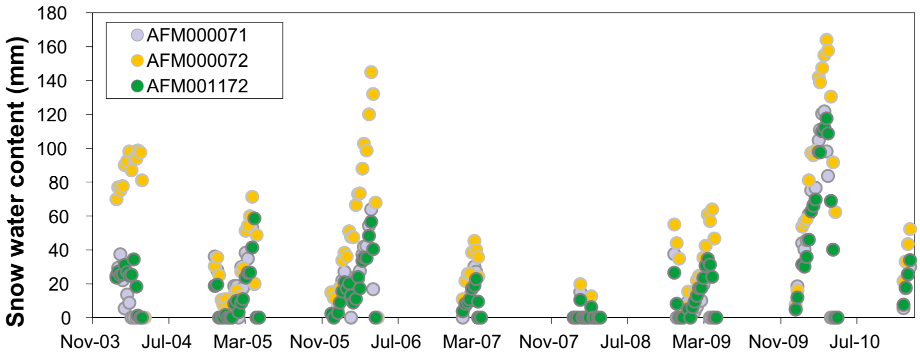


Figure 2-11. *Average water content (mm) in accumulated snow at three locations during the 2003/2004–2010/2011 winter seasons.*

Table 2-6. Summary of snow measurements during the 2002/2003 to 2010/2011 winter seasons.

Open land (AFM000071)	Max. snow depth (cm)	Max. snow water content (mm)
2002–2003	20	No data
2003–2004	19	37
2004–2005	21	53
2005–2006	25	64
2006–2007	17	30
2007–2008	17	15
2008–2009	15	38
2009–2010	47	122
2010–2011	40	86
Forest land (average of AFM000072 and AFM001172)	**Max. snow depth (cm)**	**Max. snow water content (mm)**
2002/2003	25 (AFM000072 only)	No data
2003/2004	31	66
2004/2005	25	65
2005/2006	38	101
2006/2007	24	34
2007–2008	17	15
2008–2009	21	49
2009–2010	58	141
2010–2011	52	130

In general, the ground is covered with snow from November–December to March–April. As can be seen in Table 2-6, the largest snow depths and snow water contents were measured during the 2009/2010 and 2010/2011 winter seasons, with a maximum snow depth of almost 0.6 m and a maximum snow water content of c 140 mm at the forest locations. On the contrary, the 2007/2008 winter season had very little snow, with just a few days of snow (maximum snow depth 0.17 m, maximum snow water content 15 mm) during the period January–March 2008.

During the three winter seasons 2003/2004–2005/2006, ground-frost depths were measured at two forest locations (PFM002459 at Skogsgläntan and PFM002460 at Gällsboträsket), and also at an open-land location (PFM002458 at Storskäret), see Figure 2-2. During these three winter seasons, there was ground frost during 40 and 80 days per season at the forest and open-land locations, respectively. The maximum ground-frost depth in open land was 0.46 m, whereas the maximum depth was only 0.08 m in forest. For further details, see Aquilonius and Karlsson (2003) and Heneryd (2004, 2005, 2006).

Ice-cover observations, i.e. dates for ice freeze-up and ice breakup in the beginning and end of each winter season, are made at one lake (Lake Eckarfjärden) and at a bay of the Baltic Sea, close to the Forsmark harbour. As shown in Table 2-7, Lake Eckarfjärden is typically ice covered from November/December to March/April. During the 2007/2008 winter season the lake was ice covered during a relatively short period, from the beginning of January to the middle of March.

Table 2-7. Ice-cover observations at Forsmark during the nine winter seasons 2002/2003–2010/2011.

Lake Eckarfjärden (AFM000010)	Date for ice freeze-up (YYYY-MM-DD)	Date for ice break-up (YYYY-MM-DD)	Period with ice cover (days)
2002–2003	2002-11-12	2003-04-02	141
2003–2004	2003-12-12	2004-04-06	117
2004–2005	2004-11-18	2005-04-09	143
2005–2006	2005-11-21	2005-12-01	143 (in total)
	2005-12-12	2006-04-24	
2006–2007	2006-12-18	2007-03-26	98
2007–2008	2008-01-01	2008-03-14	74
2008–2009	2008-11-26	2009-04-09	134
2009–2010	2009-12-02	2010-04-19	139
2010–2011	2010-11-09	2011-04-18	161
Sea bay at SFR (AFM000075)			
2002–2003	2003-01-07	2003-03-31	83
2003–2004	2003-12-17	2004-04-13	120
2004–2005	2004-12-21	2005-01-13	95 (in total)
	2005-01-27	2005-04-07	
2005–2006	2005-12-12	2006-04-24	133
2006–2007	2007-01-22	2007-03-22	60
2007–2008	2008-01-23	2008-01-24	9 (in total)
	2008-02-12	2008-02-12	
	2008-02-18	2008-02-21	
	2008-03-04	2008-03-05	
2008–2009	2009-01-05	2009-04-09	94
2009–2010	2009-12-18	2010-04-23	126
2010–2011	2010-11-29	2011-04-13	136

The Baltic Sea bay is usually frozen a month later than the lake, whereas the ice breakup typically occurs simultaneously with the lake. For further details, see Aquilonius and Karlsson (2003), Heneryd (2004, 2005, 2006, 2007), Nyberg and Wass (2008b, 2009b, 2010) and Wass (2011).

2.2.4 Other meteorological parameters

Figure 2-12 shows a plot of daily average air temperature, in the form of the average of the Högmasten and Storskäret stations up to the end of June 2007, and the Högmasten only during July 2007–December 2010. According to Johansson and Öhman (2008), there was a strong correlation between these two stations in terms of daily average air temperatures. For the whole period 2004–2010 the daily average air temperature for the Högmasten station was 6.7 ºC, whereas the annual average varies between 5 and 7.5 ºC for the individual years 2004–2010 (Table 2-8).

Table 2-8. Daily average air temperature at the Högmasten station for the individual years 2004–2010.

Year	Daily average air temperature (°C)
2004	6.5
2005	6.9
2006	7.5
2007	7.0
2008	7.3
2009	6.7
2010	5.0

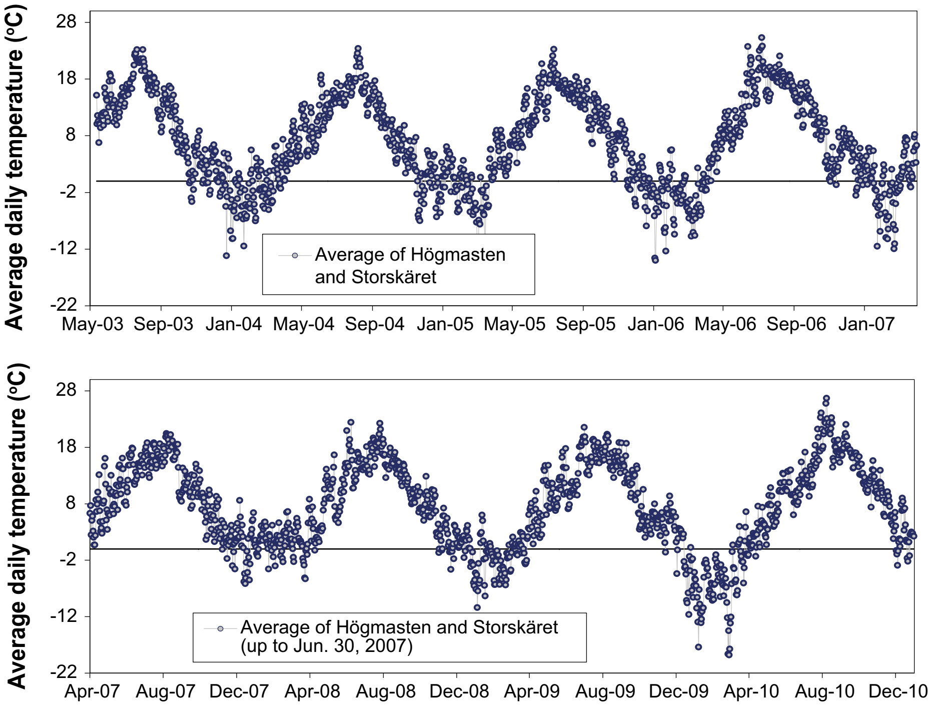


Figure 2-12. *Daily average air temperature, shown as the average of the Högmasten and Storskäret stations during the period May 12, 2003–July 1, 2007, and from the Högmasten station only during the period July 2, 2007–December 31, 2010.*

Daily average air pressure (mbar) is shown in Figure 2-13 for Högmasten (from July 9, 2003). There was a strong correlation between Högmasten and the Örskär station; for the period with data available from both stations, the average air pressure was 1,011.70 mbar at Högmasten and 1,011.73 mbar at Örskär. Moreover, the minimum and maximum air pressures were 969.50 and 1,044.98 mbar at Högmasten and 969.68 and 1,044.11 at Örskär.

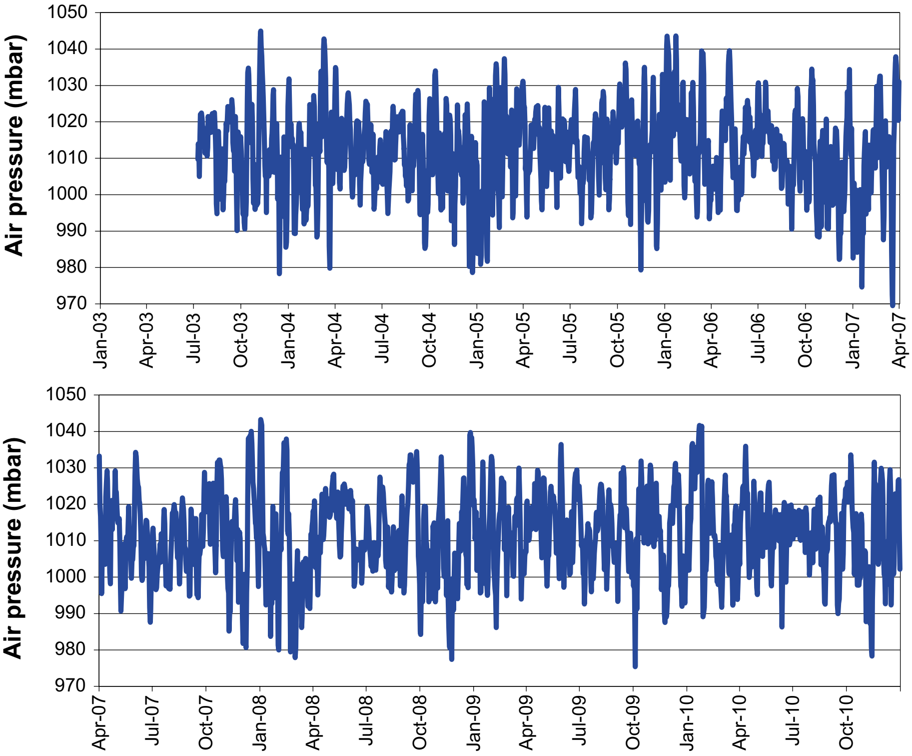


Figure 2-13. *Daily average air pressure at the Högmasten station for the period 2003–2010.*

As shown in Figure 2-14, the wind speed is substantially higher at the Örskär station (located at an exposed location on a small island) compared to the Högmasten and Storskäret stations. For the period May 2003–December 2010, the average wind speed was 5.8 $\mathrm{m \cdot s^{-1}}$ at Örskär, 1.6 $\mathrm{m \cdot s^{-1}}$ at Högmasten and 1.9 $\mathrm{m \cdot s^{-1}}$ at Storskär (up to the end of June 2009), with maximum daily average wind speeds of 30.1, 8.7 and 5.5 $\mathrm{m \cdot s^{-1}}$. The dominating wind direction is from south-west (Figure 2-15).

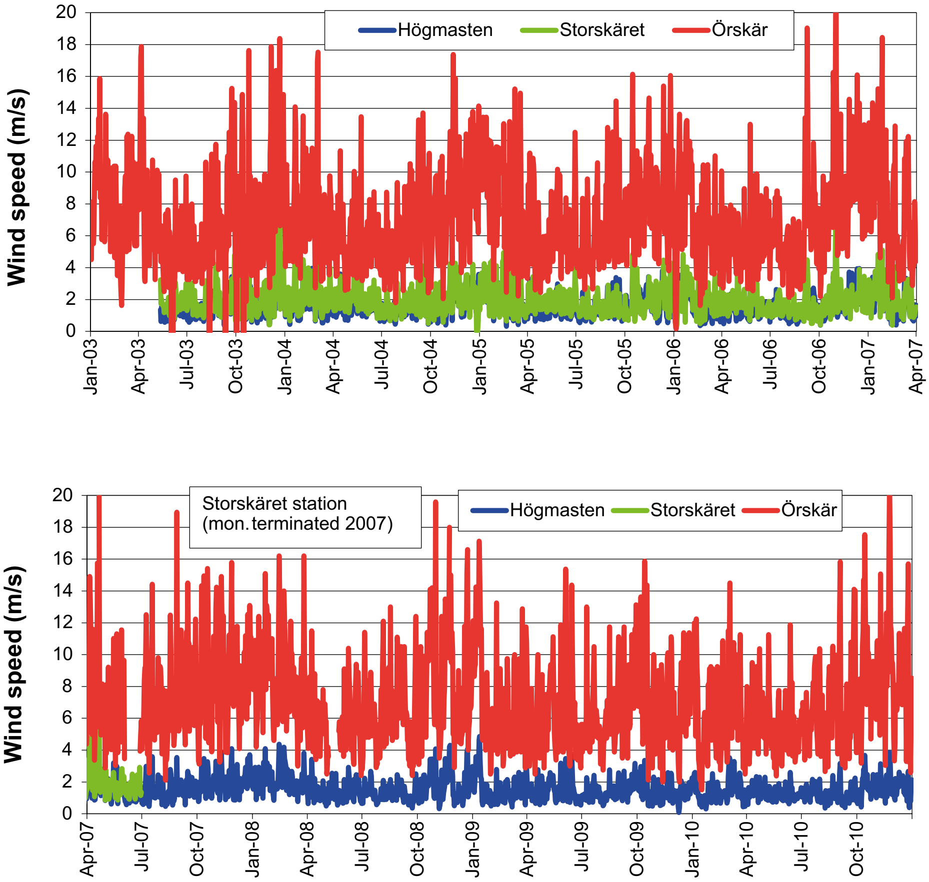


Figure 2-14. Wind speed at Högmasten, Storskäret and at the SMHI station Örskär for the period 2003–2010.

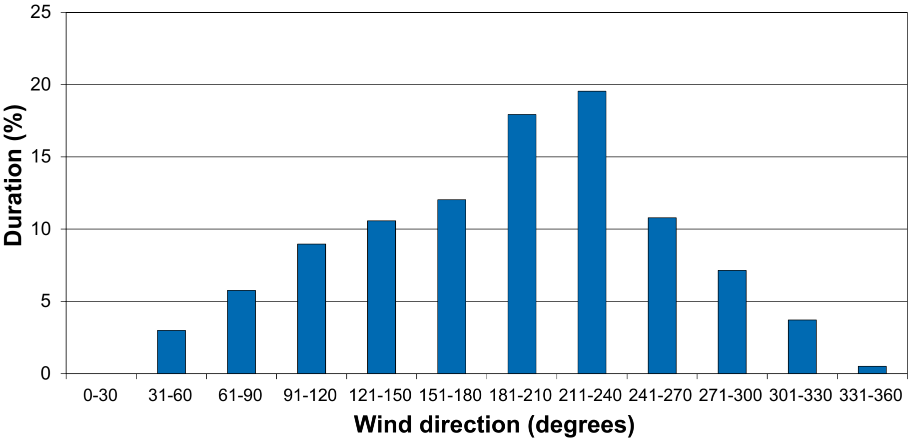


Figure 2-15. Plot of wind directions based on daily data from the Högmasten and Örskär stations during the period April 1, 2007– December 31, 2010. Wind from north = 0°, from east = 90°, from south = 180°, and from west = 270°.

The relative humidity (Figure 2-16) was very similar at the Örskär, Högmasten and Storskäret, with an average relative humidity of c 80% at all stations (up to the end of June 2007 at Storskäret).

Figures 2-17 and 2-18 show monthly averages (W·m^{-2}) and monthly sums (kWh·m^{-2}) of global radiation for the period 2004–2010 from the Högmasten station. For the period May 12, 2003–December 31, 2010, the average global radiation varies between c 4 W·m^{-2} in December and 237 W·m^{-2} in June. For the same period, the annual sum of global radiation was on average 915 kWh·m^{-2}.

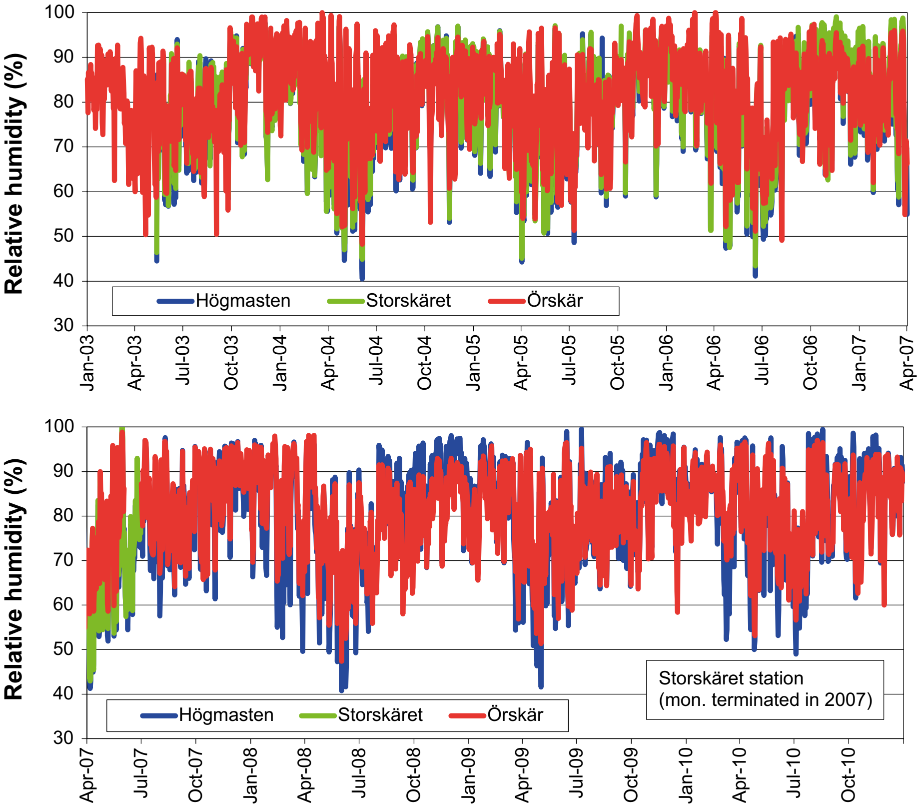


Figure 2-16. *Relative humidity at the SKB stations Högmasten and Storskäret (up to Jul. 2007) and at the SMHI station Örskär.*

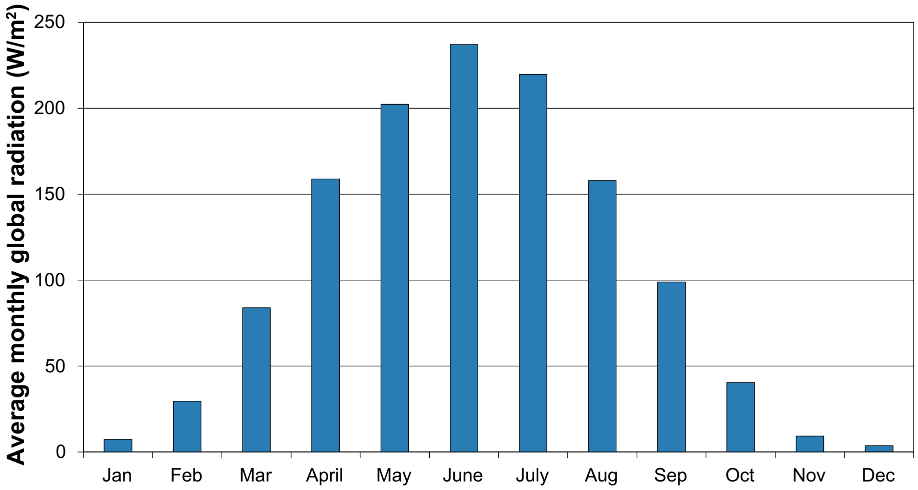


Figure 2-17. *Monthly averages of global radiation (W·m^{-2}) at the Högmasten station for the period June 2003–December 2010.*

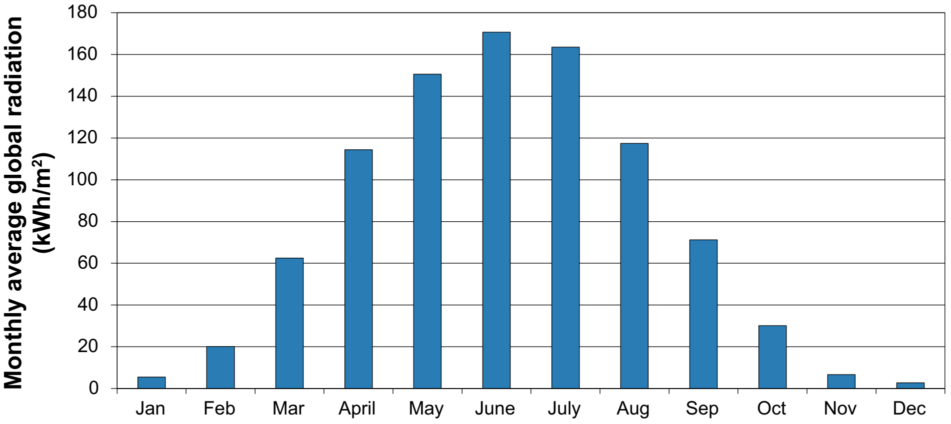


Figure 2-18. *Average monthly sums of global radiation (kWh·m^{-2}) at the Högmasten meteorological station for the period Jun. 2003–Dec. 2010.*

2.3 Surface-water levels

As of December 2010, surface-water levels are monitored in 11 surface-water level gauges installed in six lakes (Norra Bassängen, Bolundsfjärden, Eckarfjärden, Gällsboträsket, Fiskarfjärden and Tjärnpussen), five ponds (i.e. small lakes in wetlands), and at two sea-level gauges, of which one is operated SMHI, see Table 2-9 and Figure 2-19. The installations of the gauges (except the SMHI gauging station, PFM0100039) are reported in Johansson (2003), Werner and Lundholm (2004) and Werner et al. (2009). Surface-water levels were previously monitored also at SFM0043 (sea level, Kallrigafjärden) and SFM0066 (lake level, Lake Lillfjärden). Monitoring of the lake-level gauge SFM0041 in Lake Eckarfjärden was terminated in March 2011, and monitoring commenced in the new gauge SFM000127. Moreover, totally six new surface-water level gauges, SFM000128–131 (March 2012) and SFM000136–137 (March 2014) have been installed in recently constructed ponds. For gauges with ongoing monitoring in Table 2-9, stop dates during September–November 2010 for the present report are due to weak ice and/or presence of ice in gauges, preventing manual depth soundings necessary for quality control of the surface-level monitoring.

Table 2-9. Summary of surface-water level data available in the end of 2010. For gauges with ongoing monitoring, stop dates during September–November 2010 are due to weak ice and/or presence of ice in gauges, preventing manual depth soundings.

Gauge id	Comment	Start date (YYYY-MM-DD)	Stop date, (YYYY-MM-DD), this report
PFM010038 (previous id SFM0038)	Sea-water level (gauge oper. by SKB).	2003-05-22	2010-12-31
PFM010039	Sea-water level (gauge oper. by SMHI).	2004-08-01	2010-12-31
SFM0039	Lake Norra Bassängen.	2003-05-01	2010-10-12
SFM0040	Lake Bolundsfjärden.	2003-05-16	2010-11-01
SFM0041	Lake Eckarfjärden; mon. terminated in Mar., 2011 (replaced by the new gauge SFM000127).	2003-05-01	2010-10-28
SFM0042	Lake Fiskarfjärden.	2004-02-05	2010-10-28
SFM0043	Sea-water level (Kallrigafjärden), mon. terminated.	2003-05-01	2005-11-07
SFM0064	Lake Gällsboträsket.	2004-04-21	2010-09-26
SFM0066	Lake Lillfjärden; mon. terminated.	2004-05-06	2006-12-05
SFM000111	Pond in wetland object 7; see Werner et al. (2009).	2009-04-28	2010-10-18
SFM000113	Pond in wetland object 14 (Norra Labbofjärden); see Werner et al. (2009).	2009-04-28	2010-11-21
SFM000115	Pond in wetland object 16; see Werner et al. (2009).	2009-04-28	2010-10-18
SFM000117	Pond in wetland object 18 (Kungsträsket); see Werner et al. (2009).	2009-04-30	2010-10-13
SFM000119	Lake Tjärnpussen.	2009-05-07	2010-10-18
PFM004513	Ephemeral pond in wetland object 23 (gauging scale on gw.-mon. well SFM000118); see Werner et al. (2009).	No data	

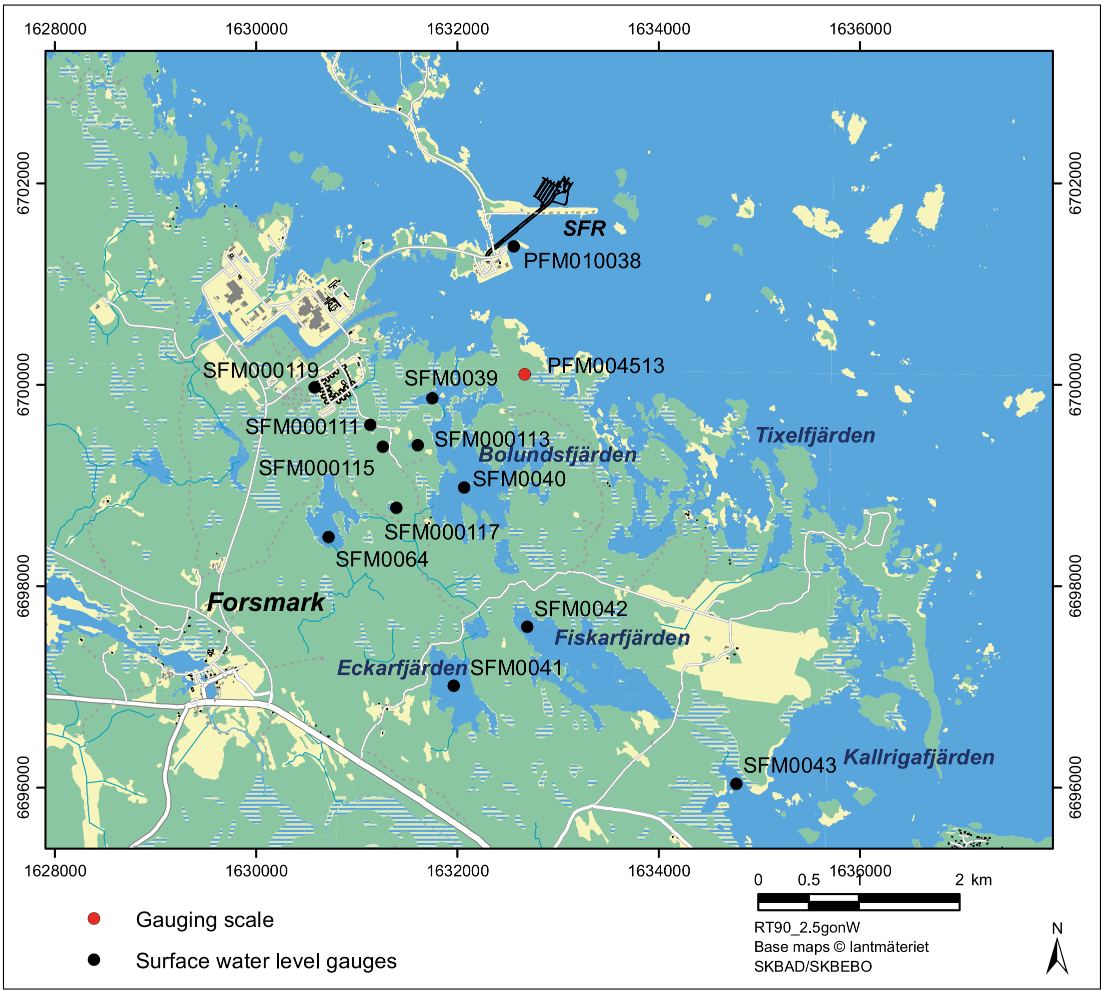


Figure 2-19. *Locations of surface-water level gauges. The outside of groundwater-monitoring well SFM000118 (cf. Figure 2-24) is used as gauging scale for manual surface-water level measurements at PFM005413 (see Werner et al. 2009).*

Table 2-10 shows levels of surface-water level gauges SFM0039, -40, -42 and -64 (top of casing, ToC), and the results of new levelling done in October–November 2010. ToC is the reference point for manual depth soundings, which are used to check, and, if required, adjust conversions of pressure data to surface-water levels (m). According to the 2010 levelling, two of the gauges (SFM0040 and -42) have been displaced vertically, on the order of 0.1 m, since they were installed in 2003. These displacements are likely due to winter-time ice shear in the lakes, whereas the vertical displacements are rather small (0.001–0.006 m) for the gauges SFM0039 and -64.

