P-05-152

Forsmark site investigation

Analysis of meteorological data, surface water level data, and groundwater level data

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May 2005

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Keywords: AP PF 400-04-98, Meteorological data, Surface water level data, Groundwater level data, Monitoring wells in soil, Data analysis, Times series, Correlation analysis.

Abstract

In the report time series and correlation analyses are presented for meteorological data, surface water level data and groundwater level data collected within the Forsmark site investigation. For precipitation data comparisons were also made with nearby SMHI stations.

The corrected precipitation at the two meteorological stations in the site investigation area was 619 and 641 mm at Storskäret and Högmasten, respectively, for the period Aug. 2003–July 2004. The correlation between the stations was good, $R^2 = 0.85$. Based on data from the two stations the potential evpotranspiration for Aug. 2003–July 2004, was calculated to 472 mm by Penman's equation for a short grass crop. For the period with available overlapping data at data freeze 1.2 (July–Dec. 2003), the precipitation was slightly higher than at SMHI's station at Örskär but considerably lower than at the more inland SMHI station at Lövsta.

Surface water levels were measured in six lakes and at two locations in the Baltic sea. The time series available showed that sea water intruded the lakes Lillfjärden, Norra Bassängen and Bolundsfjäden at some occasions while the level of Lake Fiskarfjärden was always higher than that of the sea.

The topographical positions of the groundwater monitoring wells in soil were fairly representative for the study area, though low areas were somewhat over-represented.

The groundwater levels in soil were very shallow with most of the wells showing levels between 0 and 1 m below ground for most of the year. The annual level amplitudes were between 0.5 and 1.5 m for most of the wells. There was a high correlation between the groundwater level time series with an $R^2 > 0.8$ for most of the wells and $R^2 > 0.95$ for quite a few of them.

With few exceptions the correlation between groundwater levels in the wells and the sea water level was very low (the exceptions were wells with their screen located below the sea bottom). However, a good correlation was observed between the groundwater levels and the cumulative difference between precipitation and potential evapotranspiration.

For some wells below and in the immediate vicinity of the lakes Eckarfjärden and Bolundsfjärden groundwater levels well below the lake water levels were observed during the dry summer 2003, implying possible seepage from the lakes to the aquifers.

Diurnal fluctuations coupled to the variation in evapotranspiration were observed in several wells during the dry summer 2003.

Comparisons of groundwater levels in soil and bedrock in nearby wells at the Core drill sites indicated considerably higher groundwater levels in the soil than in the bedrock (approximately 2 m).

Sammanfattning

I rapporten presenteras tidsserie- och korrelationsanalyser för meteorologiska data, samt yt- och grundvattennivådata från platsundersökningarna i Forsmark. För nederbördsdata görs också en jämförelse med data från närliggande SMHI-stationer.

Den korrigerade nederbörden var 619 respektive 641 mm vid platsundersökningens två mätstationer, Storskäret och Högmasten, under perioden augusti 2003–juli 2004. Korrelationen var hög mellan mätningarna vid de båda stationerna, $R^2 = 0,85$. Utifrån data från de båda stationerna beräknades den potentiella evapotranspirationen till 472 mm för samma period. För den period som överlappande data var tillgängliga vid datafrys 1.2 (juli–dec. 2003), var nederbörden något högre än vid SMHI:s station på Örskär men avsevärt lägre än vid stationen i Lövsta som ligger längre in i landet.

Ytvattennivåer har mätts i sex sjöar och på två ställen i havet. Tidsserierna visade att saltvatten trängt in i Lillfjärden, Norra Bassängen och Bolundsfjärden vid några tillfällen medan Fiskarfjärdens nivå hela tiden legat högre än havets nivå.

Från topografisk synpunkt representerar grundvattenrörens lägen relativt väl områdets topografi men lågt liggande områden är något överrepresenterade.

Grundvattenytan ligger nära markytan; i de flesta mätpunkterna mellan 0 och 1 m under markytan under större delen av året. De årliga variationerna i grundvattennivån är mellan 0,5 och 1,5 m i de flesta rören. Grundvattennivåerna i observationsrören är väl korrelerade med $R^2 > 0,8$ för större delen av rören och med $R^2 > 0,95$ för flera av dem.

Med få undantag var korrelationen mellan grundvattennivån i rören och havsnivå låg. Undantagen gäller rör med intagssilar direkt under havsbotten. Däremot kunde god korrelation konstateras mellan grundvattennivåerna och den accumulerade skillnaden mellan nederbörd och potentiell evapotranspiration.

I några grundvattenrör under och i omedelbar närhet av Eckarfjärden och Bolundsfjärden observerades grundvattennivåer som var avsevärt lägre än nivåerna i sjöarna under den torra sommaren 2003. Detta innebär att det fanns förutsättningar för läckage av vatten från sjöarna till grundvattenmagasinen.

Dygnsvariationer i grundvattennivån kopplade till variationer i evapotranspirationen observerades i flera observationsrör under den torra sommaren 2003.

En jämförelse av grundvattennivåerna i jord och berg i närbelägna observationspunkter vid kärnborrplatserna visade på en avsevärt högre grundvattennivå i jord än i berg, ca 2 m.

Contents

1 Introduction

This document reports the results from an analysis of time series and correlation analyses of meteorological data, surface water level data and groundwater level data, specifically from monitoring wells in soil, available at Forsmark data freeze 1.2, July 31, 2004. Most of the data are gathered within the site investigation at Forsmark, but comparisons are also made with meteorological data from nearby SMHI stations. In general, the site investigation data are available in SKB's SICADA and GIS databases. However, due to technical problems, the time series data from SKB's meteorological stations, surface water level gauges, and groundwater wells were not available in SICADA for the present work. Instead, quality assured data from SKB's HMS database were used. See /Johansson, 2003/, /Werner and Lundholm, 2004/ and /Werner et al. 2004/ for data on location, design etc. of the surface water level gauges and the groundwater wells, and /Nyberg et al. 2004/ for time series of surface water and groundwater levels. Coordinates for all the observation points within the site investigation area used in this report are given in Appendix 1.

In Table 1-1 the SKB internal controlling document for performing this activity is listed.

The locations of the meteorological stations within the site investigation area are presented in Figure 1-1 and the location of all surface water level gauges and all groundwater wells in soil are shown in Figure 1-2.

The data references are given in Table 1-2.

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

Activity plan	Number	Version
Analysis of meteorologicial data, surface water level data, and groundwater level data	AP PF 400-04-98	1.0

Table 1-2. Data references.

Subactivity	Database	Identity number
Meteorology, SMHI-stations	SICADA	ID codes PFM0107225 and PFM010832
HMS Data Meteorology	HMS	
HMS Data Surface water level data	HMS	
HMS Data Groundwater level data	HMS	
Digital elevation model	GIS	Field Note 174, UMEU_FM_HOJ_2077
Orthophotographical map	GIS	LMV_OST_ORF_42

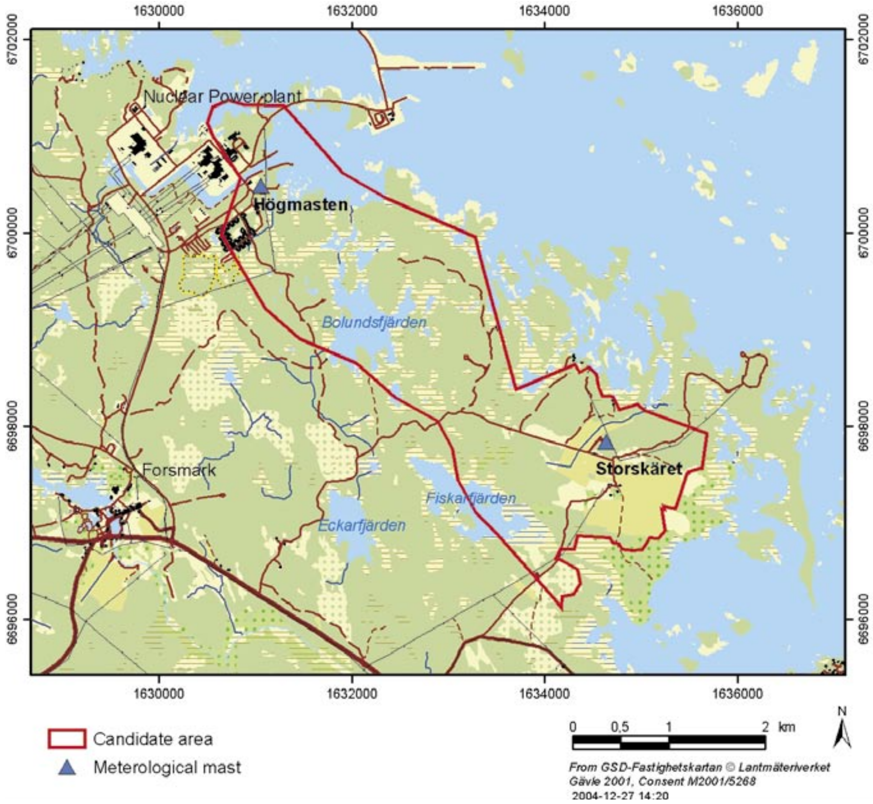

Figure 1-1. *Location of the meteorological stations within the site investigation area.*

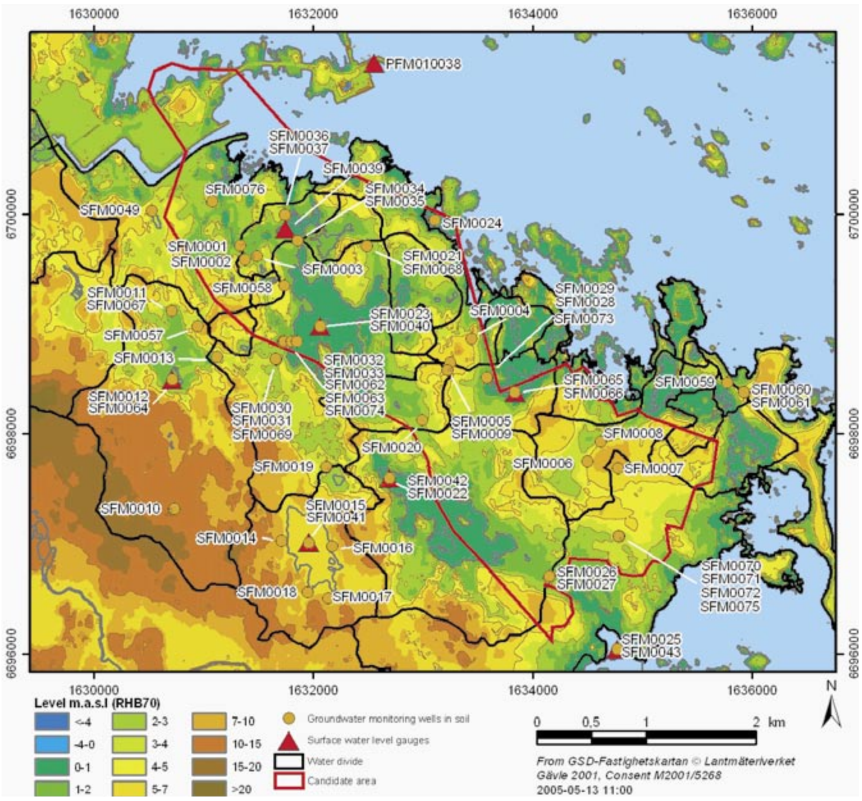

Figure 1-2. *Location of the surface water level gauges and groundwater wells in soil.*

2 Objective and scope

The objectives and scope of the present work were to study:

- the representativity of the different observation points; specifically regarding topographical position of the groundwater monitoring wells in soil,
- the correlation between the data from the meteorological stations; both between the two site investigation stations and with regard to selected nearby SMHI stations,
- the surface water level variations and relation between the sea water level and some low-lying lakes,
- groundwater levels and their variations related to depth below ground surface,
- correlation between groundwater levels measured in wells in soil but also between some selected wells in soil and nearby percussion-drilled boreholes in bedrock,
- correlation between groundwater levels and meteorological conditions,
- correlations between groundwater levels and surface water levels,
- impact of some known hydraulic disturbances (pumpings).

3 Execution

3.1 Data handling and processing

Data on position of all observation points were retrieved from SKB's SICADA database as well as meterorological data from the SMHI stations, while all other time series data were taken from SKB's HMS database. The GIS data (DEM) for the analysis of the representativity of the position of the groundwater wells were taken from the SKB GIS database.

For the analyses all retrieved data were compiled in Microsoft Excel files.

3.2 Analyses and interpretations

All the time series and correlation data analyses were performed with Microsoft Excel (MS Office, 2000) and the GIS-analyses were performed with ArcGIS, version 8.3. Standard tools included in this software were used for the analyses.

3.3 Nonconformities

The main part of the study of the representativity of the position of the groundwater monitoring wells was excluded and performed and presented within the site descriptive modelling work /Johansson et al. 2005/.

4 Results

4.1 Analysis of meteorological data

4.1.1 Rainfall and potential evapotranspiration

Figure 4-1 shows a comparison of daily time series for corrected precipitation measured at Storskäret and Högmasten for the period May, 2003–July, 2004. The measured precipitation data were corrected by SMHI by +10% if the temperature was < 1°C and by +6% if ≥1°C. There are two intervals in the Storskäret precipitation time series with missing data: July 5–9, 2003 (during which no rain was reported at Högmasten) and August 11–20, 2003 (during which heavy rain was reported at Högmasten). Figure 4-2 shows a cross-plot of daily precipitation recorded at these two stations and in general the data correlated well ($R^2 = 0.85$).

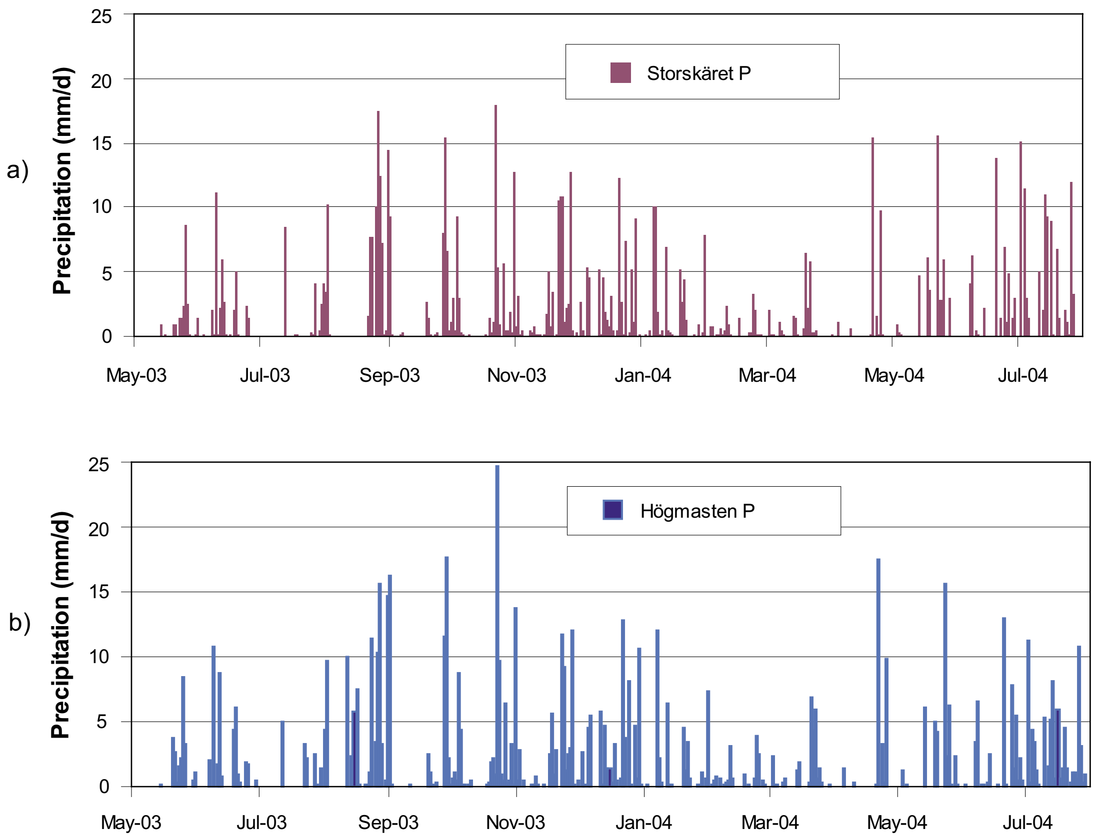

Figure 4-1. *Time series of daily corrected precipitation for a) Storskäret and b) Högmasten.*

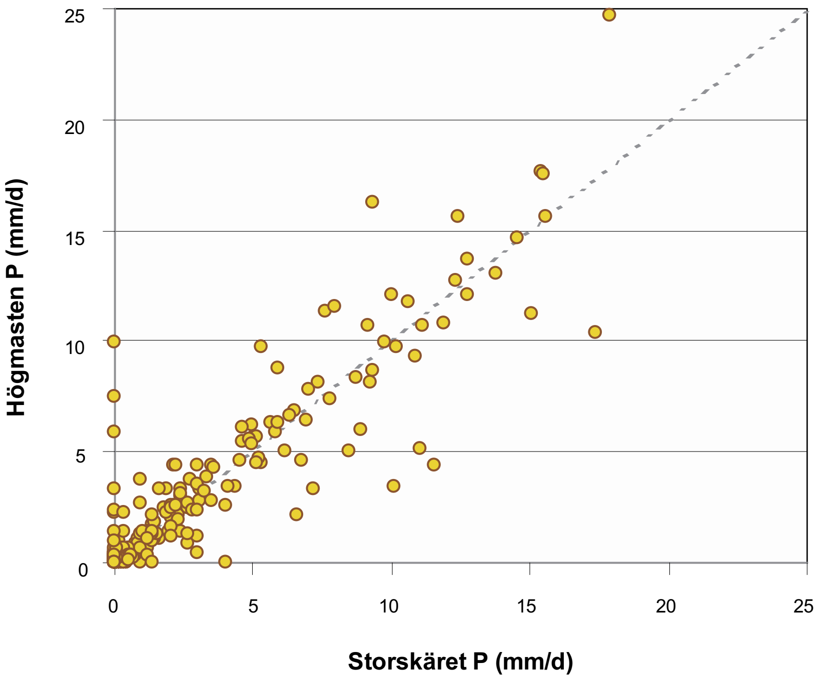

Figure 4-2. *Cross-plot of daily precipitation recorded at Storskäret and Högmasten.*

Figure 4-3 displays a comparison of monthly total values for corrected precipitation (P) and potential evapotranspiration (PET) reported at Storskäret and Högmasten. The difference in reported P between the two stations during the month of August is in part explained by the missing data in the Storskäret time series during this period. Annual total rainfall for the period of August, 2003–July, 2004 was 619 mm and 641 mm for Storskäret and Högmasten, respectively. The PET data was estimated from meteorological data using the Penman equation for a short grass crop. The annual total PET for the period of August, 2003–July, 2004 was 472 mm.

