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Summary

The Swedish Nuclear Fuel and Waste Management Company (SKB) is conducting site investigations at two different locations, Forsmark and Simpevarp, with the objective of siting a geological repository for spent nuclear fuel. The results from the investigations at these sites are used as a basic input to the development of Site Descriptive Models (SDM). The SDM shall summarise the current state of knowledge of each site, and provide parameters and models to be used in further analyses within Safety Assessment, Repository Design and Environmental Impact Assessment.

This report is a background report describing the meteorological conditions and the modelling of surface hydrology and near-surface hydrogeology in support of the Laxemar version 1.2 SDM for the Simpevarp area, based on the primary data available in the Laxemar 1.2 "data freeze" (November 1, 2004). The main objective of the present work is to update the previous Simpevarp 1.2 description of the meteorological, surface hydrological and near-surface hydrogeological conditions in the Simpevarp area. Based on the Laxemar 1.2 dataset, an updated conceptual-descriptive model of the surface and near-surface water flow conditions is presented. The report also describes the results of quantitative water flow modelling, undertaken in order to develop the understanding of the site, to support the site descriptive modelling, and to produce basic output data to the ecosystems modelling within the SurfaceNet modelling project. As in the previous Simpevarp 1.2 model version, the Laxemar 1.2 quantitative water flow modelling is performed using the process-based MIKE SHE-MIKE 11 software packages. In addition, extended GIS-based hydrological modelling is performed, applying the PCRaster-POLFLOW modelling approach.

The Simpevarp area is characterised by a relatively small-scale topographical undulation and shallow Quaternary deposits (QD). Almost the entire area is below 50 metres above sea level, and the whole Simpevarp regional model area is located below the highest coastline. The annual (corrected) precipitation in the Simpevarp area is on the order of 600–700 mm, and the annual average specific discharge (or runoff) has previously been estimated to be in the range 150–180 mm. Within the regional model area, 26 catchment areas have been delineated, ranging in size from 0.07 to 40.98 km^2. These 26 catchment areas are further divided into totally 96 subcatchment areas. There are six lakes within the area. The maximum depth of the five lakes for which morphometry parameters are available (Lake Grangöl was not included in the field investigation programme) ranges from c 2 to 11 m, and the size of these lakes is between 0.03 and 0.24 km^2.

Except for catchment area 11, there are watercourses in all catchments areas. The largest watercourse is Laxemarån in catchment area 10; the other watercourses are small. Surface water discharge in most of the watercourses is a highly transient process during the year. There are relatively short "peaks" in the discharge, occurring in connection with precipitation events and/or snow melt periods; in between these events/periods, small or even zero discharges are observed. Man-made drainage is a general characteristic of the Simpevarp area. Modelling results show that without these land-management operations, many areas would have been lakes or wetlands. Field data on ditches and other drainage systems, as well as on watercourses that were missing on the pre-existing maps of the model area, are being collected; these objects will be included in future model versions.

Large parts (c 35%) of the regional model area consist of shallow or exposed bedrock, predominantly in high-altitude areas. In the Laxemar subarea, there is less shallow/exposed bedrock and more abundant QD compared to the Simpevarp subarea. The average depth

of the QD is c 2 metres with exposed/shallow bedrock areas included, and c 3 metres with these areas excluded. The QD mainly consist of sandy (at some locations sandy-gravelly) till, covering c 43% of the land surface in the regional model area. In the valleys, where the thickest QD layers are found, the till is often covered by postglacial sediments, such as gyttja clay, peat and/or fluvial outwash.

The update of the conceptual-descriptive model includes a more detailed description of the flow domains, in particular the Hydraulic Soil Domains (HSD). Based on several types of data, a geometrical model of the HSD has been developed using the ArcGIS extension GeoEditor. In that model, the HSD are divided into three layers; there are also three locally present layers ("lenses"), which represent peat, glaciofluvial deposits, and artificial fill (not strictly QD). In the present modelling, the hydraulic conductivity K of the till is assigned a value of $K = 4 \cdot 10^{-5}$ $\mathrm{m \cdot s^{-1}}$, based on hydraulic (slug) tests and particle-size distribution curves. For other types of QD, and for the storage properties of all QD, the hydraulic properties are assigned based on generic (literature) data.

Groundwater recharge from precipitation (and snow melt) is considered the dominant source of groundwater recharge. Although there is yet no field evidence that could support conclusions regarding the groundwater-surface water interactions, the Laxemar 1.2 modelling results indicate that lakes in the Simpevarp area do not contribute to groundwater recharge, not even during dry periods when the groundwater levels are low. The groundwater level in the QD is generally shallow, on the order of 0.5–1.5 metres below the ground surface. The variation (the difference between the maximum and minimum levels) is also generally small, c 0.5–1 metres. As the near-surface groundwater in the QD is shallow, it is assumed that the boundaries of the 26 catchment areas (areas contributing to the discharge to surface waters) are water divides for the near-surface groundwater.

The thickness and the hydraulic conductivity of the sediments at the bottom of the sea, the lakes and the wetlands are crucial for their functions as discharge areas for groundwater. Based on site investigation data and the conceptual-descriptive model of the QD in the Simpevarp area, the QD at the bottom of the lakes are assumed to consist of low-permeable layers of gyttja and clay, and the QD below peat areas (wetlands) and the QD at the bottom of the sea are assumed to consist of gyttja (peat areas) and clay (the sea), respectively. This type of sediment stratigraphy limits the contact between groundwater and surface water in these areas.

The water balance and the specific discharge are strongly dependent on the meteorological conditions (primarily the precipitation and the potential evaporation). These quantities vary from year to year, and also during individual years, as controlled by the period-specific meteorological conditions. The quantitative water flow modelling shows that there are some differences in the water balance and the specific discharge between the catchment areas. These results indicate that the water balance and the specific discharge most properly are calculated and reported on a catchment-by-catchment area basis, rather than applying one "average" value for the whole Simpevarp area. The model-calculated annual average specific discharge for the land parts of the present model area is 189 mm; this modelling is based on meteorological data measured at the local SKB station on Äspö during 2004. This specific discharge is slightly larger than the estimated "regional" value of the long-term annual average specific discharge (150–180 mm).

The transient nature of the water flow system implies that the discharge areas are somewhat larger during a dry period, as compared to a wet period. Hence, the spatial distribution of recharge and discharge varies with time, due to seasonal or short-term variations in the meteorological conditions. There are also permanent recharge and discharge areas. For instance, areas in the vicinity of the main watercourses and Lake Frisksjön are permanent discharge areas, whereas the high-altitude areas are permanent recharge areas.

It should also be noted that in the present MIKE SHE-MIKE 11 modelling, the bottom boundary (located at 150 metres below sea level) is assumed to be a no-flow boundary. Obviously, the coupling between the groundwater in the rock and that in the QD must be further studied, in order to facilitate the development of integrated flow and transport models. However, since the flow across the QD/rock interface is small compared to the flow in the surface/near-surface system, the approximation of a no-flow boundary in the rock is considered reasonable for the purposes of the present analysis. In addition, the sensitivity analyses performed as a part of the Laxemar 1.2 modelling show that the vegetation-related parameters used in the modelling of evapotranspiration processes in MIKE SHE may have large effects on the modelling results; since these parameters can also be regarded as uncertain, they need to be further investigated.

Further, the Laxemar 1.2 data freeze contains only a relatively small amount of time series data, which obviously limits the present possibilities for development of conceptual-descriptive models and calibration of quantitative water flow models. More detailed analyses would require groundwater level data, and associated meteorological and hydrological data, for a period of at least one (hydrological) year. This means that such analyses must be postponed to future model versions, when longer time series are available. This type of comparisons (and model calibrations in general) will be part of forthcoming modelling. Furthermore, the representativity of the existing wells in QD should be investigated; there is likely a bias in the present dataset, due to the fact that most of the wells are located primarily in lower-lying areas.

For many types of site investigation data, the Laxemar 1.2 data freeze is essentially the first batch of data available for the description of the Laxemar subarea. Although significant steps have been taken in the conceptual-descriptive and quantitative water flow modelling, more time series data are judged crucial for improving the site understanding and the quantitative models of the Simpevarp area. Most of the groundwater level measurements currently performed in the Laxemar subarea have been initiated during 2005, which means that it will take some time before useful time series data are available.

It is not expected that the continued site investigations will add that much hydraulic conductivity data or other information on the geological and hydrogeological properties of the near-surface system; the majority of the planned drillings and installations of groundwater monitoring wells in QD have been performed. The main exceptions are the investigations performed in transects across valleys (i.e. along selected sections in “typical” valleys within the model area), and the additional investigations to be performed within the area prioritised for the deep repository. A detailed evaluation of the existing database, performed to identify the need for further investigations, is performed as a part of the ongoing Laxemar 2.1 modelling.

Sammanfattning

Svensk Kärnbränslehantering (SKB) genomför platsundersökningar på två olika platser, Forsmark och Simpevarp, i syfte att lokalisera ett djupförvar för använt kärnbränsle. Resultaten från platsundersökningarna används som underlag för framtagande av platsbeskrivande modeller. Platsmodellerna sammanfattar den aktuella kunskapen om platserna och tillhandahåller parametrar och modeller som används i de vidare analyserna inom säkerhetsanalys, förvarsprojektering och miljökonsekvensbeskrivning.

Denna rapport är en bakgrundsrapport som beskriver de meteorologiska förhållandena och modelleringen av ythydrologi och ytnära hydrogeologi som underlag för platsmodell version Laxemar 1.2 för Simpevarpsområdet, baserat på primärdata tillgängliga i "datafrysen" Laxemar 1.2 (som inföll den 1 november 2004). Huvudsyftet är att uppdatera den tidigare platsmodellen Simpevarp 1.2 avseende beskrivningen av de meteorologiska, hydrologiska och ythydrogeologiska förhållandena i Simpevarpsområdet. Baserat på den datamängd som finns tillgänglig för Laxemar 1.2-modelleringen, presenteras en uppdaterad konceptuell-beskrivande modell av de ytliga och ytnära flödesförhållandena.

Rapporten presenterar också resultat från den kvantitativa flödesmodellering som utförs för att utveckla platsförståelsen, stödja den platsbeskrivande modelleringen och ta fram data till den systemekologiska modellering som utförs inom ramen för SKB-projektet SurfaceNet. Liksom i den tidigare modellversionen Simpevarp 1.2, utförs den kvantitativa flödesmodelleringen med det processbaserade programpaketet MIKE SHE-MIKE 11. Dessutom har utökad GIS-baserad hydrologisk modellering utförts genom tillämpning av modelleringsverktygen PCRaster-POLFLOW.

Simpevarpsområdet karaktäriseras av en relativt småskalig topografi och grunda kvartära avlagringar. Nästan hela området är beläget lägre än 50 meter över havets nivå, och hela Simpevarpsområdet är beläget under högsta kustlinjen (HK). Den korrigerade årsnederbörden i Simpevarpsområdet är i storleksordningen 600–700 mm, och den årliga genomsnittliga specifika avrinningen har tidigare uppskattats vara i intervallet 150–180 mm. Inom Simpevarpsområdet har 26 avrinningsområden karterats, varierande i storlek från 0,07 till 40,98 km^2. Dessa 26 avrinningsområden är uppdelade i 96 delavrinningsområden. Inom området finns sex sjöar. Det största djupet i de fem sjöar för vilka morfometriska parametrar finns tillgängliga (sjön Grangöl ingick inte i fältundersökningsprogrammet) varierar från ca 2 meter till ca 11 meter, och sjöarnas storlek varierar mellan 0,03 och 0,24 km^2.

Med undantag för avrinningsområde 11 finns det vattendrag i alla avrinningsområden. Det största vattendraget är Laxemarån i avrinningsområde 10. De andra vattendragen i området är små och kan närmast karakteriseras som diken. De flesta vattendragen uppvisar kraftigt varierande ytvattenflöden under året. Det finns relativt kortvariga toppar i ytvattenflödet, vilka förekommer i samband med nederbördstillfällen och/eller snösmältningsperioder; mellan dessa tillfällen/perioder är det lågt eller inget ytvattenflöde. Konstruerade diken/dräneringar är allmänt förekommande i Simpevarpsområdet. Modelleringsresultaten visar att om dessa inte fanns, skulle många områden sannolikt vara sjöar eller våtmarker. Fältundersökningar av diken, dräneringar och "saknade" vattendrag pågår, och dessa kommer att beaktas i kommande modellversioner.

Stora delar (ca 35%) av det regionala modellområdet består av ytligt berg eller berg i dagen, främst i högre belägna områden. Det är en lägre andel ytligt/exponerat berg och mäktigare jordlager i delområde Laxemar, jämfört med delområde Simpevarp. Den genomsnittliga jordlagermäktigheten är ca 2 meter om områdena med ytligt/exponerat berg räknas med,

och ca 3 meter om dessa områden exkluderas. De kvartära avlagringarna består främst av sandig (på vissa platser sandig-grusig) morän, vilken täcker c 43% av landytan i det regionala modellområdet. I dalgångarna, där de mäktigaste kvartära avlagringarna finns, täcks ofta moränen av postglaciala sediment, till exempel gyttjelera, torv och/eller svallat material.

Uppdateringen av den konceptuella och beskrivande modellen inkluderar en mer detaljerad beskrivning av flödesdomänerna, speciellt Hydraulic Soil Domains (HSD; hydrauliska jorddomäner). Baserat på flera typer av data har en geometrisk modell av dessa HSD utvecklats med ArcGIS-tillägget GeoEditor. I denna modell delas HSD upp i tre lager; det finns också tre lokala lager ("linser"), vilka representerar torv, glaciofluviala avlagringar och fyllning (inte strikt en kvartär avlagring). I modelleringen har den hydrauliska konduktiviteten K för moränen ansatts ett värde på $K = 4 \cdot 10^{-5}$ $\mathrm{m \cdot s^{-1}}$, baserat på hydrauliska (slug)tester och kornstorlekskurvor. För andra typer av kvartära avlagringar, och för magasinsegenskaperna i alla kvartära avlagringar, har de hydrauliska egenskaperna ansatts baserat på generiska (litteratur)data.

Grundvattenbildningen bedöms domineras av nederbörd (och snösmältning när sådan förekommer). Även om det saknas fältdata som stödjer detta, indikerar Laxemar 1.2-modelleringen att sjöarna i Simpevarpsområdet inte bidrar till grundvattenbildningen, inte ens under torrperioder då grundvattennivåerna är låga. Grundvattennivån i de kvartära avlagringarna ligger generellt mycket nära markytan (i storleksordningen 0,5–1,5 meter under markytan). Variationen mellan den högsta och den lägsta nivån är också generellt liten, c 0,5–1 meter i flertalet grundvattenrör. Marknära grundvatten i de kvartära avlagringarna innebär att gränserna för de 26 avrinningsområdena (de områden som bidrar till ytvattenavrinning) antas vara vattendelare även för det ytnära grundvattnet.