There is no information on when actual displacements did occur, and the new ToC levels are set to be valid from the end of the levelling campaign (November 4, 2010). In the dataset of the present report, there are no approved data from these gauges during the period November 4–December 31, 2010 (cf. Table 2-8). Gauge displacements may take place every winter, and levelling campaigns are to be repeated annually from 2010 and onwards. As a result of these campaigns, adjusted ToC levels will be set at the end of the ice-covered period, using the ice-breakup date based on ice observations in Lake Eckarfjärden (cf. Section 2.2.3).

As was also noted by Johansson and Öhman (2008), the SKB and SMHI sea-level gauges show good agreement in terms of the temporal sea-level variability (Figure 2-20). However, it is noted that the SKB level gauge systematically shows slightly lower sea level compared to the SMHI gauge. For the common data period (August 1, 2004 –December 31, 2010), the average sea level measured at the SKB gauge is –0.05 m, whereas the corresponding average for the SMHI gauge is –0.02 m. It is also noted that there are some periods with missing data. In particular, in July–September and November–December 2003, there are no sea-level data available from neither the SKB nor the SMHI gauge.

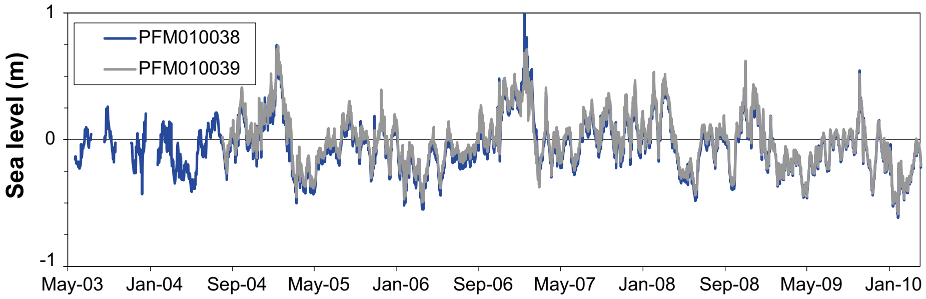


Figure 2-20. *Daily average sea level measured at the SKB (PFM010038) and the SMHI (PFM010039) level gauges in the Forsmark harbour. Data from the SMHI gauge are available from August 1, 2004.*

Table 2-10. Original and 2010 levelling of surface-water level gauges. ToC = top of casing (levels obtained from the Sicada database).

Well id	ToC (m), original levelling (reference)	ToC (m), 2010 levelling (valid from 2010-11-04)	Vert. displacement (m)
SFM0039 (Lake Norra Bassängen)	1.404 (Johansson 2003).	1.410	+0.006
SFM0040 (Lake Bolundsfjärden)	1.568 (Johansson 2003; confused with SFM023 in the report).	1.681 (2006 levelling: 1.604)	+0.113
SFM0042 (Lake Fiskarfjärden)	1.532 (Werner and Lundholm 2004; given as 1.53 m in the report).	1.629	+0.097
SFM0064 (Lake Gällsboträsket)	2.800 (Werner and Lundholm 2004).	2.799	–0.001

Since measurements were initiated in May 2003, the highest daily average sea level recorded at the SKB sea-level gauge PFM010038 is 0.99 m. This occurred on January 14, 2007, during the storm “Per”, whereas the lowest daily average is –0.61 m (January. 26, 2010). The current SMHI sea-level gauge at Forsmark (SKB id PFM010039, SMHI station id 2179) has been in operation since 1975 (SMHI 2009). Prior to 1975, older types of sea-level gauges have been installed at or in the vicinity of Forsmark, including a so called mareograph (a mechanical device) and a diagramme recorder that were operated 1891–1978 at Björn, c 30 km to the north of Forsmark. According to data from these previous measurements, the storm “Per” was associated with the highest recorded sea level also in a long-term perspective, i.e. since 1891 (SMHI 2009).

Figure 2-21 shows plots of the cumulative frequency (i.e. the ogive) of daily average (upper plot) and daily maximum (lower plot) sea levels measured at the current SMHI gauge at Forsmark. These plots are based on hourly values during the 37-year period September 1, 1975–August 31, 2013, hence including the extreme event in a 100-year perspective. The SMHI sea-level data, which are given in the coordinate system RH 2000, are for the present purposes transformed to the RHB 70 system. This is done by subtracting 0.18 m, which is an approximation of the land uplift in Forsmark during the 30-year period 1970–2000 (Söderbäck 2008). The average of the high-resolution SMHI dataset is c 0.19 m in RH 2000, whereas the corresponding average of the transformed, high-resolution dataset is c 0.01 m in RHB 70.

The highest daily average sea level recorded at the SMHI gauge during the 37-year period 1975–2013 is 0.97 m (upper plot of Figure 2-21). This occurred on January 18, 1983, during which day the high-resolution dataset (hourly values) shows a peak value of 1.24 m and the sea level is above 1 m during several hours. On Jan. 14, 2007 (during the storm “Per”), the daily average sea level at the SMHI gauge is 0.80 m (0.99 m at the SKB gauge). During this day, the high-resolution SMHI dataset shows a peak of 1.37 m (lower plot of Figure 2-21), whereas the corresponding peak at the SKB gauge is 1.39 m. At the SMHI gauge, recorded sea levels are otherwise lower on this day compared to Jan. 18, 1983, which gives a smaller daily average. The SKB gauge typically stores data every second hour, but data are stored more frequent (down to 5-minute intervals) during storm events associated with large level changes. This implies that the daily average sea level on January 14, 2007 is higher at the SKB gauge than the SMHI gauge.

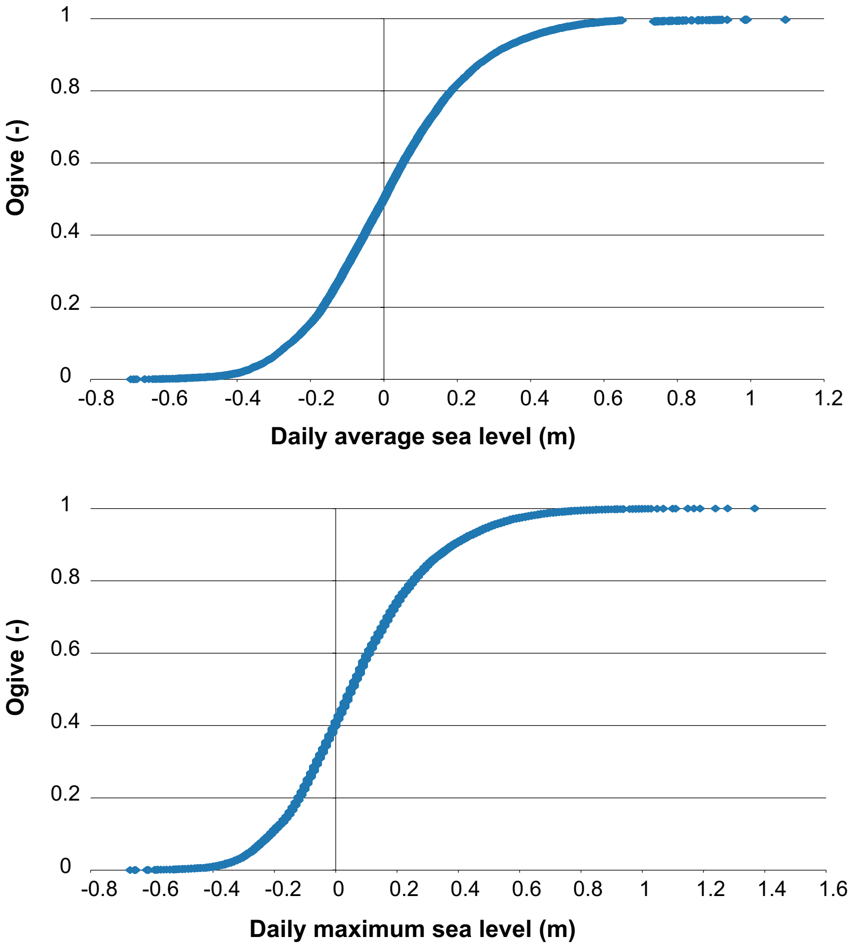


Figure 2-21. *Cumulative-distribution function of daily average (upper plot) and daily maximum (lower plot) sea level during the period September 1, 1975–August 31, 2013, measured at the SMHI sea-level gauging station 2179 at Forsmark.*

The daily average sea level recorded at the SMHI gauge is above 0.9 m only during a single day during the analysed 37-year period (cf. above). On the other hand, as shown in the lower plot of Figure 2-21 the high-resolution dataset contains 34 hourly values above 0.9 m (c one hour per year on average). The corresponding data for hourly values above 1, 1.1, 1.2 and 1.3 m are 14, 7, 3 and one value, respectively. Hence, according to the SMHI dataset the sea level at Forsmark is on average above 0.9 m during one hour almost every year, and above 1 m during one hour every third year.

The upper plot of Figure 2-22 shows daily average surface-water levels in lakes and ponds, whereas the lower plot shows a close-up of the four lakes with surface-water levels close to sea level. As can be seen in the lower plot, the lake level of Lake Lillfjärden (SFM0066, now terminated) is mainly influenced by the sea level. The lake levels of Lake Norra Bassängen (SFM0039) and Lake Bolundsfjärden (SFM0040) mainly seem to be controlled by the lake thresholds and surface water and groundwater inflow from the inland.

As discussed further in Johansson and Öhman (2008), the sea level occasionally rises above the lake thresholds of the lakes located close to the sea shoreline, e.g. during the major storms in January 2005 and January 2007 ("Gudrun" and "Per", respectively). These sea-water inflow occasions are shown as EC (electrical conductivity) peaks at PFM002292 (monitoring is now terminated) in the channel between Lake Norra Bassängen and Lake Bolundsfjärden in Figure 2-23.

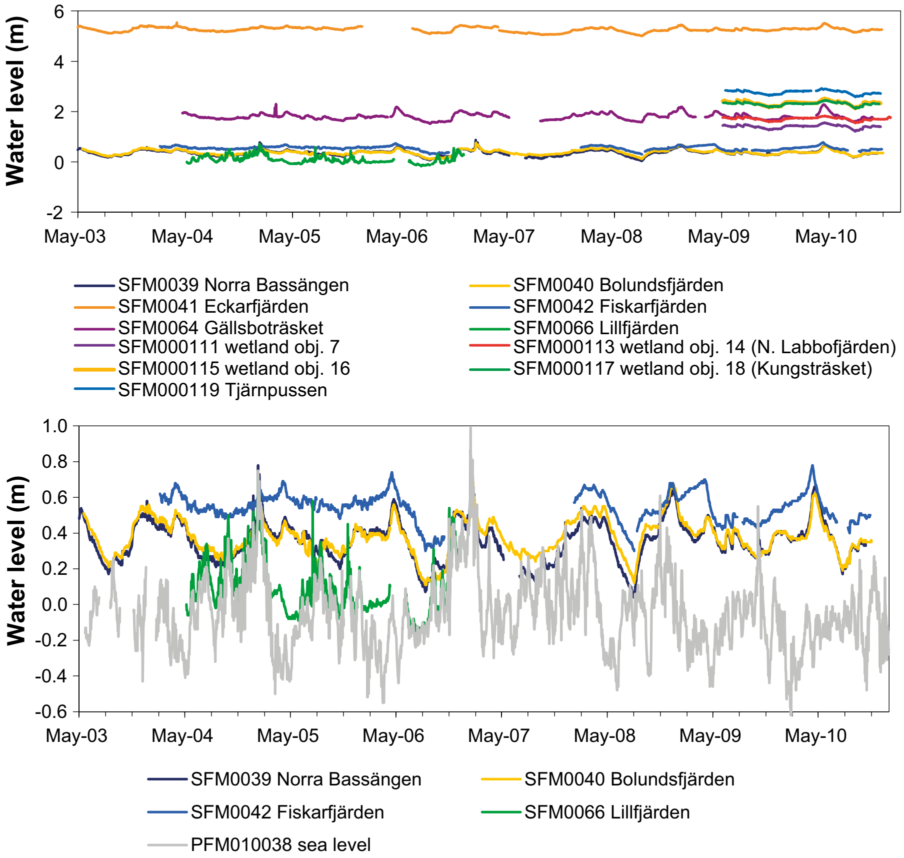


Figure 2-22. *Daily average surface-water levels of the sea, lakes and ponds. The upper figure shows data from all surface-water level gauges, whereas the lower figure show data from the sea-level gauge and for gauges installed in four of the lakes with the lowest surface-water levels.*

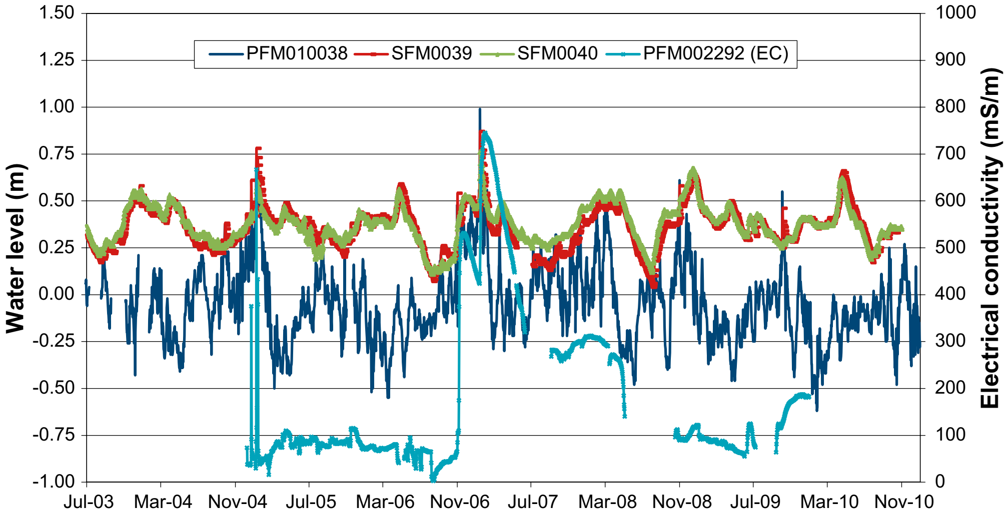


Figure 2-23. *Sea level (PFM010038), lake levels in Lake Norra Bassängen (SFM0039) and Lake Bolundsfjärden (SFM0040), and EC (electrical conductivity) in the channel connecting the two lakes (PFM002292). There are no PFM002292 EC data for year 2010 (Johansson and Juston 2011b).*

2.4 Groundwater levels in regolith

As of December 2010, totally 79 groundwater-monitoring wells are installed in regolith. Of these 79 wells, 74 are installed for groundwater-level monitoring and 5 wells are installed to also enable interference pumping tests. 64 wells are installed on land and 15 are installed in regolith below surface waters (lakes, ponds or the sea), see overview map in Figure 2-24. In December 2010, automatic groundwater-level monitoring was ongoing in 45 of the 79 wells, of which 34 are installed on land and 11 below surface waters. In addition, 10 BAT-type filter tips have previously been installed for pore-pressure and hydraulic-conductivity measurements in low-permeable regolith (10 filter tips), whereas 10 BAT-type filter tips have been installed for water sampling (Figure 2-24); the pore-pressure measurements were terminated in 2009.

Table 2-11 provides a summary of the groundwater-level monitoring data from the regolith available as of December 2010. The well and BAT tip installations are reported in Claesson and Nilsson (2003a, b, c), Johansson (2003, 2004), Werner and Lundholm (2004) and Werner et al. (2004, 2006, 2009). Totally 18 wells have been installed subsequent to 2010. In April 2011 five wells (SFM000121–125) were installed in the planned industrial area for the final repository for spent nuclear fuel, and in January 2012 three wells were installed in the SFR pier (SFR000001–3). In March 2011, a new well (SFM000126) was installed as replacement for SFM0015 and in September 2012 four wells (SFM132–135) were installed for monitoring of an infiltration test at wetland object 16 (Werner et al. 2014). Finally, in June 2014, five wells (SFM000138–142) were installed in five fens. For wells with ongoing monitoring below lakes and ponds in Table 2-11, stop dates during September–November 2010 for the present report are due to weak ice and/or presence of ice in wells, preventing manual depth soundings necessary for quality control of the groundwater-level monitoring.

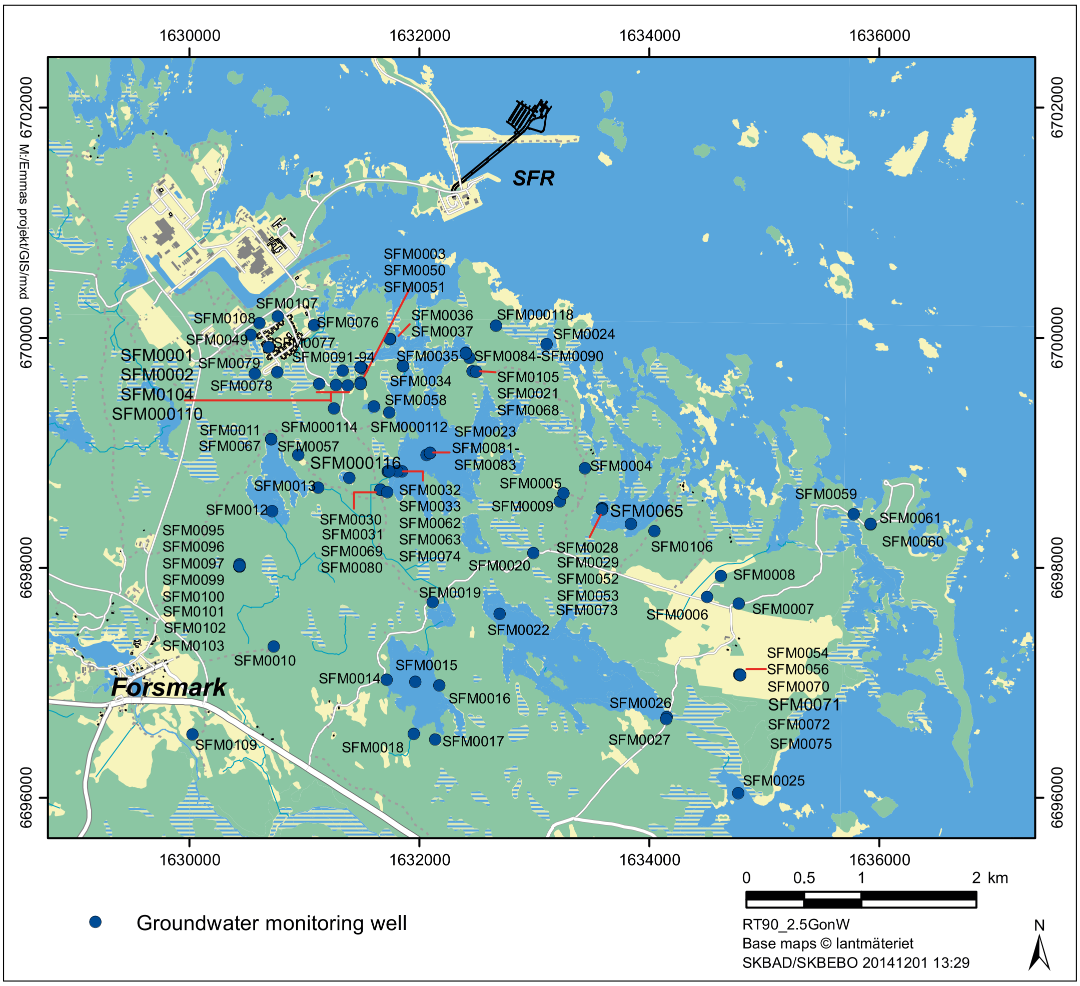


***Figure 2-24.** Locations of groundwater-monitoring wells in regolith.*

Table 2-11. Summary of groundwater-level data from the regolith available in the end of 2010. If not stated otherwise, the wells are installed on land. For wells with ongoing monitoring below lakes and ponds, stop dates during September–November 2010 are due to weak ice and/or presence of ice in wells, preventing manual depth soundings.

Well ID	Comment	Start date (YYYY-MM-DD)	Stop date (YYYY-MM-DD), this report
SFM0001		2003-05-01	2010-12-31
SFM0002	Mon. terminated	2003-05-01	2006-05-03
SFM0003		2003-05-01	2010-12-31
SFM0004		2003-05-01	2010-12-31
SFM0005		2003-05-01	2010-12-31
SFM0006		2003-12-10	2010-12-31
SFM0007	No mon. data (the well is dry)		
SFM0008		2003-08-21	2010-12-31
SFM0009	Mon. terminated	2003-05-01	2006-01-12
SFM0010		2003-05-14	2010-12-31
SFM0011		2003-05-01	2010-12-31
SFM0012	Below Lake Gällsboträsket	2003-05-09	2010-09-26
SFM0013		2003-05-01	2010-11-23
SFM0014		2003-05-01	2010-12-31
SFM0015	Below Lake Eckarfjärden; mon. terminated in Mar. 3, 2011 (replaced by the new well SFM000126)	2003-05-01	2010-10-28
SFM0016	Mon. terminated	2003-05-01	2006-02-12
SFM0017	Mon. terminated	2003-05-01	2008-09-18
SFM0018	Mon. terminated	2003-05-01	2006-02-12
SFM0019		2003-05-01	2010-12-31
SFM0020	Mon. terminated	2003-05-01	2006-05-03
SFM0021		2003-05-01	2010-12-31
SFM0022	Below Lake Fiskarfjärden	2004-09-16	2010-10-28
SFM0023	Below Lake Bolundsfjärden	2003-05-16	2010-09-15
SFM0024	Below sea bay (Stånggrundsfjärden), mon. terminated	2003-05-25	2003-12-03
SFM0025	Below sea bottom (Kallrigafjärden), mon. terminated	2003-05-01	2008-11-05
SFM0026		2003-08-18	2010-12-31
SFM0027	No mon. data		
SFM0028		2003-05-01	2010-12-12
SFM0029	No mon. data		
SFM0030		2003-05-01	2010-12-31
SFM0031	No mon. data		
SFM0032	No mon. data		
SFM0033		2003-05-23	2010-11-23
SFM0034		2003-05-01	2010-12-31
SFM0035	No mon. data		
SFM0036		2003-05-01	2010-12-19
SFM0037	No mon. data		
SFM0049		2003-05-13	2010-11-29
SFM0050	BAT filter tip (only perm. test)		
SFM0051	BAT filter tip (only chem. sampling)		
SFM0052	BAT filter tip (only perm. test)		
SFM0053	BAT filter tip (only chem. sampling)		
SFM0054	BAT filter tip (only perm. test)		
SFM0056	BAT filter tip (only chem. sampling)		
SFM0057		2003-12-12	2010-12-31
SFM0058		2004-05-27	2010-12-31
SFM0059	Mon. terminated	2004-02-16	2006-05-02
SFM0060	No mon. data		
SFM0061		2004-02-16	2010-12-31
SFM0062	Below Lake Bolundsfjärden	2004-06-05	2010-11-01
SFM0063	Below Lake Bolundsfjärden, no mon. data		

Well ID	Comment	Start date (YYYY-MM-DD)	Stop date (YYYY-MM-DD), this report
SFM0065	Below Lake Lillfjärden, mon. terminated	2004-04-28	2005-11-07
SFM0067	No mon. data		
SFM0068	No mon. data		
SFM0069	No mon. data		
SFM0070	No mon. data		
SFM0071	No mon. data		
SFM0072	No mon. data		
SFM0073	No mon. data		
SFM0074	No mon. data		
SFM0075	No mon. data		
SFM0076	Mon. terminated	2005-01-10	2005-01-24
SFM0077		2005-10-18	2010-12-31
SFM0078		2005-10-18	2010-12-31
SFM0079		2005-10-18	2010-12-31
SFM0080		2006-10-02	2010-12-31
SFM0081	Below Lake Bolundsfjärden	2006-10-01	2010-11-01
SFM0082	BAT filter tip (pore-press. meas., terminated)	2006-10-11	2009-01-08
SFM0083	BAT filter tip (only chem. sampling)		
SFM0084		2006-06-19	2010-10-07
SFM0085	BAT filter tip (pore-press. meas., terminated)	2006-10-10	2009-01-12
SFM0086	BAT filter tip (only chem. sampling)		
SFM0087		2006-06-19	2010-11-16
SFM0088	BAT filter tip (pore-press. meas., terminated)	2006-10-10	2009-01-12
SFM0089	BAT filter tip (only chem. sampling)		
SFM0090	No mon. data		
SFM0091		2006-06-08	2010-11-18
SFM0092	BAT filter tip (pore-press. meas., terminated)	2006-10-10	2009-01-08
SFM0093	BAT filter tip (only chem. sampling)		
SFM0094	No mon. data		
SFM0095		2006-06-01	2010-12-31
SFM0096	BAT filter tip (pore-press. meas., terminated)	2006-10-10	2009-01-07
SFM0097	BAT filter tip (only chem. sampling)		
SFM0099	BAT filter tip (pore-press. meas., terminated)	2006-10-10	2009-01-07
SFM0100	BAT filter tip (only chem. sampling)		
SFM0101	BAT filter tip (pore-press. meas., terminated)	2006-10-10	2009-01-07
SFM0102	BAT filter tip (only chem. sampling)		
SFM0103	No mon. data		
SFM0104		2006-06-19	2010-12-31
SFM0105		2006-06-19	2010-12-31
SFM0106		2006-06-19	2010-12-31
SFM0107		2006-06-20	2010-12-31
SFM0108	No mon. data		
SFM0109	No mon. data		
SFM000110	Below pond (wetland object 7; Werner et al. 2009)	2009-04-28	2010-10-18
SFM000112	Below pond (wetland object 14; Werner et al. 2009)	2009-04-28	2010-11-21
SFM000114	Below pond (wetland object 16; Werner et al. 2009)	2009-04-28	2010-10-18
SFM000116	Below pond (wetland object 18; Werner et al. 2009)	2009-04-30	2010-11-23
SFM000118	Below wetland (wetland object 23; Werner et al. 2009)	2009-05-06	2010-11-16

Table 2-12 shows levels of groundwater-monitoring wells SFM0003, -12, -15, -22 and -23 (top of casing, ToC), and the results of new levelling done in October–November 2010. The 2010 levelling indicates that wells installed below open water have been displaced vertically, on the order of 0.01–0.1 m, since they were installed in 2002–2003. These displacements are likely due to winter-time ice shear in the lakes, whereas the vertical displacement is lower (0.005 m) for well SFM0003, which is installed on land.