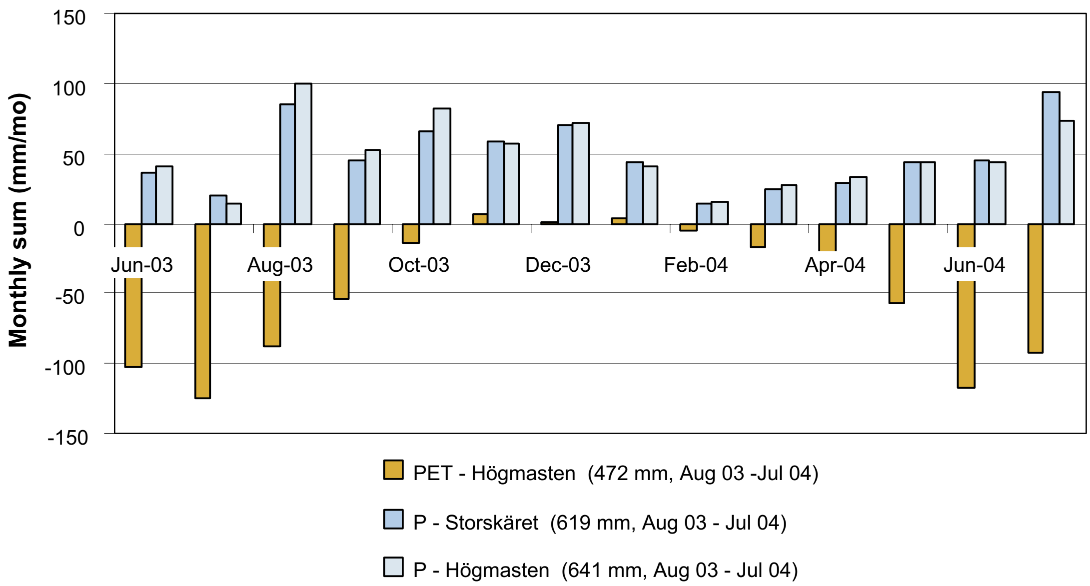

Figure 4-3. *Monthly values for corrected precipitation at Storskäret and Högmasten and potential evapotranspiration at Högmasten.*

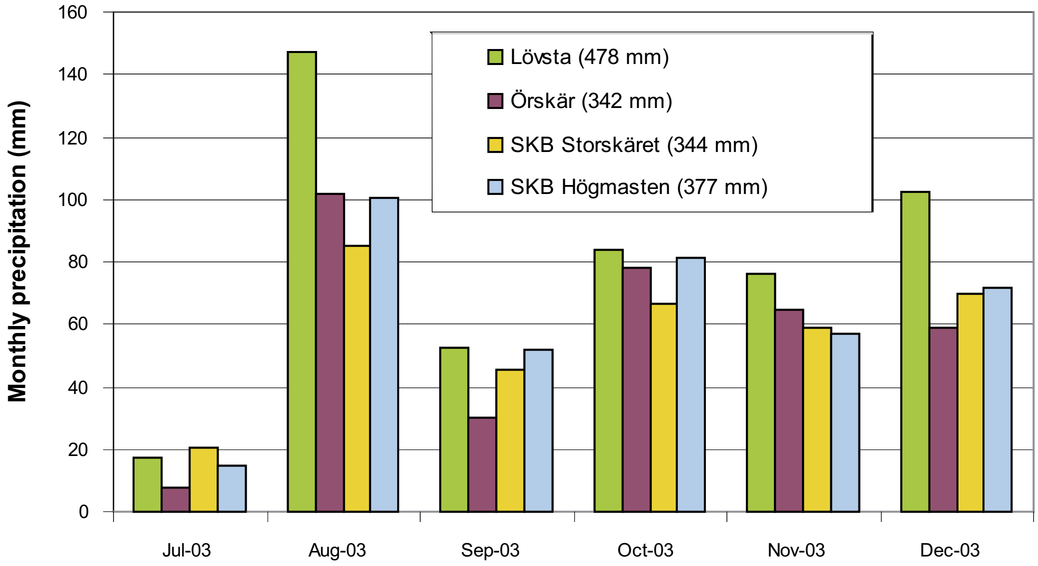

Figure 4-4. *Comparison of precipitation data from Storskäret and Högmast with regional SMHI data from Lövsta and Örskär.*

Figure 4-4 illustrates a comparison of monthly corrected precipitation for a six-month period from the two SKB data sites with regional data measured by SMHI at Lövsta and Örskär. In general, the data compares favourably. The SMHI data from Örskär were similar in magnitude and trend to the data from the SKB study area. On the other hand, the reported precipitation from Lövsta was generally higher than the SKB data, which would be expected due to its more inland location.

4.1.2 Surface water levels

Surface water level gauges have been installed in six lakes (SFM0039-42, SFM0064 and SFM0066) and at two locations in the Baltic sea, at the Forsmark harbour (SFM0038, now changed to PFM010038) and at Kallrigafjärden (SFM0043). The measurement locations are shown in Figure 1-2. SMHI also independently measures the sea level at the Forsmark harbour, in the immediate vicinity of the SKB station. Time series (daily averages) from the surface water level gauges are presented in Figure 4-5.

The reported SMHI sea levels at the Forsmark Harbour averaged about 6 cm higher than the reported SKB measurements (SFM0038) with a range of +16 cm to –6 cm. At the time of this writing, this difference is difficult to explain given the close proximity of the sensors (within a few metres) and it is recommend that this issue is resolved. The reported SKB data at Kallrigafjärden (SFM0043) averaged about 12 cm less than the SKB data at the Forsmark Harbour. In general, the three time series showed similar trends in sea level amplitudes, despite the differences in absolute amplitudes.

The available time series for Lillfjärden (SFM0066) is very short. However, the dataset at hand indicates that the lake level is mainly determined by the sea level. The lake levels of Norra Bassängen (SFM0039) and Bolundsfjärden (SFM0040) are also quite low, but these levels seem to be determined mainly by the lake thresholds and the groundwater and surface water inflow from the inland. However, during the period for which level measurements were available, the sea level was higher than the water levels in Norra Bassängen and Bolundsfjärden at a few occasions, thus allowing for sea water intrusion in to these lakes. The level of Fiskarfjärden is slightly higher than the levels of Norra Bassängen and Bolundsfjärden, and during the period for which level measurements were available, the level of this lake was always higher than that of the sea.

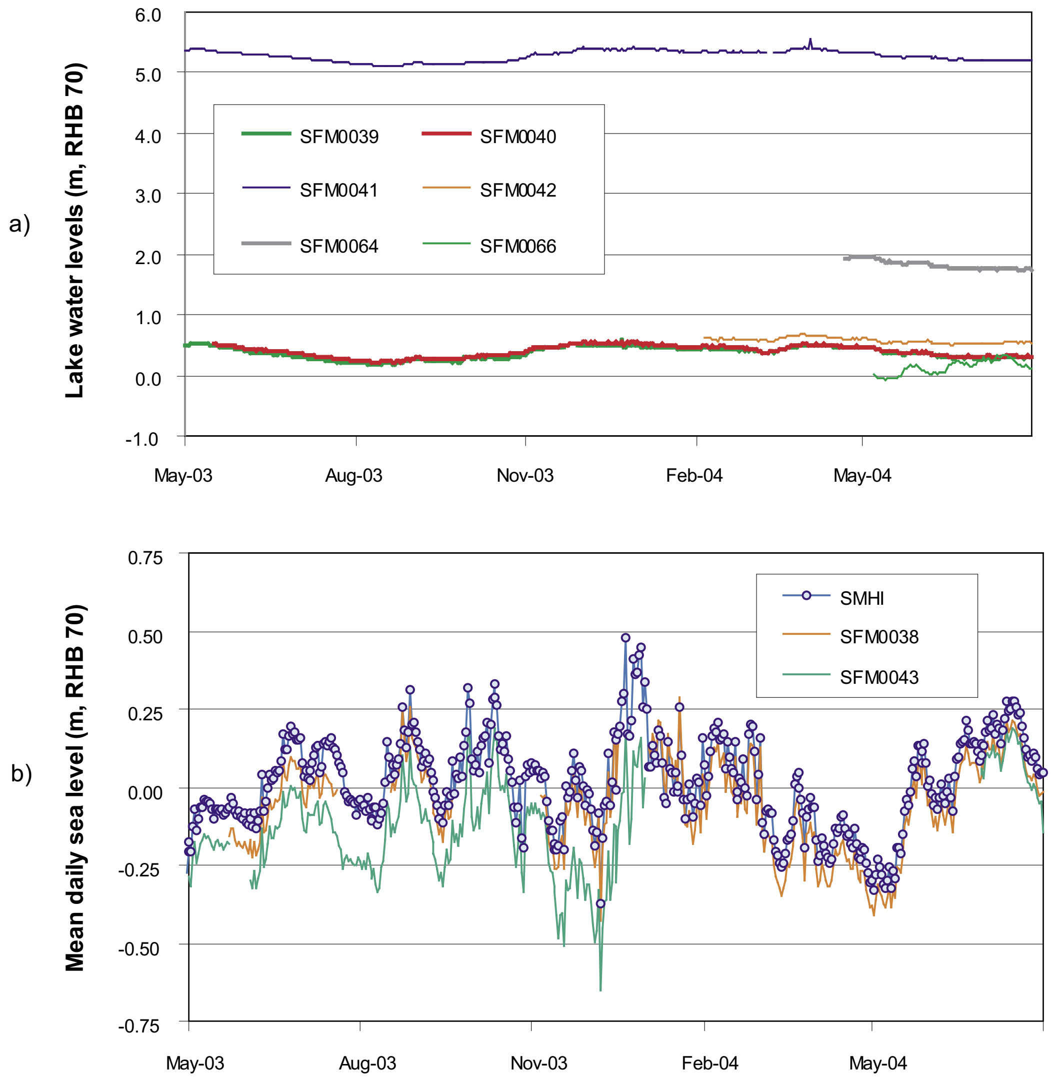

Figure 4-5. *Comparison of surface water measurements for a) lake water levels and b) sea water level.*

4.2 Analysis of well data

4.2.1 Data representativity

Figure 4-6 shows a comparison of the frequency distribution of ground elevations for the groundwater monitoring wells in soil to the overall topography of the study area. The distribution for the groundwater wells was based on ground elevations from 29 of the 56 wells in the SKB database and did not include below water wells (SFM0012, 15, 22, 23, 24, 25, 62, 63, 65), or wells with no reported data (SFM0007, 27, 29, 31, 32, 35, 37, 60, 67–76). The distribution of topographical elevations was derived from a GIS analysis of the Digital Elevation Map in SKB GIS /Brydsten, 2004/. The comparison suggests that the groundwater monitoring wells generally over-represent lower ground elevations. There is only one SKB well with a ground elevation above 7 m (SFM0010) while 36% of the study area has ground elevations greater than 7 m. In the range of elevations less than 7 m, the wells somewhat over-represent the 0–1 m and 5–7 m ranges and under-represent the 2–3 m range. Although it would be most desirable to have evenly-matched distributions, these deviations are viewed as minor and are not felt to significantly effect the relevance of the remainder of this analysis.

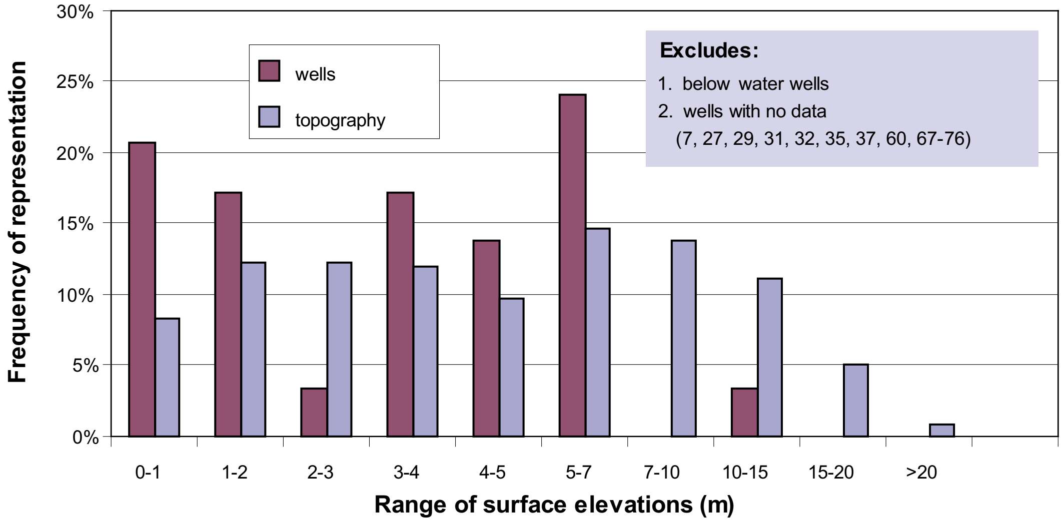

Figure 4-6. *Frequency distribution of ground elevations of near surface wells compared to the study area topography.*

4.2.2 Raw data time series

Figure 4-7 shows a plot of daily average groundwater elevations from 36 groundwater monitoring wells in soil in the study area including wells below surface waters. The reported groundwater elevations range from about –1 to +13 m (RHB 70). Figure 4-8 presents a plot of the same data for 29 of these wells (excluding wells below surface waters) represented as groundwater depth below surface. The majority of the wells (24 of 29) form a tight-packed cluster with reported groundwater depths in the range of +0.2 to –1.25 m relative to surface. The wells typically show a strong uniformity in response to the dry conditions of July and August 2003. Similarly, the wells typically display a strong uniformity in response to multiple recharge events following major precipitation and snowmelt events.