Mäktigheten och den hydrauliska konduktiviteten hos sedimenten på bottnarna i hav, sjöar och våtmarker är avgörande för deras funktion som utströmningsområden för grundvatten. Baserat på platsundersökningsdata och den konceptuella-beskrivande modellen av de kvartära avlagringarna i Simpevarpsområdet, antas botten av sjöarna bestå av lågpermeabla lager med gyttja och lera; områden under torvmarker (våtmarker) och havsbotten antas bestå av gyttja (torvmarker) respektive lera (havsbotten). Denna typ av sedimentlagerföljd begränsar kontakten mellan grundvatten och ytvatten i dessa områden.

Vattenbalansen och den specifika avrinningen i Simpevarpsområdet beror på de meteorologiska förhållandena (främst nederbörd och potentiell avdunstning). Vattenbalansen och den specifika avrinningen varierar därför från år till år och givetvis även under enskilda år, beroende på de periodspecifika meteorologiska förhållandena. Den kvantitativa flödesmodelleringen visar att det finns vissa skillnader i vattenbalansen och den specifika avrinningen mellan avrinningsområdena. Dessa resultat indikerar att vattenbalansen och den specifika avrinningen lämpligen beräknas och rapporteras per avrinningsområde, istället för att tillämpa ett genomsnittsvärde för hela Simpevarpsområdet. I medeltal är den modellberäknade årliga specifika avrinningen för landområdena inom det modellerade området 189 mm, vilket är något högre än det uppskattade regionala medelvärdet på den årliga avrinningen (150–180 mm). Denna beräkning baseras på lokala meteorologiska data uppmätta under år 2004 i SKB:s station på Äspö.

Vattenflödessystemet är transient, vilket innebär att det är något större utströmningsområden under en torrperiod, jämfört med förhållandena under en våtperiod. In- och utströmningsområdenas rumsliga fördelning varierar med tiden, beroende på säsongs- och korttidsvariationer i de meteorologiska förhållandena. Det finns också permanenta in- och utströmningsområden. Som exempel utgör områden nära de största vattendragen och sjön Frisksjön permanenta utströmningsområden, medan högre belägna områden utgör permanenta inströmningsområden.

Det bör noteras att i den aktuella MIKE SHE-MIKE 11-modelleringen antas inget flöde ske över modellens bottenrand, som är belägen på nivån 150 meter under havsytan. Kopplingen mellan grundvatten i berg och grundvatten i jord bör studeras närmare, för att underlätta utvecklingen av integrerade flödes- och transportmodeller. Eftersom vattenflödet mellan jord och berg är litet jämfört med flödet i det ytliga/ytnära systemet, bedöms antagandet om nollflöde i berget vara rimligt för den aktuella analysens syften. De känslighetsanalyser som utförts som en del av Laxemar 1.2-modelleringen visar också att de vegetationsparametrar som används vid modelleringen av avdunstningsprocesserna i MIKE SHE kan ha stor inverkan på resultaten; eftersom dessa parametrar också kan betraktas som relativt osäkra, måste de studeras vidare i den fortsatta modelleringen.

Datafrysen Laxemar 1.2 innehåller en relativt liten mängd tidsseriedata, vilket begränsar möjligheterna att utveckla konceptuella och beskrivande modeller och att kalibrera kvantitativa flödesmodeller. Mer detaljerade analyser skulle kräva grundvattennivådata, och tillhörande meteorologiska och hydrologiska data, för en period av åtminstone ett (hydrologiskt) år. Detta innebär att sådana analyser måste skjutas upp till kommande modellversioner, när längre tidsserier kommer att finnas tillgängliga. Jämförelser mellan beräknings- och mätresultat (och modellkalibrering i allmänhet) kommer att utföras som del av kommande modellering. Vidare bör representativiteten för befintliga jordrör undersökas. Det är troligen en ojämn fördelning i befintliga data (dvs att rören inte är representativa för området som helhet), eftersom rören främst är installerade i de lägre belägna delarna av respektive avrinningsområde.

För flertalet typer av primärdata som används i den hydrologiska/hydrogeologiska modelleringen utgör datafrysen Laxemar 1.2 väsentligen den första tillgängliga datamängden som kan användas för att beskriva delområde Laxemar. Även om viktiga framsteg har gjorts i den konceptuella-beskrivande och den kvantitativa modelleringen, finns det ett stort behov av längre tidsserier för att förbättra modellerna; sådana data kommer också att bli tillgängliga framöver. Det skall dock noteras att större delen av de automatiska (och därmed detaljerade) grundvattennivåmätningar som för närvarande pågår inom delområde Laxemar har påbörjats under 2005, varför det kommer att dröja ett tag innan användbara (långa) tidsserier kommer fram från undersökningarna i Laxemar.

Framtida platsunderökningar förväntas inte ge väsentligt mer hydraulisk konduktivitetsdata eller annan information om de geologiska och hydrogeologiska egenskaperna i de kvartära avlagringarna. Huvuddelen av de planerade borrningarna och rörinstallationerna har utförts. De viktigaste undantagen är de undersökningar som nyligen utförts i ett antal transekt inom modellområdet (”typsektioner” i utvalda dalgångar) och de undersökningar som kommer att göras inom det område som prioriteras för det planerade förvaret. En detaljerad utvärdering av den befintliga databasen, ett arbete som syftar till att identifiera behovet av ytterligare undersökningar, utförs inom ramen för den pågående Laxemar 2.1-modelleringen.

Contents

1 Introduction

1.1 Background

The Swedish Nuclear Fuel and Waste Management Company (SKB) is conducting site investigations at two different locations, the Forsmark and Simpevarp areas, with the objective of siting a geological repository for spent nuclear fuel. The investigations are divided into an initial site investigation phase and a complete site investigation phase. The results of the present initial investigation phase will be used as a basis for deciding on the subsequent complete investigation phase, which, in turn, will provide the basis for the application for the licence required to build and operate the repository /SKB 2001/.

The results from the investigations at the sites are used as a basic input to the site descriptive modelling. A Site Descriptive Model (SDM) is an integrated description of the site and its regional setting, covering the current state of the geosphere and the biosphere as well as ongoing natural processes of importance for long-term safety. The SDM shall summarise the current state of knowledge of the site, and provide parameters and models to be used in further analyses within Safety Assessment, Repository Design and Environmental Impact Assessment.

The first steps of the site descriptive modelling have been taken with the version 1.1 and 1.2 models of the Simpevarp and Forsmark areas; the version 1.1 models are presented in /SKB 2004a/ (Simpevarp) and /SKB 2004b/ (Forsmark) and the version 1.2 models in /SKB 2005a/ (Simpevarp) and /SKB 2005b/ (Forsmark). The 1.2 models, which also include the present one (cf below), are the final model versions that will be presented in the initial site investigation stage.

Models are developed on a regional scale (hundreds of square kilometres) and on a local scale (tens of square kilometres). The Simpevarp regional model area contains two candidate areas, i.e. two subareas within which the more detailed investigations and modelling in the next investigation stage could be focused. These areas are referred to as the Simpevarp subarea and the Laxemar subarea, respectively, cf Figure 1-1.

This implies that two models are developed in the version 1.2 modelling of Simpevarp, such that the present Laxemar 1.2 model follows the previous model Simpevarp 1.2. At the end of the 1.2 modelling stage, an evaluation of the Simpevarp 1.2 and Laxemar 1.2 models will be performed and one of the subareas will be selected for further investigations during the complete site investigation.

Note, however, that this focusing has different implications for different types of investigations and modelling, as determined by the different “end users”. For surface hydrology and near-surface hydrogeology, which are strongly related to biosphere modelling in Safety Assessment and to Environmental Impact Assessment, also forthcoming models versions will to large extent deal with the regional model area. Furthermore, the modelling should consider subareas of specific interest for, e.g. radionuclide release, which likely to some extent will be located outside the subarea prioritised for geological investigations for the repository.

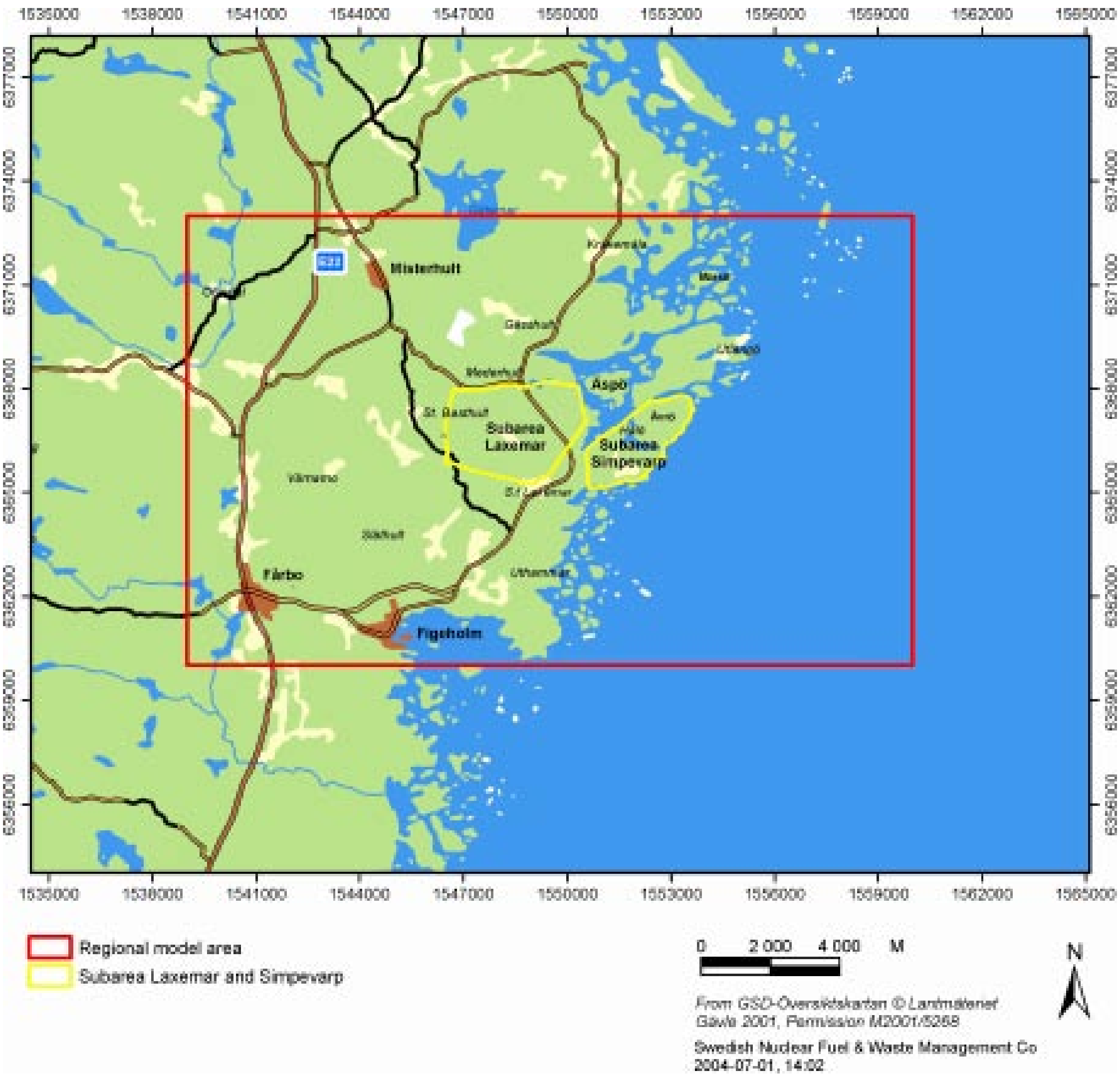

***Figure 1-1**. Overview of the Simpevarp area and identification of the Simpevarp and Laxemar subareas.*

1.2 Objectives and scope

The general objectives of the site descriptive modelling of the Simpevarp area and the specific objectives of the Laxemar 1.2 modelling are presented in /SKB 2006a/. The present report is a background report describing the modelling of climate, surface hydrology and near-surface hydrogeology in support of the Laxemar 1.2 model. Concerning these disciplines, it may be noted that they were not covered by background reports in the version 1.1 modelling. The available datasets were analysed and the results were integrated and described directly in the SDM reports. However, a background report corresponding to the present one was produced in the Simpevarp 1.2 modelling /Werner et al. 2005/.

The objectives of the modelling reported in the present document are to:

- analyse and present the data available in the Laxemar 1.2 dataset,
- update the conceptual-descriptive model presented in the previous Simpevarp 1.2 model version /SKB 2005a, Werner et al. 2005/,

- present the results of the quantitative water flow modelling, undertaken in order to develop the understanding of the site and to support the conceptual-descriptive modelling and the ecosystems modelling,
- summarise and present the results in the form of an updated site description.

As further described below, there was still a relatively small amount of site data (especially time series) available at the time for the Laxemar 1.2 "data freeze" (November 1, 2004). This implies that the work performed in the areas of data evaluation and, in particular, quantitative water flow modelling have been limited, as compared to the modelling effort that would be possible if longer time series of e.g. discharge and groundwater level measurements were available. It should also be noted that the Laxemar 1.2 data freeze has not been applied strictly as a last date for data import to the present work. In particular, the time series for presentation of meteorological parameters have been extended to June 2005. The motivation for using data from after the data freeze is that this type of data is crucial for the development of the conceptual-descriptive and quantitative water flow models of the site; since the available site-specific time series are very short, the basis for the modelling is considerably improved when a few additional months of measurements are utilised.

Thus, it is emphasised that although significant steps have been taken in the conceptual-descriptive and quantitative water flow modelling compared to the previous Simpevarp 1.1 and 1.2 models, there are still substantial uncertainties in the model description. The main reason for this is the limited amount of site investigation data (primarily time series). It should also be noted that for many types of site investigation data (e.g. the detailed map of Quarternary deposits and exposed bedrock, and groundwater levels in the Quaternary deposits), the Laxemar 1.2 data freeze is essentially the first batch of data available for the Laxemar subarea. This means that the present model version represents the first step in the development of site understanding and the quantification of parameter values for the Laxemar subarea.

A complete descriptive model of the hydrological and hydrogeological conditions at a site involves a description of the integrated (continuous) hydrogeological-hydrological system. This system includes groundwater in bedrock, groundwater in Quaternary deposits and surface waters, as well as the interactions with the atmospheric water (i.e. the processes contributing to the evapotranspiration). The focus of the present description is on the surface- and near-surface conditions. For instance, in the present report, models of the hydrogeological properties of the bedrock are used but not described in detail. Unless otherwise stated, the terms "hydrology" and "hydrogeology" refer to "surface hydrology" and "near-surface hydrogeology", respectively.

1.3 Setting

The Simpevarp area is located in the province of Småland (County of Kalmar), within the municipality of Oskarshamn, and immediately adjacent to the Oskarshamn nuclear power plant and the Central interim storage facility for spent fuel (Clab). The Simpevarp area (including the Simpevarp and Laxemar subareas) is located close to the shoreline of the Baltic Sea. The regional model area shown in Figure 1-1 covers approximately 273 km^2, extending from some distance into the sea in the east to west of the E22 highway in the western direction.