Table 2-12. Original and 2010 levelling of groundwater-monitoring wells. ToC = top of casing (levels obtained from the Sicada database).

Well id	ToC (m), original levelling (reference)	ToC (m), 2010 levelling (valid from 2010-11-04)	Vert. displacement (m)
SFM0003 (on land)	1.944 (Claesson and Nilsson 2003a).	1.939	–0.005
SFM0012 (below Lake Gällsboträsket)	2.853 (Johansson 2003).	2.865	+0.012
SFM0015 (below Lake Eckarfjärden)	5.766 (Johansson 2003; erroneous level in report).	5.652	–0.114
SFM0022 (below Lake Fiskarfjärden)	1.487 (Werner and Lundholm 2004; given as 1.49 in report).	1.618	+0.131
SFM0023 (below Lake Bolundsfjärden)	1.064 (Johansson 2003; confused with SFM0040 in the report).	1.180	+0.116

There is no information as to when actual well displacements did occur, and the new ToC levels are set to be valid from the end of the levelling campaign (November 4, 2010). In the dataset of the present report, there are only monitoring data available from well SFM0003 during the period November 4 –December 31, 2010, whereas there are no approved data from the other wells during this period (cf. Table 2-11). The level adjustment for SFM0003 is very small and can therefore not be noted in the dataset. Well displacements may take place every winter, and levelling campaigns are to be repeated annually from 2010 and onwards. As a result of these campaigns, adjusted ToC levels will be set at the end of the ice-covered period, using the ice-breakup date based on ice observations in Lake Eckarfjärden (cf. Section 2.3).

As part of the present study, a groundwater-level data screening has been performed to attain a groundwater-level dataset not affected by disturbances, i.e. groundwater-level influencing activities that are not representative for the natural, undisturbed system. A screened dataset is valuable for analysing the natural, undisturbed system, and also for flow-model calibration purposes. The data screening was performed by matching potential disturbances in the time series of daily average groundwater levels and potentially disturbing activities, such as water-sampling activities recorded in the Sicada database (Nilsson et al. (2003, 2010), Nilsson and Borgiel (2004, 2005, 2007, 2008), Johansson (2005a), Qvarfordt et al. (2008), Berg et al. (2009), SKBdoc 1334707). Data days that are screened out from the raw (unscreened) dataset are presented in Table 2-13. With one exception, all screened out data days are associated with water sampling, but it should also be noted that not all water-sampling activities motivate screening out data.

Table 2-13. Summary of screened out data days in the groundwater-level dataset.

Well id	Dates screened out (YYYY-MM-DD)
SFM0001	2007-08-07–09, 2007-10-10, 2008-01-15, 2008-04-09, 2008-08-05, 2008-09-02 (unknown disturbance).
SFM0004	2008-10-31–11-02, 2009-07-07–08.
SFM0011	2008-10-09.
SFM0022	2004-10-15.
SFM0023	2007-08-10–12, 2007-10-12–14, 2008-01-18–20, 2008-04-10–12, 2010-01-22–24, 2010-04-16–18, 2010-10-13–16.
SFM0026	2009-07-02, 2009-10-07.
SFM0049	2007-08-07–08, 2007-10-10, 2008-01-16, 2008-04-07, 2008-08-27, 2008-10-28–29, 2009-02-03, 2009-05-05, 2009-09-01, 2009-10-27, 2010-02-10, 2010-05-04, 2010-08-31, 2010-11-03.
SFM0081	2007-08-07–10, 2007-08-08–11, 2008-01-14–18, 2008-04-06–11.
SFM0084	2007-08-10, 2007-10-08–12, 2008-01-14–16, 2008-04-06–07, 2009-07-03.
SFM0087	2007-08-07–08, 2007-10-09, 2008-01-15, 2008-04-07, 2009-06-12.
SFM0091	2006-06-16, 2006-11-14, 2007-01-18, 2007-03-26, 2007-08-09–10, 2007-10-10–11, 2008-01-14–15, 2008-04-10, 2009-06-30.
SFM0095	2007-08-09, 2007-10-09, 2008-01-16, 2008-04-09.

Johansson and Öhman (2008) did not perform a corresponding screening of the groundwater-level dataset available for their study. The present screening is focused on the period 2007-04-01–2010-12-31, whereas some obvious disturbances are screened out also for the prior period (SFM0022 and -91, see Table 2-13). The largest number of screened out dates is noted for SFM0023, which is characterised by slow recovery subsequent to water sampling.

Figure 2-25 presents daily average groundwater levels in regolith (screened data), expressed as elevations (m, lower figure) and depth below ground surface (m, lower figure) for the 42 groundwater-monitoring wells installed on land with automatic groundwater-level monitoring. These 42 wells include 8 wells with terminated monitoring (cf. Table 2-11). Juston and Johansson (2005) analysed correlations (in terms of coefficients of determination, R^2) between groundwater-monitoring well time series, taking into account groundwater-level data (> 200 data days) for wells SFM0001–0057 up to data freeze Forsmark 1.2 (July 31, 2004). The present analysis (Appendix 1) analyses intra-well correlations (in terms of correlation coefficients, R) for groundwater-level variations in wells SFM0001–000118 up to the end of December 31, 2010, including wells installed below surface water (marked blue in Appendix 1).

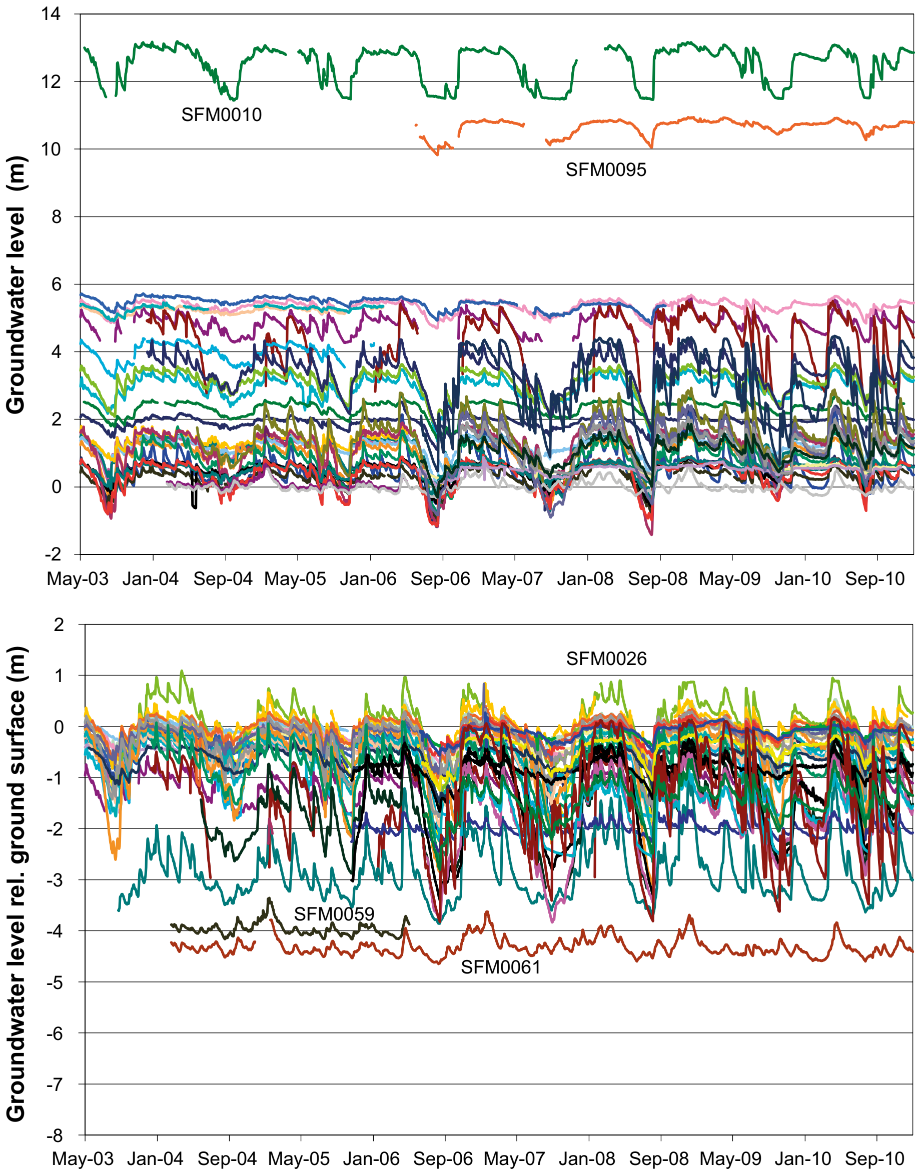


Figure 2-25. *Daily average groundwater levels in regolith (screened data) in wells installed on land, including 8 wells where monitoring has been terminated. Levels are expressed as elevation (m) in the upper figure, and as depth below ground surface (m) in the lower figure.*

As was also noted by Juston and Johansson (2005), there is a very strong correlation (R ≈ 0.8–0.9) between most groundwater-monitoring wells, hence indicating that groundwater-level responses to variations of the hydrometeorological conditions are similar at most monitored locations. However, some wells demonstrate weak correlations, e.g. SFM0024 and -25 (monitoring terminated) installed below the sea bottom. Moreover, correlations are also weak for wells SFM0059 and -61 that are installed in the vicinity of the sea shoreline in the Börstilåsen esker.

Figure 2-26 shows a plot of cumulative frequency distributions of the data shown in the lower figure of Figure 2-25. The daily average groundwater level relative to ground surface for each of the 42 wells (the orange curve) shows that some 80% of the site average groundwater levels were between 0.4 and 1.3 m below ground surface. The cumulative distribution of pooled data of the 42 individual wells (the blue curve) shows that 80% of the daily average groundwater levels were between 0.1 and 2.1 m below ground surface. Irrespective of analysis methodology, Figure 2-26 demonstrates that the groundwater level in regolith is shallow in the Forsmark area.

Figure 2-27 plots overall averages and ranges of groundwater-level data for 40 wells installed on land and with more than 150 data days, in the form of depths below ground surface and co-plotted with depths to the rock surface. The data are ranked according to increasing average groundwater level in the upper plot, and according to decreasing depth to the rock surface in the middle plot. As shown in the upper plot, overall average groundwater levels range from c 4 m below ground surface (SFM0061) to an overall average groundwater level at the ground surface (e.g. SFM0026 and -0028). According to the middle plot, the rock surface is located between 1–7 m below ground surface at the well locations shown in the plot. To improve readability, rock-surface levels are not shown for SFM0026 (–15.4 m elevation, 16.1 m below ground surface) and SFM0003 (–8.7 m elevation, 10.2 m below ground surface).

The lower plot shows averages and ranges of groundwater levels, co-plotted with rock-surface and ground-surface levels. As shown in the lower plot, overall average groundwater levels are above 0 m elevation, whereas some wells (e.g. SFM0008, -0026 and -0028) exhibit daily average groundwater levels below 0 m elevation. As is also shown in Figure 2-28, there is a strong correlation between overall average groundwater levels and local ground-surface levels.

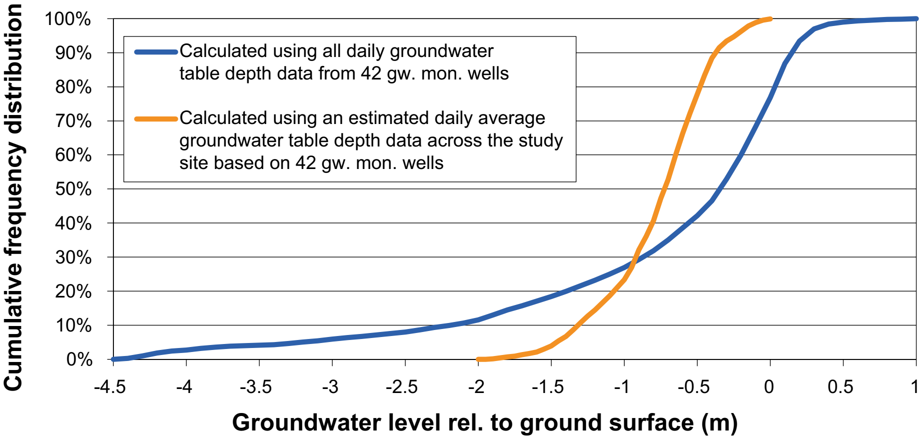


Figure 2-26. *Cumulative frequency distribution of the depth to the groundwater table for the 42 monitoring wells installed on land for the period May 1, 2003–December 31, 2010, including 8 wells where monitoring has been terminated.*

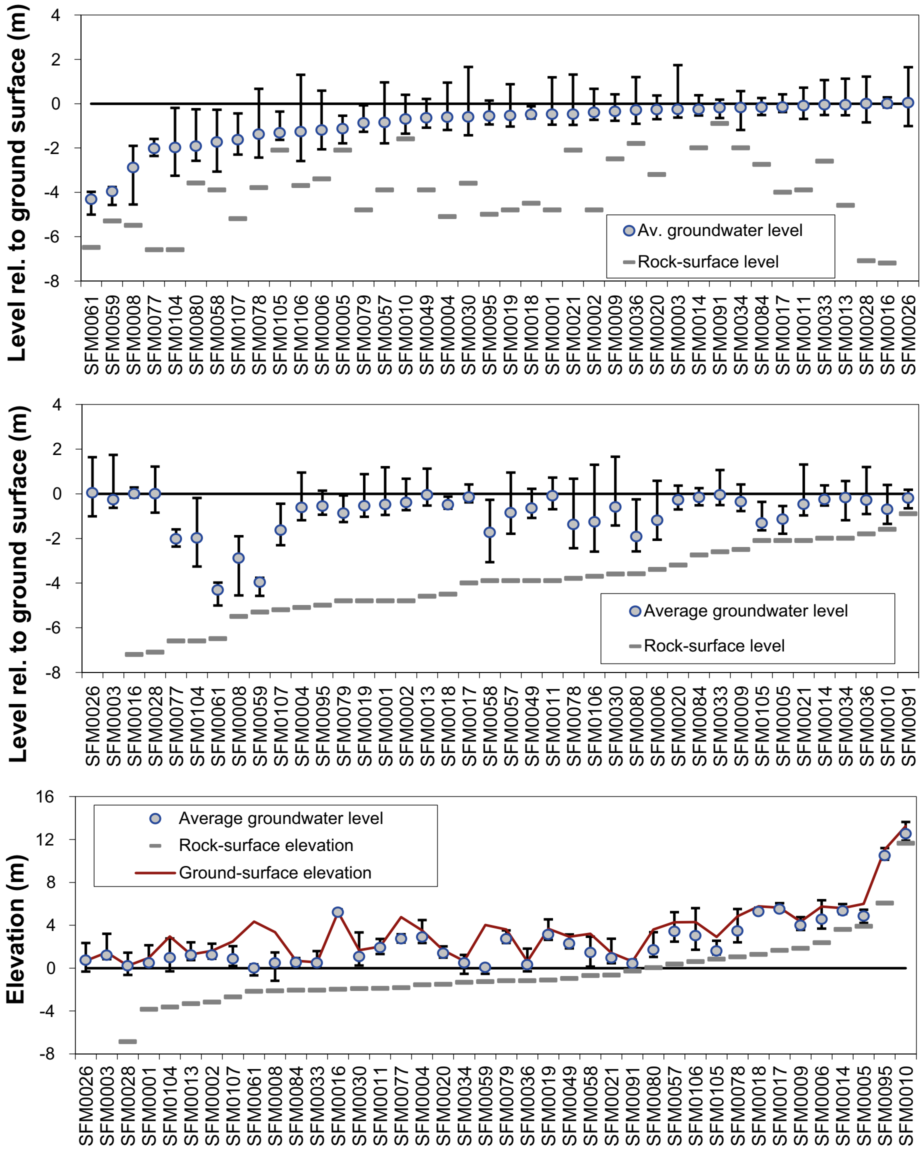


Figure 2-27. *Groundwater levels (overall averages and ranges) and rock-surface elevations, ranked according to overall average groundwater level (upper plot) and rock-surface elevation (middle plot). Data are shown for wells with more than 150 data days. The lower plot shows the data ranked according to ground-surface elevation. Note that rock-surface levels are not shown for SFM0026 (–15.4 m elevation, 16.1 m below ground surface) and SFM0003 (–8.7 m elevation, 10.2 m below ground surface).*

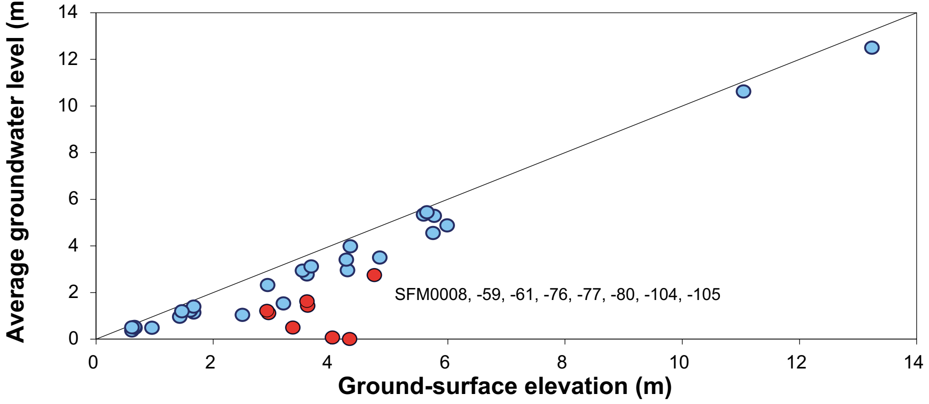


Figure 2-28. *Cross plot of overall average groundwater levels and ground-surface levels for 40 groundwater-monitoring wells installed on land with more than 150 data days. The red dots indicate outliers.*

2.5 Hydrogeological monitoring data from the rock

This section provides a brief summary of hydrogeological monitoring data collected in the upper c 150 m of the rock. As described further in Johansson and Öhman (2008), measured groundwater levels in the rock should be regarded as point-water heads if not stated otherwise. Specifically, the present report presents three groundwater-level datasets and one groundwater inflow dataset from the rock:

- SDM-Site percussion-drilled boreholes: Groundwater levels measured in percussion-drilled boreholes drilled from the surface within the site investigations at Forsmark 2002–2007 (SKB 2008).
- SDM-PSU percussion-drilled and core-drilled boreholes: Groundwater levels measured in percussion-drilled and (short) core-drilled boreholes drilled from the surface in the vicinity of the SFR facility within the SFR site investigation 2008–2009 (SKB 2013).
- SFR tunnel boreholes: Groundwater levels measured in core-drilled boreholes drilled from tunnels of the SFR facility.
- Groundwater inflow to SFR: Inflow of groundwater to the SFR facility, measured in terms of water pumped from drainage pits.

As part of the present study, and for the same reasons as stated regarding groundwater-monitoring wells (Section 2.4), a data screening has been performed to attain an undisturbed dataset in terms of groundwater levels in the rock. Johansson and Öhman (2008) performed a corresponding screening of the groundwater-level dataset available for their study (up to March 31, 2007), and the present screening was therefore focused on the period April 1, 2007–December 31, 2010. The data screening was performed by matching potential disturbances in the time series of daily average groundwater levels and potentially disturbing activities, such as borehole drilling, water sampling and hydraulic tests. The data screening performed by Johansson and Öhman (2008) involved the SDM-Site percussion-drilled boreholes HFM01–38 (Section 2.5.1), whereas the present data screening also includes SDM-PSU boreholes and SFR tunnel boreholes.

Specifically, the present data screening mainly considers the following types of potentially disturbing activities during the period April 1, 2007–December 31, 2010:

- Pumping and interference tests, e.g. interference tests in percussion-drilled boreholes HFM14 and HFM33 during 2007 (Gokall-Norman and Ludvigsson 2008a, b), and hydraulic tests at SFR in boreholes HFR101, HFR102, KFR27 and KFR105 during 2008–2010 (Walger et al. 2010).
- Borehole drilling and associated activities at SFR during 2008–2009 (Walger et al. 2010).
- Water sampling (Berg and Nilsson 2008, Berg et al. 2009, Nilsson et al. 2010).

2.5.1 SDM-Site percussion-drilled boreholes

The percussion-drilled boreholes HFM01–38 (Figure 2-29) were drilled as part of the 2002–2007 site investigations for the repository for spent nuclear fuel. Table 2-14 provides a summary of the groundwater-level monitoring data from these boreholes available as of December 2010. The drillings of the boreholes are reported in Claesson and Nilsson (2003d, e, 2004a–f, 2006a, b, 2007a, b).

Table 2-14. Summary of groundwater-level data from SDM-Site percussion-drilled borehole sections (numbered from borehole bottom and up) available in the end of 2010. GWL = groundwater level.

Borehole id (no. of borehole sections)	Start date (YYYY-MM-DD)	Stop date (YYYY-MM-DD), this report
HFM01 (1, 3)	2003-06-16 and 2005-08-11 (open borehole) 2006-12-06 (borehole sections)	2003-08-27 and 2006-10-24 (open borehole) 2010-12-31 (borehole sections)
HFM02 (1, 3)	2002-12-10 (open borehole) 2004-03-25 (borehole sections)	2004-03-15 (open borehole) 2010-12-31 (borehole sections)
HFM03 (1, 2)	2003-01-30 (open borehole) 2004-04-04 (borehole sections)	2003-03-05 (open borehole) 2010-12-31 (borehole sections)
HFM04 (1, 3)	2003-12-10 (open borehole) 2004-03-19 (HFM04.1) 2004-03-11 (HFM04.2) 2004-03-16 (HFM04.3)	2004-02-23 (open borehole) 2010-12-31 (borehole sections)
HFM05 (1, 2)	2004-05-12 (open borehole) 2007-06-25 (HFM05.1) 2007-07-04 (HFM05.2)	2007-05-28 (open borehole) 2010-12-31 (borehole sections)
HFM06	2003-01-24	2003-03-02
HFM07 (1)	2003-02-17	2010-12-31
HFM08 (1, 2)	2003-02-27 (open borehole) 2005-03-22 (borehole sections)	2003-03-14 (open borehole) 2010-12-31 (borehole sections)
HFM09 (1)	2003-12-25	2010-12-31
HFM10 (1, 2)	2003-12-30 (open borehole) 2004-11-22 (borehole sections)	2004-11-02 (open borehole) 2010-12-31 (borehole sections)
HFM11 (1, 2)	2004-01-22 (open borehole) 2005-04-26 (borehole sections)	2005-03-15 (open borehole) 2010-12-31 (borehole sections)
HFM12 (1, 2)	2004-01-22 (open borehole) 2005-04-20 (borehole sections)	2005-03-15 (open borehole) 2010-12-31 (borehole sections)
HFM13 (3)	2005-02-27 (HFM13.1–2) 2005-02-21 (HFM13.3)	2010-12-31
HFM14 (1)	2004-01-21	2010-12-31
HFM15 (1, 2)	2004-01-23 (open borehole) 2005-02-27 (HFM15.1) 2005-02-23 (HFM15.2)	2005-01-30 (open borehole) 2010-12-31 (borehole sections)
HFM16 (1, 3)	2003-11-26 (open borehole) 2005-12-14 (borehole sections)	2005-11-17 (open borehole) 2010-12-31 (borehole sections)
HFM17 (1)	2003-12-10	2010-12-31
HFM18 (1, 3)	2005-05-04 (open borehole) 2005-12-15 (borehole sections)	2005-12-07 (open borehole) 2010-12-31 (borehole sections)
HFM19 (3)	2004-02-15	2010-12-31
HFM20 (1, 4)	2004-06-19 (open borehole) 2005-03-10 and 2005-03-13 (borehole sections)	2005-02-13 (open borehole) 2010-12-26 (borehole sections)
HFM21 (1, 4)	2004-06-15 (open borehole) 2007-04-01 (borehole sections)	2006-09-23 (open borehole) 2010-12-31 (borehole sections)
HFM22 (1)	2004-10-24	2010-12-31
HFM23 (1)	2006-01-01	2010-12-31
HFM24 (3)	2005-12-17 (open borehole) 2007-04-11 and 2007-04-13 (borehole section)	2006-11-28 (open borehole) 2010-12-31 (borehole sections)
HFM25 (1)	2007-10-20	2010-12-31
HFM26 (1)	2006-10-01	2010-12-31
HFM27 (4)	2005-12-06 (open borehole) 2006-05-14 (HFM24.1–2) 2006-05-24 (HFM24.3) 2006-10-01 (HFM27.4)	2005-12-31 (open borehole) 2010-12-31 (borehole sections)
HFM28 (1)	2006-10-01	2010-12-31
HFM29 (1)	2006-10-01	2010-12-31
HFM30 (1, 4)	2006-10-01 (open boerhole) 2007-06-25 (borehole sections)	2007-04-17 (open borehole) 2010-12-31 (borehole sections)
HFM31 (1)	2006-06-09	2010-12-31
HFM32 (4)	2006-02-01	2010-12-31
HFM33 (1)	2006-05-18	2010-12-31
HFM34 (3, 2 are monitored)	2006-08-16 (HFM32.2–3)	2010-12-31 (HFM32.2–3)
HFM35 (4)	2006-08-23	2010-12-31
HFM36 (1, 3	2006-09-05 (open borehole) 2007-12-13 (borehole sections)	2007-06-26 (open borehole) 2010-12-31 (borehole sections)
HFM37 (1)	2006-09-05	2010-12-31
HFM38 (3)	2006-07-03 (open borehole) 2007-04-11 (borehole sections)	2007-02-26 (open borehole) 2010-12-31 (borehole sections)