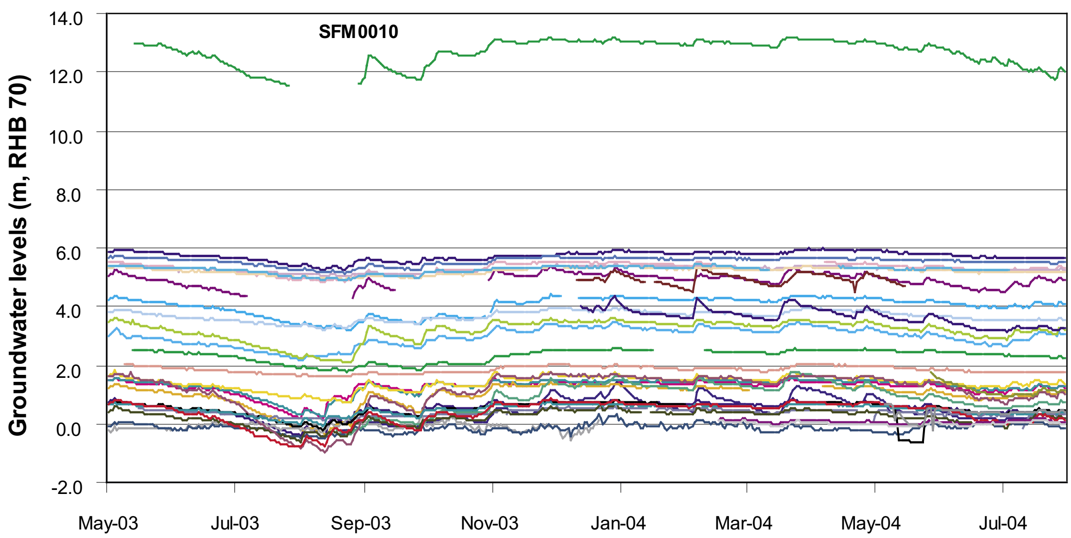

Figure 4-7. *Daily average groundwater elevations for groundwater monitoring wells in soil.*

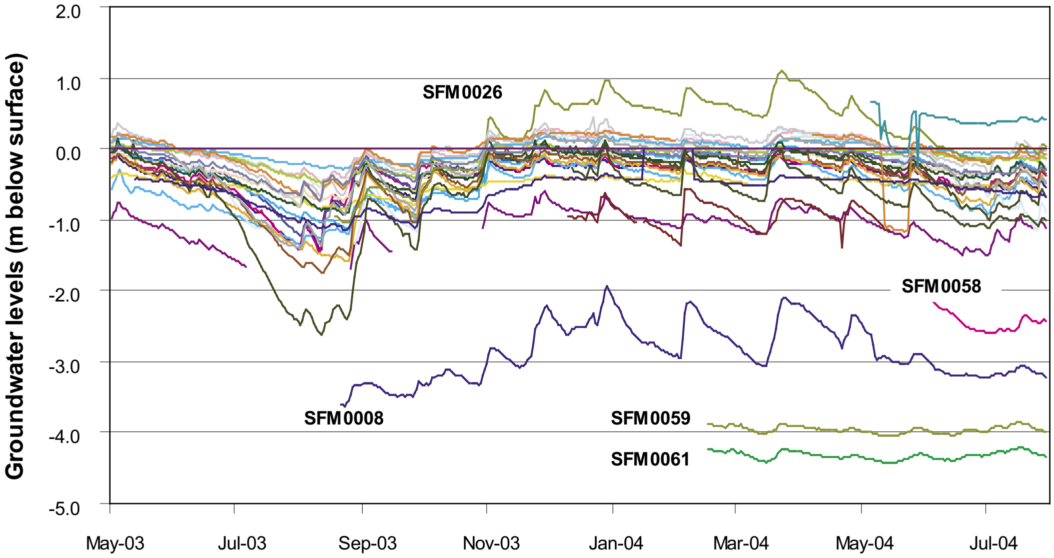

***Figure 4-8.** Daily average depth below ground surface for groundwater monitoring wells in soil, excluding below water wells.*

4.2.3 Response amplitudes

Figure 4-9 provides a summary of the range of water level amplitudes in all reported data for surface water gauges and groundwater wells in soil. Note that some of these reported values represent an amplitude range from only a limited period of available data, while others are representative of complete or near-complete time series for the May, 2003–July, 2004 period. For example, the reported response amplitudes for SFM0058, 62, 64, 65 and 66 were based on less than 100 reported daily data values while SFM006, 42, 59 and 61 had between 100–200 values. Response amplitudes for all other stations were based on greater than 200 data days with the majority exceeding 390 (max. possible = 457). As would be expected, the range of amplitudes for lake water levels was typically less than the range of amplitudes for groundwater and sea water level amplitudes. Of the lakes, Lillfjärden (SFM0066) reported the highest amplitude (in spite of its short time series) and Fiskarfjärden the lowest (SFM0042). For groundwater wells with more than 200 data days, amplitudes ranged between 0.4 to 2.9 m. The highest amplitude was reported at SFM0030, followed by SFM0026 (2.3 m).

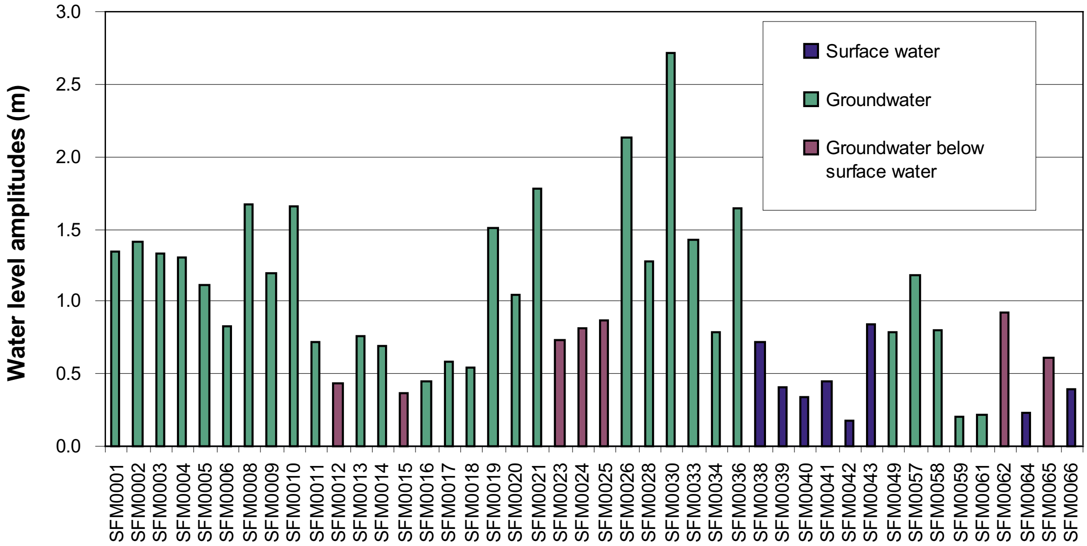

***Figure 4-9.** Water level amplitudes for the surface water gauges and the groundwater wells in soil, including wells below surface waters.*

4.2.4 Correlations between groundwater monitoring well time series

There is a very high correlation between the groundwater level time series from most wells. In the correlation analysis only wells with > 200 days time series were considered. Most R^2-values were well above 0.8 and quite a few above 0.95, see Appendix 2 for a complete correlation matrix.

The exceptions from the high correlations are the two wells below water directly influenced by the sea water level (SFM0024 and SFM0025). The two wells on the Börstil Esker (SFM0059 and SFM0061), for which only shorter time series were available, also showed significantly lower R^2-values. Besides that these two wells are the only wells in the investigation area placed in glaciofluvial material, and therefore may exhibit a different bahaviour from the remaining wells, the wells can also be assumed to be influenced by the sea water level.

4.2.5 Correlations of well data to surface hydrology data

To provide deeper insight into the observed groundwater fluctuations, the covariance of the groundwater time series data to sea level data and to the cumulative difference between precipitation and potential evapotranspiration was assessed. A snow routine similar to the one in the SMHI PULS model /Carlsson et al. 1987/ was employed to correct the effective precipitation for snow accumulation and melting during winter months. Figure 4-10 demonstrates groundwater depths below ground surface (the same data as in Figure 4-8) plotted along with these two surface hydrology profiles. Visually, little correlation is evident between sea level and groundwater dynamics in most time series. On the other hand, the cyclic nature of the cumulative P-PET differential bears strong resemblance to the overall cyclic trend in many groundwater observations, although the cycles are slightly out of phase.

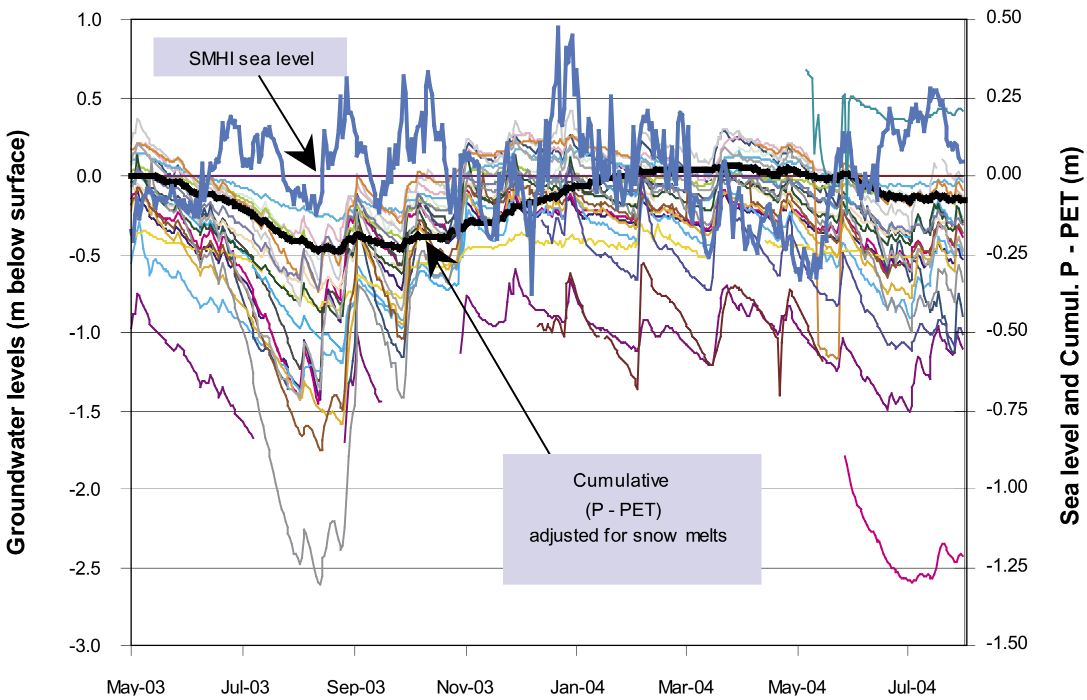

Figure 4-10. *Daily average groundwater depth below surface plotted along with daily average sea level and the cumulative difference between daily precipitation (adjusted with a snow routine) and potential evapotranspiration.*

Figure 4-11 shows correlation coefficients (R^2) that were calculated for sea level and P-PET profiles with groundwater data for wells with time series greater than 200 data days. Only two groundwater wells exhibited significant correlations with the SMHI sea level data, and these two were located below open water directly influenced by the sea level (SFM0024 and 25). On the other hand, most other wells showed some correlation with the cumulative P-PET profile, with 13 of the 36 wells demonstrating correlations greater than $R^2 = 0.50$. Only two wells (SFM0005 and 33) showed no significant correlation to either profile ($R^2 < 0.10$).

4.2.6 Response to sea level changes

To further investigate the possible coupling between sea level and groundwater elevations within the study area, the response of groundwater elevations to two large fluctuations in sea level elevations was investigated: a 0.44 m increase during September 2003 and a 0.85 m increase during December 2003 (see Figure 4-10). Figure 4-12 is a close-up of the September 2003 period. There was very little rain during the two week period that sea level increased +0.44 m and the general trend in all groundwater well elevations during this interval was downward. An increasing trend in groundwater levels after rainfall on September 27–29 was clearly evident. However, there appeared to be no evidence of a groundwater response associated with sea level changes.

Figure 4-13 presents a close-up of the December 2003 period. Here, precipitation has been adjusted for snow accumulation and melting. As with the September period above, there was little or no evidence of a response in groundwater well elevations to the 0.85 m increase in sea level.

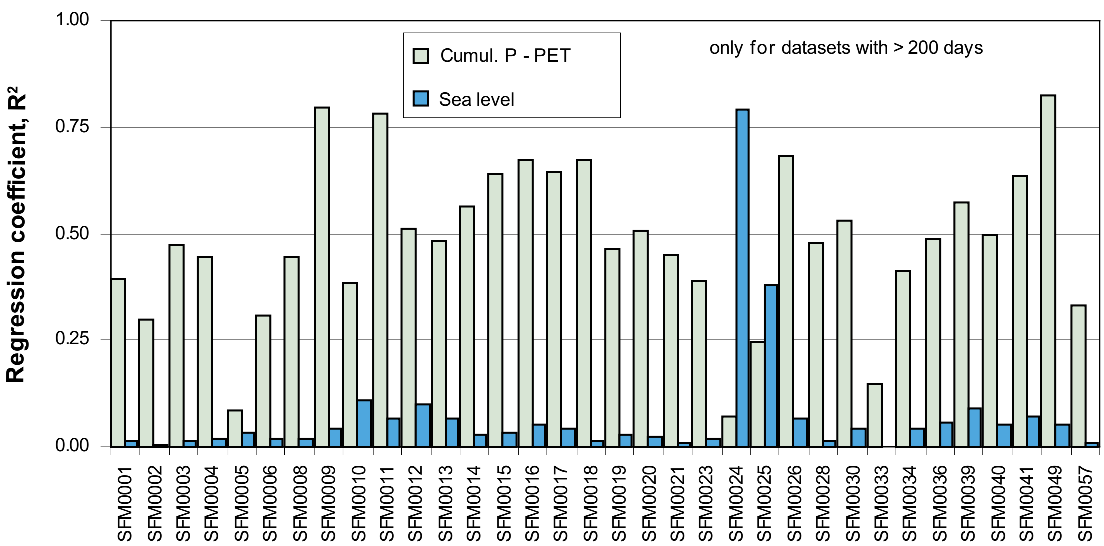

Figure 4-11. *Correlation coefficients for groundwater level in soil data to sea level data and cumulative P-PET differential.*

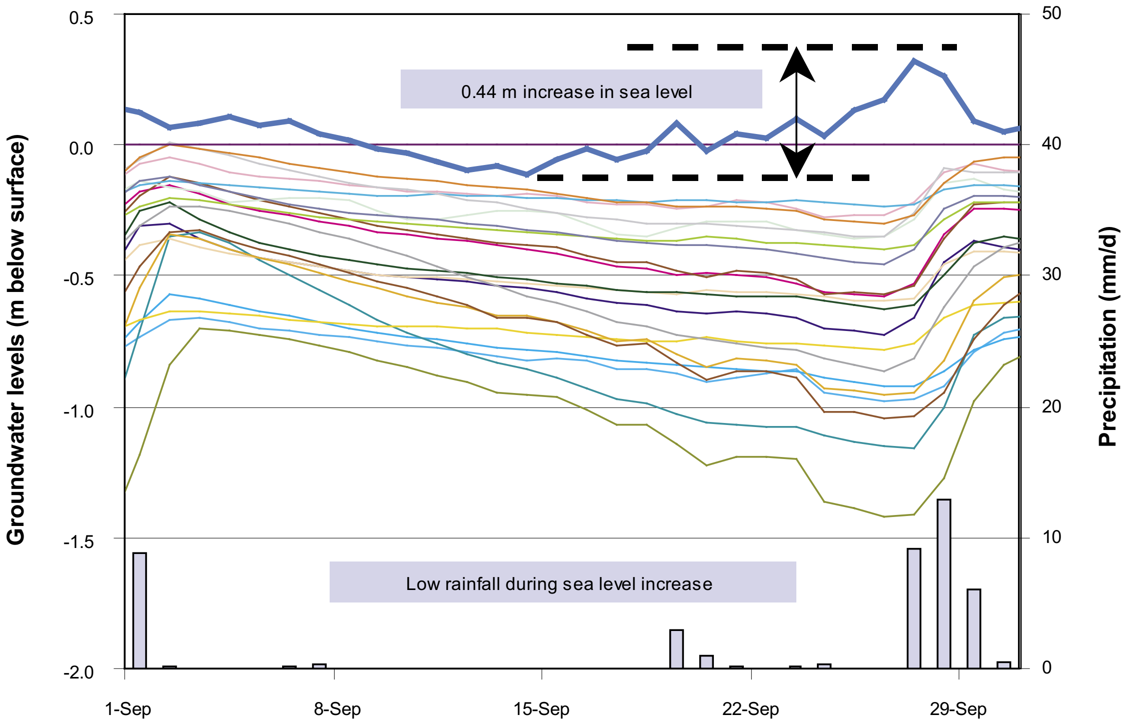

Figure 4-12. *Close view of groundwater depths during a one-month period when sea level increased +0.44 m.*

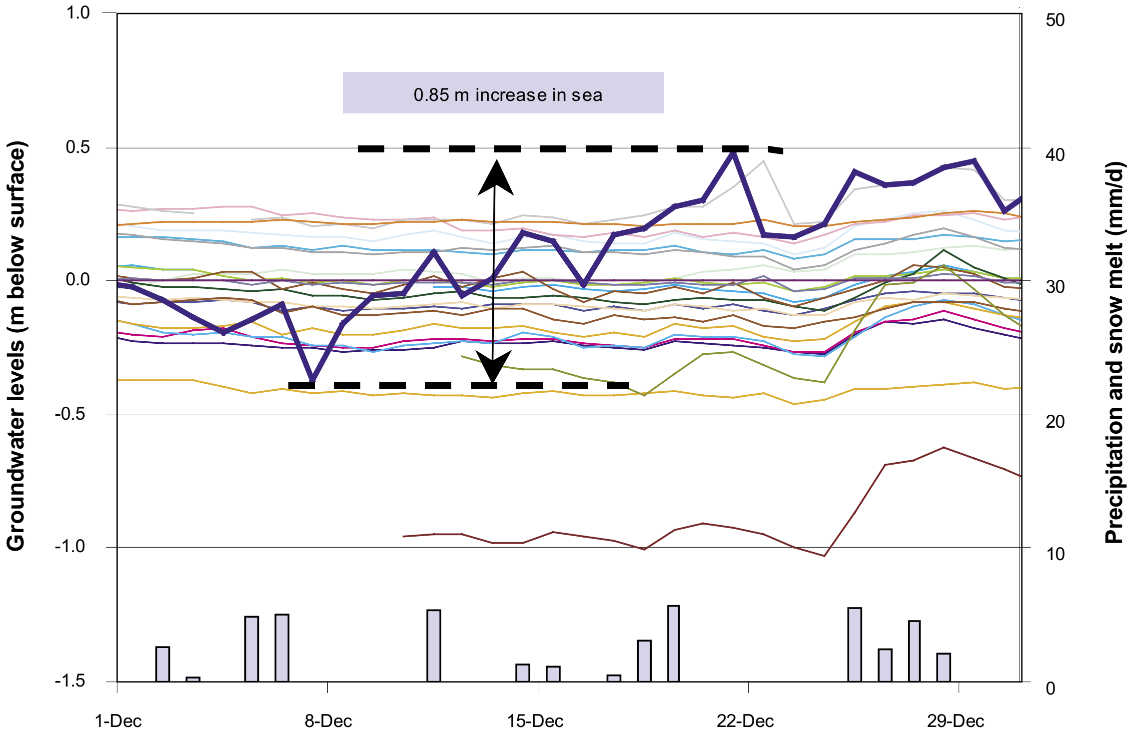

Figure 4-13. *Close view of groundwater depths during a one-month period when sea level increased +0.85 m.*

4.2.7 Wells in proximity to Eckarfjärden

Figure 4-14 presents the time histories of one well within and 4 wells in close proximity to Eckarfjärden compared with the lake water level. As would be expected, the lake water elevation (SFM0041) showed the smallest response amplitude, followed by the below water well (SFM0015). During the dry summer season of 2003, the data suggested that the lake provided a groundwater recharge source for water (via seepage) to its surroundings. Thus, the hydrology of the lake and local groundwater appear to be closely coupled, thus providing a buffering effect on groundwater amplitudes close to the lake. This helps explain why the response amplitudes in SFM0014, 16, 17 and 18 were amongst the lowest reported for groundwater wells (see Figure 4-9).