The easternmost land part of the regional area, the Simpevarp subarea, includes the Simpevarp peninsula, which hosts the nuclear power plant and Clab, and the islands Hålö and Ävrö. The island of Äspö, under which the Äspö Hard Rock Laboratory (Äspö HRL) is located, is situated some two kilometres north of the Simpevarp peninsula. The Laxemar subarea is located on the mainland, with a shoreline along the bays surrounding Äspö. The areal size of the Simpevarp subarea is approximately 6.6 km^2, whereas the Laxemar subarea covers some 12.5 km^2.

1.4 Methodology and organisation of work

1.4.1 Methodology

The methodology for the descriptive modelling of surface water hydrology and hydrogeology in the overburden was presented in the modelling strategy report for Hydrogeology /Rhén et al. 2003/. The strategy report describes the input data, the modelling process and the resulting descriptive model, based on a systems approach in which the descriptive model of the surface and near-surface system is presented as a set of Hydraulic Soil Domains (HSD). The HSD are to be specified in terms of geometry and hydrogeological parameters.

The description based on HSD provides a suitable framework for conveying the site modellers' interpretation of the site conditions, especially if the result is to be used as a basis for developing a hydrogeological model. However, other users may be interested in other aspects of the site descriptive modelling. In particular, the biosphere modelling within Safety Assessment uses "box models", which require input data on the water turnover in the various "biosphere objects" that are modelled. In these cases, the site descriptive modelling should provide spatial distributions of, e.g. the total discharge or specific components of the water balance, such that water turnover times can be calculated for arbitrary spatial objects. Furthermore, a descriptive model organised in terms of "hydrological elements" such as sub-catchments, with associated parameters, may be more relevant in some applications, and is also presented in this report. Other "hydrological elements" that are described include lakes, wetlands and watercourses.

The methodology used in the version 1.2 modelling work is illustrated in Figure 1-2. The data evaluation and modelling activities are carried out in a number of steps. In the first step, simply termed "Data evaluation" in the figure, each data type is evaluated and presented separately. The second step, "Surface hydrology integration" consists of an integration of the different types of hydrological data available. For example, correlations between time series of groundwater levels and precipitation could be studied (no such analyses were performed in the present Laxemar modelling).

In the "Integration and quantitative modelling" step, data and models from other modelling disciplines are included in the modelling. These inputs and integrations are required in order to develop descriptive models and quantitative flow models of the site. It should be noted that flow models and coupled models (models in which flow is coupled to other physical and/or chemical processes) are developed also by other modelling disciplines. Specifically, the surface system is part of the model domains considered in the modelling of groundwater flow in the deep rock (performed within HydroNet). Furthermore, coupled hydrogeological and hydrogeochemical modelling is performed within the framework of the hydrogeochemical modelling (ChemNet). In these cases, the interactions could imply deliveries of surface hydro(geo)logical data to the modellers, and feedback in the form of "import" of some of the results to the surface system description.

Whereas the interactions indicated in Figure 1-2 indeed have taken place in the form of inputs to the numerical flow modelling presented herein, feedbacks from the present modelling to those providing the inputs have been quite limited. Interactions (iterations) regarding, for instance, the hydraulic interface between rock and overburden, need to be further developed in future model versions.

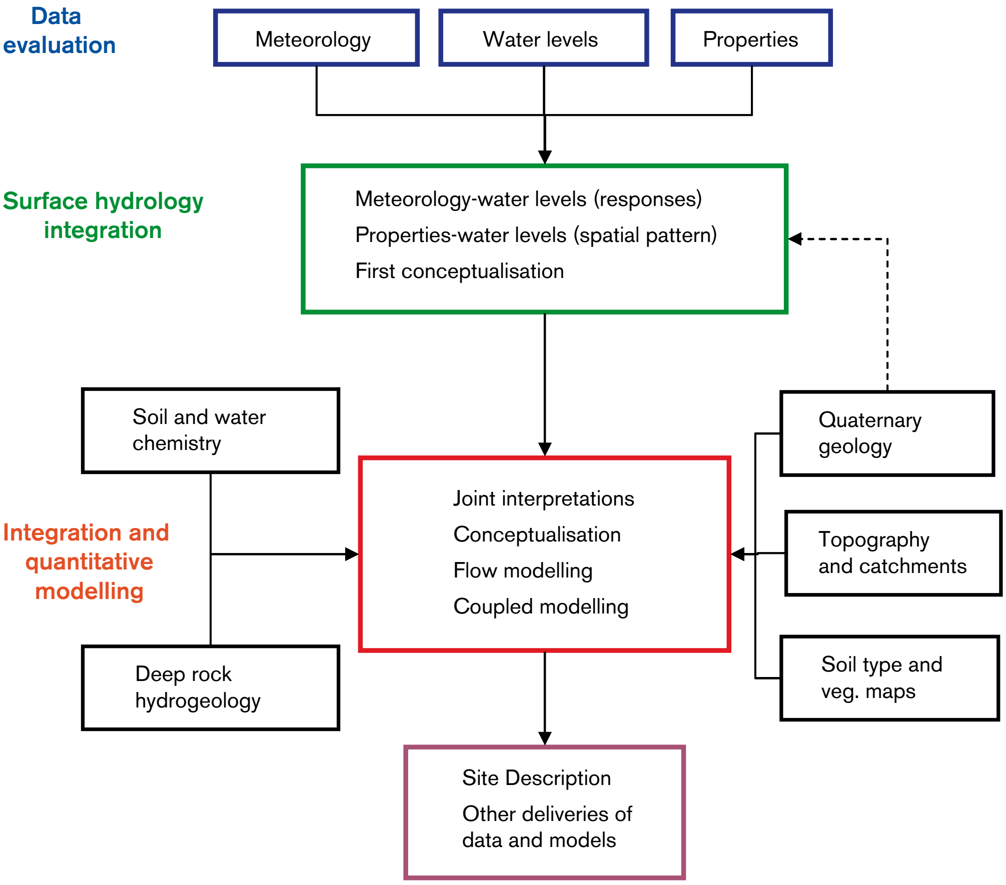

Figure 1-2. *Overview of the modelling process.*

1.4.2 Terminology

/Rhén et al. 2003/ establish the terminology to be used within the site descriptive hydrogeological modelling. Since the term "hydrology" often refers to all aspects of the hydrological cycle, i.e. atmospheric, surface and subsurface processes and subsystems, it should be noted that the following distinction is made between "hydrology" and "hydrogeology" in the data handling within SKB's site investigation programme:

- *Hydrology* refers to the surface water system only; hydrological data include water levels and flow rates in watercourses and lakes, and surface water divides and the associated catchments and subcatchments.
- *Hydrogeology* refers to the subsurface system, i.e. the groundwater, including the unsaturated and saturated parts of the subsurface; hydrogeological data include groundwater levels and hydraulic parameters for unsaturated and saturated groundwater flow.

Thus, the terminology is clear as far as the input data are concerned; hydrological data are obtained on the ground surface and in surface waters, and hydrogeological data from the subsurface, primarily from drillings and observation wells (soil sampling for analysis of hydraulic properties has also been made in pits and trenches).

The above distinction is made also within the site descriptive modelling /Rhén et al. 2003/. However, in some cases additional qualifiers are used; "surface hydrology" clarifies that the modelling is dealing with the surface part of the hydrological cycle, whereas "near-surface hydrogeology" or "hydrogeology in overburden/Quaternary deposits" is used when there is a need to distinguish the modelling from that focusing on the deep rock. Obviously, there is an overlap between "near-surface" and "deep rock" hydrogeological models, since they must incorporate components of each other in order to obtain an appropriate parameterization and identification of boundary conditions.

1.4.3 Organisation of work

The Laxemar 1.2 modelling of hydrology and hydrogeology within and related to the surface system has been performed as part of the SurfaceNet project. This project incorporates all site descriptive modelling of the surface system, i.e. both abiotic aspects such as hydrology and hydrogeology, and models of the biotic parts of the system. A project group with representatives for all the surface system modelling disciplines has been formed. Most disciplines have additional modellers associated with the project group.

The interactions with related modelling disciplines, primarily Hydrogeology and Hydrogeochemistry, have taken place both by informal contacts and discussions and by participation in project meetings with the HydroNet and ChemNet modelling teams. As indicated above, the results of these contacts reported in connection with the models presented are limited; the aim, given the recent initiation of SurfaceNet and the limited time and data available, has been to divide the responsibilities and identify the main issues to be dealt with in future modelling.

The SurfaceNet modelling for Laxemar 1.2 is reported in /Lindborg 2006/, which provides input to the Laxemar 1.2 SDM report /SKB 2006a/. Thus, the contents of the present background report is used as a basis for the corresponding parts of the SurfaceNet report, which are then summarised in the SDM report.

1.5 This report

The disposition of this report follows the overall disposition of the SDM reports: first data presentation and evaluation, followed by conceptual-descriptive and quantitative flow modelling, and then the resulting description. Specifically, Chapter 2 summarises the relevant available site investigation data and provides an overview of their usage, whereas Chapter 3 contains a presentation of the actual data in the form of figures and tables. The conceptual-descriptive and quantitative models are described in Chapter 4. Finally, the resulting site description is presented in Chapter 5.

2 Overview of site investigations and available data

2.1 Previous investigations

The site descriptive models (SDM) for the Simpevarp area version 0 /SKB 2002/, version 1.1 /SKB 2004a/ and version 1.2 /SKB 2005a/ are for simplicity in the following referred to as S0, S1.1 (data freeze July 1, 2003) and S1.2 (data freeze April 1, 2004), respectively. Correspondingly, the present site descriptive model, Laxemar version 1.2 (data freeze November 1, 2004), is abbreviated L1.2.

S0 was developed before the beginning of the site investigations in the Simpevarp area. It was therefore based on information from the feasibility study /SKB 2000/, selected sources of pre-existing data, and additional data collected and compiled during the preparatory work for the site investigations, especially related to the discipline "Surface ecosystems". S0 was regional in character, as local data were scarce in the official databases. The data inventory established in the S0 modelling work also served as a platform for prioritising analyses for the subsequent S1.1 modelling.

The investigations that provided the basis for S1.1 /SKB 2004a/ in terms of climate, surface hydrology, and near-surface hydrogeology included airborne photography, airborne and surface geophysical investigations, and mapping of Quaternary deposits. In addition, a few environmental monitoring boreholes were established in the overburden. The still very limited amount of site-specific data implied that also S1.1 was mostly based on regional and/or generic meteorological, hydrological and hydrogeological data.

The S1.2 data freeze (April 1, 2004) included site investigation (local) data from the following meteorological, surface hydrological and near-surface hydrogeological investigations:

- Establishment of a local meteorological station on Äspö.
- Delineation and description of catchment areas, watercourses and lakes.
- Establishment of hydrological stations for discharge measurements.
- Manual discharge measurements in watercourses.
- Drilling and slug tests of groundwater monitoring wells in Quaternary deposits (QD).
- Manual groundwater level measurements in wells in QD.

2.2 Meteorological, hydrological and hydrogeological investigations in Laxemar 1.2

Between the S1.2 (April 1, 2004) and L1.2 (November 1, 2004) data freezes, the meteorological, hydrological and hydrogeological investigations comprised the following main components:

- Additional time series from the meteorological station on Äspö.
- Establishment of a new meteorological station in Plittorp, located in the western part of the Simpevarp area c 10 km west of the station on Äspö.
- Establishment of new hydrological stations for discharge measurements.
- Surveying of the main watercourses in catchment areas 6, 7 and 9.
- Continued manual discharge measurements in watercourses.
- Drilling and additional slug tests of groundwater monitoring wells in QD in Laxemar.
- Continued manual groundwater level measurements in wells in QD.
- Installation of equipment for automatic measurements of groundwater levels in wells in QD.

These investigations and the generated data are summarised in Section 2.4. Unless otherwise stated, all site investigation data and other data used in the report are taken from SKB's SICADA and GIS databases.

2.3 Other investigations providing input data

In addition to the investigations listed in Section 2.2, the modelling in L1.2 is based on other data from the official SKB SICADA and GIS databases, and additional data used and/or listed in the S0, S1.1, and S1.2 SDM reports /SKB 2002, 2004a, 2005a/. In particular, the following SKB databases are used in the L1.2 modelling:

- Topographical and other geometrical data.
- Data from surface-based geological investigations.
- Data from investigations in boreholes in QD.
- Data on the hydrogeological properties of the bedrock.
- Land use (vegetation) data.

2.4 Summary of available data

Table 2-1 provides references to site investigation reports and other reports that contain meteorological, hydrological and hydrogeological data used in the L1.2 modelling. Further, Table 2-2 provides the corresponding information with respect to other disciplines or types of investigations. Finally, Table 2-3 specifies the SKB reports referred to in Table 2-1 and 2-2. Note that these tables also include references associated with the previous model versions (S0, S1.1, and S1.2), such that they provide a cumulative account of the site data used to date.

Table 2-1. Available meteorological, hydrological and hydrogeological data and their handling in L1.2.

Available site data, data specification	Ref.	Usage in L1.2 analysis/modelling	Cf section
Meteorological data			
Regional Version 0 data			
"Regional" meteorological data prior to the site investigations.	TR-02-03 R-99-70	Description of "regional" meteorological conditions.	3.1
Site Investigation data			
Meteorological data from Äspö (Sept. 2003–June 2005 and Plittorp (July 2004–June 2005).	P-05-227	Comparison with "regional" meteorological data. Input to quantitative water flow modelling (MIKE SHE).	3.1, 4.2
Hydrological data			
Regional Version 0 data			
"Regional" discharge data prior to the site investigations.	TR-02-03 R-99-70	Description of "regional" hydrological conditions (e.g. average regional specific discharge).	3.2
Site Investigation data			
Investigation of potential locations for hydrological stations.	P-03-04	Size of catchment areas for manual and automatic discharge measurements.	3.2
Geometric data on catchment areas, lakes and watercourses.	P-04-242	Delineation and characteristics of catchment areas, lakes, and watercourses. Input to quantitative water flow modelling (MIKE SHE).	3.2, 4.2
Manual discharge measurements in watercourses.	P-04-13 P-04-75 P-04-246	Description of spatial and temporal variability of discharge.	3.2
Surface water levels in lakes and the sea.	P-05-227	Description of spatial and temporal variability of surface water levels.	3.2
Surveying of watercourses in catchment areas 6–9.	P-06-05	Input to quantitative water flow modelling (MIKE 11).	4.2
Characterisation of running waters, including vegetation, substrate and technical encroachments.	P-05-40	Identification of "missing" (parts of) watercourses. Interpretation of discrepancies between actual and model-calculated "flooded" areas.	3.2, 4.3
Discrepancies between actual watercourses and watercourses in the SKB GIS database.	P-05-70	Identification of "missing" (parts of) watercourses. Interpretation of discrepancies between actual and model-calculated "flooded" areas.	3.2, 4.3
Hydrogeological data			
Inventory of private wells.	P-03-05	General description of available hydrogeological information.	3.4
Manually measured groundwater levels in QD.	P-05-205	Description of spatial and temporal variability of groundwater levels in QD.	3.3
Automatically measured groundwater levels in QD.	P-05-205	Description of spatial and temporal variability of groundwater levels in QD.	3.3
Geological data from drilling in QD and installation of groundwater monitoring wells.	P-03-80 P-04-46 P-04-121 P-04-317 P-05-167	Conceptual-descriptive model of HSD geometry.	4.1
Hydraulic conductivity from slug tests in groundwater monitoring wells in QD.	P-04-122 P-04-318	Conceptual-descriptive modelling of hydraulic conductivity in QD.	4.1
Hydrogeological inventory in the Oskarshamn area.	P-04-277	General description of ditching, draining and other water-related activities in the Simpevarp area.	3.4

Table 2-2. Input data from other disciplines and their handling in L1.2.