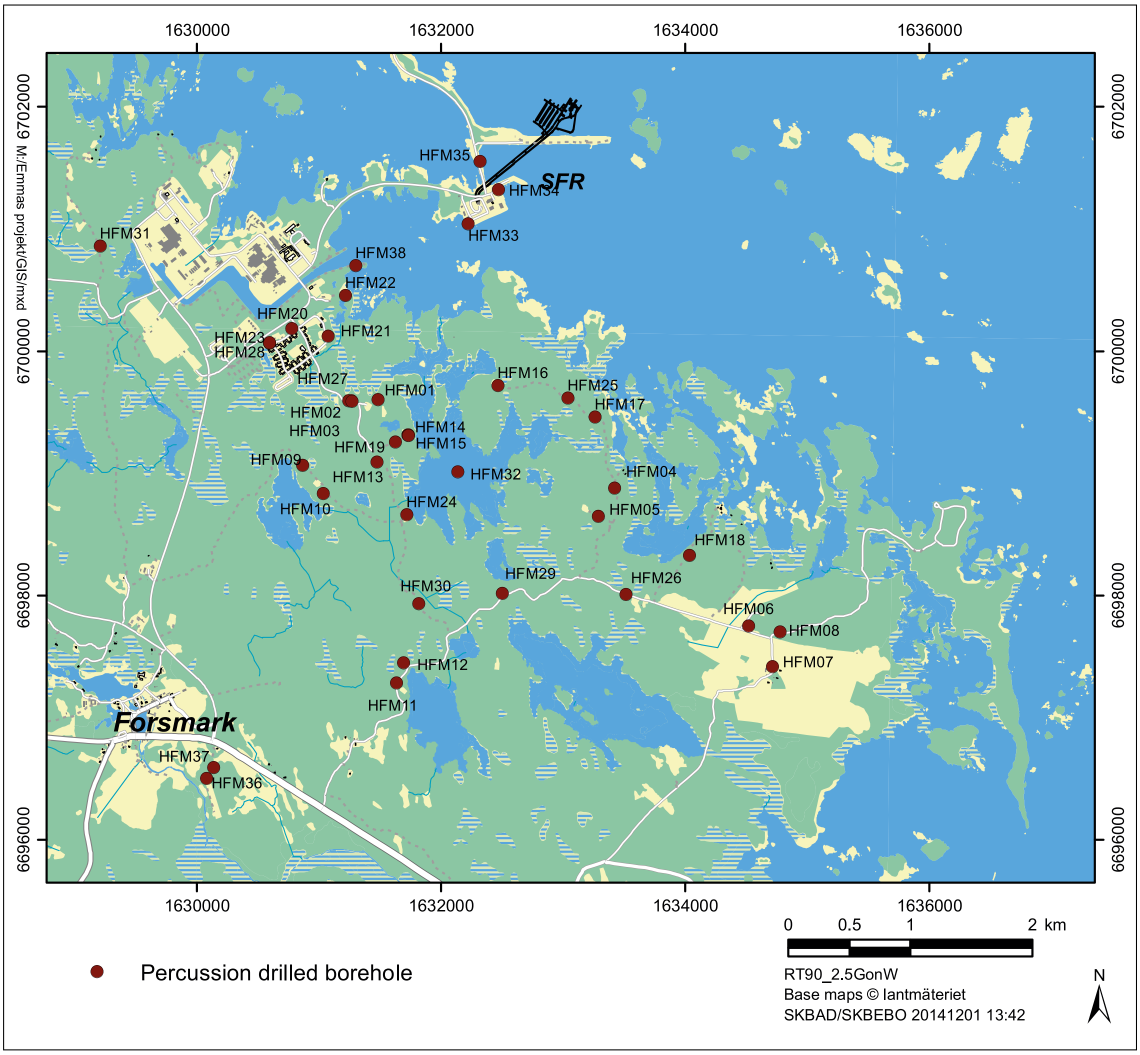


Figure 2-29. *Locations of the SDM-Site percussion-drilled boreholes HFM01–38.*

Figure 2-30 shows groundwater levels in terms of raw, unscreened data (upper plot) and screened data (lower plot), whereas screened out intervals are shown in the middle plot. As part of the regular quality control of groundwater-level data in 2010, it was discovered that an erroneous reference point had been used to check, and, if required, adjust the conversion of pressure data to groundwater levels (m) for percussion-drilled boreholes HFM32 and -34 (SKBdoc 1276796). Specifically, for HFM32 and -34 the reference-point levels had been set 0.37 m and 0,50 m, respectively, below the correct reference-point levels since initiation of monitoring in 2006. In addition, HFM32 was included in the 2010 levelling campaign (cf. Sections 2.3 and 2.4), according to which the reference-point level is 0.033 m above the original levelling. As a result of the quality control and levelling done in 2010, all groundwater-level data for HFM32 and -34 have been adjusted since initiation of monitoring. Accordingly, the present report uses the updated HFM32 and -34 datasets (Sicada delivery id 11_070, 11_070_1 and 11_070_2 of Table 2-1).

Figure 2-31 plots overall averages and ranges of groundwater-level data for HFM01–38, co-plotted with rock-surface and ground-surface elevations (levels). Data are shown for the upper borehole sections for boreholes with packers and for open boreholes with more than 150 data days after data screening, thereby excluding the open boreholes HFM03, -04, -06, -08, -13, -20, and -27. The screened dataset includes 150–300 data days for HFM01, -30, and -33. As can be seen in the upper plot, two borehole sections (HFM34.3 and HFM35.4) demonstrate overall average groundwater levels below 0 m elevation. As shown in the lower plot, and also in Figure 2-32, there is only a weak correlation between overall average groundwater levels and local ground-surface levels.

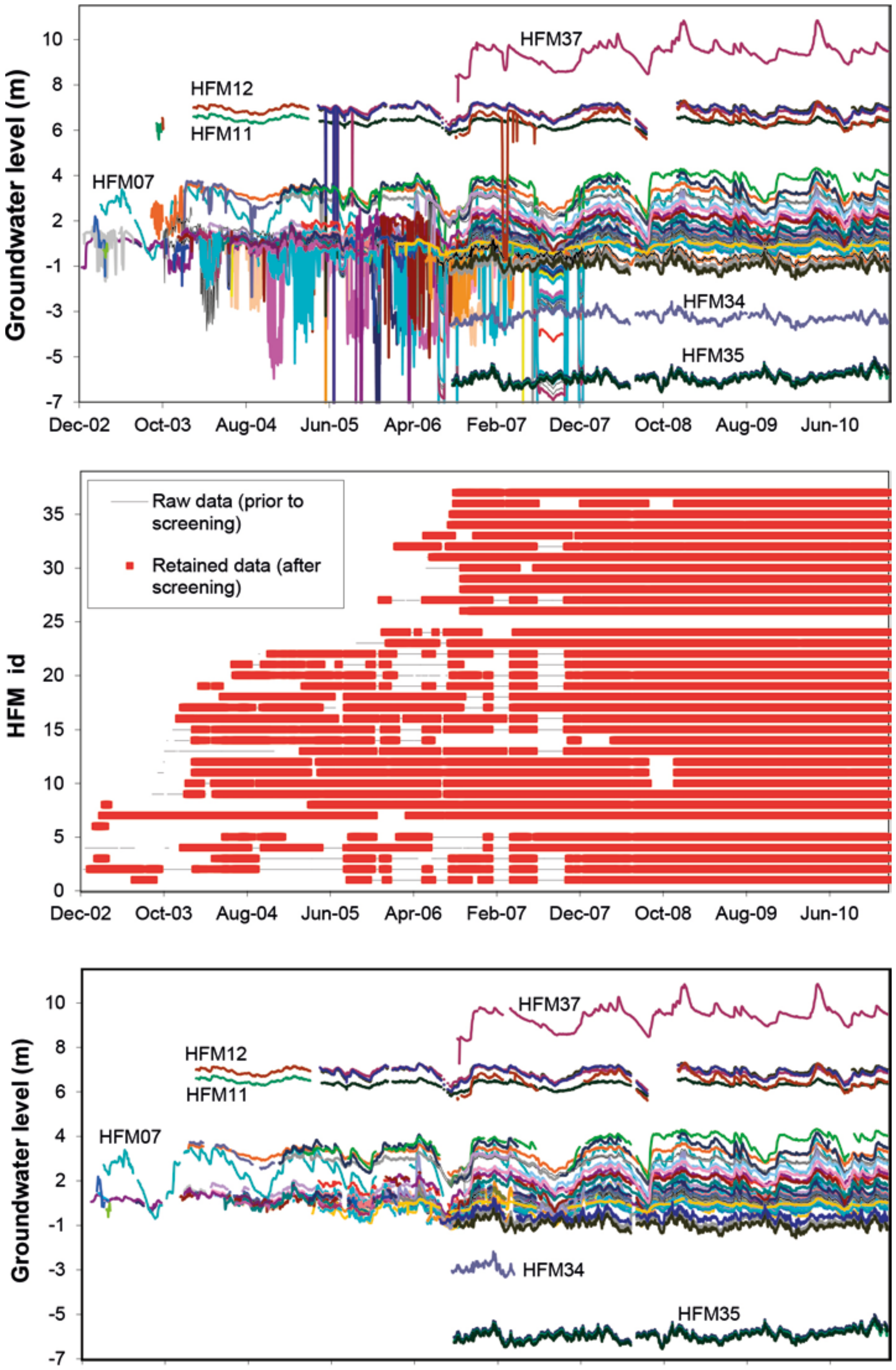


Figure 2-30. *Daily average groundwater levels in percussion-drilled boreholes HFM01–38, in terms of raw, unscreened data (upper plot) and screened data (lower plot). The middle plot shows screened out data periods.*

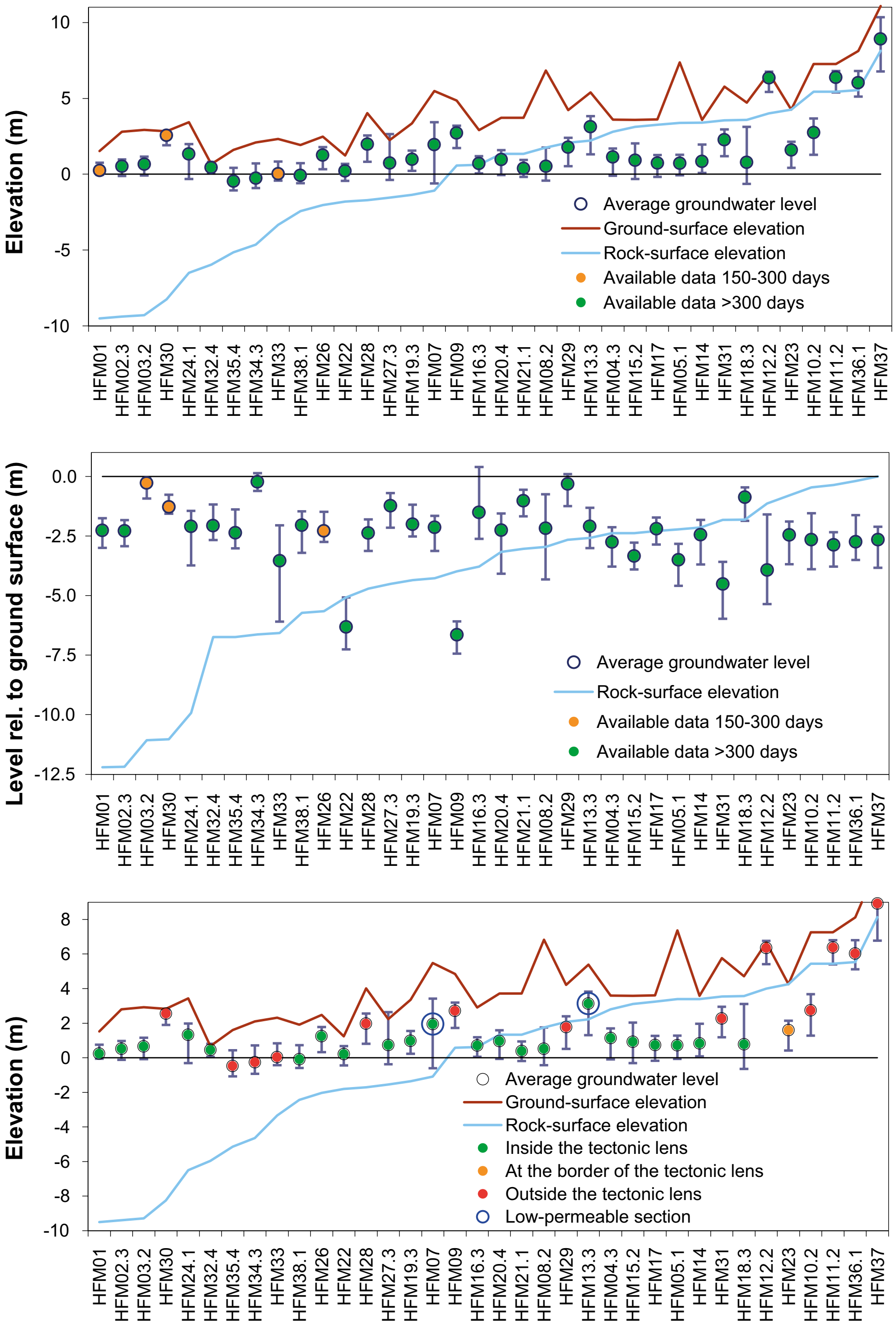


Figure 2-31. *Groundwater levels (overall averages and ranges of screened data) in percussion-drilled boreholes HFM01–38, rock-surface elevations and ground-surface elevations, ranked according to rock-surface elevation (upper plot) and groundwater levels expressed as depth below ground surface (middle plot). The lower plot shows the same data as in the upper plot, with colours according to borehole locations in relation to the so called tectonic lens (see Follin 2008). Data are shown for the upper borehole sections for boreholes with borehole packers and for open boreholes with more than 150 data days.*

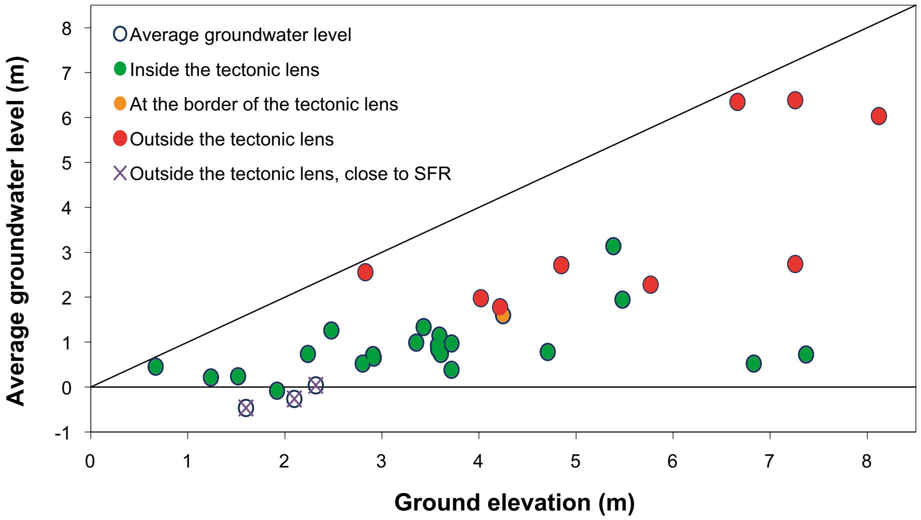


Figure 2-32. *Cross plot of overall average groundwater levels (boreholes with more than 150 data days) and ground-surface elevations, with colours according to borehole locations in relation to the tectonic lens and the SFR facility.*

2.5.2 SDM-PSU surface boreholes, SFR tunnel boreholes and SFR inflow

The calibration dataset used in the SDM-PSU MIKE SHE modelling (Werner et al. 2013) includes daily average groundwater levels from the percussion-drilled and short core-drilled boreholes listed in Table 2-15. Öhman et al. (2012) show overview maps of the locations of these boreholes, which were drilled from the surface in the vicinity of the SFR facility within the SFR site investigation 2008–2009. All boreholes were drilled from the SFR pier, except percussion-drilled borehole HFR106 and core-drilled borehole KFR106 that were drilled from a small island. Moreover, percussion-drilled borehole HFR105 is drilled from the small pier north of the SFR offices. Data days that are screened out from the raw (unscreened) dataset are presented in Table 2-16.

Table 2-15. Summary of groundwater-level data from SDM-PSU percussion-drilled and core-drilled borehole sections available in the end of 2010.

Borehole id (no. of borehole sections)	Start date (YYYY-MM-DD)	Stop date (YYYY-MM-DD), this report
HFR101 (open borehole)	2008-07-07	2010-12-31
HFR102 (2)	2009-02-24 (HFR102.1) 2009-01-01 (HFR102.2)	2010-12-31
HFR105 (4)	2009-01-01	2010-12-05
HFR106 (4)	2009-12-02	2010-12-31
KFR27 (3); extension of existing borehole	2008-08-27	2010-12-31
KFR101 (3)	2009-01-01	2010-12-31
KFR102A (8)	2009-03-06 (KFR102A.1–7) 2008-03-09 (KFR102A.8)	2010-12-31
KFR102B (3)	2009-01-01	2010-12-31
KFR103 (3)	2009-01-01	2010-12-31
KFR104 (3)	2008-12-16	2010-12-31
KFR106 (3, of which 2 are monitored)	2009-12-03 (KFR106.1–2) 2009-12-04 (KFR106.3)	2010-11-30

Table 2-16. Summary of screened out data days in the SDM-PSU borehole dataset.

Well id	Dates screened out (YYYY-MM-DD)
HFR101	2008-09-03–04, 2008-12-17–19, 2009-04-06–12.
HFR102	2008-05-13, 2008-05-28, 2008-09-01–29, 2008-10-03–04, 2008-10-06, 2008-10-28, 2008-11-03–04, 2008-11-15–21, 2008-12-11, 2009-04-21–06-04, 2009-06-12, 2009-06-16–17, 2009-06-22–08-11, 2009-08-14–08-21, 2010-01-13–02-19, 2010-03-03–05, 2010-12-03.
HFR105	2008-04-23–29, 2008-05-13–15, 2008-05-22–26, 2008-08-25–09-01, 2008-09-02–29, 2008-10-03–04, 2008-10-06, 2008-10-17, 2008-10-28, 2008-11-03–04, 2008-11-15–21, 2008-12-11, 2009-04-06–09.
HFR106	2009-06-23, 2009-07-07–08, 2009-07-10, 2009-08-19–09-03, 2009-09-14–17, 2009-10-03–07, 2009-10-16, 2009-10-21, 2009-11-04–05.
KFR27	2008-05-06–13, 2008-06-12–07-01, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-15–18, 2008-08-28–29, 2008-09-01–09-02, 2008-09-18–20, 2008-09-23–26, 2008-10-02–21, 2008-10-09, 2008-10-15, 2008-10-27–30, 2008-11-04–05, 2008-11-23–27, 2008-11-25, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-02-05, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2009-04-21–06-04, 2009-06-12, 2009-06-16–17, 2009-06-22–07-02, 2009-07-09, 2009-07-14–08-11, 2009-08-14–21, 2010-01-13–02-19, 2010-03-03–04, 2010-11-19, 2010-11-24, 2011-11-26, 2010-12-02–03, 2010-12-17.
KFR101	2008-05-08, 2008-06-02–12, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-15–26, 2008-08-28–29, 2008-09-01–02, 2008-09-18–20, 2008-09-23–26, 2008-10-09, 2008-10-02–22, 2008-10-27–30, 2008-11-04–05, 2008-11-10–17, 2008-11-15–12-12, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–27, 2010-11-19, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR102A	2008-11-23–27, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2009-04-21–06-02, 2009-06-02–04, 2009-06-12, 2009-06-16, 2009-06-17, 2009-06-22–07-02, 2009-07-09, 2009-07-14–08-11, 2009-08-14–21, 2010-01-13–02-19, 2010-03-03–04, 2010-11-19, 2010-11-24 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR102B	2008-06-02–07-02, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-15–26, 2008-08-28–29, 2008-09-01–02, 2008-09-18–20, 2008-09-23–26, 2008-10-09, 2008-10-02–22, 2008-10-15, 2008-10-27–30, 2008-11-04–05, 2008-11-10–17, 008-11-23–27, 2008-12-12, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2009-06-02–04, 2009-06-12, 2009-06-16–17, 2009-06-22–07-02, 2009-07-09, 2009-07-14–08-11, 2009-08-14–21, 2010-01-13–02-19, 2010-03-03–04, 2010-11-19, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR103	2008-05-07–08, 2008-06-02–07-02, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-06–13, 2008-08-15–29, 2008-09-01–02, 2008-09-18–20, 2008-09-23–26, 2008-10-02–22, 2008-10-27–30, 2008-11-04–05, 2008-11-23–27, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2009-04-21–06-04, 2009-06-12, 2009-06-16–17, 2009-06-22–07-02, 2009-07-07–10, 2009-07-14–08-11, 2009-08-14–09-03, 2009-09-14–17, 2009-10-03–07, 2009-10-16, 2009-10-21, 2009-11-04–06, 2010-01-13–02-19, 2010-03-03–04, 2010-11-19, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR104	2008-05-13, 2008-05-28, 2008-09-01–29, 2008-10-03–04, 2008-10-06, 2008-10-17, 2008-10-28, 2008-11-03–04, 2008-11-15–21, 2008-12-11, 2009-02-05, 2009-04-06, 2009-04-21–06-02, 2009-06-02–04, 2009-06-12, 2009-06-16–17, 2009-06-22–07-02, 2009-07-09, 2009-07-14–08-11, 2009-08-14–21, 2010-01-13–02-19, 2010-03-03–04, 2010-11-30–12-03.
KFR106	2009-09-14–17, 2009-10-03–07, 2009-10-16, 2009-10-21, 2009-11-04–06.

The calibration dataset available for the SDM-PSU MIKE SHE modelling includes daily average groundwater levels from the SFR tunnel boreholes listed in Table 2-17. Öhman et al. (2012) show overview maps of the locations of these boreholes. Note that SFR tunnel borehole data are stored as pressure (manual measurements 1985–2008), which therefore need to be converted to groundwater levels. This conversion assumes fresh-water density (1,000 $\text{kg}\cdot\text{m}^{-3}$) in borehole sections and hoses that connect sections to pressure gauges, which implies that resulting groundwater levels should be regarded as fresh-water heads. Data days that are screened out from the raw (unscreened) dataset are presented in Table 2-18.

The calibration dataset available for the SDM-PSU MIKE SHE modelling includes data on groundwater inflow to the SFR facility (Figure 2-33). Inflow has been continuously measured since January, 1988 (Carlsson and Christiansson 2007). The inflow has decreased from approximately 720 $\text{L}\cdot\text{min}^{-1}$ (12 $\text{L}\cdot\text{s}^{-1}$) to 285 $\text{L}\cdot\text{min}^{-1}$ (5 $\text{L}\cdot\text{s}^{-1}$) in 2010 (Öhman et al. 2012). As can be seen in Figure 2-33, approximately 20% of the total groundwater inflow enters disposal rooms and the operational area, as measured at pumping pit UB. 80% enters the access tunnel (c 160 $\text{L}\cdot\text{min}^{-1}$) and the lower construction tunnel (70 $\text{L}\cdot\text{min}^{-1}$), as measured at pumping pit NDB. For further details, see Öhman et al. (2012).

Table 2-17. Summary of groundwater-level data from SFR tunnel borehole sections available in the end of 2010. Borehole KFR105 was drilled during the SDM-PSU site investigations.

Borehole id (no. of borehole sections)	Start date (YYYY-MM-DD)	Stop date (YYYY-MM-DD), this report
KFR01 (2)	2008-04-04	2010-12-31
KFR02 (4)	2008-04-04 (KFR02.1–2) 2008-07-01 (KFR02.3) 2008-04-02 (KFR02.4)	2010-12-31
KFR03 (4)	2008-04-11	2010-12-31
KFR04 (4)	2008-04-02 (open borehole) 2009-01-26 (KFR04.1) 2008-04-02 (KFR04.2–4)	2009-01-25 (open borehole) 2010-12-31 (sections)
KFR05 (4)	2008-04-02 (KFR05.1–2, KFR05.4) 2008-04-03 (KFR05.3)	2010-12-31
KFR07A (3)	2008-04-10	2010-12-31
KFR07B (2)	2008-04-08	2010-12-31
KFR08 (3)	2008-04-03	2010-12-31
KFR09 (open borehole)	2006-04-20	2010-12-31
KFR13 (3)	2008-04-02	2010-12-31
KFR19 (4)	2008-04-02	2010-12-31 (KFR19.1–3) 2010-12-07 (KFR19.4)
KFR55 (4)	2008-04-02	2010-12-31
KFR56 (open borehole)	2008-04-03	2010-12-31
KFR105 (5)	2009-07-12 (KFR105.1) 2009-07-14 (KFR105.2) 2009-07-11 (KFR105.3-4) 2009-07-16 (KFR105.5)	2010-12-31

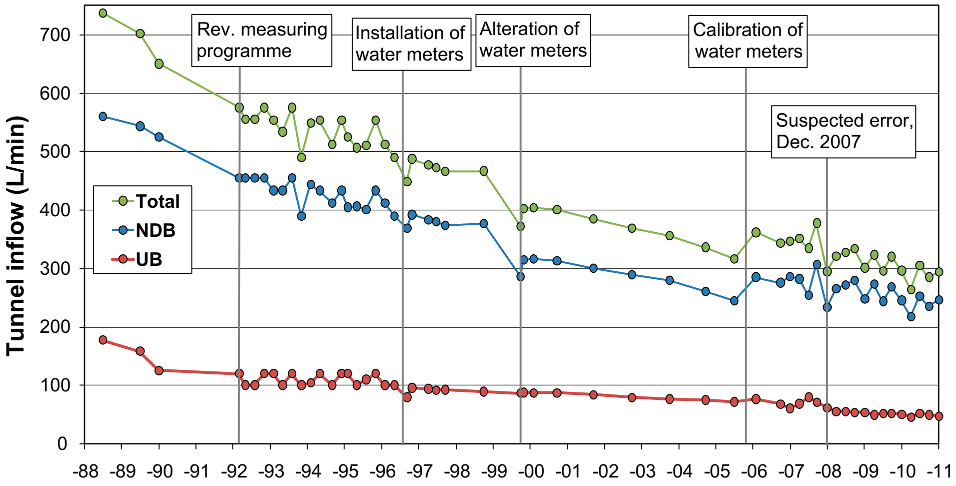


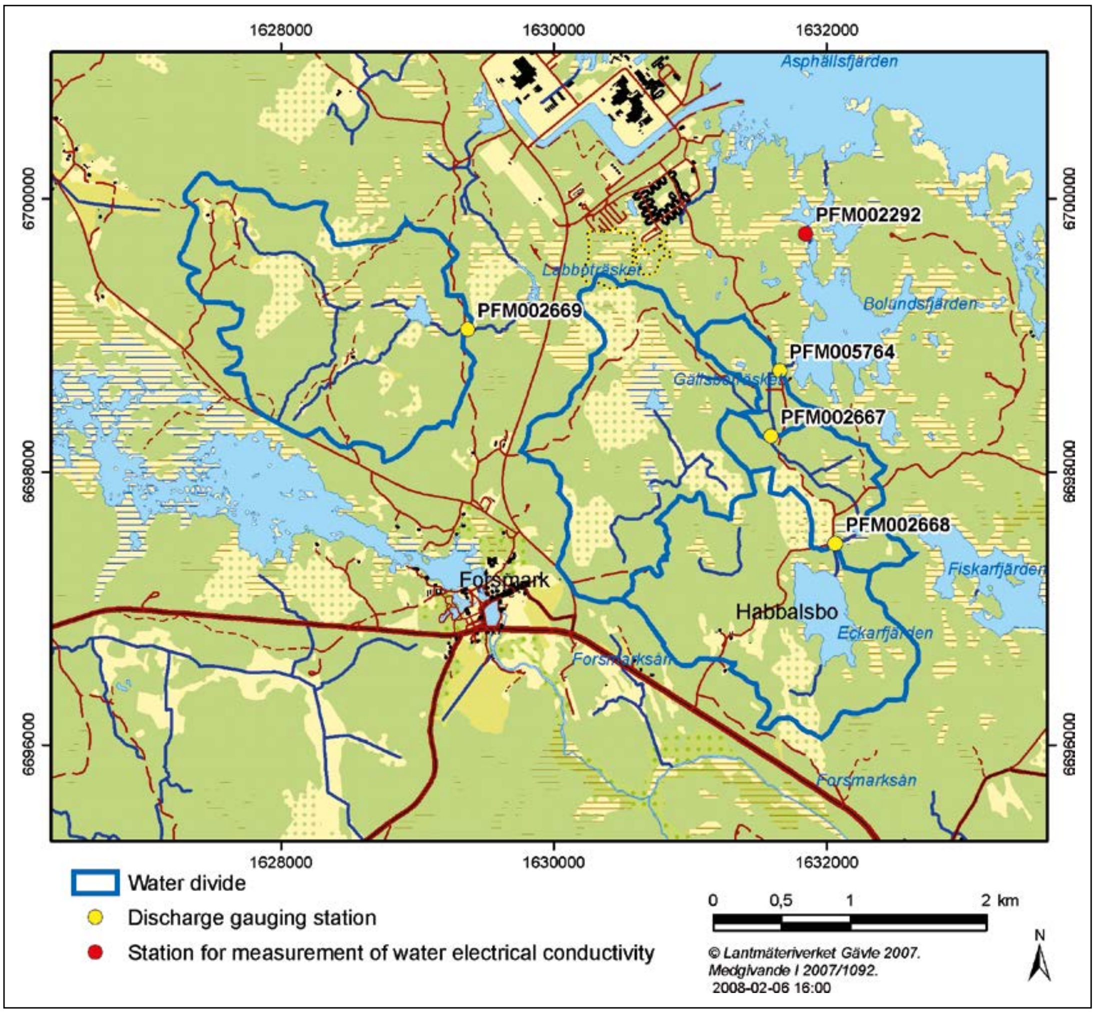
Figure 2-33. Plot of measured groundwater inflow (L·min^{-1}) to SFR during the period 1988–2010 (Öhman et al. 2012).