4.2.8 Wells in proximity to Bolundsfjärden

Figure 4-15 shows similar data for wells in the vicinity of Bolundsfjärden. Once again, the positive differential during the summer 2003 between lake surface elevations and local groundwater elevations suggested that the lake was seeping water to the local aquifer during this period. During other periods, the mostly negative differential suggests the lake as a discharge area for the surrounding aquifer. As with the wells close to Eckarfjärden, SFM0033 (excluding the disturbance in May 2004) and SFM0034 had amongst the lowest reported response amplitudes in groundwater wells (see Figure 4-9). However, SFM0030 which is located a little more than one hundred metres southwest of the lake had the highest reported amplitude of all wells. The very low groundwater level at this well during the summer 2003 indicated a strong influence on the groundwater level from evapotranspiration.

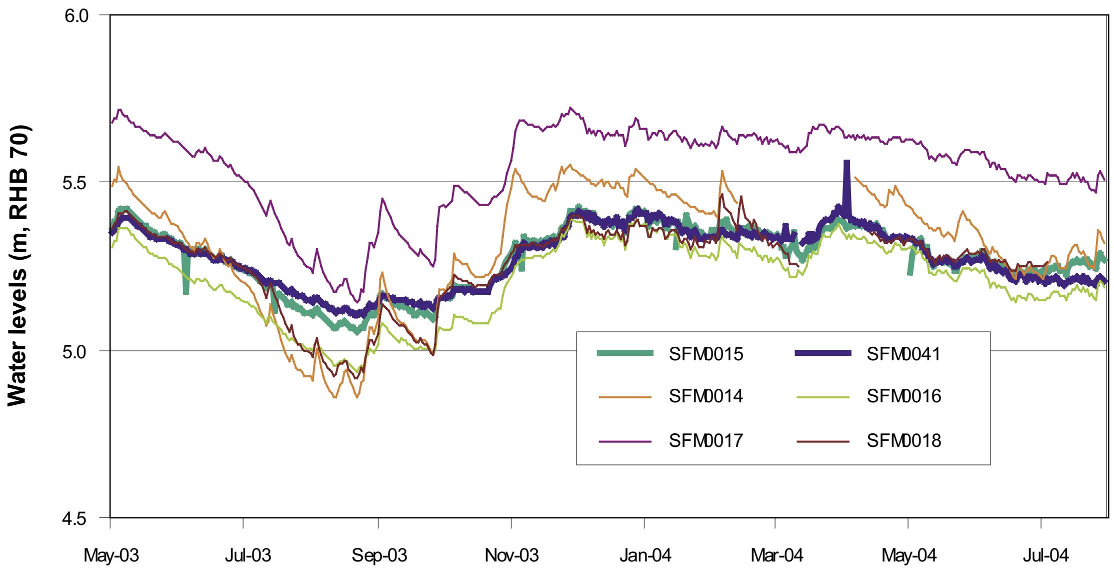

Figure 4-14. *Time series of the lake water level in Eckarfjärden (SFM0041) and groundwater levels below (SFM0015) and in the vicinity of the lake.*

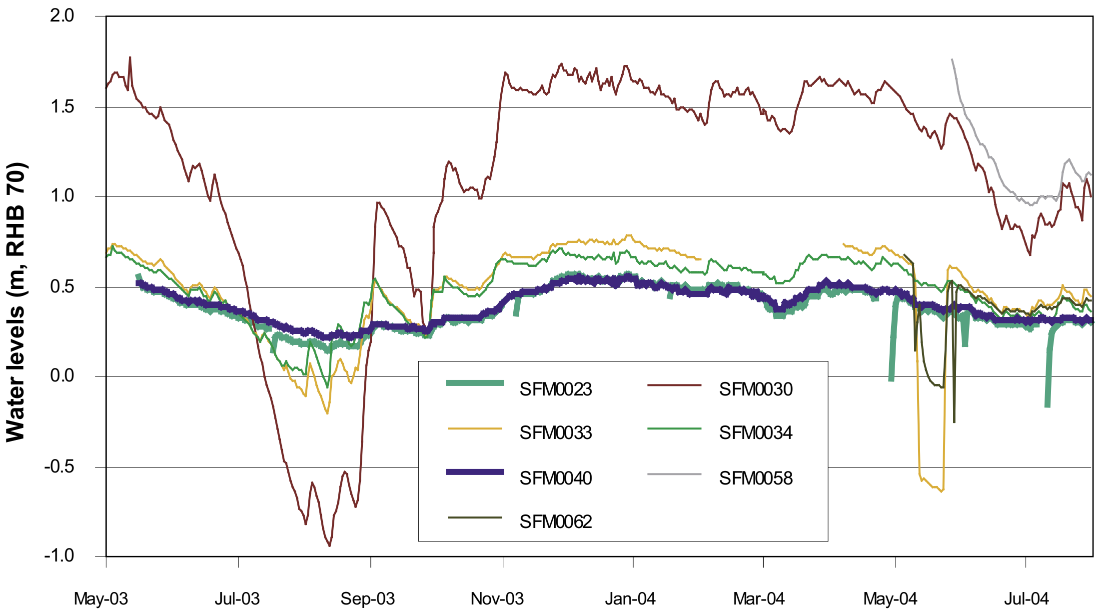

***Figure 4-15.** Time series of the lake water level in Bolundsfjärden(SFM0040) and groundwater levels below (SFM0023 and SFM0062) and in the vicinity of the lake.*

4.2.9 Diurnal fluctuations

Diurnal fluctuations driven by evapotranspiration cycles were evident in the data from most of the groundwater wells. Figure 4-16 and Figure 4-17 display examples of diurnal ET-driven cycles for shallow groundwater (SFM0034) and deeper groundwater (SFM0030) wells, respectively, with one-hour resolution data for an 8-day period in August 2003. As would be expected, the location with shallower groundwater depth exhibited a stronger diurnal response (~6 cm) compared to the location with deeper groundwater depth (~0.5 cm). Additionally, the shallow system exhibited a sharper and higher amplitude response to precipitation beginning on August 12.

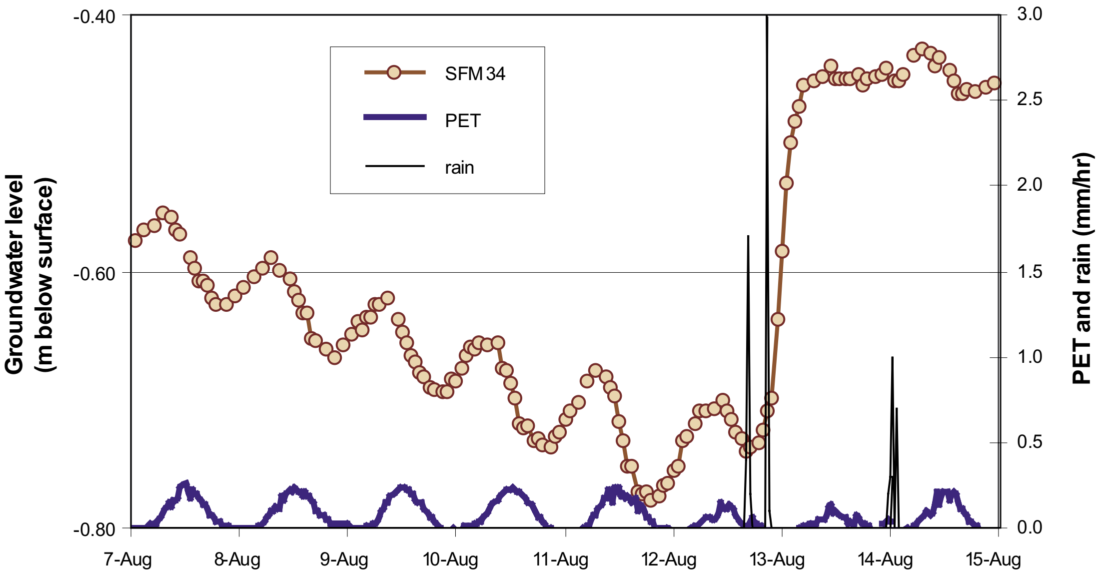

***Figure 4-16.** Diurnal fluctuations in groundwaterlevel in a location with shallow groundwater.*

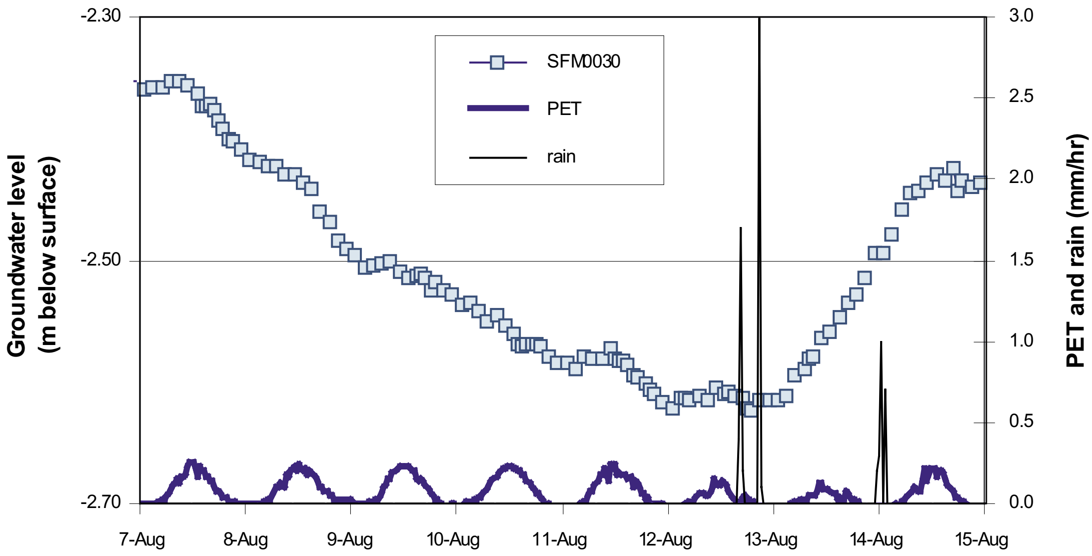

Figure 4-17. *Diurnal fluctuations in groundwater level in a location with deeper groundwater.*

4.3 Comparison of groundwater levels in wells in soil and nearby wells in bedrock

4.3.1 Core drill site 1

Figures 4-18 and 4-19 present positions, and groundwater elevations and depths below surface for groundwater wells in soil (SFM) and percussion drilled wells (HFM) in bedrock in the vicinity of Core drill site 1.

Ideally, relatively close distances between wells (in the range of 20–30 m rather than 100–220 m) would provide a stronger basis for drawing conclusions about the vertical direction of groundwater flow. Over larger distances, the effects of ground surface topography complicate the assessment. For instance, reported groundwater elevations at SFM0001 are indeed less than at HFM02.1 and HFM03.1 (deepest sections of the wells sealed off by packers) for part of the time series. However, the ground elevation at SFM0001 is approximately 2 m less than at either of the percussion well sites and it is situated more than 100 m away. When the data are presented in terms of water depth below surface, a consistent downward direction of flow seems evident. In cases such as this with greater than desirable distances between well locations, the groundwater elevations and depth below surface must be interpreted together to assess the vertical direction of groundwater flow. In general, it appears that the groundwater flow had been in a consistently downward direction at site 1 during this period.

Figure 4-20 shows a close-up of five-months of the groundwater data that were plotted in Figure 4-19. In this plot, bedrock well data are plotted on an enlarged scale on the second Y-axis. Clearly, there is good correlation between soil and bedrock well time series over this interval, however, the amplitude of the deeper groundwater is diminished (less than half) in comparison to the upper levels. These data suggest that there exists coupling between near-surface and deeper groundwater, but perhaps only through low conductivity pathways.

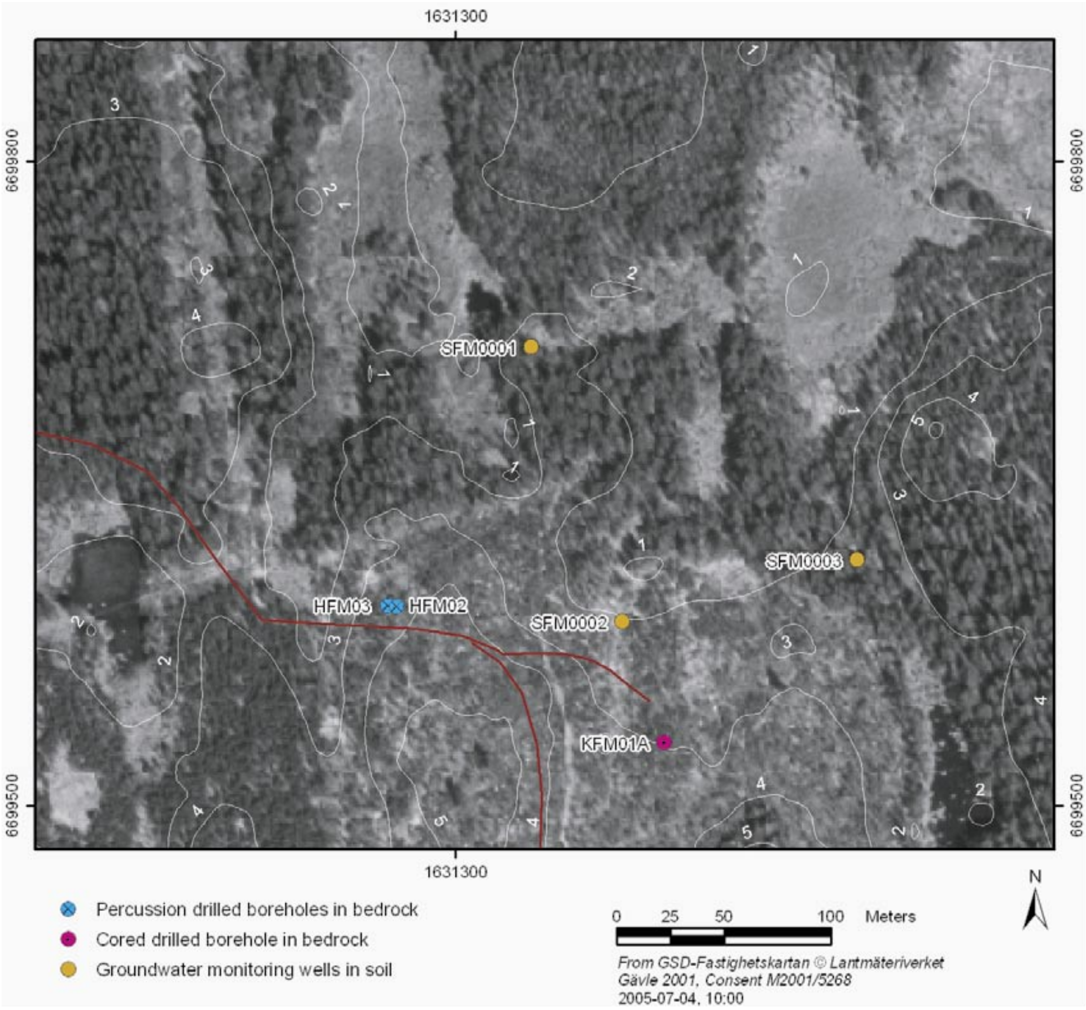

Figure 4-18. *Groundwater monitoring wells in soil (SFM) and percussion drilled boreholes (HFM) at Core drill site 1.*