Available site data, data specification	Ref.	Usage in L1.2 analysis/modelling	Cf section
Geometrical and topographical data			
Digital Elevation Model (DEM).	P-04-03 R-05-38	Input to quantitative water flow modelling (MIKE SHE).	4.2
Geometrical model of depth and stratigraphy of QD in the Simpevarp area.	R-05-54	Conceptual-descriptive model of HSD geometry. Input to quantitative water flow modelling (MIKE SHE).	4.1.2
Surface-based geological data			
Soil type investigation.	R-05-15 P-04-243	General description of QD.	4.1
Geological mapping of Quaternary deposits.	P-04-22 P-05-47 P-05-49	Conceptual-descriptive model of HSD geometry and properties. Input to quantitative water flow modelling (MIKE SHE).	4.1.2
Airborne geophysical data.	P-03-17 P-03-100	Data are used to construct the QD map, which is used in the conceptual-descriptive and quantitative water flow modellling.	4.1.2
Investigation of sediments, peat lands and wetlands.	P-04-273	Characterisation of QD at bottom of lakes, wetlands, and peat areas.	3.2, 4.1
Geological data from boreholes and bedrock data			
Drilling and sampling in Quaternary deposits.	P-03-80 P-04-46 P-04-121 P-04-317	Conceptual-descriptive model of HSD geometry and properties.	4.1
Bedrock hydrogeological properties and calculated groundwater head.	R-05-08 R-05-11	Hydrogeological bedrock properties and calculated groundwater head from the S1.2 DarcyTools modelling are used in the quantitative water flow modelling (MIKE SHE).	4.2
Vegetation data			
Vegetation map.	P-03-83 P-04-20	Input to quantitative water flow modelling (MIKE SHE).	4.2
Water chemistry data			
Evaluation, visualisation and statistical analysis of chemical data from surface water, precipitation, shallow groundwater, and regolith.	R-06-12 R-06-18	Interpretation of water flow systems.	4.4

Table 2-3. Reports in the SKB series P, R and TR that are referred to in Tables 2-1 and 2-2.

P-03-04	**Lärke A, Hillgren R.** Rekognocering av mätplatser för ythydrogeologiska mätningar i Simpevarpsområdet.
P-03-05	**Morosini M och Hultgren H.** Inventering av privata brunnar i Simpevarpsområdet, 2001–2002.
P-03-17	**Thunehed H, Pitkänen T.** Simpevarp site investigation. Electrical soundings supporting inversion of helicopterborne EM-data. Primary data and interpretation report.
P-03-80	**Ask H.** Oskarshamn site investigation. Installation of four monitoring wells, SSM000001, SSM000002, SSM000004 and SSM000005 in the Simpevarp subarea.
P-03-83	**Boresjö Bronge L, Wester K.** Vegetation mapping with satellite data from the Forsmark, Tierp and Oskarshamn regions.
P-03-100	**Triumf C-A, Thunehed H, Kero L, Persson L.** Oskarshamn site investigation. Interpretation of airborne geophysical survey data. Helicopter borne survey data of gamma ray spectrometry, magnetics and EM from 2002 and fixed wing airborne survey data of the VLF-field from 1986.
P-04-03	**Brydsten L.** A method for construction of digital elevation models for site investigation programs in Forsmark and Simpevarp.
P-04-13	**Ericsson U, Engdahl, A.** Oskarshamn site investigation. Surface water sampling at Simpevarp 2002–2003.
P-04-14	**Ericsson U.** Oskarshamn site investigation. Sampling of precipitation at Äspö 2003. Äspö sampling site.
P-04-20	**Andersson, J.** Oskarshamn site investigation. Vegetation inventory in part of the municipality of Oskarshamn.
P-04-22	**Rudmark L.** Oskarshamn site investigation. Investigation of Quaternary deposits at Simpevarp peninsula and the islands of Ävrö and Hålö.
P-04-46	**Ask H.** Oskarshamn site investigation. Drilling and installation of two monitoring wells, SSM000006 and SSM000007 in the Simpevarp subarea.
P-04-75	**Ericsson U, Engdahl A.** Oskarshamn site investigation. Surface water sampling in Oskarshamn – Subreport October 2003 to February 2004.
P-04-121	**Johansson T, Adestam L.** Oskarshamn site investigation. Drilling and sampling in soil. Installation of groundwater monitoring wells.
P-04-122	**Johansson T, Adestam L.** Oskarshamn site investigation. Slug tests in groundwater monitoring wells in soil in the Simpevarp area.
P-04-242	**Brunberg A-K, Carlsson T, Brydsten L, Strömgren M.** Oskarshamn site investigation. Identification of catchments, lake-related drainage parameters and lake habitats.
P-04-243	**Lundin L, Björkvald L, Hansson J, Stendahl J.** Oskarshamn site investigation. Surveillance of soils and site types in the Oskarshamn area.
P-04-246	**Morosini M, Lindell L.** Oskarshamn site investigation. Compilation of measurements from manually gauged hydrological stations, October 2002–March 2004.
P-04-273	**Nilsson G.** Oskarshamn site investigation. Investigation of sediments, peat lands and wetlands. Stratigraphical and analytical data.
P-04-277	**Nyborg M, Vestin E, Wilén P.** Oskarshamn site investigation. Hydrogeological inventory in the Oskarshamn area.
P-04-317	**Johansson T, Adestam L.** Oskarshamn site investigation. Drilling and sampling in soil. Installation of groundwater monitoring wells in the Laxemar area.
P-04-318	**Johansson T, Adestam L.** Oskarshamn site investigation. Slug tests in groundwater monitoring wells in soil in the Laxemar area.
P-05-40	**Carlsson T, Brunberg A-K, Brysten L, Strömgren M.** Oskarshamn site investigation. Characterisation of running waters, including vegetation, substrate and technical encroachments.
P-05-47	**Bergman T, Malmberg-Persson K, Persson M, Albrecht J.** Oskarshamn site investigation. Characterisation of bedrock and Quaternary deposits from excavations in the southern part of Laxemar subarea.
P-05-49	**Rudmark L, Malmberg-Persson K, Mikko H.** Oskarshamn site investigation. Investigation of Quaternary deposits 2003–2004.
P-05-70	**Svensson J.** Platsundersökning Oskarshamn. Fältundersökning av diskrepanser gällande vattendrag i GIS-modellen (in Swedish).
P-05-167	**Henrik A, Morosini M, Samuelsson L-E, Ekström L, Håkanson N.** Oskarshamn site investigation. Drilling of cored borehole KLX03.

P-05-205	**Nyberg G, Wass E, Askling P.** Oskarshamn site investigation. Groundwater Monitoring Program. Report for December 2002–October 2004.
P-05-227	**Lärke A, Wern L, Jones J.** Oskarshamn site investigation. Hydrological and meteorological monitoring at Oskarshamn during 2003–2004.
P-06-05	**Strömgren M, Brydsten L, Lindgren F.** Oskarshamn site investigation. Measurements of brook gradients.
R-99-70	**Lindell S, Ambjörn C, Juhlin B, Larsson-McCann S, Lindquist K.** Available climatological and oceanographical data for site investigation program.
R-05-08	**SKB, 2005.** Preliminary site description. Simpevarp subarea – version 1.2.
R-05-11	**Follin S, Stigsson M, Svensson U.** Variable-density groundwater flow simulations and particle tracking – Numerical modelling using DarcyTools.
R-05-15	**Lundin L, Lode E, Stendahl J, Björkvald L, Hansson J.** Oskarshamn site investigation. Soils and site types in the Oskarshamn area.
R-05-38	**Brydsten L, Strömgren M.** Digital elevation models for site investigation programme in Oskarshamn. Site description version 1.2.
R-05-54	**Nyman H.** Depth and stratigraphy of Quaternary deposits in the Simpevarp area. An application of the GeoEditor modelling tool.
R-06-12	**SKB, 2006.** Hydrogeochemical evaluation. Preliminary site description Laxemar subarea – version 1.2.
R-06-18	**Tröjbom M, Söderbäck B.** Chemical characteristics of surface systems in the Simpevarp area. Visualisation and statistical evaluation of data from surface water, precipitation, shallow groundwater, and regolith.
TR-02-03	**Larsson-McCann S, Karlsson A, Nord M, Sjögren J, Johansson L, Ivarsson M, Kindell S.** Meteorological, hydrological and oceanograpical data for the site investigation program in the community of Oskarshamn.

3 Presentation and evaluation of site investigation data

3.1 Meteorological data

The meteorological conditions in the region where the Simpevarp area is situated are described by /Lindell et al. 1999, Larsson-McCann et al. 2002/. They list meteorological stations of interest for describing the conditions in the region, and present long-term statistics for selected meteorological stations considered representative for different meteorological parameters. For the S0 and S1.1 model versions, meteorological data were available from relatively distant meteorological stations only, operated by SMHI (the Swedish Meteorological and Hydrological Institute), Vägverket (the Swedish National Road Administration), and, for some meteorological parameters, OKG (the company operating the nuclear power plant at Simpevarp). Furthermore, since the data compilation was made in connection with the development of the S0 model, it contains data from the period prior to the site investigations only.

During the autumn of 2003, a local meteorological station was established by SKB on the northern part of the island of Äspö. For the S1.2 model version, meteorological data were available for a one-year period (September 2003 to September 2004) from this station. Another meteorological station was established during July 2004 in Plittorp, located in the western part of the Simpevarp regional model area, c 10 km west of the station on Äspö. For the present model version, additional time series (up to the end of June 2005) are available from the Äspö station, and time series (from mid July 2004 up to the end of June 2005) are available from the station in Plittorp. Furthermore, snow depth, soil freezing and ice cover are measured in the Laxemar subarea, in three of the inner bays of the Baltic, and in Lake Jämsen. However, these data have not been used in the present modelling and are therefore not further discussed here.

Figure 3-1 shows the locations of the "regional" meteorological stations around the Simpevarp area /Larsson-McCann et al. 2002/. The figure also shows the locations of the local meteorological stations (Äspö and Plittorp). As explained below, some of the "regional" stations provide only limited datasets, in terms of the parameters measured and/or the time period during the year when measurements are being performed.

In order to characterize the meteorological conditions in the region around Simpevarp, Section 3.1.1 summarises some basic meteorological information and data provided by /Larsson-McCann et al. 2002/. Section 3.1.2 presents meteorological data from the two local meteorological stations on Äspö and in Plittorp. As the "regional" SMHI stations have been in operation for a relatively long time, they provide a good basis for a description of the (regional scale) long-term average meteorological conditions. On the other hand, the stations on Äspö and in Plittorp can for obvious reasons be regarded as more relevant for the local meteorological conditions in the Simpevarp area, and hence as a better basis for the site descriptive modelling. However, data from these stations are so far only available for a period of c 2 years (Äspö) and 1 year (Plittorp), respectively. Therefore, for some selected meteorological parameters, Section 3.1.2 also includes a comparison of local data and data from three of the "regional" SMHI meteorological stations.

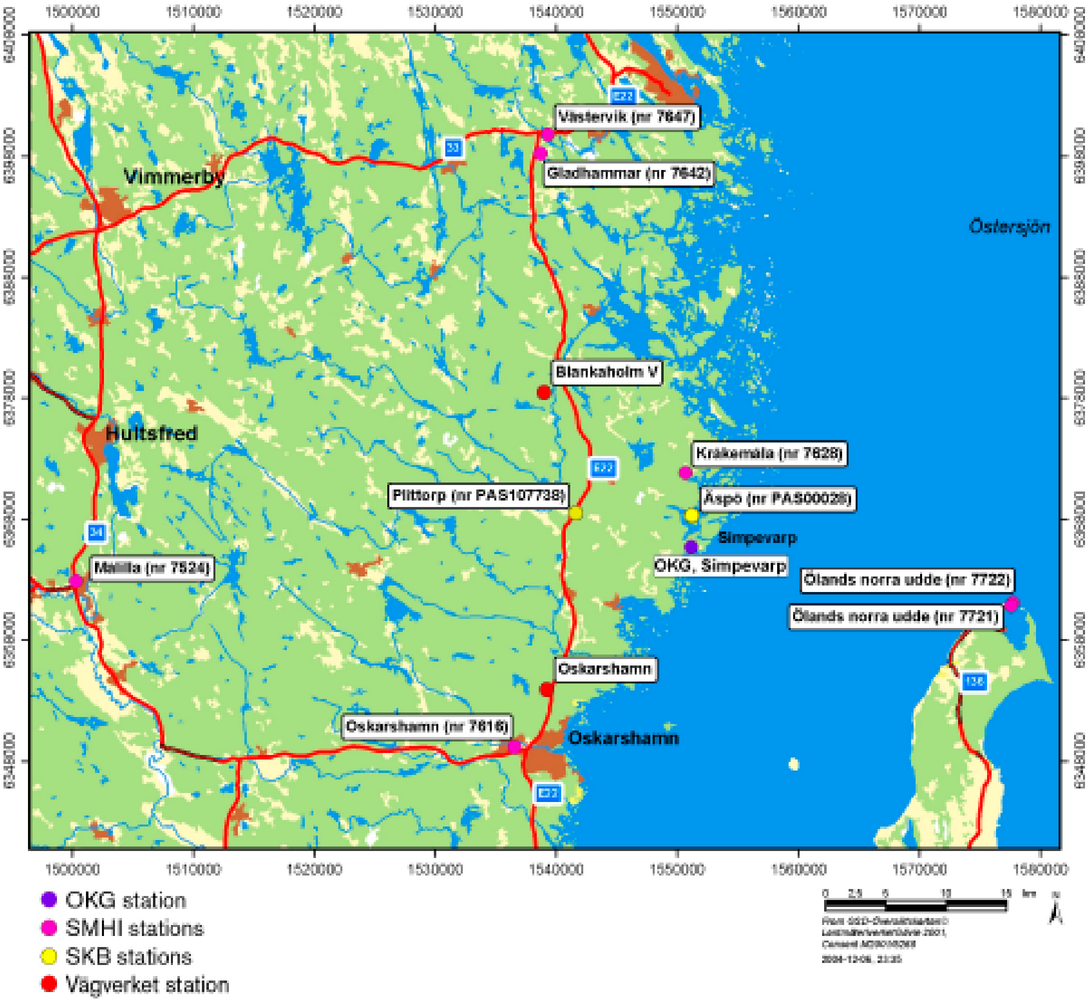

***Figure 3-1.** Local meteorological stations installed as a part of the site investigation (ID PASxxxxxx) and other local and regional stations (various operators) within and around the Simpevarp area.*

3.1.1 Regional data

The meteorological stations in the region around the Simpevarp area are listed in Table 3-1. "Reference station" in the table implies that the meteorological station is considered to be the most suitable for describing the long-term average meteorological conditions in the Simpevarp area for that particular parameter, based on the selection made in /Larsson-McCann et al. 2002/.