Table 2-18. Summary of screened out data days in the SFR tunnel borehole dataset.

Well id	Dates screened out (YYYY-MM-DD)
KFR01	2008-04-02, 2008-09-23, 2009-10-27, 2010-12-02–03.
KFR02	2008-04-23–28, 2008-05-13, 2008-05-14–15, 2008-05-22–26, 2008-08-15–26, 2008-08-28–29, 2008-09-01–29, 2008-10-03–04, 2008-10-06, 2008-10-28–29, 2008-11-03–04, 2008-11-15–21, 2008-12-11, 2009-02-05, 2009-04-06–09, 2009-06-23, 2009-06-24–07-02, 2009-07-07–08, 2009-07-10, 2009-08-19–09-03, 2009-09-14–17, 2009-10-03–07, 2009-10-16, 2009-10-21, 2009-11-04–06, 2010-11-24, 2010-11-26, 2010-11-30–12-02.
KFR03	2010-11-24–26.
KFR04	2008-05-06–13, 2008-06-02–07-02, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-06–13, 2008-08-15–18, 2008-09-01–02, 2008-09-18–20, 2008-09-23, 2008-10-09, 2008-10-02–22, 2008-10-27–30, 2008-11-04–05, 2008-11-10–17, 2008-11-23–12-12, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR05	2008-05-06–13, 2008-06-02–07-02, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-06–13, 2008-08-15–18, 2008-09-01–02, 2008-09-18–20, 2008-09-23, 2008-10-02–22, 2008-10-27–30, 2008-11-04–05, 2008-11-10–17, 2008-11-23–12-12, 2008-12-17, 2009-01-22, 2009-01-28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR07A	No data screened out
KFR07B	2008-05-06–13, 2008-06-02–07-02, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-06–13, 2008-08-15–18, 2008-09-01–02, 2008-09-18–20, 2008-09-23, 2008-10-02–22, 2008-10-27–30, 2008-11-04–05, 2008-11-10–17, 2008-11-23–27, 2008-11-25–12-12, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR08	2008-09-23, 2009-02-04, 2009-10-27, 2010-11-18, 2010-12-07, 2010-12-16, 2010-12-20–21.
KFR09	2010-12-03.
KFR13	2008-05-06–13, 2008-06-02–07-02, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-06–13, 2008-08-15–18, 2008-09-01–02, 2008-09-18–20, 2008-09-23, 2008-10-09, 2008-10-02–22, 2008-10-27–29, 2009-06-24–07-02, 2008-10-30, 2008-11-04–05, 2008-11-10–17, 2008-11-23–27, 2008-11-25–12-12, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2009-06-24–07-02, 2009-07-07–08, 2009-07-10, 2009-10-16, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR19	2010-10-28, 2010-11-09, 2010-12-07–09.
KFR55	2008-05-06–13, 2008-06-02–07-02, 2008-07-04, 2008-07-24–27, 2008-07-30–08-02, 2008-08-06–13, 2008-08-15–18, 2008-09-01–02, 2008-09-18–20, 2008-09-23, 2008-10-02–22, 2008-10-27–30, 2008-11-04–05, 2008-11-10–17, 2008-11-23–12-12, 2008-12-17, 2009-01-22–28, 2009-02-04–06, 2009-03-02, 2009-03-10–11, 2009-03-13, 2009-03-16, 2009-03-18–20, 2009-03-23, 2009-03-25, 2009-03-27, 2010-11-18-19, 2010-11-24, 2010-11-26, 2010-12-02–03, 2010-12-17.
KFR56	2009-02-04, 2010-11-09, 2010-11-18–19.
KFR105	2009-07-14–08-11, 2009-08-14–21, 2009-06-23–07-02, 2009-07-09, 2009-07-14–08-11, 2009-08-14–21, 2010-01-13–02-19, 2010-03-03–04, 2010-12-01–03.

2.6 Stream discharges and EC

Four stream-discharge gauging stations are installed in the Forsmark area (Johansson 2005b), see Table 2-19 and Figure 2-34. At these stations, the water level is measured automatically every 10 minutes at the upstream edge of flumes. Water levels are converted to water depths, which in turn are converted to stream discharge using flume-specific discharge equations and associated parameters (e.g. Johansson and Juston 2011b). Moreover, water EC (electrical conductivity) and temperature are measured automatically every 10 minutes at each gauging station. Station PFM002292 automatically measured EC in the channel between Lake Norra Bassängen and Lake Bolundsfjärden. There are no data from this station for 2010 (Johansson and Juston 2011b) and the monitoring is now terminated.



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Medgivande I 2007/1092.
2008-02-06 16:00

Figure 2-34. *Locations of the four stream-discharge gauging stations, their associated catchment areas, and the PFM002292 station for EC monitoring.*

Table 2-19. Sizes of catchment areas for stream-gauging stations (Johansson and Öhman 2008).

Gauging station id (catchment area id)	Size of catchment area (km^2)	Start date (YYYY-MM-DD)	Stop date (YYYY-MM-DD), this report
PFM005764 (AFM001267)	5.59	2004-04-14	2010-12-31
PFM002667 (AFM001268)	3.01	2004-12-08	2010-12-31
PFM002668 (AFM001269)	2.28	2004-12-08	2010-12-31
PFM002669 (AFM001270)	2.83	2004-12-08	2010-12-31
PFM002292 (EC only)			2009-12-31

Figure 2-35 shows time-series plots of calculated stream discharges at the four gauging stations. The methodology to calculate surface-water discharges was slightly revised in 2009, and a revised stream-discharge dataset, including all data from initiation of measurements (Table 2-19) to the end of 2008, was delivered to the Sicada database in the beginning of 2010 (Johansson and Juston 2009). The revised methodology only had minor effects on the stream-discharge data, affecting annual average discharges by 2% or less compared to previously reported values. The period for which data have been revised includes that of Johansson and Öhman (2008), who analysed data up to the end of March, 2007. In addition, the Sicada data delivery for the present study (sicada_080_1; Table 2-1) erroneously contains both unrevised and revised data up to the end of March, 2007. It is therefore noted that the dataset analysed in the present report has some minor errors and differs slightly from that of Johansson and Öhman (2008).

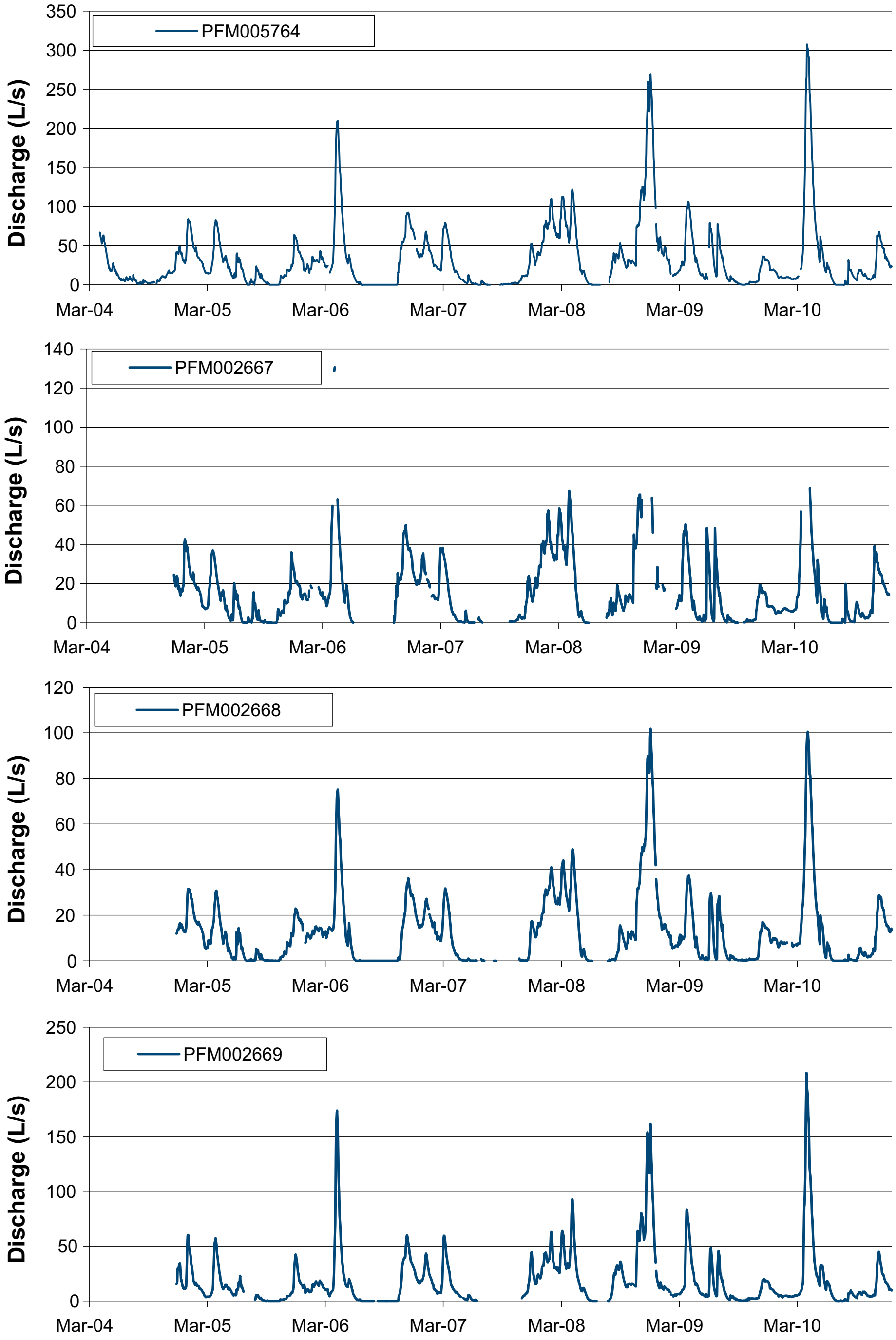

Figure 2-35. *Time-series plots of daily average stream discharges at the four gauging stations. Note the different scales of the vertical axes.*

According to the Sicada data delivery, the highest discharge from the catchment area of stations PFM005764, PFM002667, PFM002668, PFM002669 and PFM005764 up to the end of 2010 were 307, 159, 102 and 208 L/s, respectively. There was zero discharge in all monitored streams during long periods in late summers and early autumns, in particular during the years 2006–2008.

For the gauging stations equipped with two flumes covering different discharge intervals (PFM005764, -2667 and -2669), missing hourly discharge data were filled in whenever possible, prior to the respective data deliveries to the Sicada database (e.g. Johansson and Juston 2011b). As can be noted in Figure 2-35, the dataset still has some missing data periods, which need to be filled for water-balance purposes. As no systematic analysis of data-filling methods has yet been performed, linear and multiple regression analyses were tentatively used to fill in data gaps in the current discharge dataset. Specifically, daily-data gaps for the different gauging stations were filled as follows (Figure 2-36):

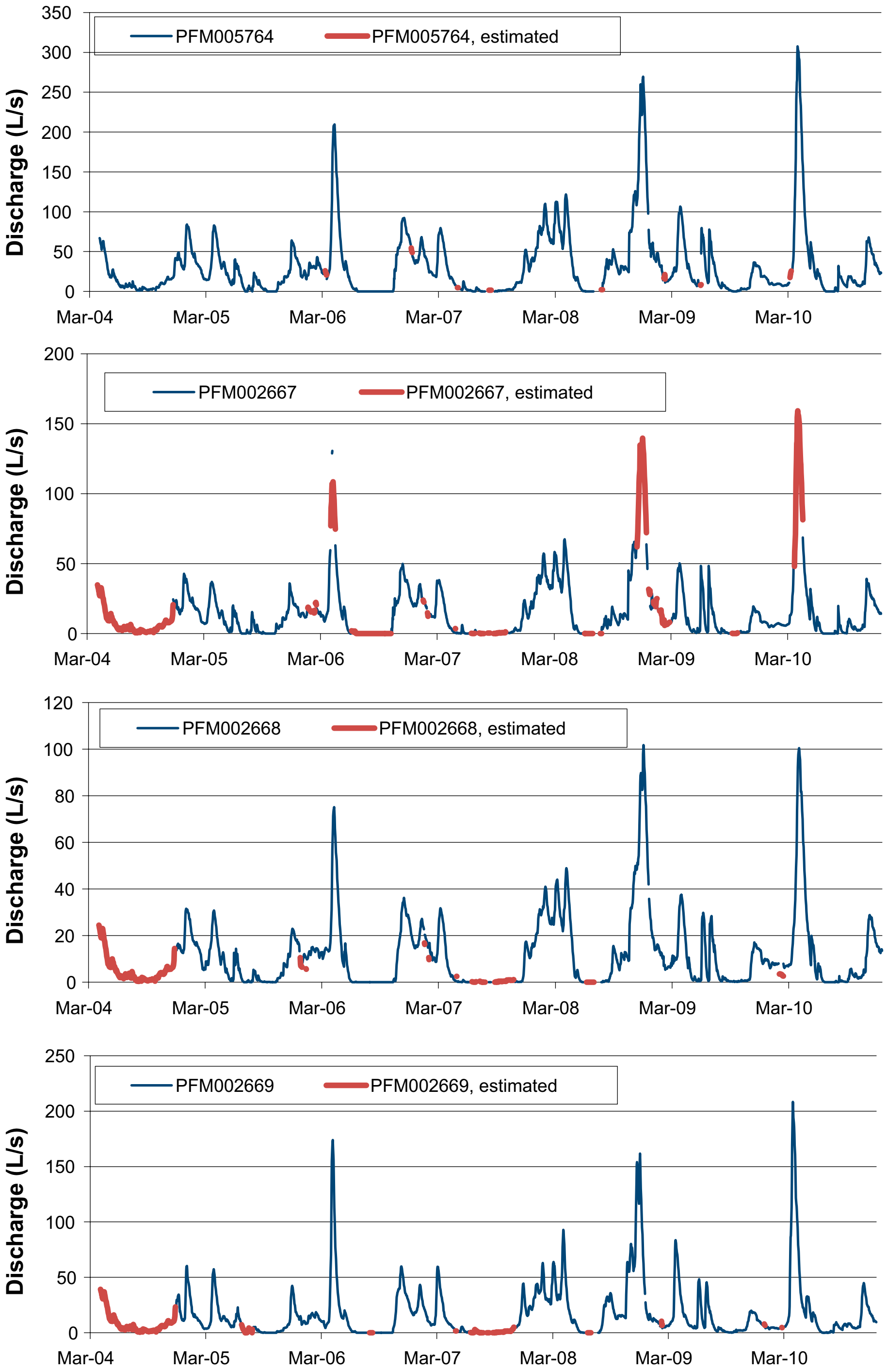

Figure 2-36. *Time-series plots of daily average stream discharges at the four gauging stations, with filled-in data days (estimated) marked in red. Note the different scales of the vertical axes.*

PFM002667:

The basic data-fill expression obtained for station PFM002667 utilises data from station PFM005764, according to PFM002667 = PFM005764·0.5183. For days without PFM005764 data, the expression is PFM002667 = PFM002668·1.002153 + PFM002669·0.203697 + 0.01138. On days without both PFM005864 and -2669 data, the expression is PFM002667 = PFM002668·1.268895 + 0.335037.

PFM002668:

The data-fill expression for station PFM002668 utilises data from station PFM005764, according to PFM002668 = PFM005764·0.3648.

PFM002669:

The basic data-fill expression for station PFM002669 utilises data from station PFM005764, according to PFM002669 = PFM005764·0.5847. For days without PFM005764 data, the expression is PFM002669 = PFM002667·0.94392 + PFM002668·0.11509 + 1.30279. On days without both PFM002667 and -5764 data, the expression is PFM002669 = PFM002668·1.526189 – 0.891387.

PFM005764:

The basic data-fill expression for station PFM005764 is PFM005764 = PFM002667·1.03841 + PFM002668·0.407445 + PFM002669·0.48118 + 3.719843. For days without PFM002667 data, the expression is PFM005764 = PFM002668·1.629568 + PFM002669·0.662413 + 2.202829. On days without PFM002669 data, the expression is PFM005764 = PFM002667·1.5 + PFM002668·0.45858 + 4.20125. On days without both PFM002667 and -2669 data, the expression is PFM005764 = PFM002668·2.638273 + 1.564762.

Table 2-20 summarises average discharges (L·s^{-1}) and average specific discharges (L·s^{-1}·km^{-2} and mm·y^{-1}) for different time periods. The average specific discharge for the gauging station with the largest catchment area (PFM005764), with a time series covering some 80.5 months (more than 6.5 years), was 5.8 L·s^{-1}·km^{-2} (182 mm·y^{-1}). The results of the EC monitoring at the gauging stations are summarised in Table 2-21. Generally, discharge and EC were inversely correlated, i.e., EC was low during high-discharge periods and vice versa.

Table 2-20. Average discharges and corresponding specific discharges for the four gauging stations for various time periods. Specific discharges that include estimated daily discharge data (see text) are shown within brackets. At PFM002667, -2668 and -2669, measurements were initiated on Dec. 8, 2004.

Time period	PFM005764	PFM002667	PFM002668	PFM002669
Apr. 15, 2004–Dec. 31, 2007				
Average discharge (L·s^{-1})	27.3	–	–	–
Specific discharge (L·s^{-1}·km^{-2})	4.9	–	–	–
Specific discharge (mm·y^{-1})	154			
Dec. 8, 2004–Dec. 31, 2007				
Average discharge (L·s^{-1})	31.0	16.8	11.5	16.6
Specific discharge (L·s^{-1}·km^{-2})	5.5	5.6	5.1	5.9
Specific discharge (mm·y^{-1})	175	175	160	185
Apr. 15, 2004–Dec. 31, 2010				
Average discharge (L·s^{-1})	32.3 (32.0)	–	–	–
Specific discharge (L·s^{-1}·km^{-2})	5.8 (5.7)	–	–	–
Specific discharge (mm·y^{-1})	182 (181)	–	–	–
Dec. 8, 2004–Dec. 31, 2010				
Average discharge (L·s^{-1})	34.3	15.2 (15.7)	13.2 (11.7)	19.5 (17.1)
Specific discharge (L·s^{-1}·km^{-2})	6.1	5.1 (5.2)	5.8 (5.1)	6.9 (6.0)
Specific discharge (mm·y^{-1})	193	160 (164)	182 (162)	218 (190)
Jan. 1–Dec. 31, 2005				
Average discharge (L·s^{-1})	25.2	12.0	9.1	12.6
Specific discharge (L·s^{-1}·km^{-2})	4.5	4.0	4.0	4.5
Jan. 1–Dec. 31, 2006				
Average discharge (L·s^{-1})	32.9	22.1	12.3	17.9
Specific discharge (L·s^{-1}·km^{-2})	5.9	7.4	5.3	6.3
Jan. 1–Dec. 31, 2007				
Average discharge (L·s^{-1})	19.6	11.2	8.9	15.9
Specific discharge (L·s^{-1}·km^{-2})	3.5	3.7	3.9	5.6
Jan. 1–Dec. 31, 2008				
Average discharge (L·s^{-1})	64.9	27.1	25.5	36.6
Specific discharge (L·s^{-1}·km^{-2})	11.6	9.0	11.2	12.9
Jan. 1–Dec. 31, 2009				
Average discharge (L·s^{-1})	26.7	11.7	9.6	13.2
Specific discharge (L·s^{-1}·km^{-2})	4.8	3.9	4.2	4.7
Jan. 1–Dec. 31, 2010				
Average discharge (L·s^{-1})	36.8	10.6	13.9	20.3
Specific discharge (L·s^{-1}·km^{-2})	6.6	3.5	6.1	7.2

Table 2-21. Electrical conductivity (EC) at the gauging stations (based on high-resolution data). Very low EC values (< 5) were not included in the calculations.

Gauging station id	Catchment area ID	Average EC ($mS\cdot m^{-1}$)	Approximate EC range ($mS\cdot m^{-1}$)
PFM002667 (Dec. 8, 2004–)	AFM001268	25	10–40
PFM002668 (Dec. 8, 2004–)	AFM001269	26	10–75
PFM002669 (Dec. 8, 2004–)	AFM001270	37	15–60 (single value of c 200)
PFM005764 (Mar. 21, 2004)	AFM001267	37	15–125

3 Relations between datasets

3.1 Rainfall, snowmelt and potential evapotranspiration

Johansson and Öhman (2008) used a simple snow accumulation and snow-melt model to derive a rainfall/snowmelt time series based on precipitation and air temperature time series. The model is based on the following assumptions:

- Precipitation that occurs on days with average daily air temperatures above –0.4°C is rainfall that infiltrates across the ground surface, or adds to the water content of the above-ground snow storage if present.
- Precipitation that occurs on days with average daily air temperatures below –0.4°C accumulates on the ground surface in the form of snow.
- The accumulated water content in the above-ground snow storage melts on days when the mean daily air temperature is above –0.807°C, with a rate of 0.837 $\mathrm{mm \cdot °C^{-1}}$ above –0.807°C according to a standard degree-day formulation.

Specifically, the model syntax is as follows:

- **Daily snow accumulation:** If the daily average air temperature (average of Högmasten and Storskäret up to the end of June 2007, Högmasten only thereafter) is lower than –0.4°C, the daily accumulated precipitation (average of Högmasten and Storskäret up to the end of June 2007, Högmasten only thereafter) accumulates as snow. Otherwise, the daily snow accumulation is 0.
- **Preliminary daily snow melt:** If the net water content of snow for the previous day is larger than zero, and if the daily average air temperature (average of Högmasten and Storskäret up to the end of June 2007, Högmasten only thereafter) is above –0.807°C, the preliminary daily snow melt (mm) is calculated as 0.837·(daily average air temperature at Högmasten – (–0.807).
- **Final snow melt:** If the preliminary daily snow melt (the step above) is higher that the net water content of snow for the previous day, the final snow melt is equal to the net water content of snow for the previous day (i.e. all snow water storage melts). Otherwise, the final snow melt is equal to the preliminary daily snow melt.
- **Preliminary snow water content:** If the net water content for the previous day + daily snow accumulation – final snow melt is equal to or larger than zero, the preliminary snow water content is equal to the daily snow accumulation – final snow melt. Otherwise, i.e. if net water content for the previous day + daily snow accumulation – final snow melt is less than zero, the preliminary snow water content is set to zero.
- **Rain that adds to snow:** If the daily average air temperature (average of Högmasten and Storskäret up to the end of June 2007, Högmasten only thereafter) is higher than –0.4°C, and if the preliminary snow water content is larger than zero (there is a snow cover), the daily accumulated precipitation (average of Högmasten and Storskäret up to the end of June 2007, Högmasten only thereafter) adds to the snow water content in the form of rain.
- **Snow water content:** The snow water content is calculated as the sum of the preliminary snow water content + rain that adds to snow.

Johansson and Öhman (2008) estimated the snow/rain threshold (–0.4°C), the snow-melt threshold (–0.807°C) and the snow-melt rate constant (0.837 $\mathrm{mm \cdot °C^{-1}}$ above –0.807°C) using time series up to the 2006/2007 winter season of average snow water content at the two forest locations AFM000072 and AFM001172 (cf. Figures 2-2 and 2-11). The open-land location (AFM000071) was excluded from their estimation procedure, as forest is the dominating land use.

Figure 3-1 shows a time-series plot of the model-calculated snow water content up to the end of December 2010, simulated using the thresholds and the rate constant mentioned above. The plot also shows the average of the estimated snow water content at all three locations (AFM000072, AFM001172 and AFM000071). As can be seen in the figure, the model adequately captures the site-average snow water-content dynamics up to the 2008/2009 winter season ($R^2 = 0.86$), whereas the model fit is poorer ($R^2 = 0.57$) if the remaining winter seasons up to the end of 2010 are taken into account. In particular, the model overestimates the snow water content during the 2008/2009 winter season, during which the daily average air temperature fluctuates around 0°C for long periods characterised by cold nights and warm days. During these periods, the actual daytime snow melt is likely more intense than the simulated snow melt, which is based on the daily average air temperature.