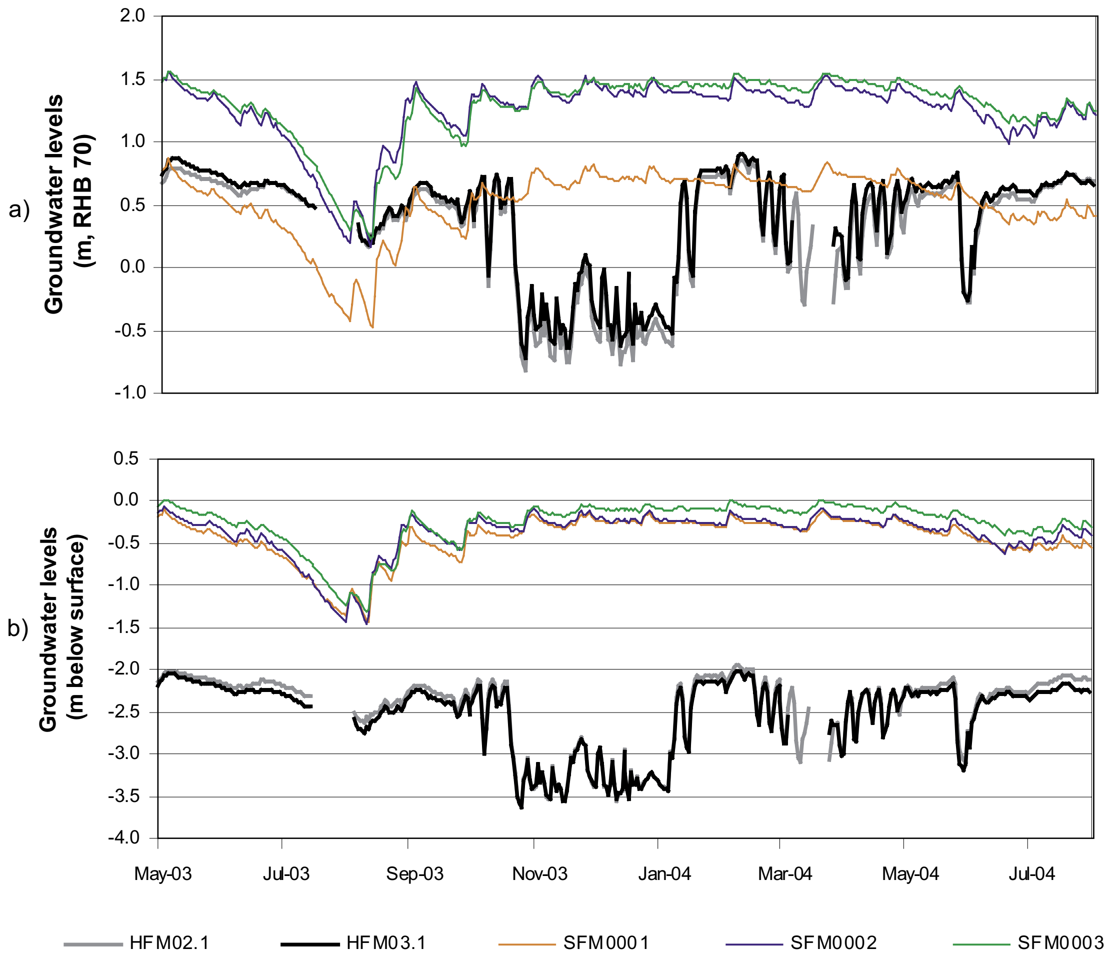

Figure 4-19. *Comparison of groundwater levels in wells in soil (SFM001-3) and in the deepest section of the bedrock wells (HFM02.1 and HFM03.1) at Core drill site 1 in terms of a) metres above sea level and b) depth below ground surface.*

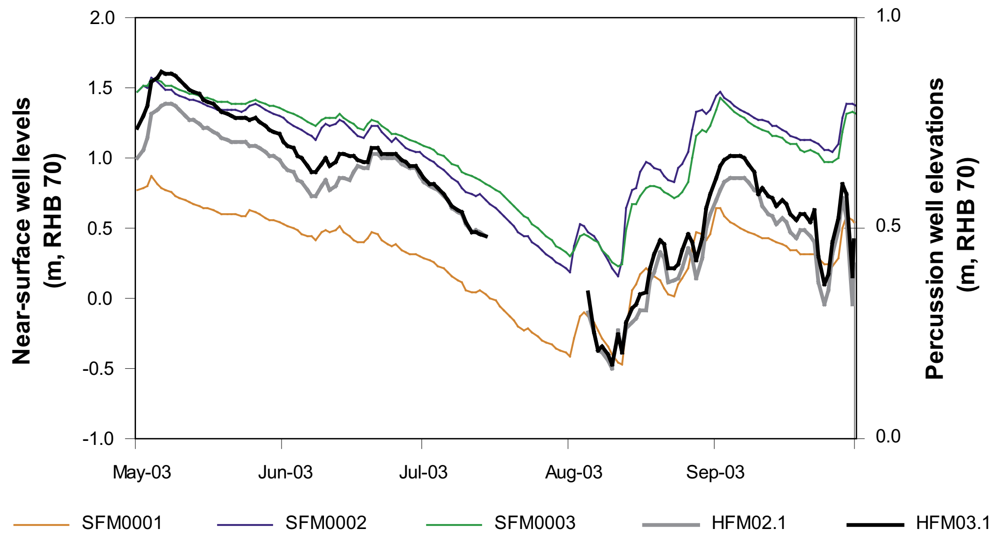

Figure 4-20. *Close-up view of groundwater levels for a 5-month period at Core dill site 1 with soil (SFM) and bedrock (HFM, deepest sections) well data plotted on separate axes for greater resolution.*

Figure 4-21 and Figure 4-22 show groundwater elevations in different sections of the bedrock wells HFM02 and 03, separated by well packers. The groundwater levels in the different sections were very similar as well as the responses to the hydraulic disturbances caused by pumping in nearby wells. Thus, the big difference in groundwater level is between the level in the soil and the bedrock and not between different depths in the bedrock.

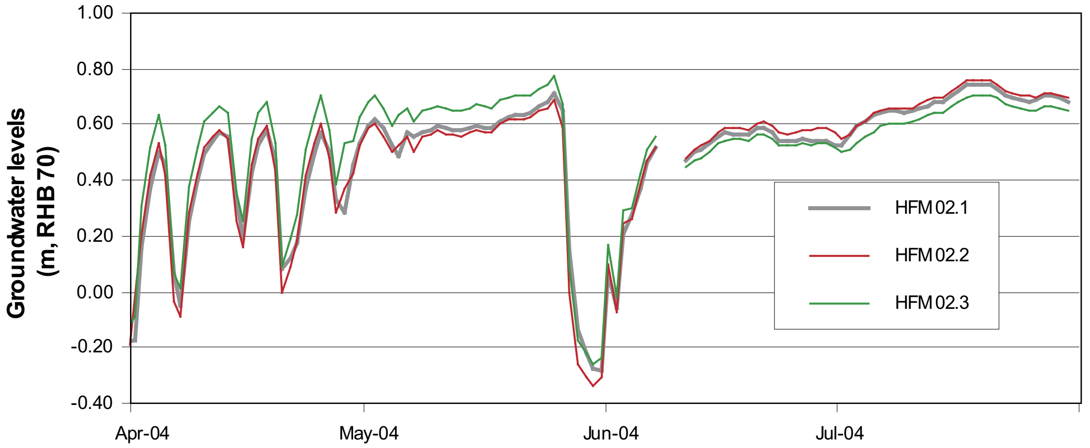

Figure 4-21. *Groundwater levels in three sections (separated with packers) of HFM02. Section 1 (HFM02.1) measures groundwater level between 49.0–100.0 m below ground, Section 2 (HFM02.2) between 38.0–48.0 m below ground, and Section 3 (HFM02.3) above 37.0 m below ground.*

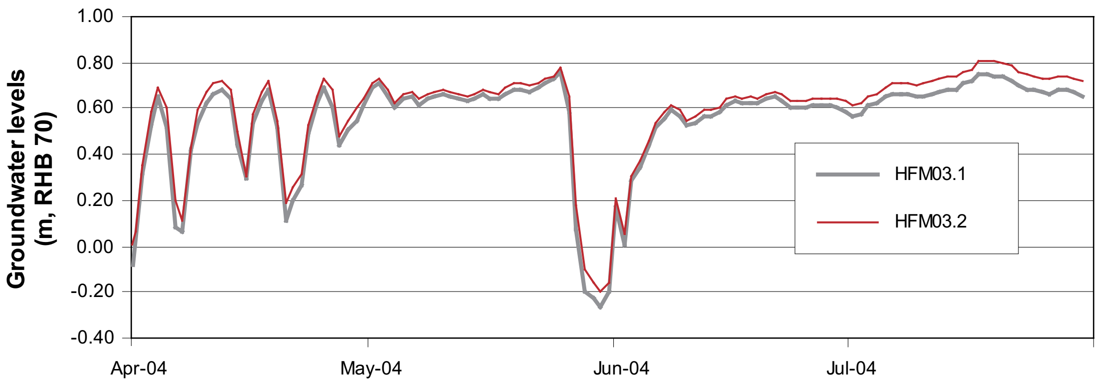

Figure 4-22. *Groundwater levels in two sections (separated with packers) of HFM03. Section 1 (HFM03.1) measures the groundwater level between 19.0–26.0 m below ground and Section 2 above 18.0 m below ground.*

4.3.2 Core drill site 2

Figures 4-23 and 4-24 illustrate positions, and groundwater elevations and depths below surface for soil and percussion drilled bedrock wells at Core drill site 2.

Here, the soil well SFM0004 is located close to the bedrock well HFM04 (24.4 m) while SFM0009 is separated by 360 m.There were several lengthy periods of missing data in the bedrock well time series, but the data seem to indicate that a consistent downward gradient existed in this region for groundwater flow. Compared with the ground surface, the groundwater level in soil is about 2 m higher than the level in the bedrock.

The close-up data in Figure 4-25 suggest that some coupling exists between soil and bedrock groundwater elevations (similarities in overall slope as well as some shared response events), however the coupling does not appear as strong as was observed at Site 1 (see Figure 4-20). Figure 4-26 shows a plot of groundwater elevations from three sections of HFM04 that were separated by packers. As for the wells at Site 1, the big difference in groundwater level is between the soil and the bedrock and not between different depths in the bedrock. The uppermost section of the bedrock well had a slightly higher groundwater level than the two deeper ones (approximately 0.3 m).

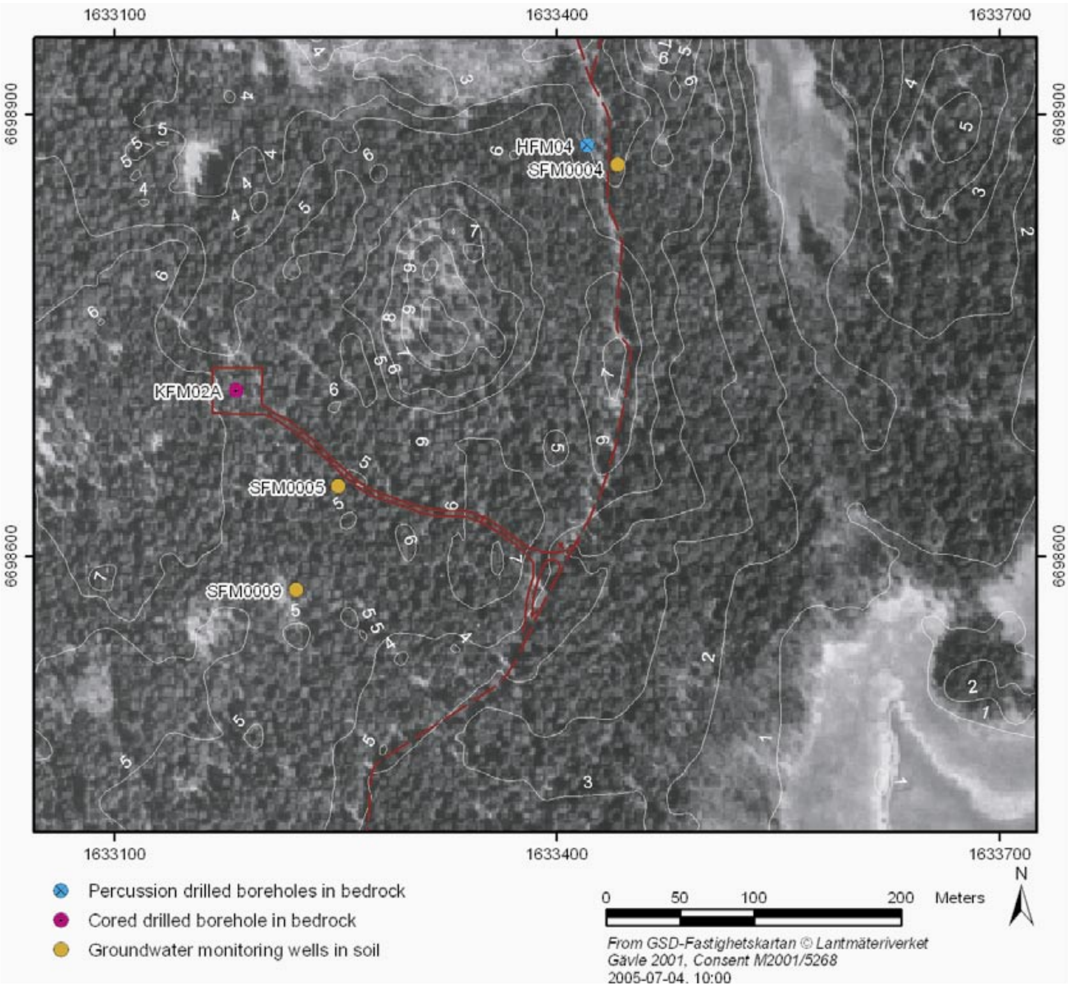

Figure 4-23. *Groundwater monitoring wells in soil (SFM) and percussion drilled boreholes (HFM) at Core drill site 2.*

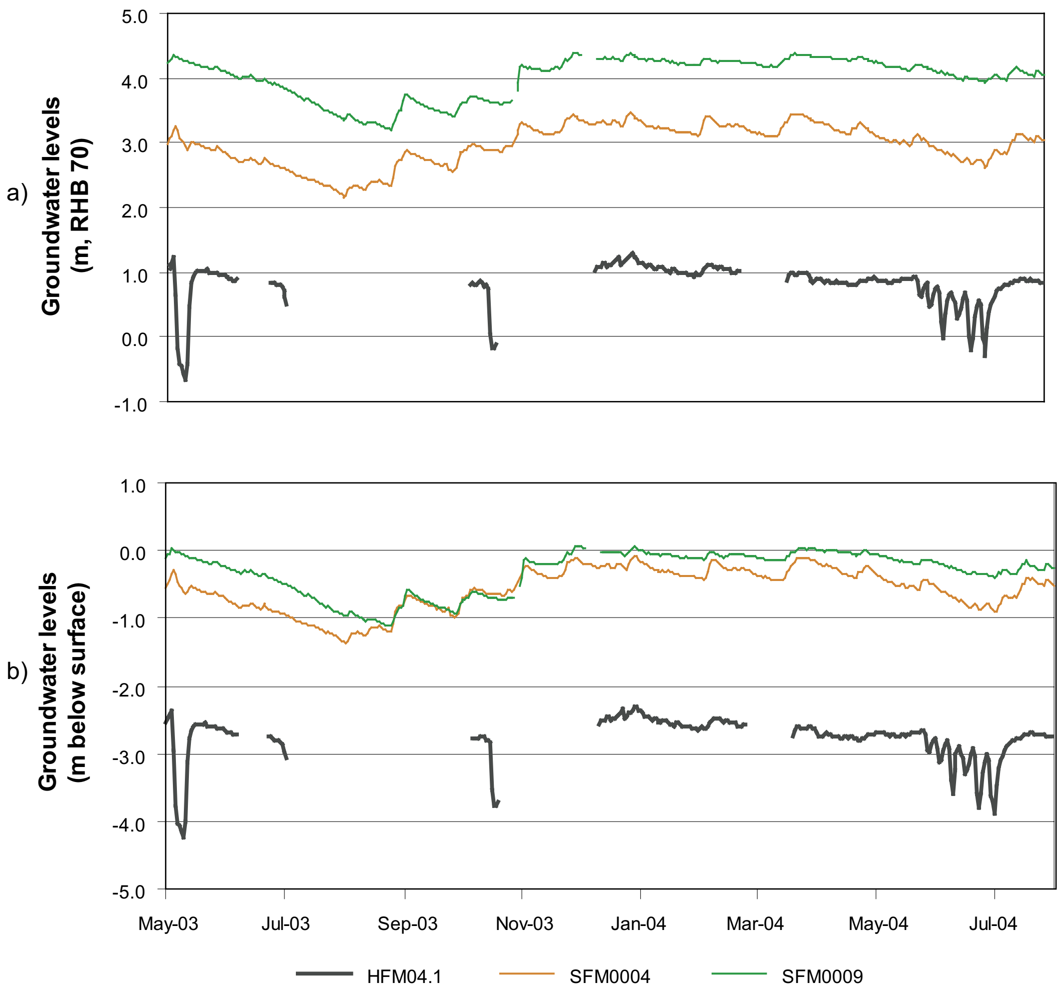

Figure 4-24. *Comparison of soil (SFM) and bedrock (HFM, deepest section) groundwater monitoring wells at Core drill site 2 in terms of a) metres above sea level and b) depth below ground surface.*