The following sections provide a brief description of the meteorological parameters considered most relevant for hydrological and hydrogeological modelling. The sections also give some basic meteorological information and data provided by /Larsson-McCann et al. 2002/, relevant for the long-term average meteorological conditions in the region around Simpevarp.

Table 3-1. Meteorological stations[1] and data of interest for the region around Simpevarp /Larsson-McCann et al. 2002/.

Station no. (cf Figure 3-1)	Station name	Period	Comments[5]
7722	Ölands norra udde	1880–1995	
7721	Ölands norra udde A	1996–	"Reference station" for relative humidity, air pressure, global radion and wind; one of three "reference stations" for potential evapotranspiration
7616	Oskarshamn	1918–	"Reference station" for air temperature and precipitation; only these two parameters are measured at the station
7628	Kråkemåla	1990–	Only precipitation is measured at the station
7524	Målilla	1931–	One of three "reference stations" for potential evapotranspiration
7647	Västervik	1951–1995	
7642	Gladhammar A	1995–	One of three "reference stations" for potential evapotranspiration
823	Blankaholm V[2]	1990–	
822	Oskarshamn[3]	1990–	
	OKG, Simpevarp[4]	1971–	

[1] Parameters: Temperature, precipitation, relative humidity, air pressure, and wind (direction and speed).
[2] Vägverket station, not stored in SMHI´s database. Operates during winter only.
[3] Vägverket station, not stored in SMHI´s database. Operates during winter and summer only.
[4] OKG meteorological station at the Simpevarp peninsula. Measures wind speed and direction at 25 and 100 m above ground, temperature at 2 m above ground, temperature difference between 2 and 70 m, and 2 and 100 m above ground. Data available for the period 1996–2000.
[5] "Reference station" refers to meteorological stations selected in /Larsson-McCann et al. 2002/.

Precipitation

First, it should be pointed out that the precipitation collected (measured) in manual or automatic rain gauges is always smaller than the actual precipitation. This error is due to losses from wind, evaporation and adhesion. In particular, wind losses are large when the precipitation is in the form of snow. Hence, in order to obtain a representative value of the actual precipitation at a meteorological station, some sort of correction for these losses must be made. Unless otherwise stated, "precipitation" in this report always refers to the actual (corrected) precipitation, not the measured (uncorrected) one. However, it should also be noted that this correction is a source of uncertainty in the hydrological modelling.

According to /Larsson-McCann 2002/, the correction factor to be used in order to obtain the actual precipitation from the measured precipitation is c 1.15 on an annual basis for the SMHI station in Oskarshamn. On a monthly basis, the correction factor varies between 1.089 (in September and October) and 1.277 (in January). The average annual (note: corrected) precipitation at the SMHI station in Oskarshamn is 633 mm for the standard normal period 1961–1990, and 645 and 681 mm for the periods 1961–2000 and 1991–2000, respectively. About 20% of the annual precipitation falls in the form of snow.

In the region, there is a tendency of higher precipitation in inland areas, compared to areas closer to the coast. The average monthly and annual precipitation values at Oskarshamn are shown in Figure 3-2 and Figure 3-3. For comparison, monthly and annual average values of the precipitation for the standard normal period 1961–1990 are shown in Table 3-2 for the meteorological stations in Oskarshamn, Ölands norra udde (situated on the northern cape of the island of Öland), and Målilla. These data clearly demonstrate that the smallest precipitation is recorded on the island of Öland. The precipitation is also somewhat larger at the inland location (Målilla) than on the coast (Oskarshamn).

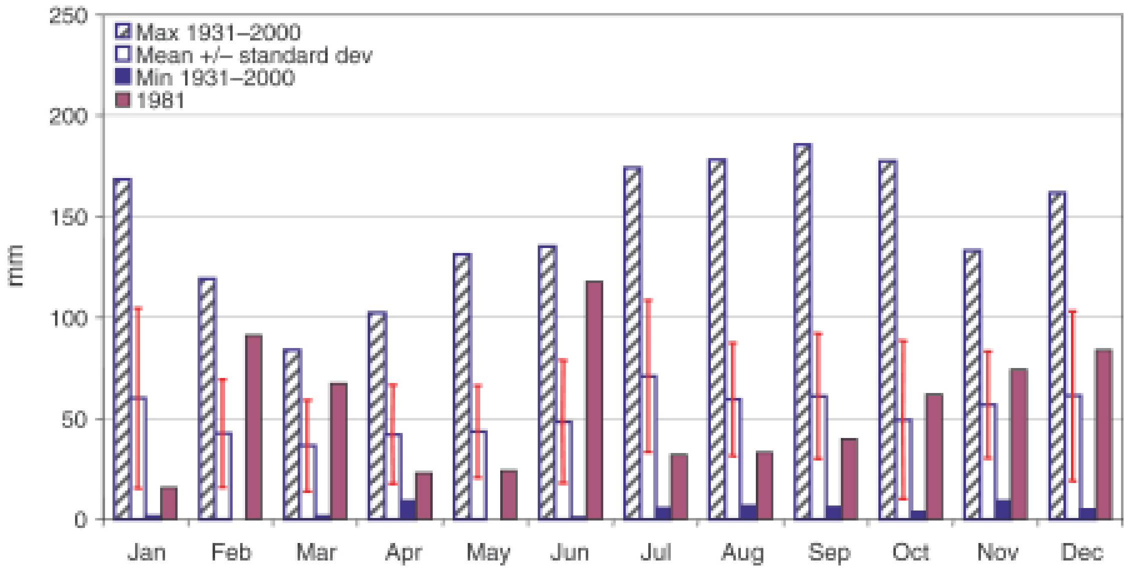

Figure 3-2. *Mean ± 1 standard deviation (vertical lines) of the monthly precipitation for the standard normal period 1961–1990 for the SMHI meteorological station Oskarshamn. The figure also shows extreme (max and min) values for the period 1931–2000 for the same station. The red bars show monthly values for the "representative year" 1981 /Larsson-McCann et al. 2002/; see explanation in the text.*

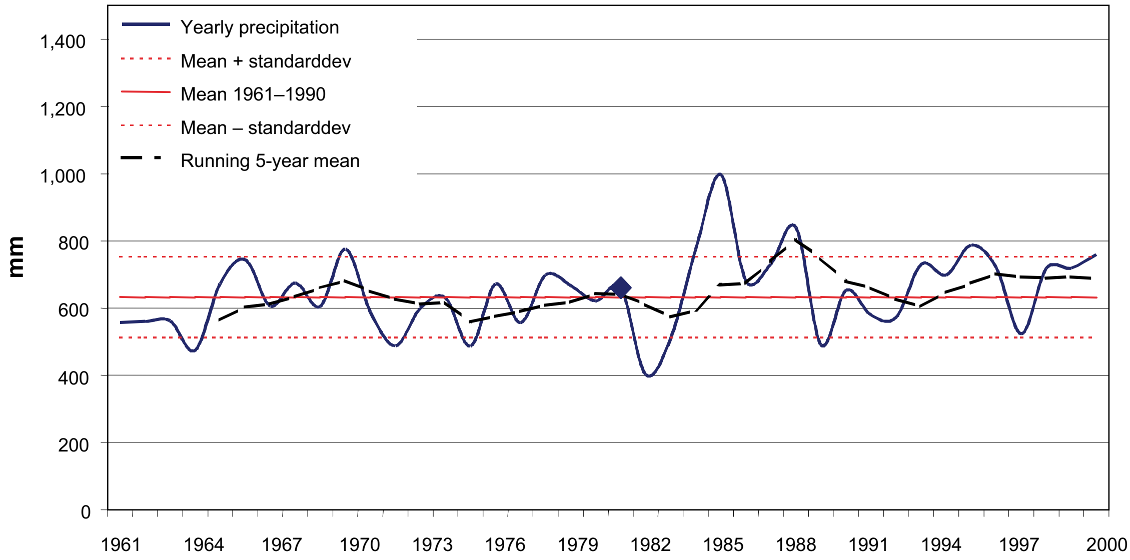

Figure 3-3. *5-year running averages of the annual precipitation, and average annual precipitation, for the standard normal period 1961–1990 for the SMHI meteorological station Oskarshamn. Dashed lines show ± 1 standard deviation from the mean /Larsson-McCann et al. 2002/.*

Table 3-2. Monthly and annual average actual precipitation (mm) for the standard normal period 1961–1990 and the "representative year" 1981 for SMHI's meteorological stations in Oskarshamn, Ölands norra udde and Målilla /Larsson-McCann et al. 2002/.

Month	Oskarshamn	Ölands norra udde	Målilla
January	60	46	55
February	43	31	42
March	36	31	40
April	42	29	41
May	44	37	50
June	48	38	56
July	71	47	72
August	60	54	68
September	61	61	67
October	49	45	53
November	57	58	58
December	61	53	64
Year	633	530	665
"Representative year" 1981	660	578	763

In /Larsson-McCann 2002/, the year 1981 was chosen as a "representative year", i.e. a year during which the values of monthly and annual precipitation are closest to the monthly and annual averages for the standard normal period 1961–1990. The parameters precipitation and air temperature were considered most important for the selection of the representative year. However, it was also considered important that as many of the meteorological parameters as possible are measured at the same meteorological station. Based on these considerations, the meteorological station at Ölands norra udde was chosen; the station in Oskarshamn only measures precipitation and air temperature (see Table 3-1). Meteorological data, with a high temporal resolution (daily values), from Ölands norra udde during the representative year 1981 were used in the S1.2 modelling /Werner et al. 2005/.

As mentioned above, there is a tendency of higher precipitation in inland areas, compared to areas closer to the coast. Table 3-2 shows that the average annual precipitation (and also the precipitation during the representative year 1981) at Ölands norra udde is about 100 mm less than at Oskarshamn. Hence, the use of precipitation data from Ölands norra udde in the Simpevarp modelling may imply an underestimation of the actual precipitation in the Simpevarp area. In the present L1.2 modelling, local meteorological data from Äspö are used, which were not available in the previous S1.2 modelling.

Potential evapotranspiration

Potential evapotranspiration is a calculated parameter, which gives a measure of the ability of the atmosphere to remove water from the land surface. The term "potential" indicates that no shortage of water is assumed for the evapotranspiration process. The potential evapotranspiration can be used to calculate the actual evapotranspiration, which depends also on the actual water availability at the land surface. To calculate the actual evapotranspiration, one must therefore also consider factors such as land use, vegetation, soil type, and depth to the groundwater table.

The potential evapotranspiration for the meteorological stations Ölands norra udde, Målilla and Västervik/Gladhammar has been calculated by SMHI, using the Penman formula. Input data to the Penman formula are global radiation, air temperature, air humidity, and wind speed. This formula provides a realistic estimate of the potential evapotranspiration from grass surfaces and short crops /Larsson-McCann et al. 2002/. The monthly potential evapotranspiration for Västervik/Gladhammar is shown in Figure 3-4. Monthly and annual values of the potential evapotranspiration for the standard normal period 1961–1990 are shown in Table 3-3, comparing the meteorological stations Ölands norra udde (note: period 1963–1990), Målilla and Västervik/Gladhammar.

Table 3-3. Monthly and annual average potential evapotranspiration (mm) for the standard normal period 1961–1990 and the "representative year" (1981) for SMHI's meteorological stations at Ölands norra udde, Målilla, and Västervik/Gladhammar /Larsson-McCann et al. 2002/.

Month	Ölands norra udde[1]	Målilla	Västervik/Gladhammar
January	10	1	2
February	14	5	7
March	26	17	20
April	47	43	45
May	84	83	83
June	110	102	106
July	112	98	102
August	88	73	77
September	53	36	40
October	24	11	13
November	11	1	2
December	7	0 (–1)	0
Year	**587** (sum of monthly averages: 586)	**468** (sum of monthly averages: 470)	**458** (sum of monthly averages: 470)
Representative year (1981)	**556**	**458**	**488**

[1] The averages are calculated for the period 1963–1990 (i.e. not the standard normal period 1961–1990).

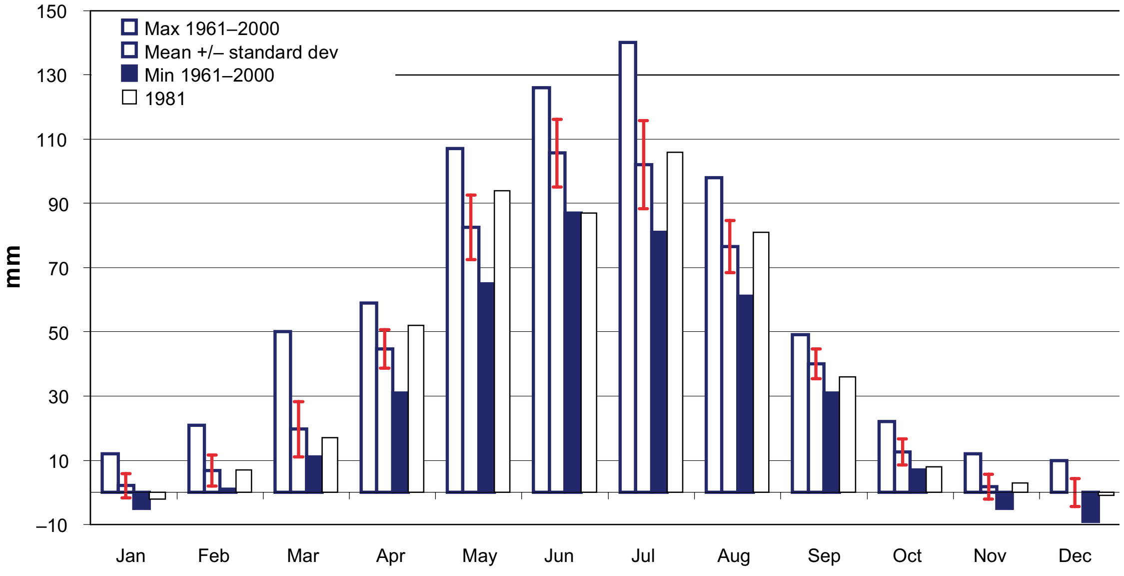

Figure 3-4. *Mean ± 1 standard deviation (vertical lines) of the monthly potential evapotranspiration for the standard normal period 1961–1990 for the SMHI meteorological station Västervik/ Gladhammar. Unfilled bars to the right in each group of bars show monthly values for the selected representative year 1981 /Larsson-McCann et al. 2002/.*

Note that the potential evapotranspiration has not been calculated for the station in Oskarshamn, as the parameters global radiation, air humidity and wind speed (required in calculations with the Penman formula) are not measured at that station. It can also be seen in Table 3-3 that there are deviations between the sums of the monthly average values and the annual sums. The reason for these deviations is that missing data are not included in the calculation of monthly averages, and that the average monthly mean is used instead of actual data for months with missing data /Larsson-McCann et al. 2002/.