Figure 3-2 shows daily rainfall and estimated snow melt during the period May 1, 2003–December 31, 2010. As stated above, precipitation is set as rain that infiltrates the ground surface on days with an average daily air temperature above –0.4°C, if there is no above-ground snow storage. Figure 3-3 shows the corresponding monthly sums, co-plotted with monthly PET sums (cf. Figure 2-9).

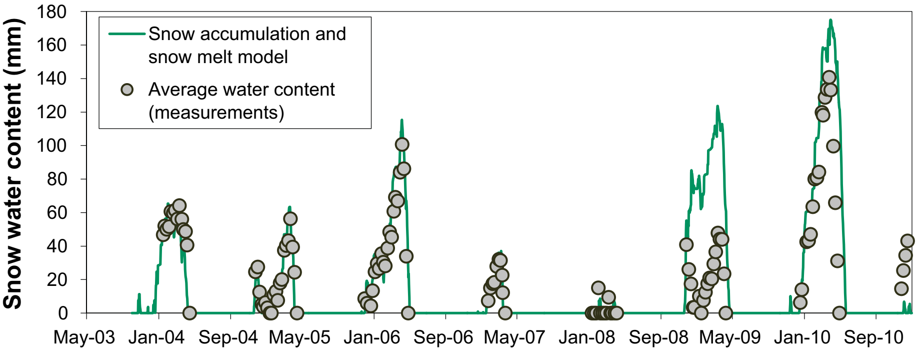

Figure 3-1. *Measured and simulated daily site-average snow water content during the period Oct. 1, 2003–Dec. 31, 2010, based on a simple degree-day snowmelt model.*

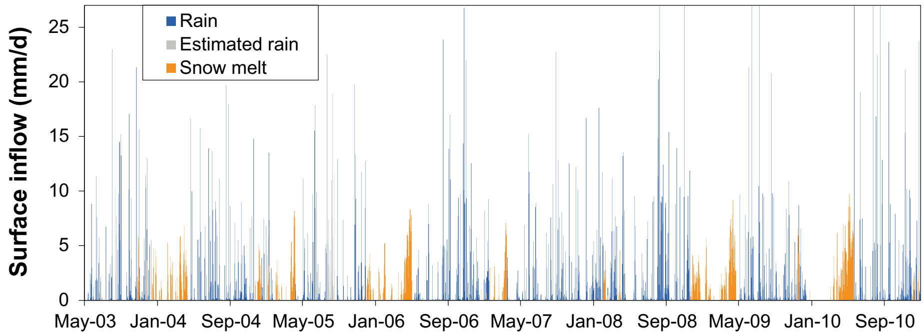

Figure 3-2. *Daily rainfall and estimated site-average snowmelt during the period May 1, 2003–December 31, 2010. Rain is the average of Högmasten and Storskäret up to the end of June 2007, and Högmasten only thereafter.*

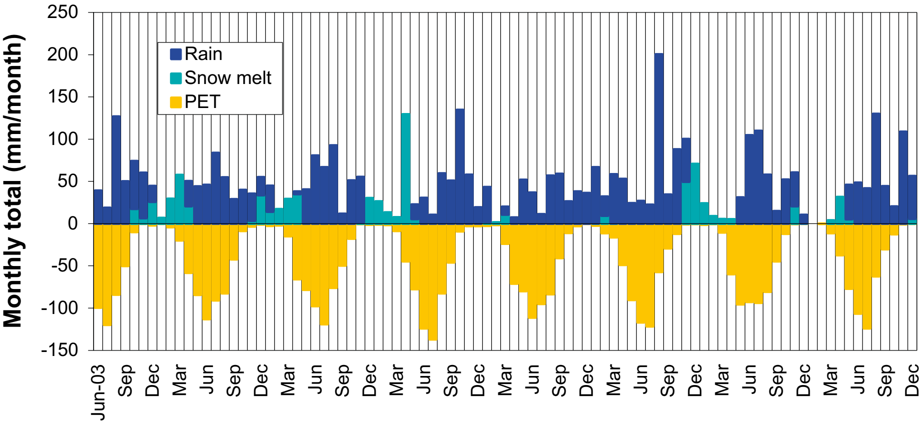

Figure 3-3. *Monthly rainfall + snowmelt and PET for the period June 2003 –December 2010. Negative daily PET sums are set to zero. Note that for presentation purposes, PET values (zero or positive) are shown as negative numbers in the figure.*

3.2 Comparisons between groundwater levels and precipitation, snowmelt and evapotranspiration

As is also shown in Figure 3-4, Johansson and Öhman (2008) provided evidence of the influence of rainfall, snowmelt, and evapotranspiration on groundwater-level and stream-discharge time series, both in terms of long-term cycles and short-term event-driven responses.

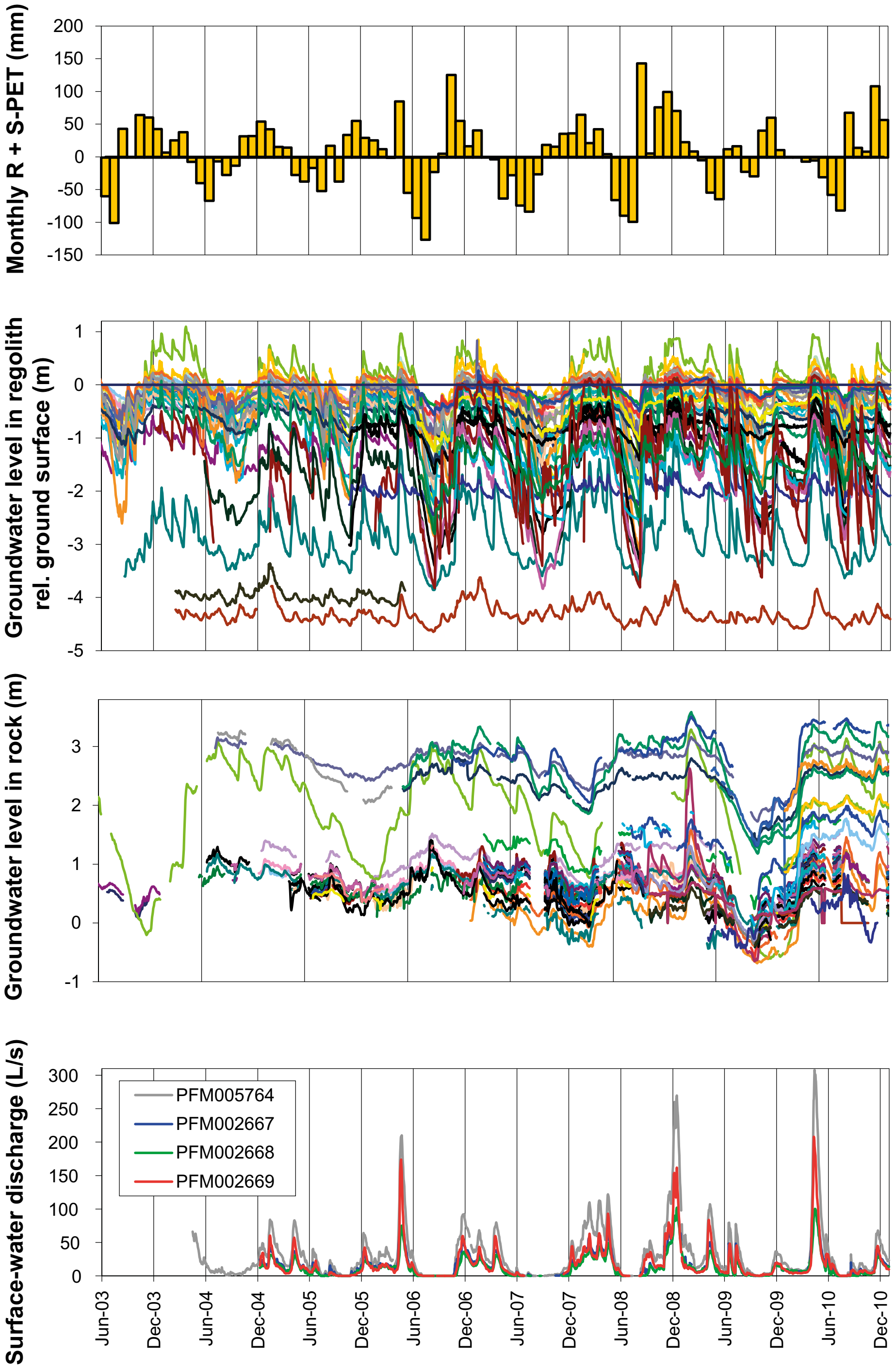

Figure 3-4. *Time series of, from top to bottom, monthly rainfall plus snowmelt minus potential evapotranspiration (negative daily PET sums are set to zero), daily average groundwater levels in regolith relative to ground surface (excluding wells installed below open water), daily groundwater levels in rock (for better visibility, HFM11, -12, -34.2, -35.1-3, -36 and -37 are excluded), and daily average stream discharge (missing data days are not filled in).*

Figure 3-4 shows plots of, from top to bottom, monthly totals of rainfall + snowmelt – PET, daily average groundwater levels in regolith relative to ground surface (excluding wells installed below open water), daily average groundwater levels in rock (excluding some boreholes, see figure caption), and daily average stream discharges (missing data days are not filled in).

Figure 3-5 shows correlations (coefficients of determination, R^2) for groundwater levels in regolith (excluding wells installed below open water) with the rainfall + snowmelt – PET time series. The correlations were estimated using monthly average groundwater levels in order to reduce influences of short-term dynamics. Month-to-month correlations were typically low in most wells, whereas correlations to the antecedent two months rainfall + snowmelt – PET was substantially higher.

3.3 Comparisons between groundwater levels and the sea level

Figure 3-6 shows time-series plots of sea level, groundwater levels in regolith and groundwater levels in rock (HFM01–38) for the period May 1, 2003–December 31, 2010. For the time period up to the end of March, 2007, Johansson and Juston (2008) used different methods to analyse correlations between these datasets, including linear regression, PCA (principal component analysis), ICA (independent component analysis) and PLS (partial least squares). For an overview of these methods, see Juston et al. (2007).

It was found that groundwater levels in regolith and point-water heads in rock generally have low correlations with the sea level. The exceptions are groundwater-monitoring wells SFM0059 and -61 ($R^2 \approx 0.6$–0.7), which are installed in glaciofluvial material in the esker Börstilåsen less than 100 m from the sea shoreline. Moreover, higher correlations with the sea level ($R^2 \approx 0.9$) are also noted for percussion-drilled boreholes HFM33, -34 and -35, which are located on the SFR peninsula. According to PCA and ICA analyses, rainfall + snowmelt – PET variability explains c 80% of the point-water head variations, whereas sea-level fluctuations explains only c 10% of the variations (Johansson and Öhman 2008).

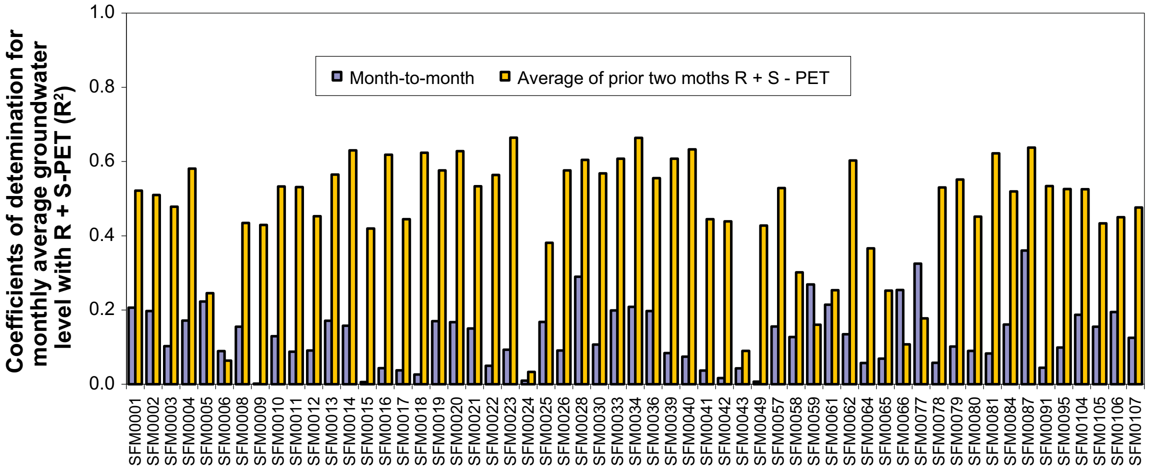

Figure 3-5. *Correlation of monthly average groundwater levels in regolith with monthly and bi-monthly rainfall + snowmelt – potential evapotranspiration differences (R + S – PET). Negative daily PET sums are set to zero.*

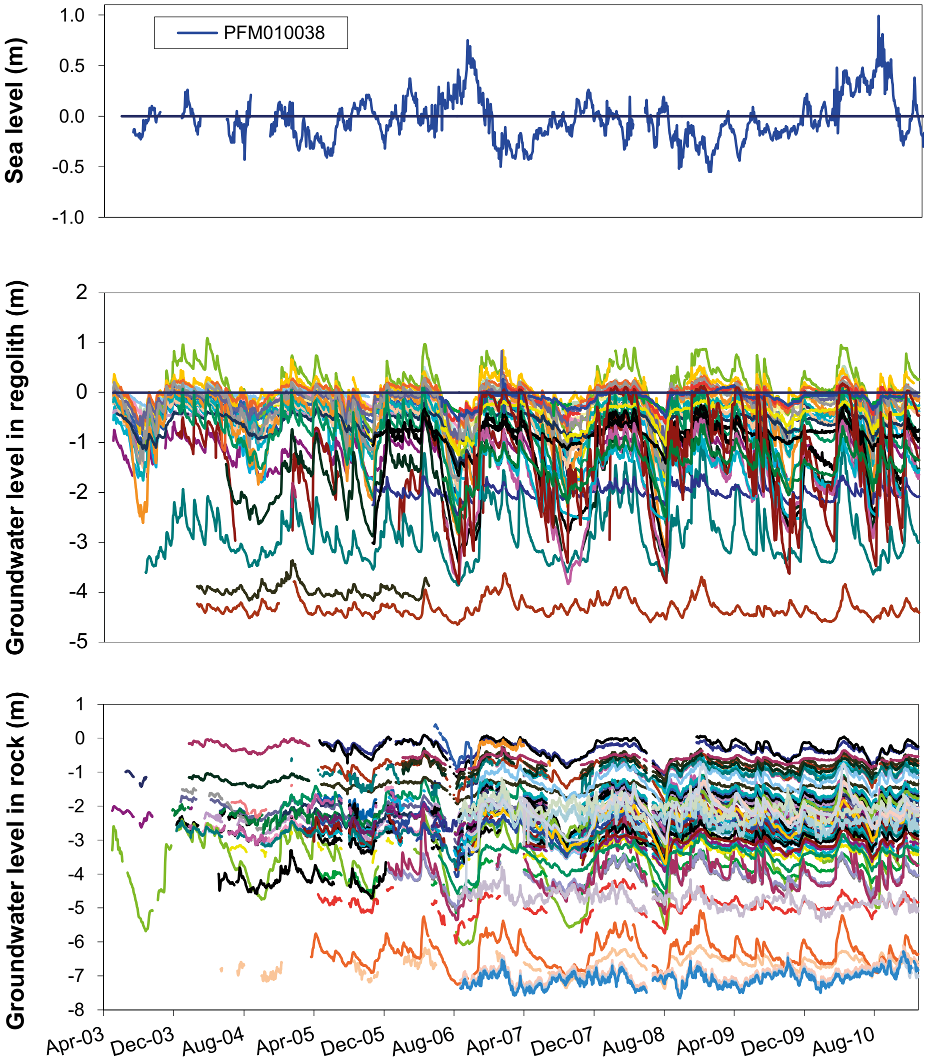

Figure 3-6. *Time-series plots of sea, groundwater levels in regolith (excluding wells installed below open water), and groundwater levels in rock (HFM01–38) for the period May 1, 2003–December 31, 2010.*

3.4 Comparisons between surface-water levels and groundwater levels

Surface-water levels and groundwater levels in the underlying regolith are measured in the lakes Bolundsfjärden, Eckarfjärden, Gällsboträsket, Fiskarfjärden and in four ponds. Groundwater-level and surface-water level measurements in Lake Lillfjärden were terminated in 2005 and 2006, respectively. Figures 3-7 and 3-8 show time-series plots of groundwater and surface-water levels, whereas Figure 3-9 and 3-10 show the same data represented as level differences (head differentials); positive values indicate upward hydraulic gradients and flow (discharge) and negative values downward gradients and flow (recharge).

For the whole periods shown in Figures 3-7 to 3-10, the average head differential is slightly negative (c –0.002 to –0.07 m) for the lakes Eckarfjärden, Gällsboträsket, Fiskarfjärden, Bolundsfjärden (considering SFM0023) and for the ponds in wetland objects 7 and 18, whereas the average head differential is c –0.2 m for Lake Lillfjärden. The average head differential is slightly positive (0.02–0.08 m) for the Lake Bolundsfjärden (considering SFM0081) and wetland objects 14 and 16. As described in Sections 2.3 and 2.4, new levelling done in October–November 2010 shows that gauges and wells installed in lakes and ponds are displaced vertically, likely due to winter-time ice shear. Vertical displacements are of the same order as the head differentials described above, which implies that there is some degree of uncertainty regarding actual hydraulic gradients.

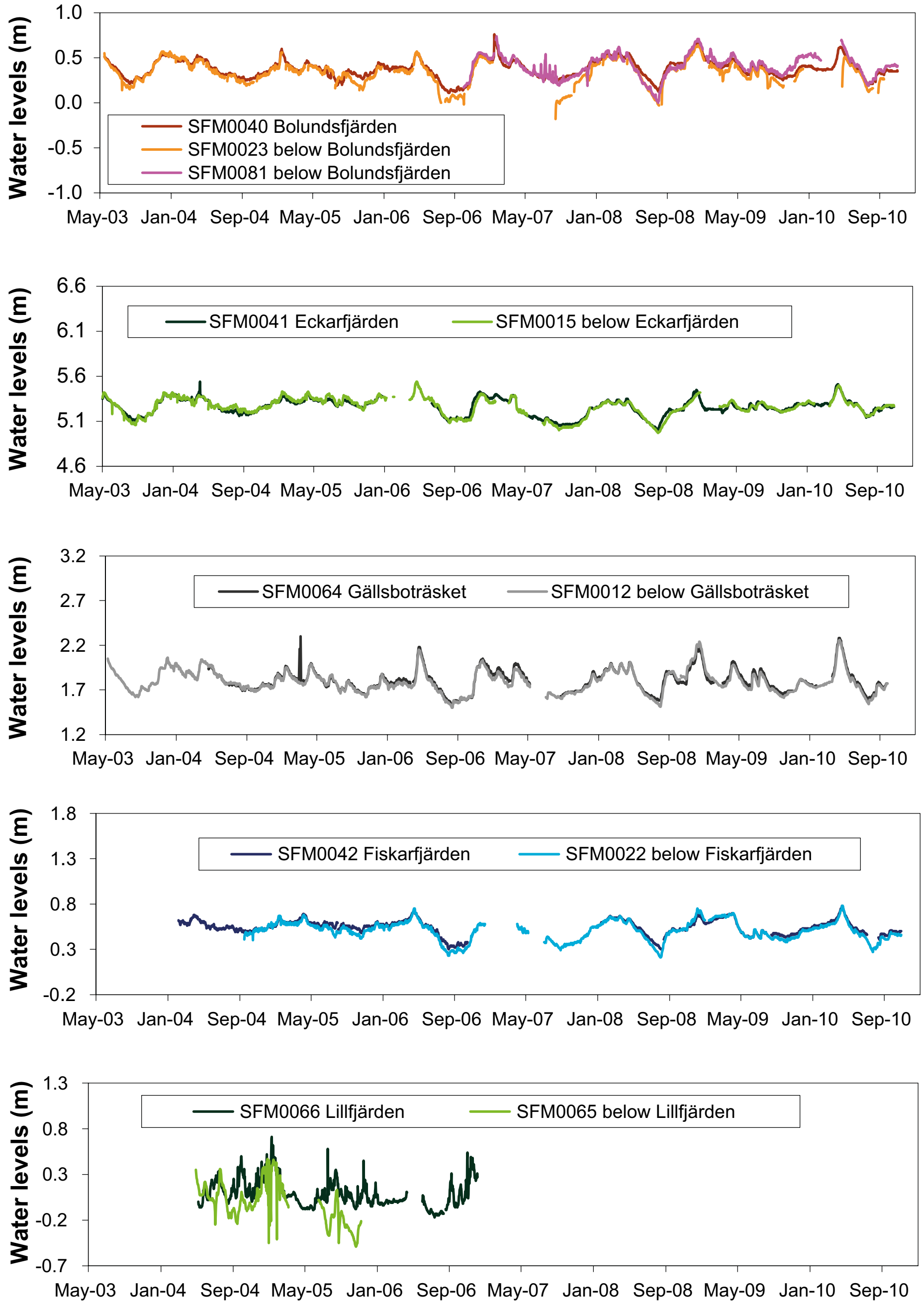

Figure 3-7. *Time-series plots of lake-water levels and groundwater levels in groundwater-monitoring wells installed below the lakes Bolundsfjärden, Eckarfjärden, Gällsboträsket, Fiskarfjärden and Lillfjärden.*

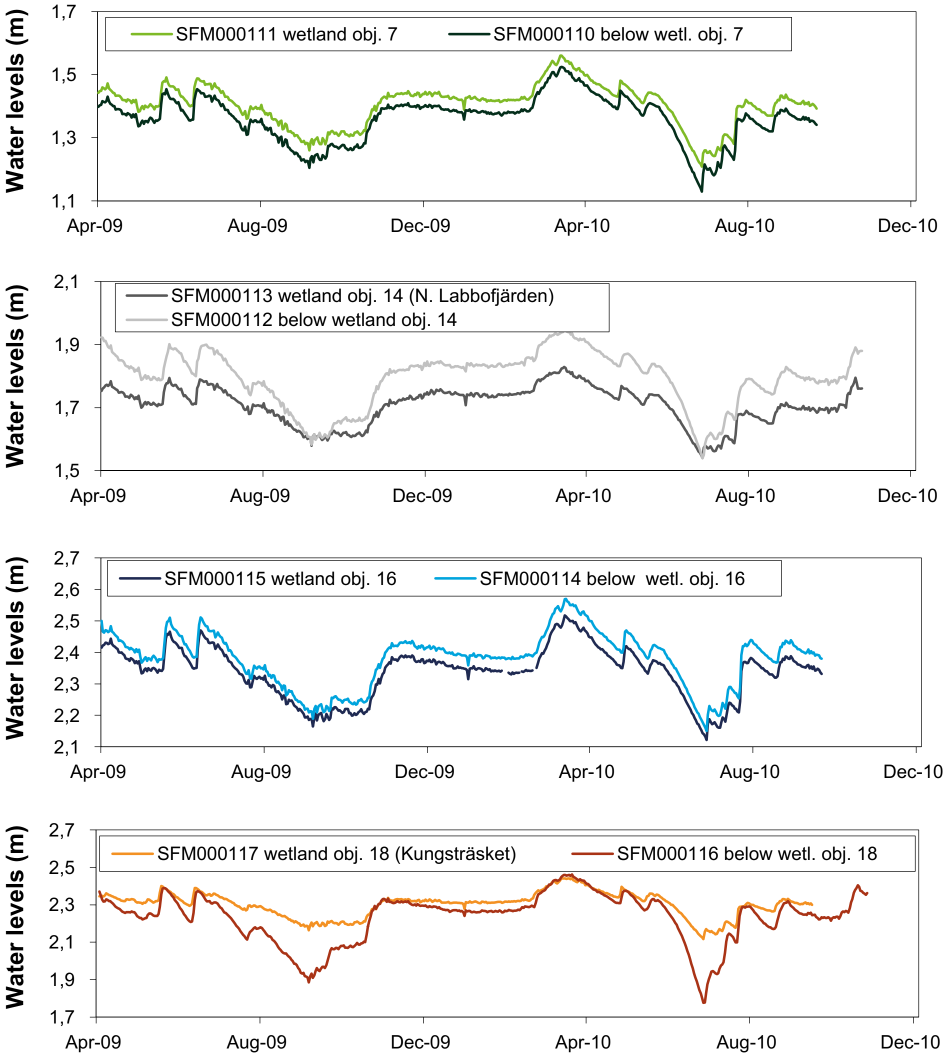

Figure 3-8. *Time-series plots of pond-water levels and groundwater levels in groundwater-monitoring wells installed below four ponds.*

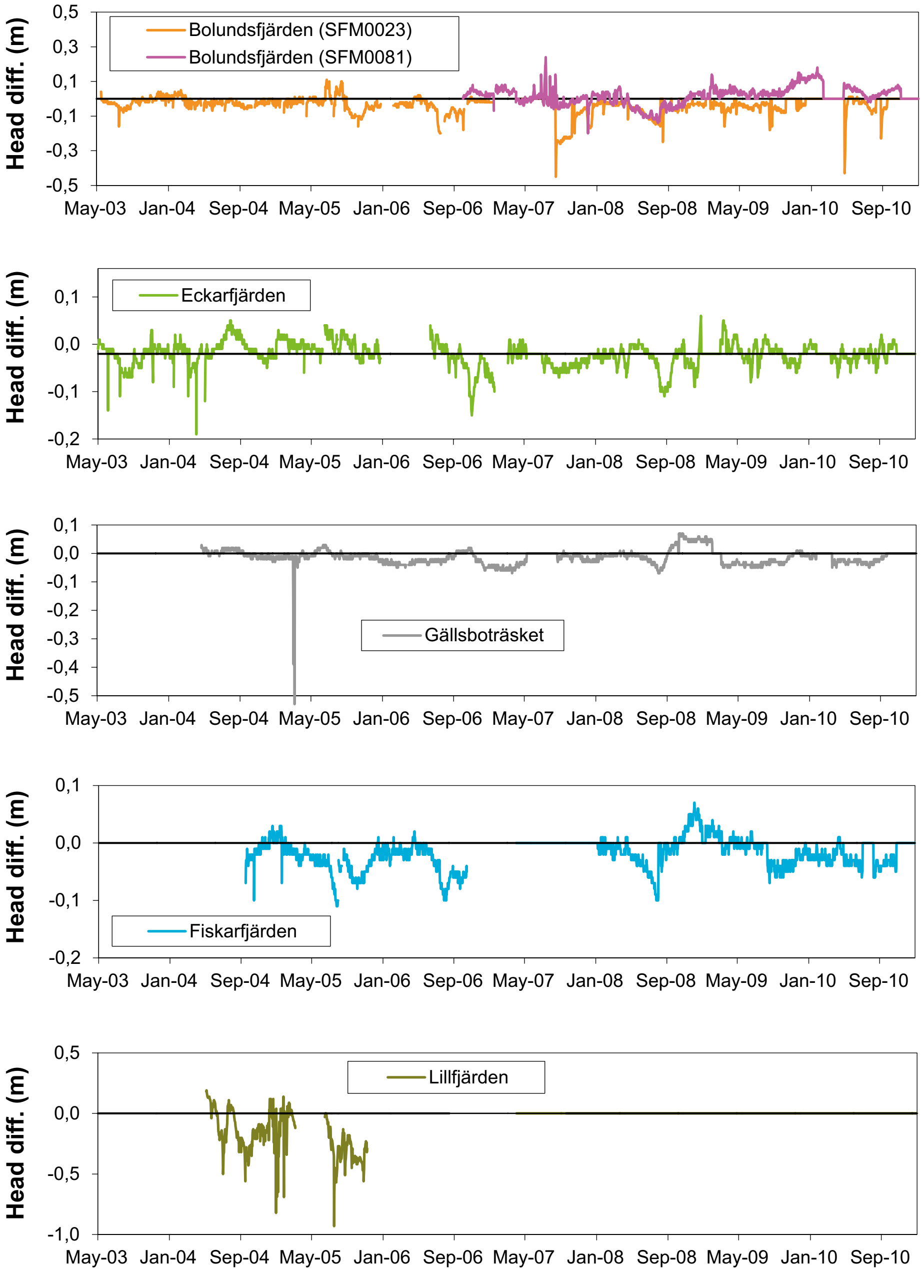

Figure 3-9. *Head differences between below-bottom groundwater-monitoring wells and surface-level gauges in the lakes Bolundsfjärden, Eckarfjärden, Gällsboträsket, Fiskarfjärden and Lillfjärden. Negative values indicate downward hydraulic gradients (groundwater recharge), whereas positive values indicate upward gradients (groundwater discharge).*