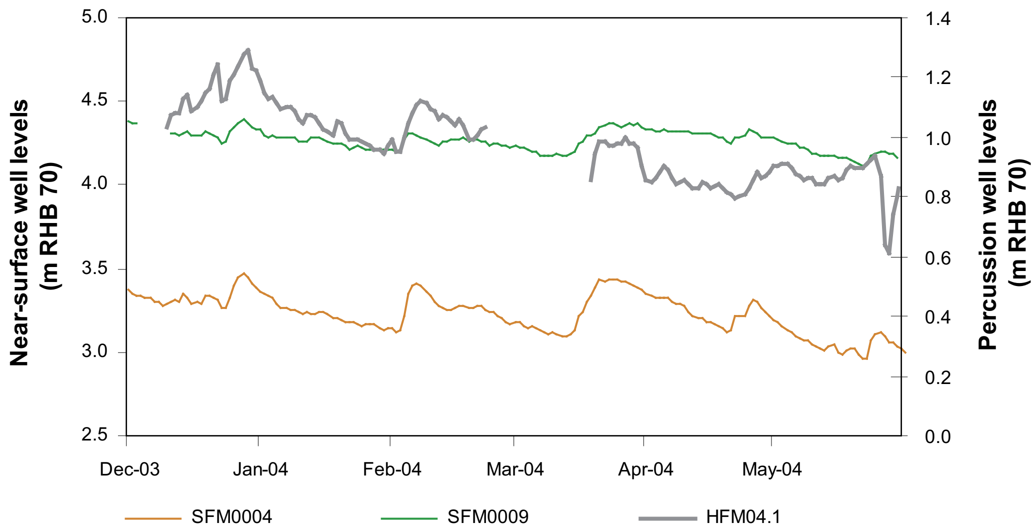

Figure 4-25. *Close-up view of groundwater elevations for a 6-month period at Core drill site 2 with soil (SFM) and bedrock (HFM, deepest section) well data plotted on separate axes for greater resolution.*

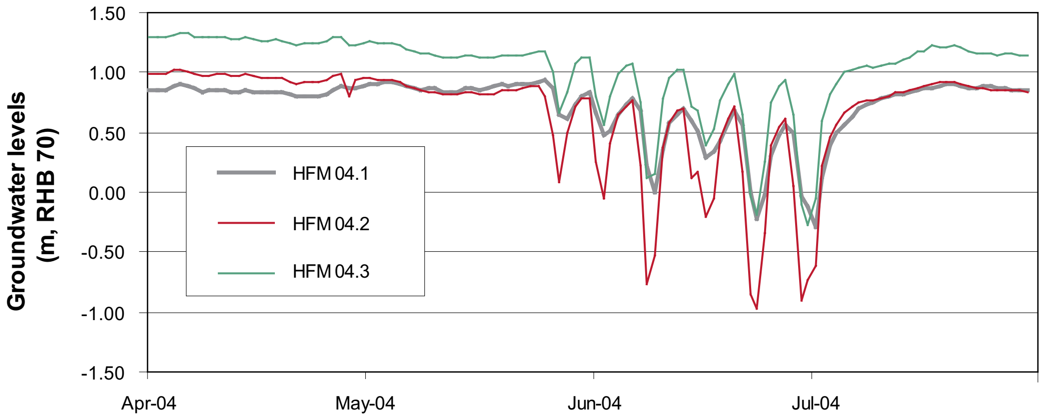

Figure 4-26. *Groundwater levels in three sections (separated with packers) of HFM04. Section 1 (HFM04.1) measures groundwater elevation between 66.9–221.7 m below ground, Section 2 (HFM04.2) between 57.9–65.9 m below ground, and Section 3 (HFM04.3) above 56.9 m below ground.*

4.3.3 Core drill site 3

Figures 4-27 and 4-28 show positions, and groundwater elevations and depths below surface for soil and percussion drilled bedrock well sites in the vicinity of Core drill site 3. Both SFM0006 and SFM0008 are separated by over 275 m from either bedrock well. SFM0007 is adjacent to HFM08. However, there were no reported data from this well.

The groundwater elevations at SFM0008 are quite close to those in HFM07 and HFM08, however it is important to note that the ground elevation is approximately 2.5 m lower at SFM0008 and that the sites are separated by several hundred metres. In general, the combined interpretation from groundwater elevations and depths below surface suggested that a consistent downward direction for groundwater flow also existed in this region. Figure 4-29 shows a close tracking between near surface and deeper groundwater elevations, which indicates that a close coupling exists in this region.

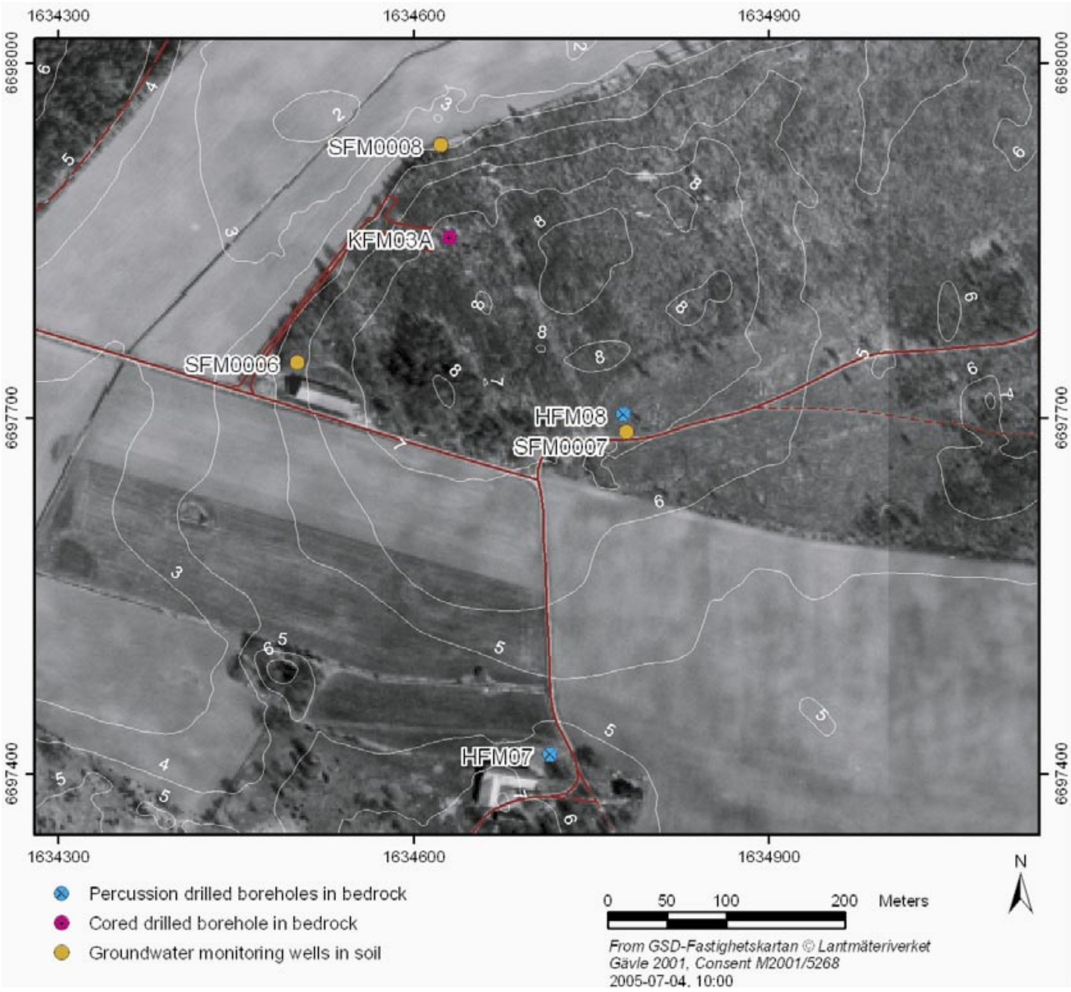

Figure 4-27. *Groundwater monitoring wells in soil (SFM) and percussion drilled boreholes (HFM) at Core drill site3.*

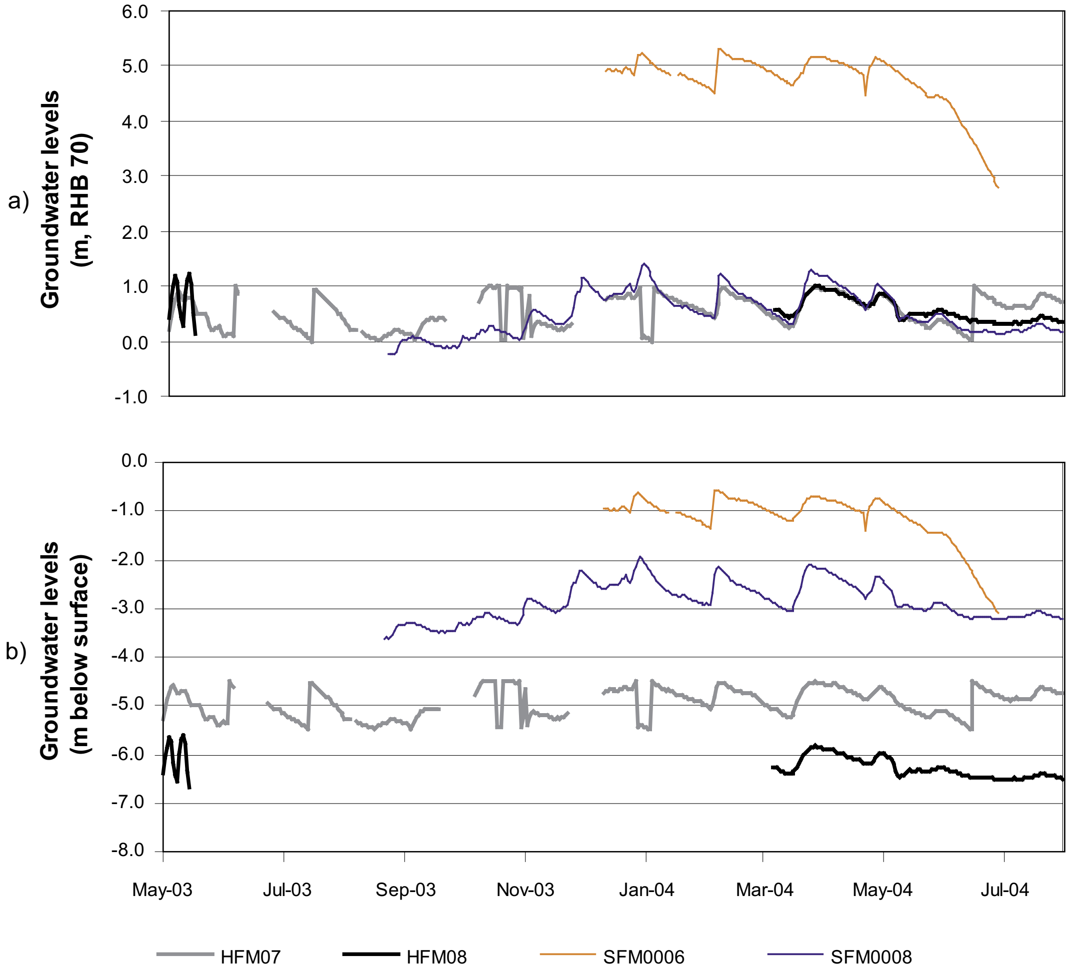

Figure 4-28. *Comparison of soil (SFM) and bedrock (HFM) groundwater monitoring wells at Core drill site 3 in terms of a) metres above sea level and b) depth below surface.*

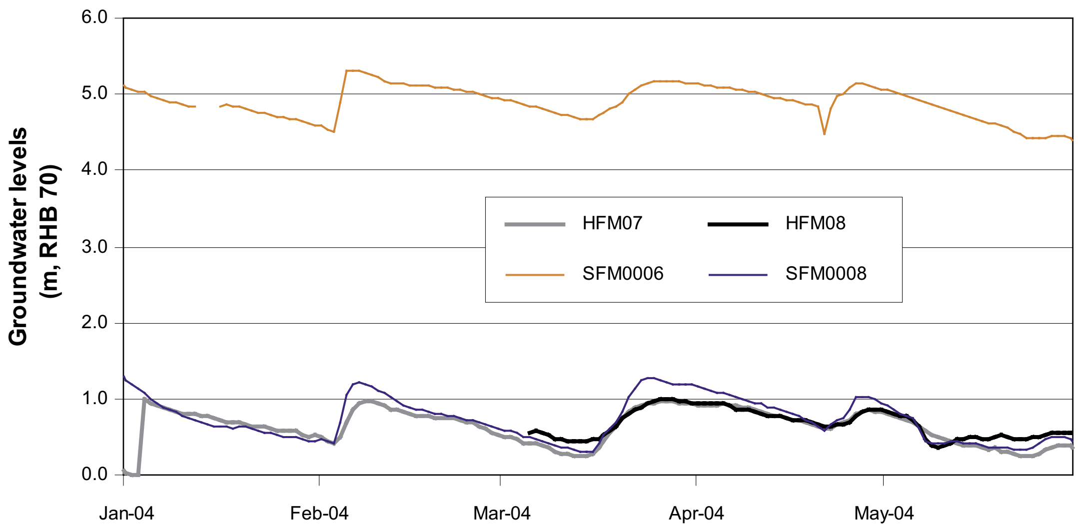

Figure 4-29. *Close-up view of groundwater elevations for a 5-month period at Core drill site 3.*

4.3.4 Core drill site 4

Figures 4-30 and 4-31 present positions, and groundwater elevations and depths below surface for soil and percussion drilled bedrock wells in the vicinity of Core drill site 4. These wells are also physically separated by 117–445 m. However, a downward gradient for groundwater flow was consistently observed. The coupling between near-surface and deeper groundwater seemed weaker at this site. While a downward trend in groundwater levels were evident in all wells from January 2004 onward, the bedrock well data did not exhibit any of the short-term response similarities that were observed at Sites 1 and 3 (see Figure 4-24 and Figure 4-28).