Table 3-3 shows that the average annual potential evapotranspiration (and also the accumulated potential evapotranspiration during the representative year 1981) at Ölands norra udde is more than 100 mm larger than at the other stations. The main reasons for this are probably higher air temperatures and stronger winds at Ölands norra udde, as compared to the other locations (cf below). Hence, the use of potential evapotranspiration data from Ölands norra udde in the Simpevarp modelling may lead to an overestimation of this parameter in the Simpevarp area. In addition, as shown in Table 3-2, the annual precipitation is on the average c 100 mm less at the Ölands norra udde station than at the station in Oskarshamn. As previously mentioned, site investigation meteorological data from Äspö are used in the present L1.2 modelling. Such data were not available in the previous S1.2 modelling, where data on potential evapotranspiration from Ölands norra udde was used.

Air temperature

The "reference station" for air temperature is the SMHI meteorological station Oskarshamn. The average monthly air temperature varies between –2°C in January–February and 16–17°C in July (Figure 3-5). The winters are slightly milder on the coast than inland; the average annual temperature at Ölands norra udde is about 2°C higher than at the more inland stations Oskarshamn and Målilla. The vegetative period (daily average temperature exceeding 5°C) is about 200 days. For comparative purposes, monthly and annual averages of the air temperature for the standard normal period 1961–1990 are shown in Table 3-4 for the meteorological stations Oskarshamn, Ölands norra udde and Målilla.

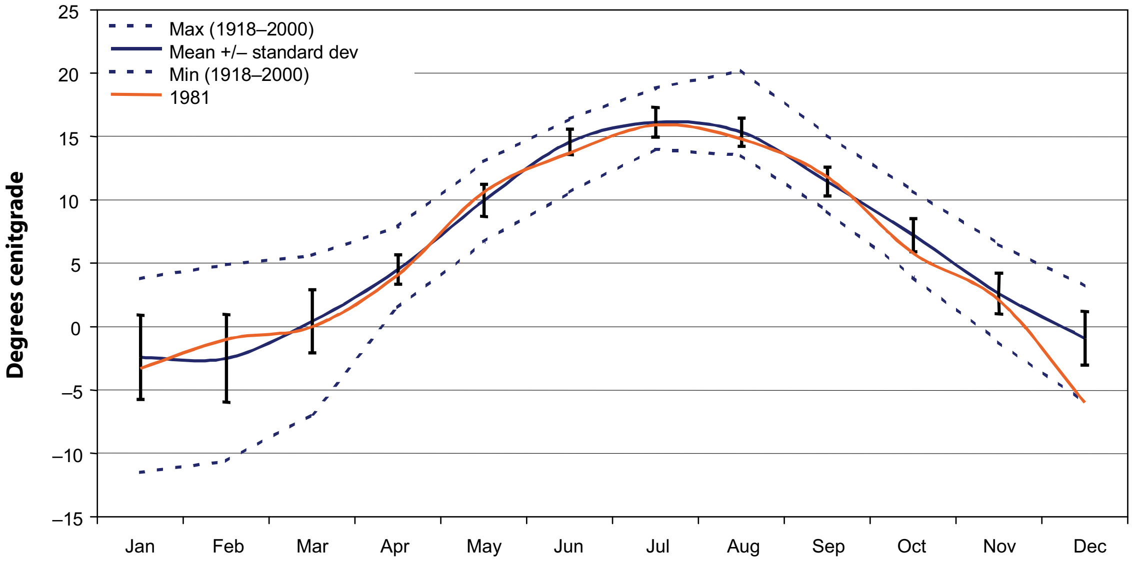

Figure 3-5. *Mean ± 1 standard deviation (vertical lines) of the monthly air temperature for the standard normal period 1961–1990 for the SMHI meteorological station Oskarshamn. Dashed lines show maximum and minimum of the monthly average air temperatures. The red line shows the monthly averages for the representative year 1981 /Larsson-McCann et al. 2002/.*

Table 3-4. Monthly and annual average air temperature (°C) for the standard normal period 1961–1990 and the "representative year" (1981) for the meteorological stations Oskarshamn, Ölands norra udde and Målilla /Larsson-McCann et al. 2002/.

Month	Oskarshamn	Ölands norra udde	Målilla
January	–2.4	–0.3	–3.2
February	–2.5	–1.1	–3.1
March	0.4	0.9	0.1
April	4.5	3.9	4.6
May	9.9	8.6	10.2
June	14.6	14.1	14.7
July	16.1	16.7	15.9
August	15.3	16.5	15.0
September	11.4	12.9	11.0
October	7.2	8.9	6.8
November	2.6	4.6	2.0
December	–0.9	1.4	–1.7
Annual average	**6.4**	**7.3**	**6.0**
Representative year (1981)	**5.7**	**6.9**	**5.5**

Table 3-4 shows that the average annual air temperature (and also the air temperature during the "representative year" 1981) at Ölands norra udde is somewhat higher than that measured in Oskarshamn, which, in turn, is somewhat higher than the average temperature in Målilla. Even though the potential evapotranspiration is not calculated for the station in Oskarshamn, this difference in air temperature between these two stations may imply that the average potential evapotranspiration is in fact smaller in Oskarshamn, compared to Ölands norra udde (cf the section on the potential evapotranspiration above).

Wind

The "reference station" for wind selected by /Larsson-McCann et al. 2002/ is the SMHI meteorological station Ölands norra udde. A wind rose is shown in Figure 3-6. The most frequent wind directions for this station are west and south-west, with some local and regional deviations. Compared to the west coast of Sweden, the conditions are somewhat less maritime on the east coast, where Simpevarp is located. This means that the differences between coastal sites and their inland neighbourhood generally are less pronounced in the Simpevarp area. However, locations near the coast are still far more exposed to strong winds than inland sites.

As the Simpevarp area to a large extent is forested, the heavy wind exposure close to the sea diminishes considerably only a few kilometres inland. Within the site investigations in Simpevarp, local meteorological wind data are obtained from one coastal (Äspö) and one inland station (Plittorp).

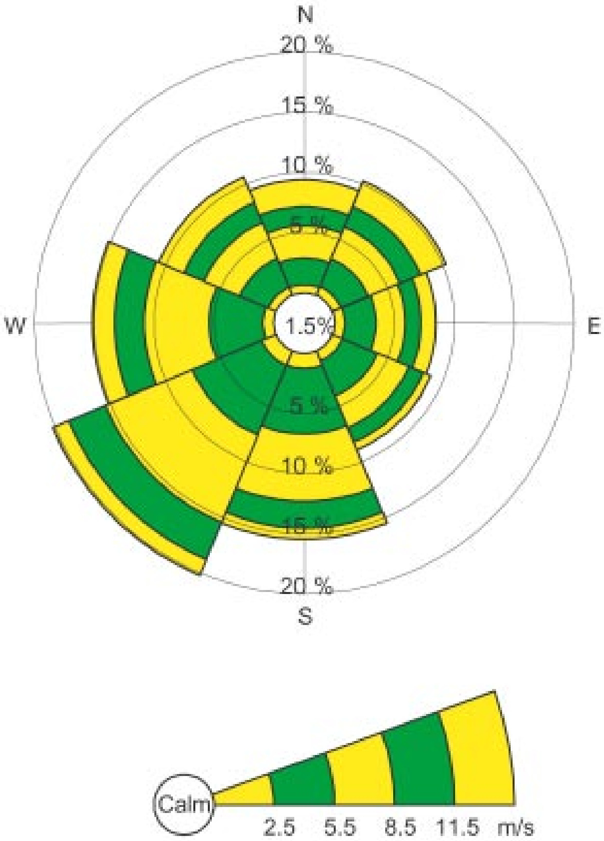

Figure 3-6. *Wind rose based on data collected 1968–1995 from the SMHI meteorological station Ölands norra udde /Larsson-McCann et al. 2002/.*

Sunshine hours, cloudiness and global radiation

The selected "reference station" for data on hours of sunshine, cloudiness and global radiation is SMHI's meteorological station at Ölands norra udde. The annual sunshine time is about 1,800 hours on the coast and slightly less inland. The annual cloudiness percentage is 60–65%, being slightly less in the summer and slightly more in the winter. In the summer, the cloudiness tends to decrease near the coast compared to inland conditions. Based on synoptic observations at the station Ölands norra udde, the average monthly sum of global radiation varies from 8.5 kWh·m^{-2} in December to c 180 kWh·m^{-2} in June. The calculated average annual sum is 1,021 kWh·m^{-2} /Larsson-McCann et al. 2002/.

Relative humidity

The "reference station" for relative humidity is the SMHI meteorological station Ölands norra udde. The relative humidity is 80–100% in the winter and 70–90% in the summer. During each period, the high values occur at night and the low values at noon /Larsson-McCann et al. 2002/.

Snow cover

The ground is covered by snow about 75 days of the year with an average annual maximum snow depth of approximately 35–40 cm. The conditions on the coast do not differ much from those inland /Larsson-McCann et al. 2002/.

Air pressure

Air pressure is usually between 950 and 1,050 hPa. The largest air pressure variations are experienced in the winter and there are only small variations during May through August /Larsson-McCann et al. 2002/.

3.1.2 Site investigation data and comparison with regional data

This section presents local meteorological data, collected during the period September 2003–June 2005 at SKB's meteorological stations on the northern part of the island of Äspö and in Plittorp. As mentioned in Section 1.2, time series for presentation of meteorological parameters have been extended to June 2005, mainly because meteorological time series data are crucial to improve the conceptual-descriptive and quantitative water flow models of the site. For reasons discussed in the beginning of this chapter, a comparison is also made between data from the Äspö and Plittorp stations and data from three of SMHI's regional meteorological stations (for a few selected meteorological parameters). The latter stations are used to characterise the long-term average meteorological conditions in the region around Simpevarp (cf above).

The meteorological measurements and the available data from Äspö and Plittorp are summarised in Table 3-5 below. Based on the measured precipitation, SMHI calculates the actual precipitation at both these stations, i.e. precipitation corrected for losses due to wind, evaporation and adhesion. Further, SMHI calculates the potential evapotranspiration for both stations. Note that global radiation data (required to calculate the potential evapotranspiration by use of the Penman formula) from Äspö are used in the Plittorp calculations, as the global radiation is not measured in Plittorp.

Table 3-5. Meteorological measurements on Äspö (station ID PAS00028) and in Plittorp (station ID PAS107738) and the period with available data for each meteorological parameter. Note that potential evapotranspiration is a calculated parameter.

Parameter	Registration interval	Äspö	Plittorp
Precipitation (2 metres above ground)	30 min. (sum)		
Measured		2003-09-09–2005-06-30	2004-07-14–2005-06-30
Actual (corrected by SMHI)		2003-09-09–2005-06-30	2004-07-14–2005-06-30
Air temperature (2 metres above ground)	30 min. (average of 1 sec.-values)	2003-09-09–2005-06-30	2004-07-14–2005-06-30
Wind direction and wind speed (10 metres above ground)	30 min. (average of last 10 min.)	2003-09-10–2005-06-30	2004-07-14–2005-06-30
Relative humidity (2 metres above ground)	30 min. (average of 1 sec.-values)	2003-10-04–2005-06-30	2004-07-14–2005-06-30
Global radiation (2 metres above ground)	30 min. (average of 1 sec.-values)	2003-09-09–2005-06-30	–
Air pressure (2 metres above ground)	30 min. (average of 1 sec.-values)	2003-09-09–2005-06-30	2004-09-27[1]–2005-06-30
Potential evapotranspiration (calculated by SMHI)	30 min. (sum)	2003-10-04–2005-06-30	2004-07-14–2005-06-30

[1] There were errors in the air pressure measurements prior to 2004-09-27 /Lärke et al. 2005/.

Table 3-6 summarises the meteorological data from the SMHI stations. These SMHI data are used for comparing data from the SKB stations with "regional" data from surrounding areas. The data from SMHI cover the years 2003 and 2004, thereby extending the "regional" dataset from the SMHI stations presented by /Larsson-McCann et al. 2002/. In the same way as for the local stations, SMHI calculates the actual precipitation, corrected for losses due to wind, evaporation and adhesion. Further, SMHI calculates daily values of potential evapotranspiration for the stations Gladhammar and Ölands norra udde, based on global radiation, air temperature, air humidity, and wind speed. Only precipitation and air temperature are measured in Oskarshamn, which implies that potential evapotranspiration is not calculated by SMHI for that station.

Table 3-6. Meteorological measurements at the SMHI meteorological stations Gladhammar (station no. 7642), Ölands norra udde (station no. 7721), and Oskarshamn (station no. 7616). Data provided by SHMI for the present work. "–" means that no data are available.

Parameter	Registration interval	Gladhammar (station no. 7642)	Ölands norra udde (station no. 7721)	Oskarshamn (station no. 7616)
Precipitation (measured and corrected for measurement errors; 2 metres above ground)	12 h (6 AM and 6 PM)	2003-01-01–2004-12-31	2003-01-01–2004-12-31	2003-01-01–2004-12-31
Air temperature (2 metres above ground)	4 h (1h, 6 AM and 6 PM for Oskarshamn)	2003-01-01–2004-12-31	2003-01-01–2004-12-31	2003-01-01–2004-12-31
Wind direction and wind speed (10 metres above ground)	4 h	2003-01-01–2004-12-31	2003-01-01–2004-12-31	–
Relative humidity (2 metres above ground)	4 h	2003-01-01–2004-12-31	2003-01-01–2004-12-31	–
Global radiation (2 metres above ground)	1 h	2003-01-01–2004-12-31	2003-01-01–2004-12-31	–
Air pressure (2 metres above ground)	4 h	–	2003-01-01–2004-12-31	–

Precipitation

The precipitation measured at the Äspö and Plittorp stations is corrected by SMHI for losses due to wind, evaporation, and adhesion. The SMHI correction is the same for both Äspö and Plittorp, see /Lärke et al. 2005/, and implies that the corrected precipitation is assumed to be 6% larger than the measured one if the air temperature is equal to or higher than +1°C (the precipitation is then assumed to be in the form of rain). The corresponding correction is 10% if the air temperature is below +1°C, when the precipitation is assumed to be in the form of snow.

Figure 3-7 and 3-8 show values of daily (note: corrected) precipitation on Äspö (mid September 2003–June 2005) and in Plittorp (mid July–June 2005). It should be noted that the "normal" period for presentation of meteorological data (e.g. applied by SMHI) refers to a time period from 6 AM a certain day until 6 AM the following day (pers. comm. with Lennart Wern, SMHI). In the present context, the corresponding time period is between 00:30 AM and midnight a certain day.

Äspö is the local meteorological station with the longest precipitation record. During the period shown in Figure 3-7, the daily precipitation was zero during c 54% of the time (354 out of 660 days). There largest daily precipitation measured on Äspö was on July 9, 2004 (corrected precipitation c 30 mm). Figure 3-9 provides a correlation plot of daily precipitation measured on Äspö and in Plittorp from mid-July 2004 to the end of June 2005.