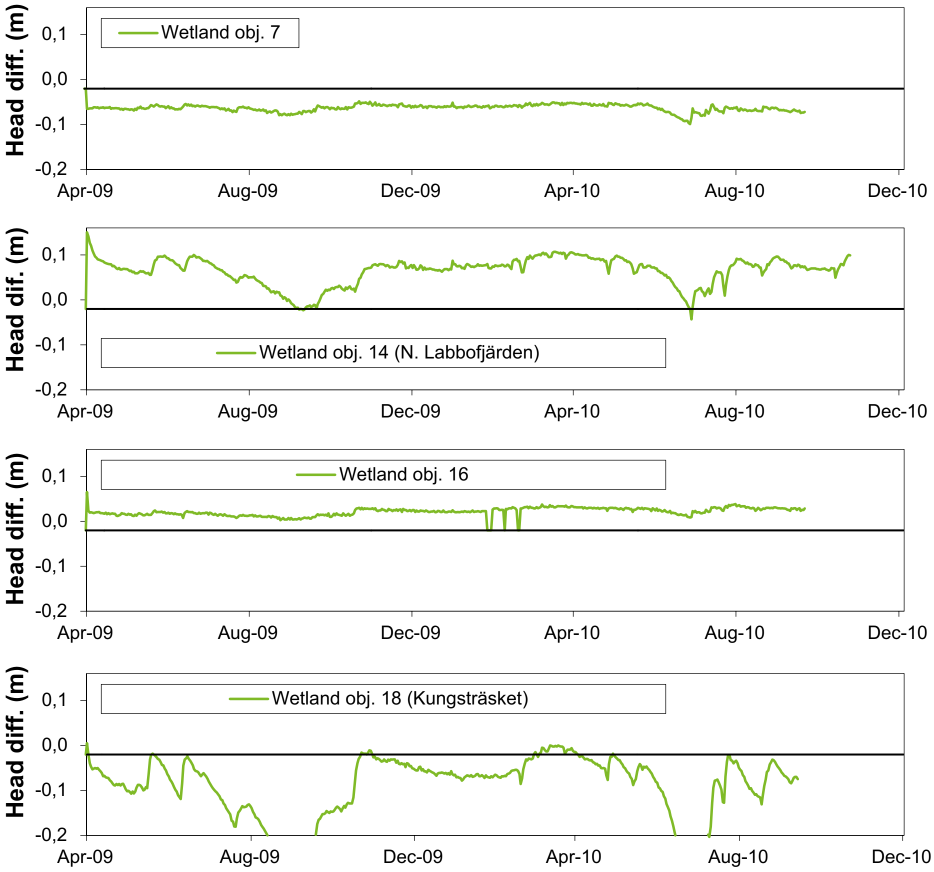

Figure 3-10. *Head differences between below-bottom groundwater-monitoring wells and surface-level gauges in four ponds. Negative values indicate downward hydraulic gradients (groundwater recharge), whereas positive values indicate upward gradients (groundwater discharge).*

The figures below compare lake levels and groundwater levels in regolith and rock (for simplicity denoted as water levels in the figures) in the vicinity of the lakes Eckarfjärden (Figure 3-11), Bolundsfjärden (Figure 3-12), Fiskarfjärden (Figure 3-13) and Tjärnpussen (Figure 3-14, see SFM000119 in Figure 2-19). As shown in these figures, lake level amplitudes are smaller than groundwater-level amplitudes in the regolith. In the vicinity of Lake Eckarfjärden, groundwater levels in the percussion-drilled boreholes HFM11 and -12 (Figure 3-11) are well above the lake level and groundwater levels in regolith. According to these figures, the groundwater level in the regolith in the vicinity of the lakes is periodically below the lake level during summers, which indicates that the lakes act as sources for groundwater recharge to the regolith close to the lake during these periods. The groundwater level close to Lake Tjärnpussen (Figure 3-14) is below the lake level during the data period of this report.

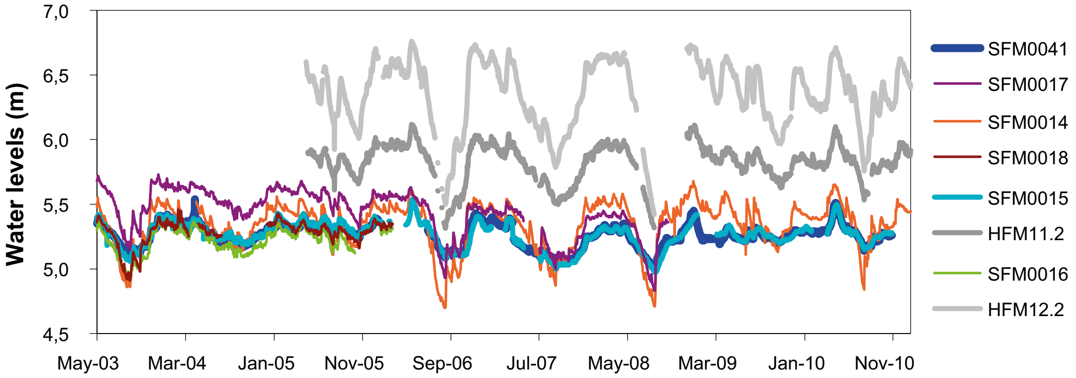

Figure 3-11. *Lake level (SFM0041), groundwater levels in regolith, and point-water heads in the upper borehole sections of percussion-drilled boreholes HFM11 and -12 in the vicinity of Lake Eckarfjärden. SFM0015 is installed below the lake, whereas SFM0014, -16, -17 and -18 are installed in its vicinity.*

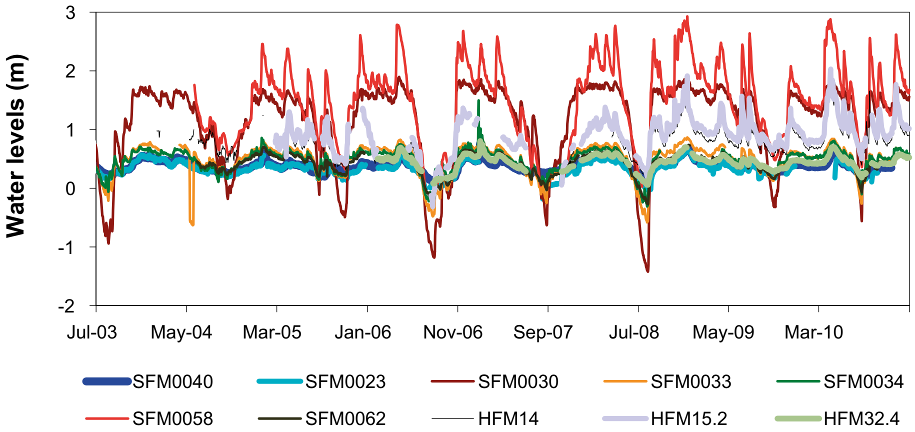

Figure 3-12. *Lake level (SFM0040) and groundwater levels in regolith in the vicinity of Lake Bolundsfjärden. SFM0023 is installed below the lake.*

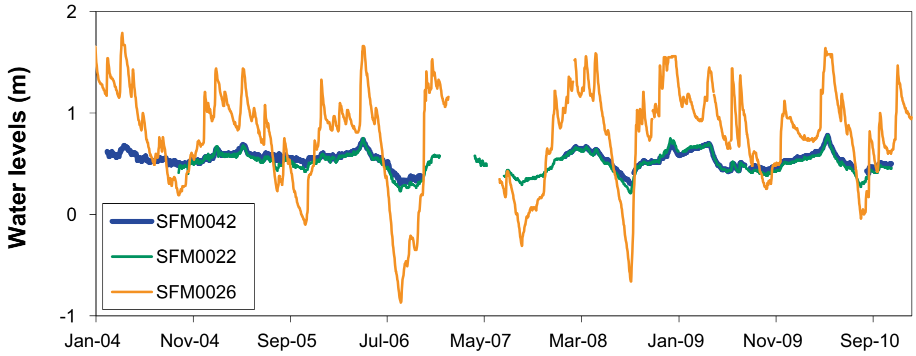

Figure 3-13. *Lake level (SFM0042) and groundwater levels in regolith in the vicinity of Lake Fiskarfjärden. SFM0022 is installed below the lake.*

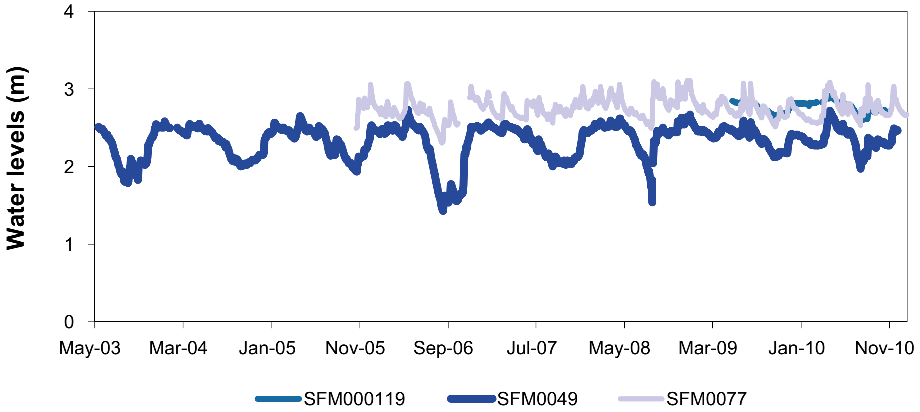

Figure 3-14. *Lake level (SFM000119) and groundwater levels in regolith in the vicinity of Lake Tjärnpussen. SFM0049 is installed at the lake shoreline.*

3.5 Comparisons between groundwater levels in regolith and rock

Comparisons of groundwater levels in monitoring wells and nearby boreholes in the rock are important for interpretation of hydraulic interactions between regolith and the underlying rock. Upward gradients, i.e. the groundwater level in the rock is above the groundwater level in the regolith, indicate groundwater flow from rock to regolith, whereas downward gradients indicate groundwater flow in the opposite direction. Figures 3-15 to 3-23 show time-series plots (May 1, 2003–December 31, 2010) of groundwater levels in groundwater-monitoring wells and groundwater levels in nearby percussion-drilled boreholes at drill sites 1–7, 9, and 10 (see Appendix A of Follin 2008). There are no groundwater-monitoring wells at drill sites 8 and 11. Moreover, well SFM0109 is located close to drill site 12, but there are no monitoring data for that well (Table 2-11). For sectioned boreholes, data are shown for the upper borehole section only. In cases of previously open, now sectioned boreholes, no data are shown from the open borehole.

In accordance with Johansson and Öhman (2008), the figures below show that the groundwater level in most groundwater-monitoring wells located at drill sites is above groundwater levels in rock, which indicates downward flow from regolith to rock. Specifically, the groundwater level in the regolith is clearly above that in the rock at most drill sites within the tectonic lens (drill sites 2, 5, 7 and 9) except for dry periods during the summer, whereas there are different vertical hydraulic-head gradients between regolith and rock for different well/borehole combinations at drill sites 1, 3, 4, 6 and 10.

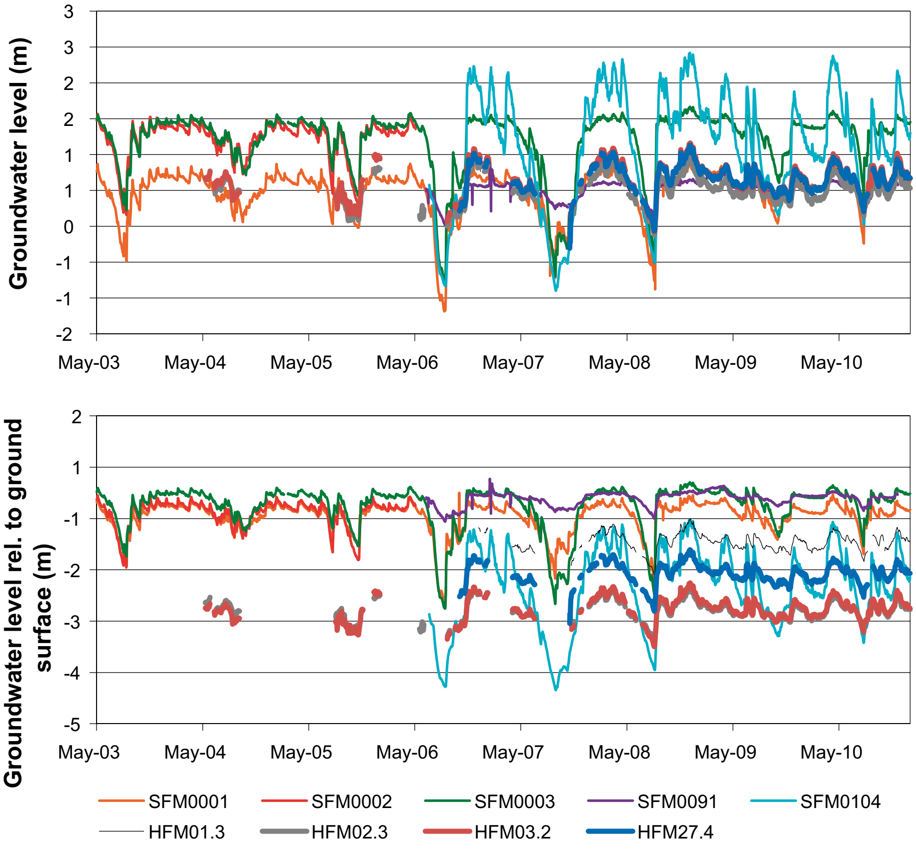

Figure 3-15. *Groundwater levels in groundwater-monitoring wells SFM0001–0003, -0091 and -0104, and groundwater levels in percussion-drilled boreholes HFM01–03 and -27 at drill site 1. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure). SFM0094 is located close to drill site 1, but there are no monitoring data for that well (cf. Table 2-11).*

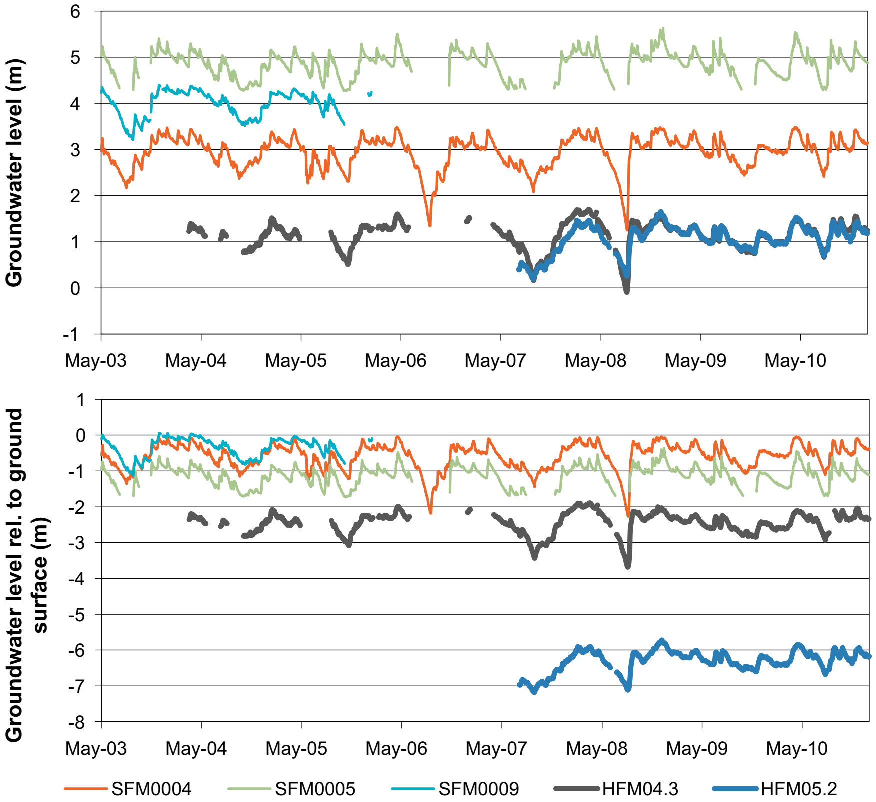

Figure 3-16. Groundwater levels in groundwater-monitoring wells SFM0004, -0005 and -0009, and groundwater levels in percussion-drilled boreholes HFM04 and -05 at drill site 2. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure).

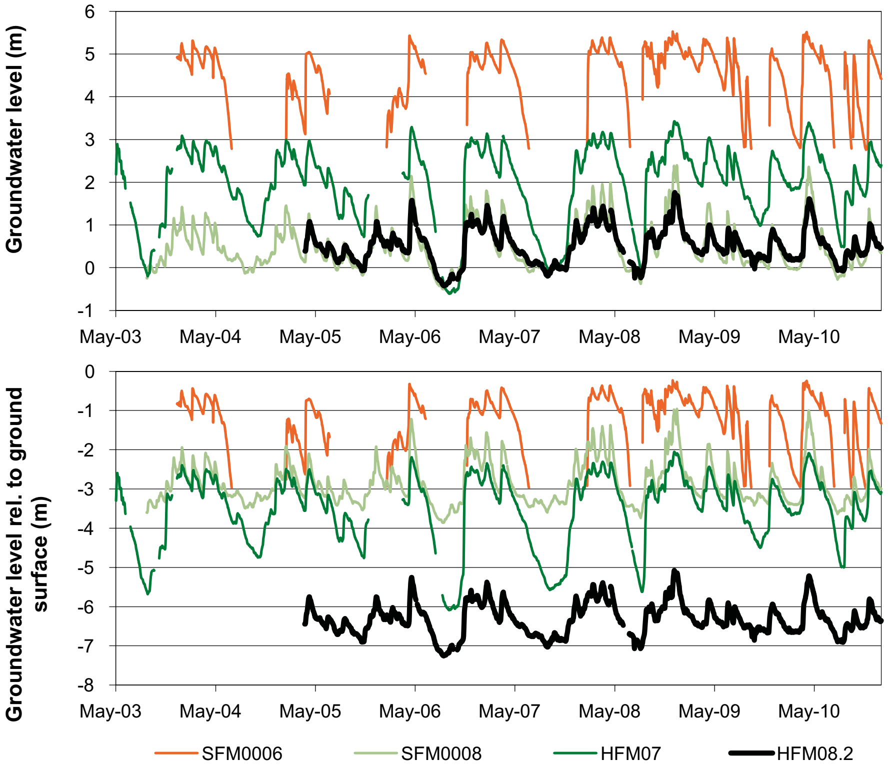

Figure 3-17. Groundwater levels in groundwater-monitoring wells SFM0006 and -0008, and groundwater levels in percussion-drilled boreholes HFM07 and -08 at drill site 3. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure). HFM06 is located at drill site 3, but there are no monitoring data after May 1, 2003 for that borehole (cf. Table 2-14). HFM07 is an open borehole.

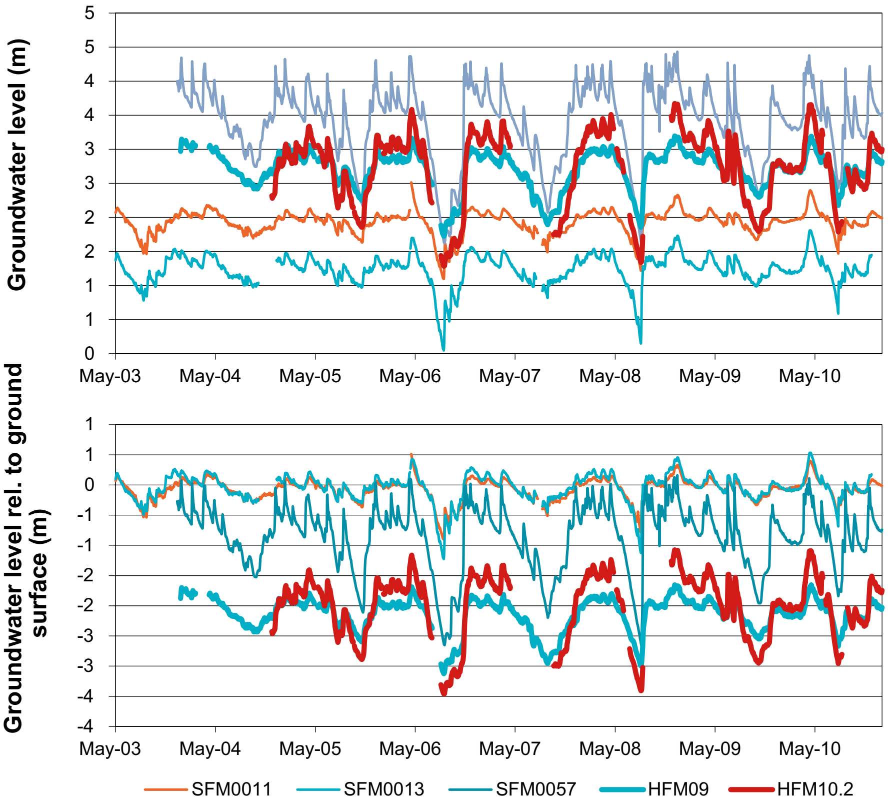

Figure 3-18. *Groundwater levels in groundwater-monitoring wells SFM0011, -0013 and -0057, and groundwater levels in percussion-drilled boreholes HFM09 and -10 at drill site 4. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure). HFM09 is an open borehole.*

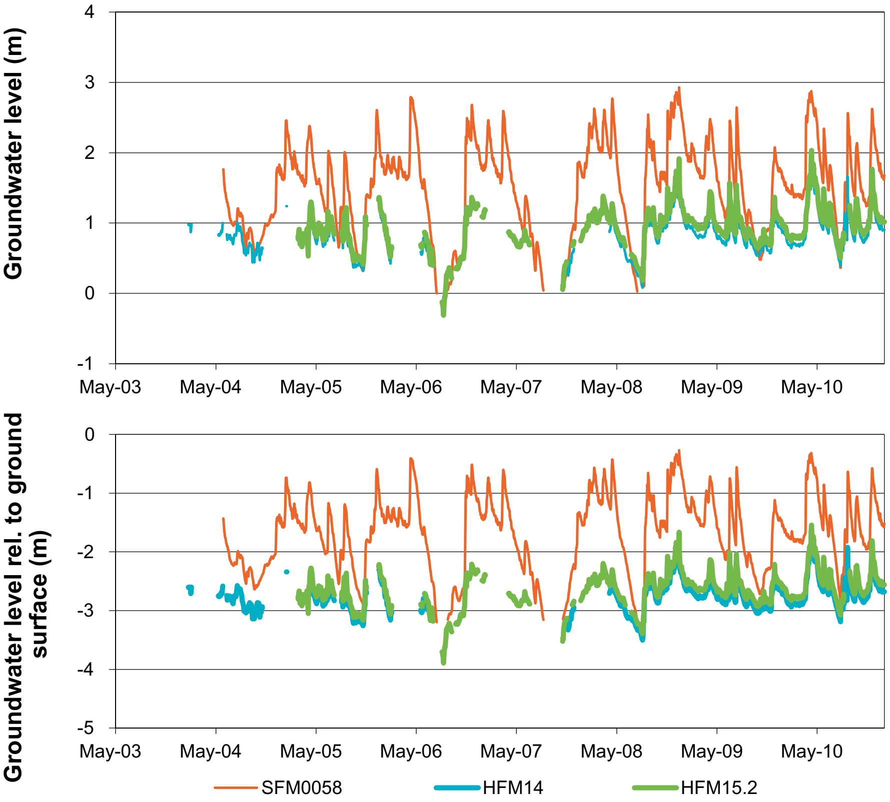

Figure 3-19. *Groundwater levels in groundwater-monitoring well SFM0058 and groundwater levels in percussion-drilled boreholes HFM14 and -15 at drill site 5. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure). HFM14 is an open borehole.*

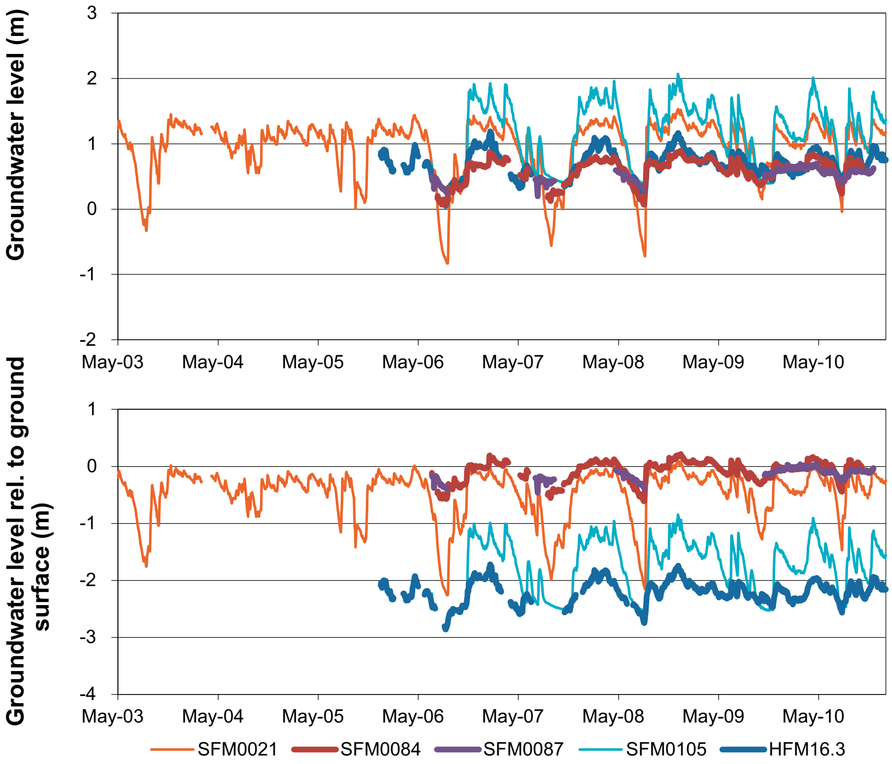

Figure 3-20. *Groundwater levels in groundwater-monitoring wells SFM0021, -84, -87, and -0105, and groundwater levels in percussion-drilled borehole HFM16 at drill site 6. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure). SFM0068 and -0090 are located close to drill site 6, but there are no monitoring data for these wells (cf. Table 2-11).*