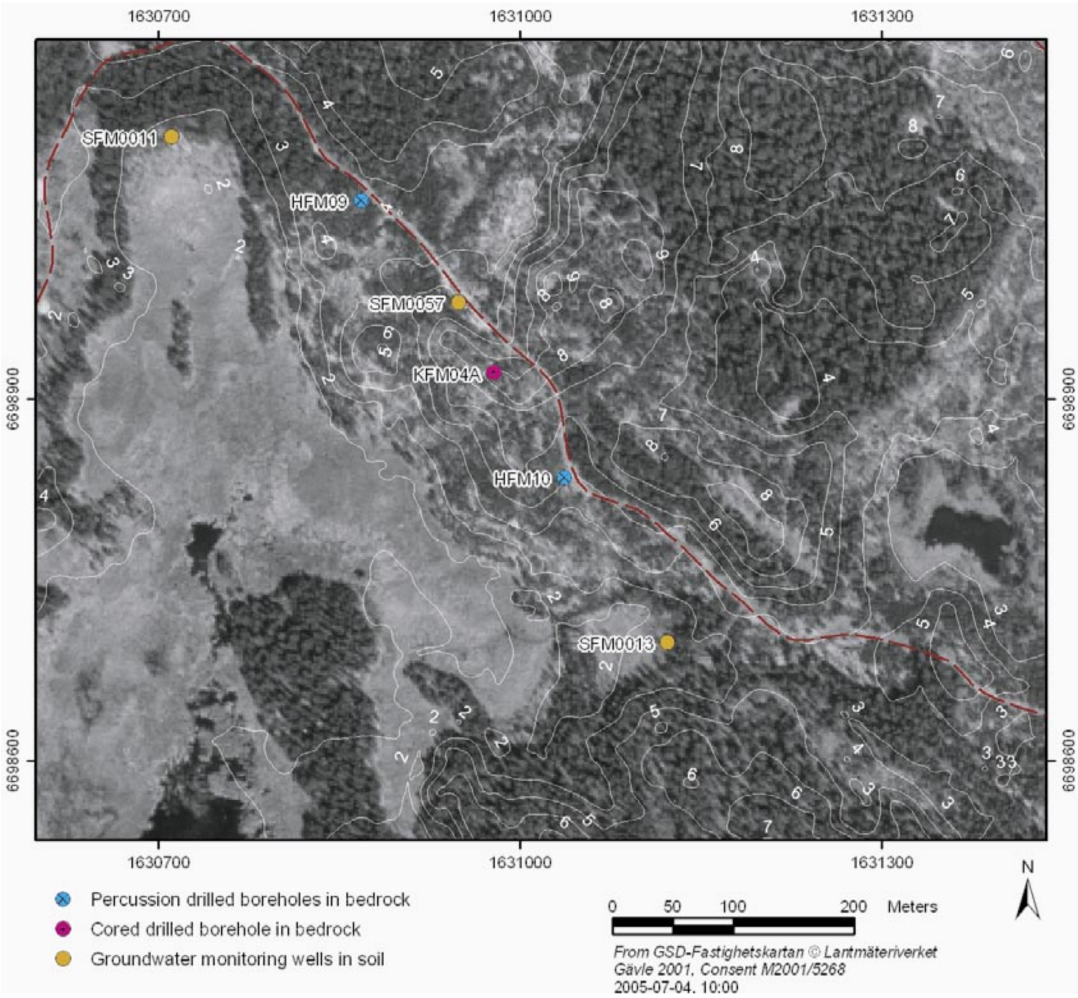

Figure 4-30. *Groundwater monitoring wells in soil (SFM) and percussion drilled boreholes (HFM) at Core drill site 4.*

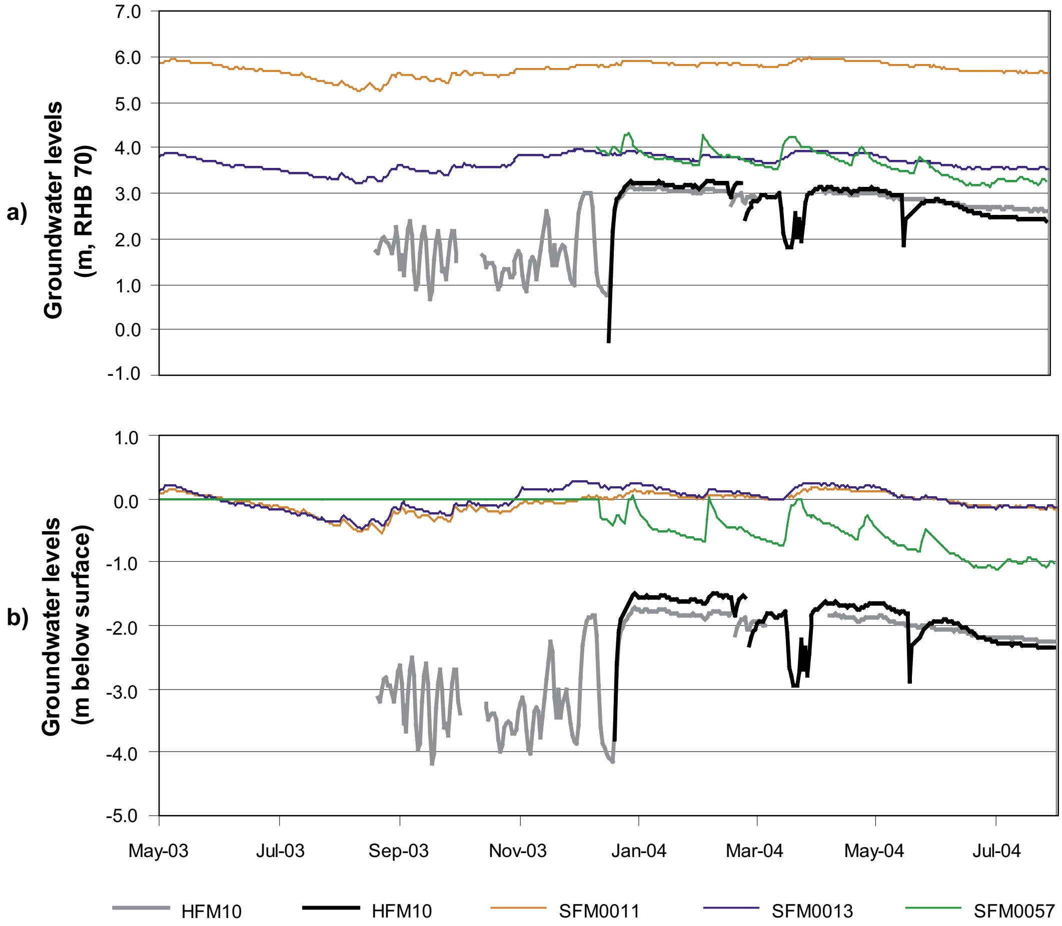

Figure 4-31. *Comparison of soil (SFM) and bedrock (HFM groundwater monitoring wells at Core drill site 4 in terms of a) metres above sea level and b) depth below surface.*

4.3.5 Core drill site 6

Figures 4-32 and 4-33 show positions, and groundwater elevations and depths below surface for SFM0021 and HFM16 at Core drill site 6. These two wells are located within 31 metres of one another. For the available time periods, the data indicated a consistent downward direction for groundwater flow in this region. However, there did now appear to be strong evidence of coupling between soil and bedrock groundwater in this region, as the two time series appeared fairly independent.

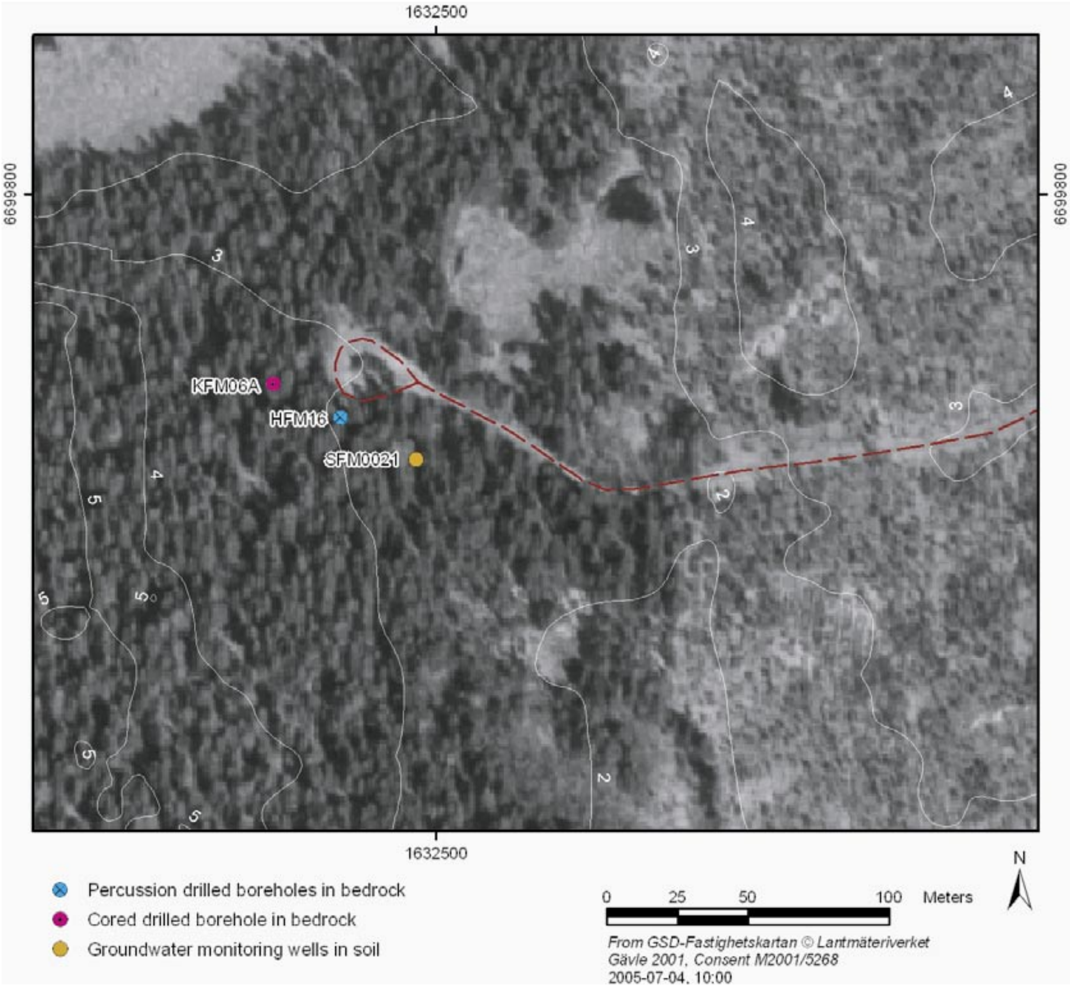

Figure 4-32. *Groundwater monitoring wells in soil (SFM) and percussion drilled boreholes (HFM) at Core drill site 6.*

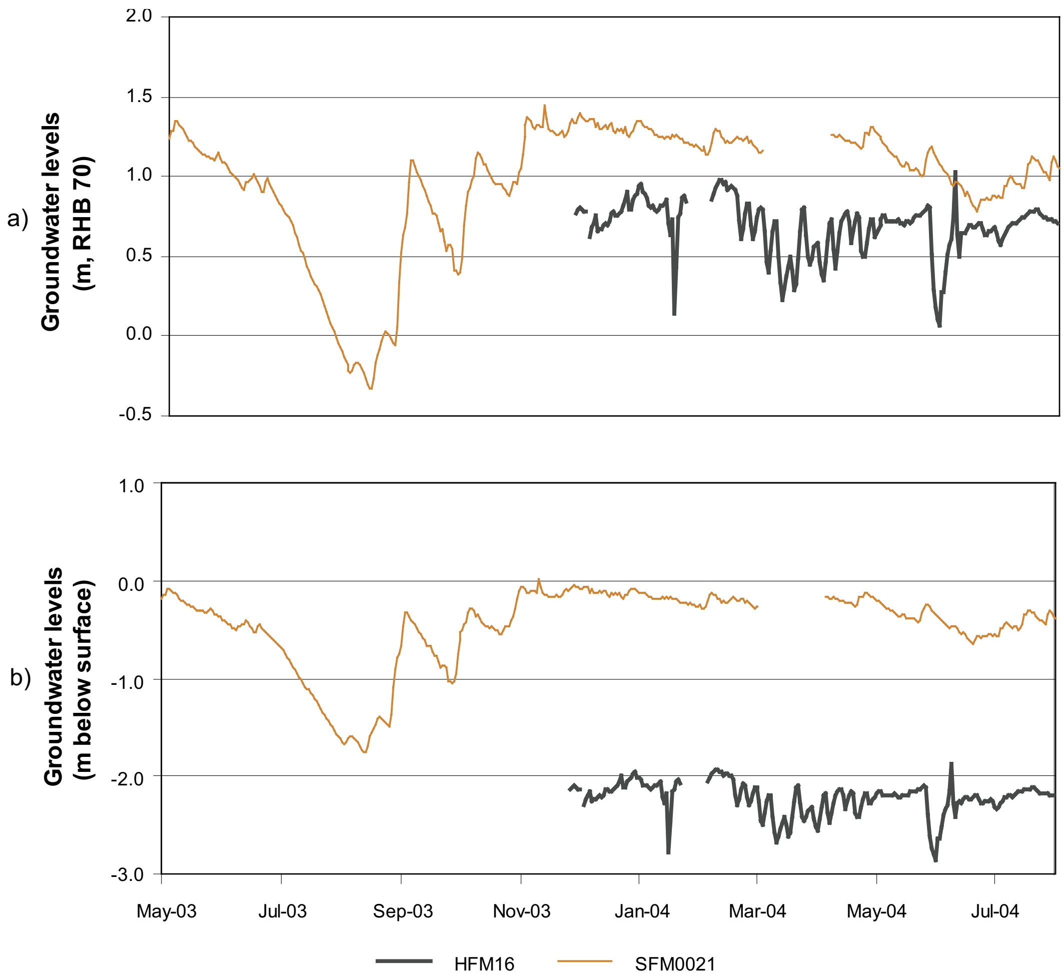

Figure 4-33. *Comparison of soil (SFM) and bedrock (HFM) groundwater monitoring wells at Core drill site 6 in terms of a) metres above sea level and b) depth below surface.*

4.3.6 Eckarfjärden

Figures 4-34 and 4-35 display positions, and groundwater elevations and depths below surface for soil and percussion drilled wells in the vicinity of Eckarfjärden. The interpretation of the vertical gradient in this region is complicated by several factors: the relatively large distances between the sites to be compared, variable ground topography in the region, and lake-aquifer seepage flows. The ground elevations at the two percussion wells were about 1.5–2.0 m higher than the average surface water elevation at Eckarfjärden (SFM0041).

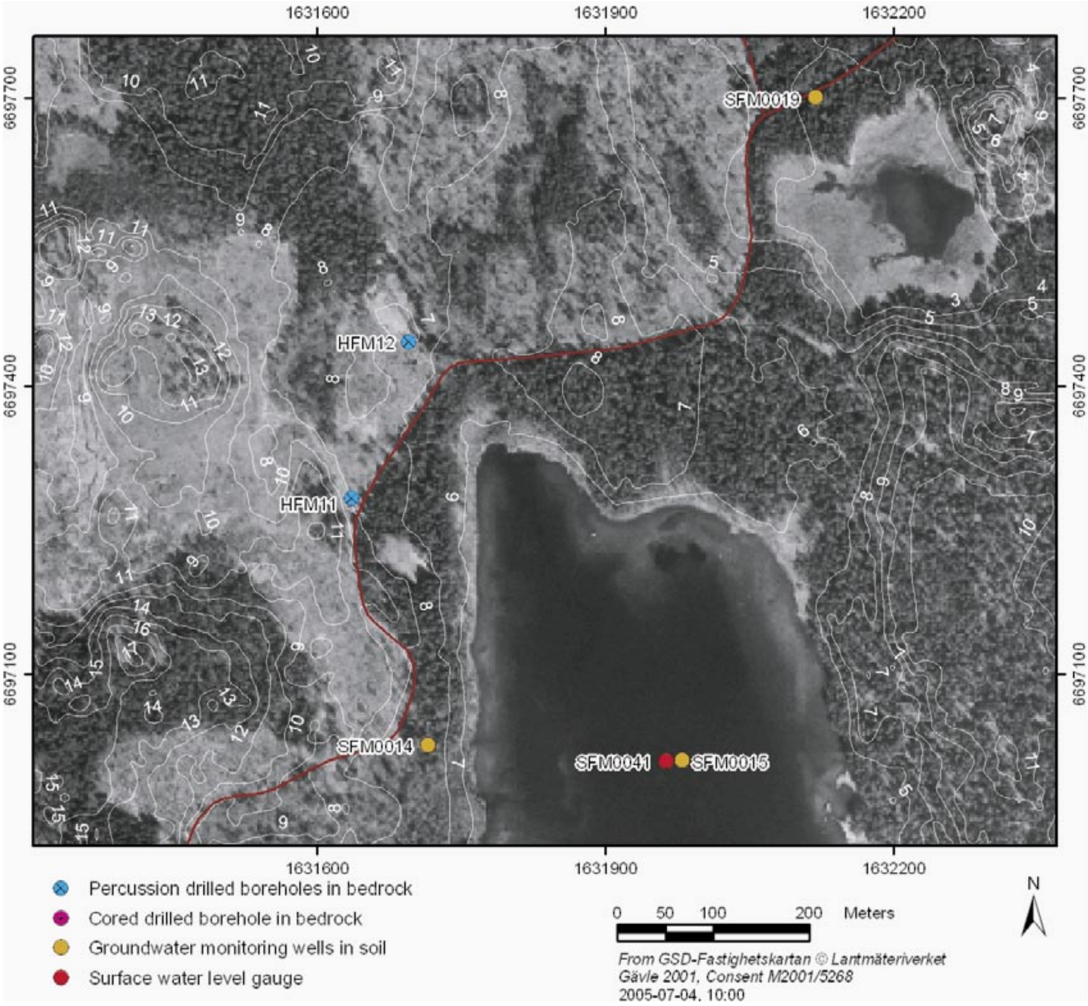

Figure 4-34. *Groundwater monitoring wells in soil (SFM) and percussion drilled boreholes (HFM) in the vicinity of Lake Eckarfjärden..*