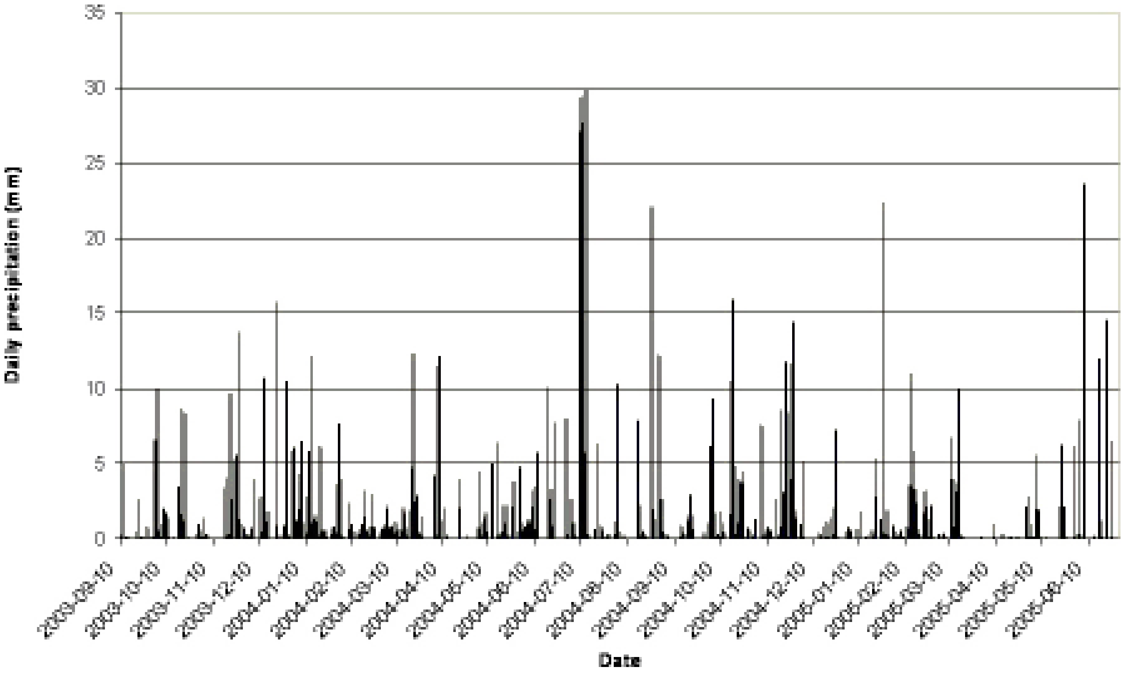

Figure 3-7. *Plot showing daily values of precipitation at the Äspö meteorological station during the period September 2003–June 2005.*

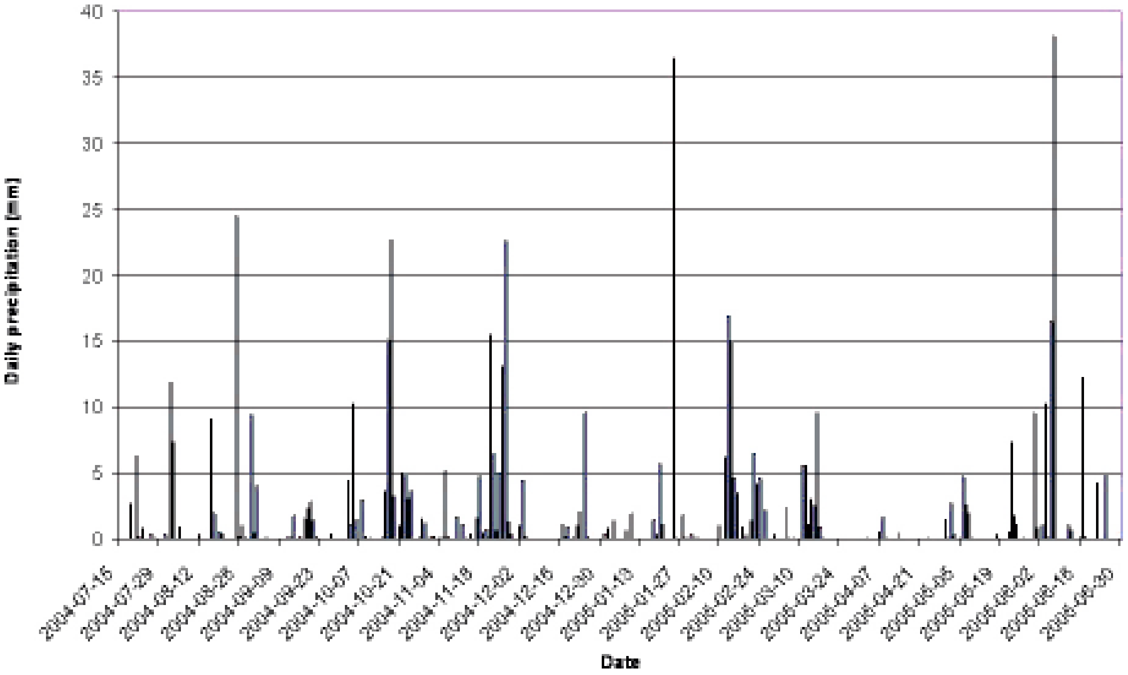

Figure 3-8. *Plot showing daily values of precipitation at the Plittorp meteorological station during the period mid July 2004–June 2005.*

As can be seen in Figure 3-9, the time series of daily precipitation match each other quite well; the correlation coefficient between the two time series is $R^2 = 0.91$. The linear fit shows that the precipitation is usually larger at the Plittorp station than at Äspö. During the period with data from both stations (August 2004–June 2005), the accumulated precipitation in Plittorp (555 mm) was 91 mm (or c 20%) larger than that at Äspö (463 mm). This observation is in line with the general tendency with more precipitation in inland areas, compared to areas closer to the coast (cf Section 3.1.1); the distance between the two stations is c 10 km. The continuing measurements will provide data on the precipitation gradient for a longer time period.

For the analysed time series, the largest difference in precipitation between the two stations is for days with the highest precipitation. During such heavy precipitation events, the measured (and also the corrected) precipitation is higher in Plittorp than on Äspö. The highest (Plittorp) and the second highest (Äspö) daily precipitation measured during the period were during June 7, 2005 (Äspö c 24 mm and Plittorp c 38 mm).

Table 3-7 presents monthly (also shown in Figure 3-10) and annually accumulated values of precipitation at the Äspö and Plittorp stations, along with corresponding data for the SMHI stations in Gladhammar, Ölands norra udde, and Oskarshamn. Local precipitation data (corrected) are available for the periods January 2004–June 2005 (Äspö) and mid-July 2004–June 2005 (Plittorp).

Table 3-7 and Figure 3-10 show that there are large differences in precipitation between years, and also between meteorological stations. The differences between years is not consistent: for instance, the accumulated precipitation in Oskarshamn 2003 and 2004 was almost the same, whereas there was c 190 mm more precipitation in Gladhammar 2004 compared to 2003. On the contrary, the precipitation at Ölands norra udde was c 115 mm less 2004 compared to 2003. However, for all analysed meteorological stations and years in Table 3-7 and Figure 3-10, the precipitation is lowest at Ölands norra udde.

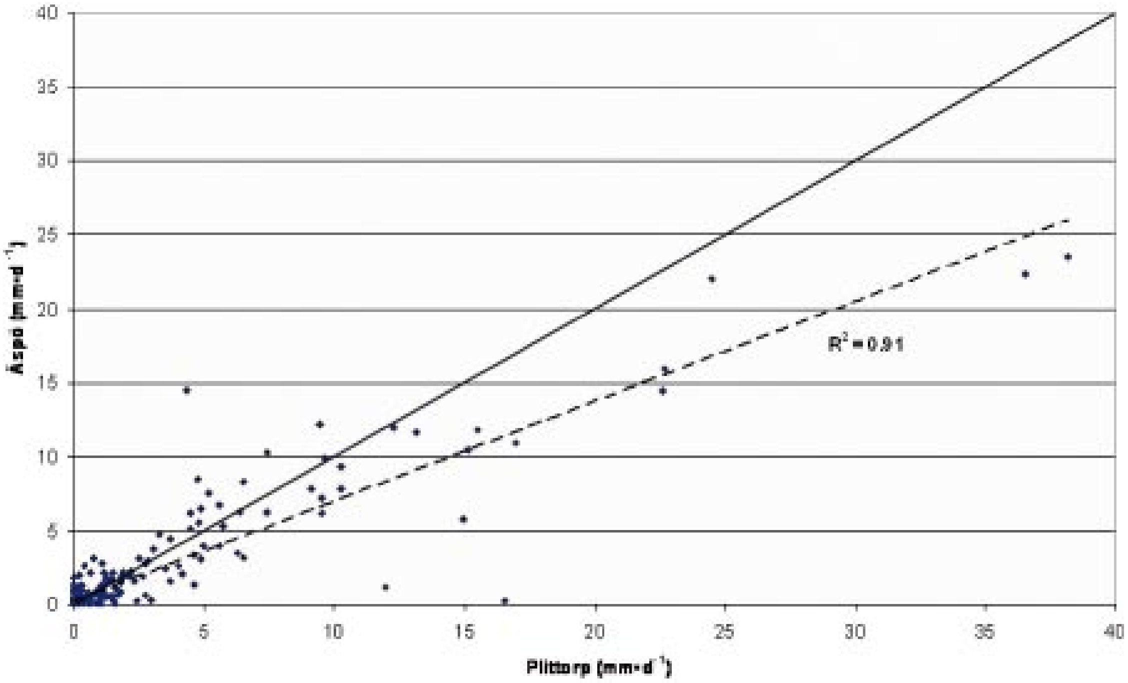

Figure 3-9. Plot showing the correlation between daily precipitation measured at Plittorp (horizontal axis) and Äspö (vertical axis) from mid-July 2004 to the end of June 2005. The dotted line is a least-square fit between the two data sets, whereas the solid line represents a perfect fit between them. R^2 denotes the correlation coefficient.

Table 3-7. Comparison of precipitation (monthly and annually accumulated values, mm) measured at the local stations Äspö and Plittorp, and the regional SMHI stations Gladhammar, Ölands norra udde and Oskarshamn (data provided by SMHI). "–" means that no data are available.

Year/month	Äspö	Plittorp	Gladhammar	Ölands norra udde	Oskarshamn
2003					
January	–	–	37.3	30.5	19.7
February	–	–	12.5	13.9	12.4
March	–	–	3.2	5.3	5.9
April	–	–	82.2	60.6	80.2
May	–	–	41.5	12.6	25.6
June	–	–	81.7	49.9	62.7
July	–	–	208.1	139.0	232.6
August	–	–	61.1	74.5	59.9
September	[1]9.6	–	7.5	17.9	10.7
October	50.3	–	43.9	33.5	46.6
November	50.3	–	66	47.8	59.0
December	53.5	–	53.7	60.8	56.2
Sum 2003			698.7	546.3	671.5
2004					
January	73.3	–	56.2	48.1	59.1
February	30.3	–	25.6	16.6	15.4
March	42.3	–	31.1	28.0	33.2
April	37.7	–	42.5	35.0	25.5
May	40.4	–	70.0	18.3	45.2
June	53.1	–	69.4	24.6	94.2
July	133.9	[2]11.1	219.9	80.3	140.7
August	61.7	68.6	76.5	41.6	58.4
September	13.5	15.3	43.8	14.8	13.2
October	74.3	86.3	144.5	49.5	91.5
November	80.0	82.2	82.9	60.7	84.2
December	20.0	21.2	25	23.8	17.6
Sum 2004	660.5		887.4	441.2	678.2
2005					
January	39.4	53.0			
February	41.7	67.6			
March	29.8	31.6			
April	3.8	4.7			
May	31.8	33.7			
June	66.7	90.6			

[1] From September 9.
[2] From July 14.

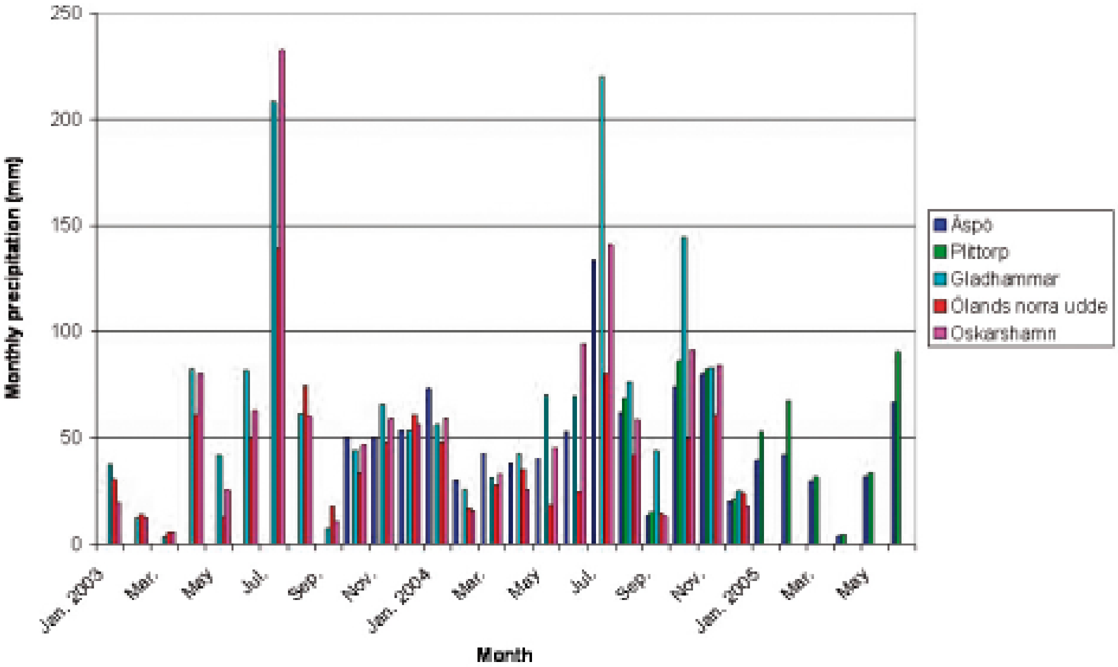

Figure 3-10. Monthly precipitation at SKB and SMHI meteorological stations.

Potential evapotranspiration

Table 3-8 presents monthly (also in Figure 3-11) and annually accumulated values of the calculated potential evapotranspiration at the stations Äspö and Plittorp, and the corresponding values at the SMHI stations in Gladhammar and Ölands norra udde (the potential evapotranspiration is not calculated for the SMHI station in Oskarshamn). Note that global radiation data (which are required to calculate the potential evapotranspiration) from Äspö are used for the Plittorp calculations, as the global radiation is not measured in Plittorp. Local potential evapotranspiration data are available from the beginning of October 2003 to the end of June 2005 (Äspö), and from mid-July 2004 to the end of June 2005 (Plittorp).