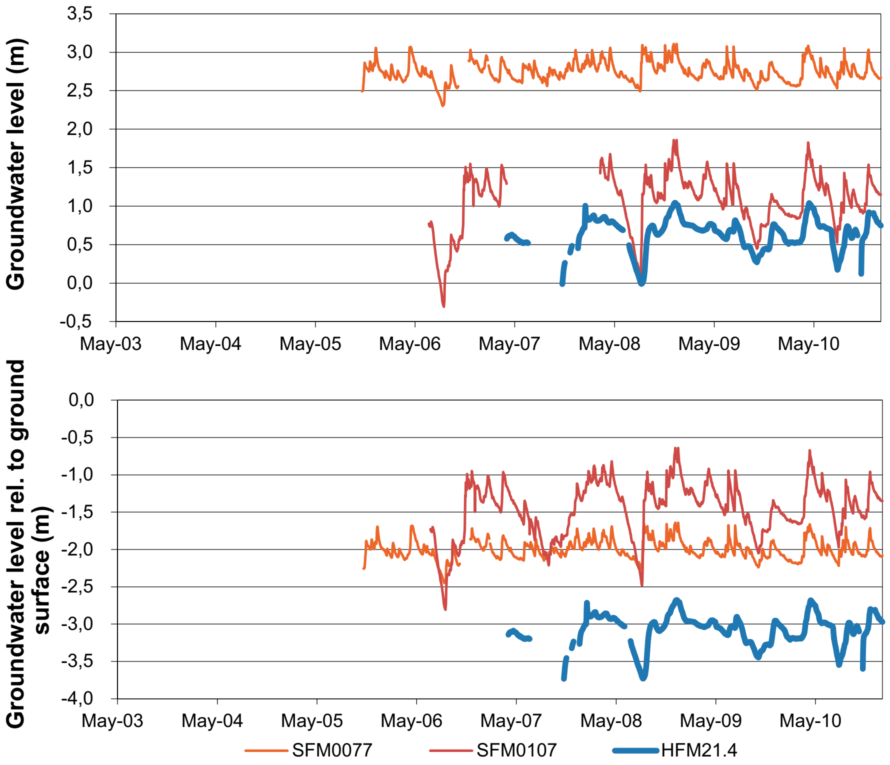

Figure 3-21. *Groundwater levels in groundwater-monitoring wells SFM0077 and -0107, and groundwater levels in percussion-drilled borehole HFM21 at drill site 7. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure). SFM0076 is also located close to drill site 7, but there are no monitoring data for that well (cf. Table 2-11).*

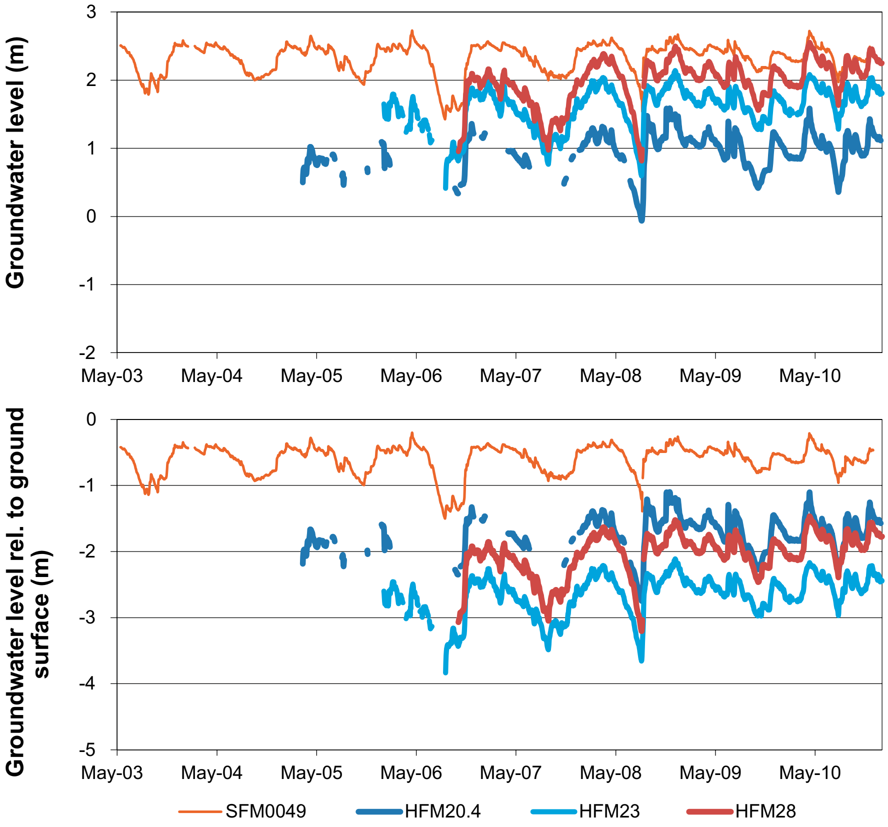

Figure 3-22. *Groundwater levels in groundwater-monitoring well SFM0049, and groundwater levels in percussion-drilled boreholes HFM20, -23 and -28 at drill site 9. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure). HFM20 and -23 are open boreholes.*

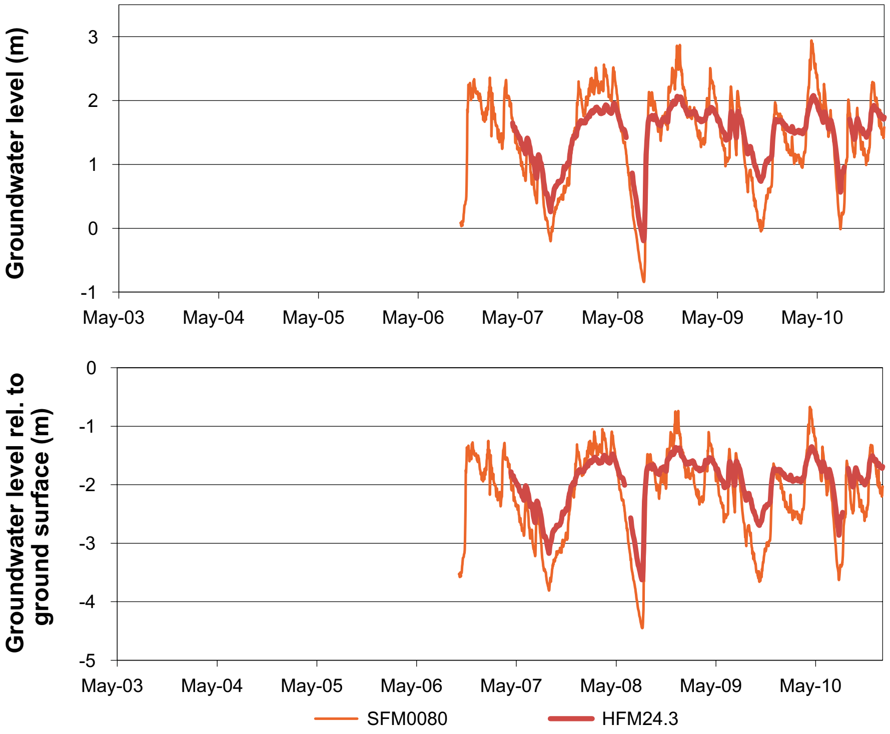

Figure 3-23. *Comparison of groundwater levels in groundwater-monitoring well SFM0080, and groundwater levels in percussion-drilled borehole HFM24 at drill site 10. Data are shown in terms of elevation (upper figure) and depth below ground surface (lower figure).*

4 Conclusions

Meteorological, hydrological and hydrogeological monitoring data from Forsmark were presented and analysed in support of the SR-PSU project, which is performed as part of the license application for the extension of the underground SFR facility. The primary objective of the report was to provide an overview of the SR-PSU dataset, which is an extension by some 3.5 years (up to the end of December 2010) of the dataset available for the previous, corresponding analysis (Johansson and Öhman 2008), performed as part of the SDM-Site project. Based on the presently available dataset, the report comments on some main observations made in previous, corresponding analyses.

The SR-PSU meteorological dataset comprises data on precipitation, air temperature, global radiation, calculated potential evapotranspiration, wind speed and -direction, humidity and air pressure from two local stations (global radiation and potential evapotranspiration from one station only). One of the stations, Storskäret, was decommissioned in 2007. The dataset also includes snow depth and snow weight (three locations) and ice coverage (two locations). Moreover, the meteorological dataset includes longer time series (17 years) from surrounding stations operated by SMHI. Regression analyses were tentatively used to fill in data gaps in the local precipitation dataset. The period 2007–2010 was characterised by more precipitation than the period 2004–2006. Specifically, for the period 2007–2010, the average monthly and annual precipitation were 54 and 632 mm, respectively, whereas the corresponding averages were 45 and 538 mm for the period 2004–2006.

The surface-water level dataset includes data from six lakes, five ponds and the sea. The level gauges in one of the lakes and the five ponds were installed subsequent to the SDM-Site project. New levelling shows that gauges in lakes and ponds are displaced vertically every year, likely due to winter-time ice shear. No major storms with associated high sea levels have occurred since the storms "Gudrun" (2005) and "Per" (2007).

As of December 2010, 79 groundwater-monitoring wells are installed in regolith (64 on land and 15 below surface waters), of which groundwater-level monitoring was ongoing in 45 wells (34 on land and 11 below surface waters). Data screening was performed to attain a groundwater-level dataset representative for the natural, undisturbed system. In accordance with previous data analyses, the SR-PSU dataset demonstrates that the groundwater level in regolith is shallow in the Forsmark area, and that there are very strong correlations between groundwater-level variations in most groundwater-monitoring wells. New levelling shows that wells installed below lakes and ponds are displaced vertically every year (cf. above).

Data are presented and analysed from the four gauging stations installed in streams. Specifically, as part of the monitoring water levels are converted to water depths, which in turn are converted to stream discharge using flume-specific discharge equations and associated parameters. Moreover, water EC (electrical conductivity) and temperature are also monitored at each gauging station. Linear and multiple regression analyses were tentatively used to fill in data gaps in the discharge dataset. The average specific discharge for the gauging station with the largest catchment area, with a time series covering some 80.5 months (more than 6.5 years), was 5.8 $\text{L}\cdot\text{s}^{-1}\cdot\text{km}^{-2}$ (182 $\text{mm}\cdot\text{y}^{-1}$).

The report provides a brief overview of hydrogeological monitoring data collected in the upper c 150 m of the rock, including groundwater levels in percussion-drilled boreholes drilled from the surface within the site investigations at Forsmark (2002–2007), groundwater levels in percussion-drilled and (short) core-drilled boreholes drilled from the surface in the vicinity of SFR (2008–2009), groundwater levels measured in core-drilled boreholes drilled from SFR tunnels, and groundwater inflow to SFR. Data screening was performed to attain a groundwater-level dataset representative for the natural, undisturbed system.

Analyses were performed on relations between meteorological, hydrological and hydrogeological data. There are no results reported from these data that contradict those made in Johansson and Öhman (2008). However, a previously developed snow accumulation and snow-melt model overestimates the snow water content during part of the 2008/2009 winter season, when the daily average air temperature fluctuates around 0°C. Under these conditions, the actual daytime snow melt is likely more intense than the simulated snow melt, which is based on the daily average air temperature. As mentioned above, new levelling of surface-water level gauges and groundwater-monitoring wells installed in lakes and ponds shows that wells and gauges are displaced vertically during the winter seasons. Even though reference levels have been adjusted as part of the monitoring, actual vertical hydraulic gradients across the bottom of lakes and ponds are associated with some degree of uncertainty.

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Correlation matrix for groundwater-monitoring wells in regolith

Appendix 1

The table presents intra-well correlation coefficients (R) for groundwater-level variations in groundwater-monitoring wells SFM0001–000118 up to the end of December 31, 2010.
Wells installed below surface water are marked blue in the table.

	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	28	30	33	34	36	49	57	58	59	61	62	65	76	77	78	79	80	81	84	87	91	95	104	105	106	107	110	112	114	116	118
1	1.00	0.96	0.95	0.90	0.84	0.67	0.68	0.80	0.84	0.90	0.74	0.91	0.93	0.67	0.83	0.79	0.79	0.94	0.92	0.95	0.80	0.83	0.12	0.48	0.86	0.91	0.92	0.90	0.93	0.95	0.79	0.89	0.90	0.42	0.46	0.91	0.69	–0.10	0.68	0.82	0.87	0.87	0.80	0.94	0.89	0.87	0.91	0.89	0.83	0.80	0.90	0.87	0.80	0.86	0.89	0.88
2		1.00	0.96	0.81	0.75	0.66	0.66	0.70	0.86	0.78	0.65	0.82	0.81	0.61	0.72	0.77	0.67	0.92	0.85	0.92	0.73	0.74	0.18	0.45	0.74	0.87	0.92	0.75	0.90	0.93	0.71	0.91	0.82	0.43	0.37	0.89	0.73	–0.21	0.65	0.64	0.75															
3			1.00	0.87	0.83	0.67	0.62	0.83	0.85	0.86	0.71	0.84	0.89	0.72	0.82	0.83	0.78	0.91	0.89	0.95	0.78	0.84	0.12	0.45	0.84	0.82	0.89	0.85	0.86	0.88	0.79	0.87	0.90	0.35	0.37	0.87	0.70	–0.03	0.58	0.84	0.84	0.82	0.74	0.94	0.89	0.88	0.92	0.90	0.79	0.73	0.88	0.92	0.90	0.92	0.96	0.94
4				1.00	0.91	0.61	0.78	0.83	0.86	0.90	0.81	0.92	0.91	0.70	0.82	0.75	0.75	0.94	0.91	0.92	0.82	0.85	–0.06	0.52	0.92	0.91	0.92	0.88	0.89	0.91	0.83	0.93	0.94	0.39	0.52	0.91	0.77	0.34	0.71	0.91	0.93	0.94	0.83	0.94	0.89	0.89	0.90	0.92	0.89	0.84	0.95	0.88	0.83	0.92	0.90	0.96
5					1.00	0.69	0.82	0.90	0.80	0.84	0.81	0.89	0.82	0.54	0.84	0.41	0.70	0.88	0.92	0.85	0.61	0.78	–0.40	0.39	0.85	0.85	0.79	0.74	0.79	0.85	0.78	0.86	0.93	0.32	0.60	0.78	0.61	–0.13	0.71	0.85	0.85	0.90	0.70	0.85	0.53	0.64	0.68	0.91	0.90	0.82	0.92	0.75	0.66	0.84	0.77	0.85
6						1.00	0.69	0.81	0.67	0.66	0.64	0.71	0.65	0.26	0.53	–0.07	0.39	0.74	0.64	0.71	0.42	0.62		0.33	0.73	0.68	0.71	0.52	0.57	0.72	0.70	0.70	0.71	0.27	0.55	0.66	0.37	–0.67	0.64	0.74	0.69	0.78	0.55	0.70	0.13	0.56	0.71	0.78	0.74	0.81	0.79	0.71	0.61	0.74	0.75	0.58
8							1.00	0.75	0.74	0.82	0.90	0.84	0.80	0.63	0.84	0.53	0.78	0.77	0.85	0.70	0.76	0.82	–0.21	0.53	0.86	0.81	0.71	0.74	0.78	0.76	0.73	0.81	0.86	0.61	0.80	0.81	0.77	0.19	0.80	0.80	0.81	0.86	0.80	0.76	0.62	0.67	0.70	0.86	0.84	0.86	0.85	0.75	0.66	0.74	0.69	0.63
9								1.00	0.78	0.92	0.83	0.88	0.85	0.87	0.92	0.91	0.91	0.84	0.89	0.77	0.80	0.83	–0.18	0.34	0.88	0.79	0.86	0.61	0.79	0.84	0.95	0.78	0.83	0.16	0.19	0.67	0.49	–0.30	0.43	0.45	0.51															
10									1.00	0.86	0.81	0.83	0.90	0.71	0.83	0.78	0.76	0.92	0.85	0.87	0.83	0.88	–0.28	0.42	0.91	0.83	0.91	0.85	0.87	0.91	0.82	0.92	0.89	0.36	0.45	0.89	0.67	–0.12	0.59	0.94	0.87	0.92	0.81	0.93	0.87	0.86	0.89	0.93	0.92	0.86	0.89	0.93	0.93	0.94	0.95	0.92
11										1.00	0.89	0.97	0.94	0.75	0.93	0.77	0.89	0.92	0.89	0.89	0.87	0.90	–0.01	0.52	0.94	0.90	0.91	0.89	0.91	0.92	0.91	0.91	0.91	0.37	0.58	0.95	0.67	0.58	0.73	0.91	0.96	0.94	0.90	0.93	0.89	0.89	0.93	0.90	0.88	0.86	0.95	0.93	0.88	0.91	0.90	0.84
12											1.00	0.89	0.83	0.73	0.81	0.74	0.69	0.82	0.78	0.76	0.82	0.91	–0.22	0.45	0.89	0.78	0.77	0.78	0.80	0.79	0.78	0.83	0.86	0.42	0.66	0.88	0.76	0.72	0.76	0.85	0.85	0.90	0.84	0.82	0.75	0.75	0.79	0.89	0.86	0.86	0.89	0.86	0.80	0.85	0.80	0.77
13												1.00	0.94	0.70	0.92	0.75	0.85	0.93	0.94	0.89	0.83	0.88	–0.12	0.51	0.92	0.93	0.90	0.91	0.93	0.92	0.86	0.91	0.92	0.47	0.63	0.95	0.68	0.29	0.78	0.87	0.94	0.93	0.88	0.91	0.86	0.85	0.89	0.88	0.85	0.87	0.94	0.89	0.81	0.87	0.85	0.80
14													1.00	0.78	0.95	0.82	0.94	0.95	0.95	0.93	0.89	0.88	–0.10	0.52	0.94	0.92	0.93	0.93	0.95	0.94	0.86	0.93	0.90	0.42	0.53	0.97	0.65	–0.16	0.68	0.90	0.94	0.93	0.90	0.95	0.92	0.90	0.94	0.93	0.87	0.87	0.93	0.93	0.85	0.86	0.90	0.81
15														1.00	0.96	0.87	0.93	0.72	0.84	0.71	0.82	0.80	–0.19	0.18	0.77	0.66	0.67	0.69	0.72	0.65	0.71	0.67	0.66	0.37	0.37	0.74	0.28	0.23	0.46	0.74	0.72	0.77	0.86	0.75	0.84	0.74	0.75	0.77	0.75	0.63	0.72	0.81	0.77	0.76	0.76	0.69
16															1.00	0.95	0.95	0.87	0.91	0.81	0.90	0.87	–0.21	0.41	0.92	0.88	0.88	0.72	0.87	0.86	0.93	0.90	0.96	0.34	0.24	0.88	0.57	0.13	0.39	0.59	0.67															
17																1.00	0.94	0.81	0.89	0.81	0.87	0.79	–0.12	–0.01	0.79	0.71	0.73	0.74	0.74	0.71	0.70	0.76	0.62	0.41	0.24	0.82	0.69	–0.14	0.54	0.83	0.82	0.92	0.88	0.92	0.80	0.88	0.87	0.89	0.90	0.90	0.90					
18																	1.00	0.84	0.87	0.84	0.88	0.76	–0.08	0.55	0.84	0.86	0.84	0.70	0.82	0.79	0.88	0.85	0.92	0.69	0.62	0.90	0.78	0.32	0.50	0.91	0.96															
19																		1.00	0.96	0.97	0.84	0.87	–0.07	0.45	0.92	0.92	0.95	0.93	0.93	0.95	0.83	0.96	0.92	0.44	0.53	0.96	0.76	–0.11	0.74	0.91	0.92	0.95	0.82	0.96	0.88	0.88	0.90	0.94	0.90	0.89	0.96	0.91	0.87	0.92	0.94	0.93
20																			1.00	0.91	0.86	0.83	–0.06	0.43	0.90	0.94	0.91	0.79	0.92	0.91	0.85	0.91	0.94	0.43	0.40	0.87	0.70	–0.34	0.80	0.72	0.93															
21																				1.00	0.80	0.84	0.00	0.48	0.88	0.89	0.94	0.90	0.90	0.92	0.80	0.92	0.90	0.43	0.48	0.92	0.69	–0.05	0.69	0.88	0.89	0.92	0.80	0.96	0.89	0.88	0.91	0.93	0.87	0.83	0.93	0.88	0.84	0.90	0.93	0.94
22																					1.00	0.87		0.46	0.89	0.80	0.80	0.86	0.84	0.79	0.81	0.84	0.80	0.34	0.48	0.89	0.75	0.05	0.58	0.87	0.91	0.85	0.87	0.87	0.87	0.91	0.86	0.85	0.83	0.79	0.85	0.84	0.79	0.76	0.78	0.70
23																						1.00	–0.18	0.44	0.92	0.82	0.85	0.84	0.86	0.84	0.84	0.87	0.87	0.47	0.62	0.92	0.74	0.93	0.67	0.92	0.89	0.91	0.91	0.91	0.86	0.85	0.90	0.91	0.88	0.85	0.90	0.86	0.85	0.81	0.85	0.79
24																							1.00	0.64	–0.37	0.03	–0.06	–0.01	0.01	–0.02	–0.17																									
25																								1.00	0.52	0.53	0.52	0.47	0.45	0.51	0.51	0.48	0.54	0.89	0.39	0.56	0.70	0.36	0.53	0.61	0.66	0.78	0.70	0.82	0.87	0.81	0.83	0.79	0.69	0.68	0.83	0.95	0.89	0.92	0.91	0.82
26																									1.00	0.90	0.91	0.87	0.88	0.90	0.91	0.94	0.94	0.44	0.58	0.94	0.82	–0.07	0.72	0.95	0.96	0.96	0.89	0.93	0.89	0.92	0.95	0.95	0.93	0.87	0.96	0.95	0.89	0.92	0.91	0.82
28																										1.00	0.90	0.91	0.94	0.94	0.80	0.90	0.89	0.67	0.67	0.92	0.76	0.19	0.76	0.85	0.90	0.90	0.85	0.91	0.87	0.84	0.87	0.87	0.86	0.87	0.91	0.85	0.76	0.85	0.85	0.85
30																											1.00	0.90	0.92	0.96	0.87	0.94	0.87	0.34	0.47	0.93	0.73	0.15	0.66	0.91	0.91	0.92	0.80	0.94	0.89	0.90	0.91	0.89	0.84	0.84	0.92	0.90	0.89	0.92	0.96	0.95
33																												1.00	0.93	0.91	0.78	0.89	0.89	0.39	0.56	0.98	0.46	0.32	0.69	0.88	0.92	0.92	0.88	0.95	0.91	0.87	0.91	0.91	0.85	0.88	0.92	0.92	0.85	0.88	0.92	0.87
34																													1.00	0.96	0.79	0.88	0.87	0.48	0.58	0.95	0.66	0.25	0.66	0.84	0.87	0.88	0.89	0.92	0.90	0.84	0.87	0.87	0.81	0.87	0.88	0.91	0.82	0.85	0.89	0.81
36																														1.00	0.84	0.92	0.91	0.38	0.53	0.93	0.73	–0.09	0.72	0.89	0.90	0.93	0.83	0.95	0.89	0.86	0.90	0.91	0.88	0.89	0.93	0.87	0.82	0.88	0.91	0.89
49																															1.00	0.87	0.82	0.28	0.47	0.84	0.66	–0.18	0.65	0.91	0.94	0.86	0.79	0.85	0.81	0.91	0.95	0.81	0.86	0.74	0.90	0.93	0.89	0.93	0.90	0.82
57																																1.00	0.92	0.43	0.55	0.92	0.78	–0.30	0.77	0.93	0.93	0.96	0.79	0.93	0.87	0.89	0.89	0.94	0.92	0.87	0.96	0.90	0.86	0.92	0.93	0.92
58																																	1.00	0.42	0.58	0.88	0.66	–0.01	0.72	0.91	0.91	0.93	0.80	0.94	0.80	0.82	0.84	0.98	0.95	0.86	0.95	0.87	0.81	0.90	0.88	0.89
59																																		1.00	0.98	0.60	0.71	0.46	0.78	0.26	0.53															
61																																			1.00	0.61	0.68	0.91	0.68	0.55	0.58	0.60	0.63	0.55	0.36	0.45	0.48	0.62	0.60	0.71	0.64	0.46	0.34	0.45	0.41	0.40
62																																				1.00	0.73	0.65	0.71	0.91	0.93	0.95	0.91	0.93	0.90	0.88	0.91	0.91	0.87	0.89	0.93	0.95	0.90	0.92	0.95	0.88
65																																					1.00	0.61	0.85	0.97	0.89															
76																																						1.00																		
77																																							1.00	0.63	0.71	0.71	0.51	0.71	0.55	0.60	0.60	0.74	0.67	0.76	0.82	0.61	0.50	0.65	0.60	0.66
78																																								1.00	0.92	0.95	0.82	0.92	0.83	0.91	0.92	0.93	0.94	0.86	0.94	0.91	0.92	0.95	0.92	0.91
79																																									1.00	0.93	0.89	0.91	0.90	0.93	0.94	0.89	0.91	0.82	0.94	0.94	0.88	0.91	0.90	0.83
80																																										1.00	0.85	0.91	0.80	0.84	0.87	0.95	0.95	0.89	0.96	0.92	0.88	0.95	0.94	0.92
81																																											1.00	0.85	0.84	0.80	0.83	0.81	0.80	0.77	0.80	0.83	0.77	0.74	0.79	0.66
84																																												1.00	0.93	0.92	0.92	0.94	0.90	0.85	0.93	0.88	0.82	0.89	0.90	0.95
87																																													1.00	0.91	0.92	0.86	0.77	0.72	0.81	0.85	0.86	0.80	0.81	0.72
91																																														1.00	0.95	0.86	0.84	0.74	0.88	0.97	0.95	0.94	0.97	0.92
95																																															1.00	0.89	0.84	0.78	0.91	0.97	0.96	0.93	0.96	0.86
104																																																1.00	0.94	0.87	0.95	0.89	0.82	0.90	0.89	0.86
105																																																	1.00	0.87	0.92	0.87	0.84	0.92	0.89	0.91
106																																																		1.00	0.89	0.85	0.79	0.87	0.85	0.83
107																																																			1.00	0.85	0.80	0.89	0.85	0.87
110																																																				1.00	0.97	0.97	0.97	0.92
112																																																					1.00	0.96	0.96	0.89
114																																																						1.00	0.96	0.95
116																																																							1.00	0.94
118																																																								1.00