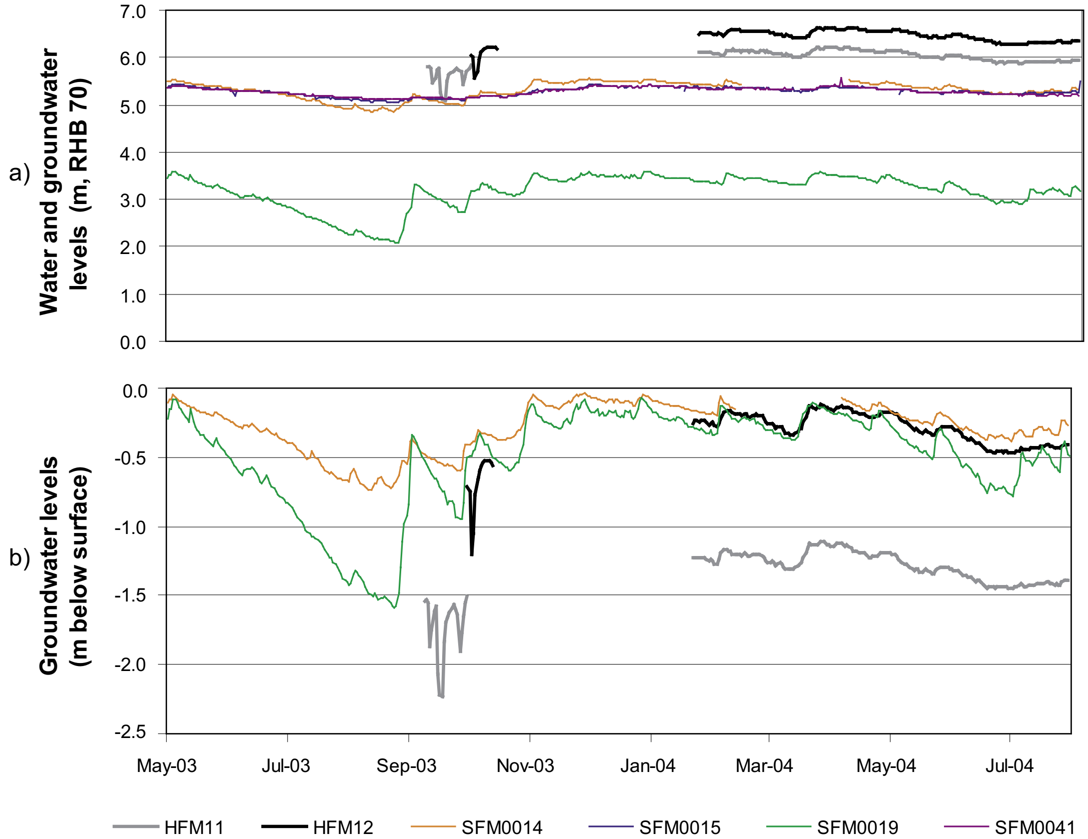

Figure 4-35. *Comparison of lake water level (SFM0041), soil (SFM) and bedrock (HFM) groundwater monitoring wells below (SFM0015) and in the vicinity of Eckarfjärden in terms of a) metres above sea level and b) depth below surface.*

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Werner K, Lundholm L, 2004. Supplementary drilling and soil sampling, installation of groundwater level monitoring wells, a pumping well and surface water level gauges. SKB P-04-139. Svensk Kärnbränslehantering AB.

Werner K, Lundholm L, Johansson P-O, 2004. Drilling and pumping test of wells at Börstilåsen. SKB P-04-138. Svensk Kärnbränslehantering AB.

Appendix 1

Description of measurement points

Meteorological stations

Coordinate system: RT 90 2.5 gon W 0:–15, RHB 70.

Station	X	Y	Type
PFM010700 Högmasten	6700525	1631046	Meteorological mast with measurements of precipitation, temperature, wind speed, wind direction, humidity, atmospheric pressure and global radiation
PFM010701 Storskäret	6697827	1634659	Meteorological mast with measurements of precipitation, temperature, wind speed, wind direction and humidity.

Surface water level gauges, groundwater monitoring wells, abstraction wells, and BAT-type filter tips

Coordinates, type, and length of time series at data freeze FM 1.2 (July 31, 2004).

Coordinate system: RT 90 2.5 gon W 0:–15, RHB 70.

Borehole	X	Y	Z	Z ground	Type	Start date for data	No. Data Days
SFM0001	6699713.31	1631335.44	1.10	0.95	Groundwater monitoring well at core-drill site	1-May-03	457
SFM0002	6699585.84	1631377.69	2.02	1.62	Groundwater monitoring well at core-drill site	1-May-03	457
SFM0003	6699614.59	1631487.30	1.94	1.54	Groundwater monitoring well at core-drill site	1-May-03	457
SFM0004	6698865.76	1633441.21	4.14	3.54	Groundwater monitoring well at core-drill site	1-May-03	457
SFM0005	6698647.55	1633252.18	6.80	6.00	Groundwater monitoring well at core-drill site	10-Dec-03	364
SFM0006	6697747.16	1634501.93	6.29	5.89	Groundwater monitoring well at core-drill site	1-May-03	154
SFM0007	6697688.66	1634780.08	7.00	6.60	Groundwater monitoring well at core-drill site	–	0
SFM0008	6697930.56	1634622.99	3.77	3.37	Groundwater monitoring well at core-drill site	22-Aug-03	345
SFM0009	6698577.50	1633223.50	4.64	4.33	Groundwater monitoring well at core-drill site	1-May-03	448
SFM0010	6697313.87	1630734.94	13.54	12.90	Groundwater monitoring well, not at core-drill site	14-May-03	412
SFM0011	6699117.11	1630711.39	6.44	5.79	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0012	6698492.25	1630719.10	2.85		Groundwater monitoring well below open water	9-May-03	449
SFM0013	6698698.54	1631122.63	4.40	3.68	Groundwater monitoring well, not at core-drill site	1-May-03	457

Borehole	X	Y	Z	Z ground	Type	Start date for data	No. Data Days
SFM0014	6697027.00	1631715.50	6.61	5.59	Groundwater monitoring well, not at core-drill site	1-May-03	404
SFM0015	6697009.79	1631964.04	5.77		Groundwater monitoring well below open water	1-May-03	453
SFM0016	6696976.14	1632173.94	6.19	5.22	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0017	6696504.81	1632138.16	6.69	5.65	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0018	6696557.50	1631950.00	6.67	5.77	Groundwater monitoring well, not at core-drill site	1-May-03	398
SFM0019	6697700.72	1632118.35	4.77	3.67	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0020	6698126.80	1632993.65	2.25	1.67	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0021	6699706.35	1632492.99	1.97	1.43	Groundwater monitoring well, not at core-drill site	1-May-03	423
SFM0022	6697597.55	1632697.18	1.49		Groundwater monitoring well below open water	–	0
SFM0023	6698982.51	1632064.42	1.06		Groundwater monitoring well below open water	16-May-03	426
SFM0024	6699944.40	1633108.79	0.47		Groundwater monitoring well below open water	1-May-04	235
SFM0025	6696039.39	1634774.05	0.86		Groundwater monitoring well below open water	1-May-04	457
SFM0026	6696702.65	1634151.84	1.59	0.70	Groundwater monitoring well, not at core-drill site	18-Aug-03	348
SFM0027	6696685.21	1634146.66	1.75		Groundwater monitoring well, not at core-drill site	–	0
SFM0028	6698507.93	1633588.91	1.07	0.22	Groundwater monitoring well, not at core-drill site	1-May-03	450
SFM0029	6698510.19	1633588.89	1.08		Groundwater monitoring well, not at core-drill site	–	0
SFM0030	6698678.20	1631662.72	2.79	1.67	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0031	6698681.55	1631661.09	2.63		Groundwater monitoring well, not at core-drill site	–	0
SFM0032	6698838.26	1631725.79	1.63	0.53	Groundwater monitoring well, not at core-drill site	–	0
SFM0033	6698839.01	1631728.18	1.69	0.67	Groundwater monitoring well, not at core-drill site	1-May-03	391
SFM0034	6699757.49	1631858.50	1.58	0.61	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0035	6699756.25	16318592.16	1.49	0.66	Groundwater monitoring well, not at core-drill site	–	0
SFM0036	6699991.99	1631746.07	1.51	0.61	Groundwater monitoring well, not at core-drill site	1-May-03	457
SFM0037	6699991.93	1631744.41	1.50	0.60	Groundwater monitoring well, not at core-drill site	–	0
SFM0038*	6701375.07	1632560.63	2.55		Surface water level gauge	22-May-03	349
SFM0039	6699867.01	1631751.42	1.40		Surface water level gauge	1-May-03	451
SFM0040	6698983.16	1632063.77	1.57		Surface water level gauge	16-May-03	442

Borehole	X	Y	Z	Z ground	Type	Start date for data	No. Data Days
SFM0041	6697010.49	1631963.34	5.93		Surface water level gauge	1-May-03	454
SFM0042	6697598.02	1632696.42	1.53		Surface water level gauge	5-Feb-04	177
SFM0043	6696040.29	1634774.45	0.40		Surface water level gauge	1-May-03	267
SFM0049	6700027.55	1630533.057	4.03	2.93	Groundwater monitoring well, not at core-drill site	13-May-03	421
SFM0057	6698979.93	1630949.38	4.82	4.27	Groundwater monitoring well, at core-drill site	3-Dec-03	232
SFM0058	6699349.27	1631739.76	3.55	3.20	Groundwater monitoring well, at core-drill site	27-May-04	65
SFM0059	6698464.48	1635777.32	4..53	4.03	Groundwater monitoring well, not at core-drill site	16-Feb-04	166
SFM0060	6698379.81	1635923.87	4.91	4.26	Groundwater monitoring well, not at core-drill site	–	0
SFM0061	6698376.67	1635923.81	5.40	4.33	Abstraction well	16-Feb-04	166
SFM0062	6698838.72	1631807.99	1.18		Groundwater monitoring well below open water	5-May-04	87
SFM0063	6698839.05	1631851.41	1.28		Groundwater monitoring well below open water	–	0
SFM0064	6698491.57	1630718.38	2.80		Surface water level gauge	21-Apr-04	101
SFM0065	6698380.94	1633841.58	0.97		Groundwater monitoring well below open water	28-Apr-04	94
SFM0066	6698380.47	1633842.38	0.89		Surface water level gauge	6-May-04	86
SFM0067	6699120.60	1630713.36	6.37	2.11	Groundwater monitoring well, not at core-drill site	–	0
SFM0068	6699706.12	1632489.56	2.07	1.61	Groundwater monitoring well, not at core-drill site	–	0
SFM0069	6698680.22	1631662.25	2.50	1.87	Groundwater monitoring well, not at core-drill site	–	0
SFM0070	6697069.55	1634783.49	3.72	3.26	Groundwater monitoring well, not at core-drill site	–	0
SFM0071	6697069.45	1634785.08	3.60	3.29	Groundwater monitoring well, not at core-drill site	–	0
SFM0072	6697069.33	1634789.30	3.69	3.27	Groundwater monitoring well, not at core-drill site	–	0
SFM0073	6698513.24	1633585.10	0.63	0.23	Groundwater monitoring well, not at core-drill site	–	0
SFM0074	6698839.08	1631738.02	0.82	0.52	Abstraction well	–	0
SFM0075	6697069.45	1634786.84	3.78	3.27	Groundwater monitoring well, not at core-drill site	–	0
SFM0076	Not surveyed				Groundwater monitoring well at core-drill site	–	0

*Renamed to PFM010038

Appendix 2

Correlations between groundwater level time series

Notation: In the table, 01 denotes SFM0001, 02 SFM0002, etc.

	01	02	03	04	05	06	08	09	10	11	12	13	14	15	16	17	18	19	20	21	23	24	25	26	28	30	33	34	36	49	57
01	**1,00**	0,98	0,98	0,91	0,92	0,92	0,82	0,81	0,89	0,84	0,80	0,89	0,90	0,78	0,80	0,84	0,82	0,94	0,92	0,95	0,76	-0,07	0,53	0,84	0,95	0,95	0,70	0,96	0,97	0,73	0,95
02		1,00	0,97	0,86	0,91	0,90	0,71	0,73	0,79	0,77	0,71	0,82	0,82	0,69	0,71	0,76	0,74	0,90	0,86	0,92	0,69	0,01	0,52	0,70	0,91	0,90	0,67	0,92	0,93	0,64	0,93
03			1,00	0,90	0,89	0,94	0,80	0,84	0,89	0,87	0,79	0,87	0,90	0,79	0,81	0,87	0,85	0,95	0,92	0,97	0,75	-0,06	0,55	0,87	0,94	0,96	0,68	0,94	0,96	0,78	0,91
04				1,00	0,92	0,92	0,90	0,87	0,84	0,83	0,84	0,93	0,93	0,84	0,87	0,84	0,83	0,94	0,95	0,92	0,81	-0,25	0,50	0,93	0,95	0,91	0,68	0,92	0,93	0,77	0,92
05					1,00	0,86	0,81	0,77	0,74	0,65	0,80	0,90	0,88	0,75	0,81	0,73	0,66	0,93	0,96	0,94	0,69	-0,47	0,16	0,77	0,94	0,83	0,54	0,89	0,89	0,56	0,87
06						1,00	0,79	0,92	0,93	0,81	0,74	0,84	0,90	0,77	0,84	0,90	0,73	0,93	0,86	0,91	0,66	0,41	0,04	0,88	0,89	0,96	0,29	0,92	0,95	0,78	0,83
08							1,00	0,83	0,79	0,86	0,90	0,91	0,86	0,87	0,90	0,81	0,85	0,79	0,86	0,77	0,80	-0,39	0,42	0,93	0,88	0,79	0,52	0,84	0,84	0,81	0,92
09								1,00	0,82	0,94	0,90	0,90	0,95	0,95	0,97	0,96	0,95	0,89	0,92	0,88	0,82	-0,29	0,58	0,95	0,89	0,91	0,60	0,85	0,88	0,98	0,93
10									1,00	0,85	0,87	0,91	0,92	0,81	0,87	0,89	0,88	0,91	0,89	0,89	0,81	-0,38	0,24	0,85	0,88	0,95	0,54	0,94	0,95	0,77	0,87
11										1,00	0,91	0,91	0,92	0,90	0,93	0,93	0,94	0,88	0,89	0,87	0,81	-0,22	0,55	0,92	0,88	0,91	0,61	0,87	0,89	0,94	0,82
12											1,00	0,96	0,94	0,92	0,96	0,91	0,91	0,85	0,89	0,84	0,89	-0,37	0,43	0,89	0,87	0,87	0,65	0,89	0,88	0,88	0,83
13												1,00	0,96	0,91	0,94	0,91	0,89	0,92	0,95	0,90	0,88	-0,32	0,46	0,90	0,94	0,92	0,70	0,95	0,94	0,85	0,91
14													1,00	0,95	0,96	0,97	0,96	0,95	0,98	0,94	0,88	-0,28	0,57	0,94	0,95	0,96	0,70	0,94	0,94	0,90	0,96
15														1,00	0,98	0,94	0,95	0,85	0,90	0,84	0,92	-0,37	0,58	0,94	0,88	0,87	0,68	0,85	0,85	0,93	0,84
16															1,00	0,96	0,95	0,88	0,92	0,86	0,89	-0,38	0,55	0,96	0,90	0,89	0,66	0,88	0,88	0,95	0,92
17																1,00	0,98	0,91	0,93	0,91	0,85	-0,27	0,57	0,92	0,90	0,94	0,66	0,89	0,89	0,94	0,94
18																	1,00	0,89	0,91	0,90	0,88	-0,25	0,67	0,94	0,88	0,92	0,66	0,87	0,86	0,94	0,84
19																		1,00	0,97	0,98	0,81	-0,23	0,53	0,85	0,96	0,98	0,71	0,94	0,94	0,80	0,94
20																			1,00	0,95	0,84	-0,25	0,56	0,90	0,97	0,95	0,71	0,94	0,94	0,85	0,95
21																				1,00	0,79	-0,17	0,58	0,85	0,95	0,98	0,71	0,93	0,94	0,81	0,92
23																					1,00	-0,35	0,49	0,82	0,85	0,82	0,65	0,86	0,83	0,79	0,74
24																						1,00	0,34	-0,49	-0,16	-0,22	-0,20	-0,19	-0,21	-0,32	0,18
25																							1,00	0,39	0,58	0,53	0,46	0,48	0,48	0,55	0,18
26																								1,00	0,90	0,89	0,50	0,84	0,89	0,91	0,95
28																									1,00	0,95	0,73	0,97	0,96	0,80	0,90
30																										1,00	0,69	0,94	0,96	0,85	0,91
33																											1,00	0,72	0,67	0,51	0,48
34																												1,00	0,98	0,78	0,93
36																													1,00	0,82	0,90
49																														1,00	0,87
57																															1,00

Shaded blue = wells below surface waters

Shaded red = correlation R^2>0.95

Excludes:
- water surface elevations
- data sets with < 200 days