Similar to the precipitation data discussed above, Table 3-8 and Figure 3-11 show that there are differences in potential evapotranspiration between years, and also between meteorological stations, and that the differences between years vary. However, the differences are not as large as for the precipitation (cf Table 3-7 and Figure 3-10). For instance, there was c 190 mm more precipitation in Gladhammar 2004 compared to 2003, whereas the accumulated potential evapotranspiration was c 30 mm less 2004 compared to 2003 there. For all analysed meteorological stations and years in Table 3-8 and Figure 3-11, the potential evapotranspiration is highest at Ölands norra udde. Figure 3-11 shows a "typical" seasonal variation of the potential evapotranspiration, which is low during the winter, and increases during the spring to reach maximum values during the summer; the potential evapotranspiration decreases during autumn.

During 2004, the annual accumulated potential evapotranspiration was c 160 mm smaller at Äspö than at the SMHI station Ölands norra udde. This supports the observation regarding the long-term average potential evapotranspiration in Section 3.1.1, where it was noted that the average annual potential evapotranspiration (and also the accumulated value during the representative year 1981) at Ölands norra udde is over 100 mm larger than than at the other SMHI stations included in the comparison (Målilla and Västervik/Gladhammar). Table 3-8 indicates that the station Gladhammar may be better suited than Ölands norra udde to serve as reference station for long-term data from "regional" SMHI stations. However, Table 3-8 does not contain time series long enough for a more thorough comparative analysis.

Table 3-8. Comparison of potential evapotranspiration (monthly and annually accumulated values, mm) calculated by SMHI for the local stations Äspö and Plittorp, and the regional SMHI stations Gladhammar and Ölands norra udde (data provided by SMHI). "–" means that no data are available.

Year/month	Äspö	[2]Plittorp	Gladhammar	Ölands norra udde
2003				
January	–	–	4.6	7.7
February	–	–	5.2	7.4
March	–	–	24	23.6
April	–	–	46	46.8
May	–	–	77	103.7
June	–	–	98.2	123.8
July	–	–	88.6	97.1
August	–	–	77	99.1
September	–	–	40	35.8
October	[1]1.8		12.4	20.7
November	0.0		3.2	2.8
December	0.1		5.9	4.4
Sum 2003			482.1	572.9
2004				
January	0.0	–	3.7	10
February	0.2	–	6.8	8.8
March	8.7	–	21.6	22.9
April	30.9	–	45.9	50.2
May	49.4	–	79.5	89.4
June	99.2	–	89.3	120.4
July	85.9	[3]57.5	84.2	114
August	92.9	96.2	73	103.3
September	56.3	59.6	38.9	52.9
October	9.6	17.4	8.4	13.4
November	0.4	6.5	1.7	4.2
December	0.0	4.0	2.0	3.6
Sum 2004	433.5		455	593.1
2005				
January	10.1	7.9		
February	7.6	6.1		
March	29.0	27.6		
April	75.5	77.3		
May	100.2	100.7		
June	124.5	120.3		

[1] From October 4.

[2] Calculated by SMHI using global radiation data from the Äspö station.

[3] From July 14.

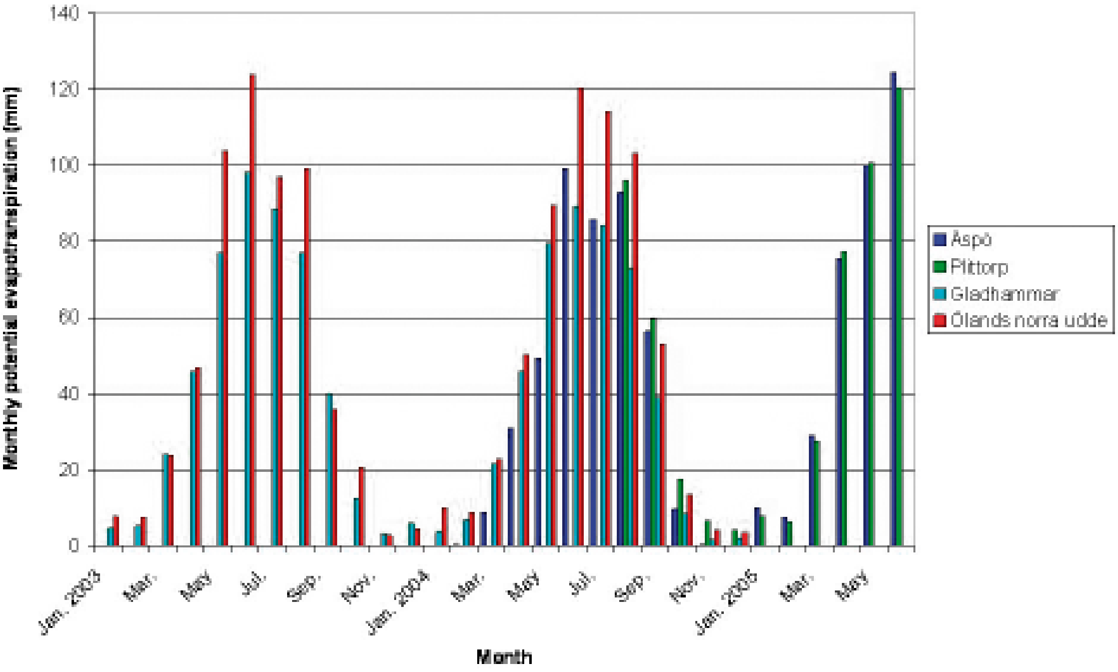

Figure 3-11. Monthly potential evapotranspiration at SKB and SMHI meteorological stations.

Air temperature

Table 3-9 presents monthly and annually averaged values of air temperature at the local stations Äspö and Plittorp, and the corresponding values for the SMHI stations Gladhammar, Ölands norra udde, and Oskarshamn (see also Figure 3-12). Local air temperature data are available for the periods mid-September 2003 to June 2005 (Äspö) and mid-August 2004 to June 2005 (Plittorp).

Table 3-9. Comparison of air temperatures (monthly and annually average values, °C) measured at the local stations Äspö and Plittorp, and the regional SMHI stations Gladhammar, Ölands norra udde and Oskarshamn (data provided by SMHI). "–" means that no data are available.

Year/month	Äspö	Plittorp	Gladhammar	Ölands norra udde	Oskarshamn
2003					
January	–	–	–2.4	–0.6	–2.4
February	–	–	–4.0	–2.4	–3.9
March	–	–	2.9	2.1	2.6
April	–	–	4.2	3.3	4.3
May	–	–	11.5	11.0	11.6
June	–	–	15.5	15.4	15.7
July	–	–	18.6	18.8	18.8
August	–	–	17.0	18.1	16.1
September	[1]13.5	–	13.0	14.5	12.8
October	5.7	–	4.9	7.5	4.7
November	5.2	–	4.7	5.9	4.7
December	2.2	–	2.0	3.5	1.8
Average 2003			7.3	8.1	7.2

Year/month	Äspö	Plittorp	Gladhammar	Ölands norra udde	Oskarshamn
2004					
January	–3.0	–	–3.7	–0.9	–3.7
February	0.1	–	–0.2	0.9	–0.5
March	2.0	–	2.0	2.6	2.3
April	5.5	–	5.8	5.4	5.7
May	10.1	–	10.5	9.4	10.7
June	14.2	–	14.2	14.7	14.3
July	15.6	[2]16.1	15.5	16.4	16.4
August	17.8	17.3	17.5	18.9	17.4
September	13.1	12.4	12.7	14.2	12.5
October	8.0	7.4	7.3	9.0	7.7
November	2.1	1.7	1.5	4.0	1.4
December	1.4	1.4	1.5	2.8	1.0
Average 2004	7.2		7.1	8.1	7.1
2005					
January	1.5	1.4			
February	–1.4	–1.8			
March	–1.4	–1.3			
April	5.2	5.5			
May	10.3	10.3			
June	14.8	14.5			

[1] From September 9.

[2] From July 14.

Table 3-9 and Figure 3-12 show that there are relatively small differences in average air temperature between years, and also between meteorological stations. For all analysed meteorological stations and years in Table 3-9 and Figure 3-12, the average air temperature is highest at Ölands norra udde. This may partly explain the higher potential evapotranspiration at that station compared to the others (see above).

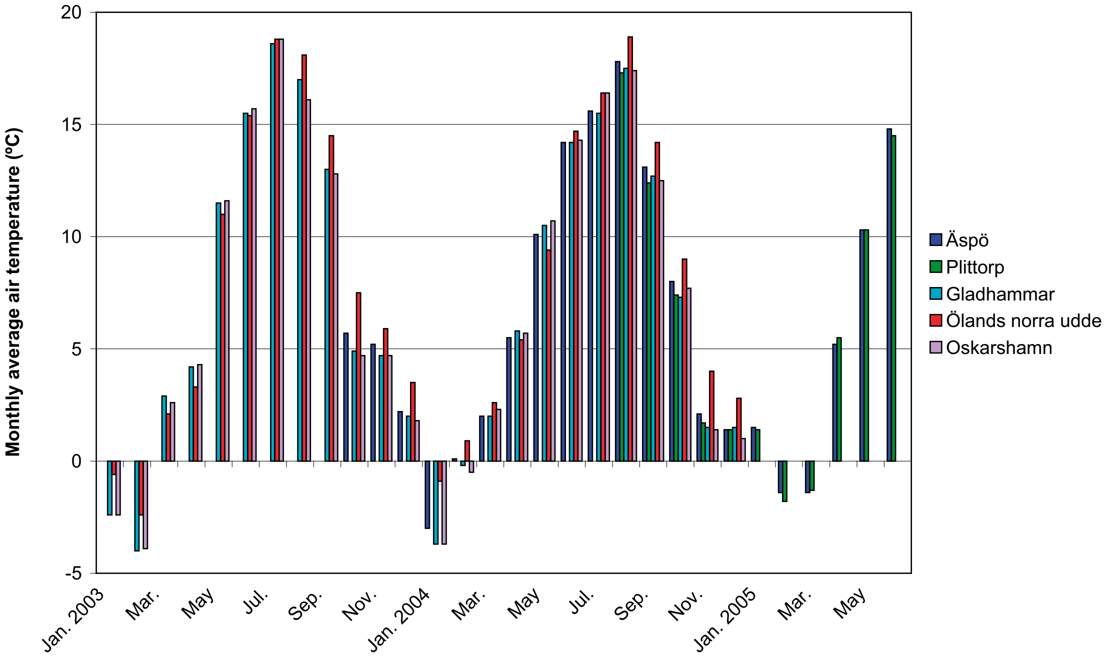

Figure 3-12. Monthly average air temperature at SKB and SMHI meteorological stations.

Hence, Table 3-9 indicates that any of the SMHI stations analysed above could be suitable for providing long-term data from “regional” SMHI stations (possibly except from Ölands norra udde). Figure 3-12 shows a “typical” seasonal variation of the average air temperature, which is low during the winter, and increases during the spring to reach maximum values during the summer; the average monthly air temperature decreases during autumn.

Wind speed

Table 3-10 presents monthly and annually (not for Plittorp) averaged values of wind speed at the local stations Äspö and Plittorp, and the corresponding values for the SMHI stations Gladhammar and Ölands norra udde (note that wind speed is not measured at the SMHI station in Oskarshamn). Local wind speed data are available for the period mid-September 2003–June 2005 (Äspö) and mid-July 2004–June 2005 (Plittorp).

It can be seen that the annual average wind speed during 2004 was slightly lower at Äspö than at the SMHI stations. In particular, the average wind speed was much higher at Ölands norra udde, which also in this case implies that this station could be less suitable as a source of long-term “regional” SMHI data than the other SMHI stations.

Table 3-10. Comparison of wind speed (monthly and annually averaged values, $m \cdot s^{-1}$) measured at the local stations Äspö and Plittorp, and the SMHI stations in Gladhammar and Ölands norra udde (data provided by SMHI). “–” means that no data are available.

Year/month	Äspö	Plittorp	Gladhammar	Ölands norra udde
2003				
January	–	–	3.2	7.4
February	–	–	2.0	5.2
March	–	–	2.5	4.9
April	–	–	3.2	6.7
May	–	–	2.5	5.3
June	–	–	2.6	5.0
July	–	–	1.9	4.3
August	–	–	2.4	5.6
September	[1]1.7	–	2.4	5.5
October	1.6	–	2.4	6.5
November	1.3	–	2.0	5.0
December	1.9	–	3.2	7.6
Average 2003			2.5	5.7
2004				
January	1.7	–	2.3	6.8
February	1.6	–	2.6	6.4
March	2.1	–	2.9	6.4
April	1.6	–	2.1	4.6
May	1.8	–	2.6	4.9
June	1.6	–	2.5	5.0
July	1.5	[2]0.8	2.1	4.6
August	1.6	1.0	2.3	4.8
September	1.7	1.2	2.7	6.0

Year/month	Äspö	Plittorp	Gladhammar	Ölands norra udde
October	1.6	1.0	2.4	6.1
November	1.6	1.2	2.6	7.0
December	1.5	1.4	2.7	6.5
Average 2004	1.7		2.5	5.7
2005				
January	2.2	1.8		
February	2.2	1.4		
March	1.6	0.9		
April	1.9	1.3		
May	1.5	1.2		
June	1.7	1.1		

[1] From September 10.
[2] From July 14.

Global radiation

Table 3-11 presents monthly and annually accumulated values of global radiation at the local station on Äspö, and the corresponding values at the SMHI stations Gladhammar and Ölands norra udde. Local radiation data from Äspö are available for the period mid-September 2003–June 2005.

Table 3-11. Comparison of global radiation (monthly and annually accumulated values, $\text{kWh}\cdot\text{m}^{-2}$) measured at the local station Äspö, and the SMHI stations in Gladhammar and Ölands norra udde (data provided by SMHI)[1]. "–" means that no data are available.

Year/month	Äspö	Gladhammar	Ölands norra udde
2003			
January	–	12.6	13.3
February	–	32.7	30.9
March	–	85.1	89.4
April	–	108.4	111.3
May	–	160.5	176.6
June	–	176.4	186.3
July	–	152.3	160.8
August	–	135.0	139.7
[2]September	58.3	96.8	101.8
October	46.9	49.1	48.4
November	11.3	12.3	13.2
December	6.3	8.6	9.1
Sum 2003		1,029.9	1,080.8
2004			
January	12.1	11.9	12.3
February	33.5	33.1	33.8
March	67.0	68.9	69.3
April	131.3	132.8	139.1

Year/month	Äspö	Gladhammar	Ölands norra udde
May	156.6	164.3	172.1
June	163.6	164.1	182.9
July	141.5	143.0	157.6
August	135.4	133.4	145.5
September	91.5	93.2	98.7
October	32.5	36.5	38.6
November	18.5	19.7	20.8
December	6.3	10.0	10.6
Sum 2004	989.8	1,011.0	1,081.3
2005			
January	12.8		
February	25.2		
March	85.7		
April	141.2		
May	157.9		
June	180.9		

[1] Global radiation is not measured at the local station in Plittorp or at the SMHI station in Oskarshamn.
[2] From September 9.

During 2004, the annual accumulated global radiation was slightly less at Äspö compared to the SMHI stations. The largest difference is between Äspö and the SMHI station Ölands norra udde, where the accumulated global radiation was c 100 $kWh \cdot m^{-2}$ (c 10%) larger. The larger accumulated global radiation at Ölands norra udde may partly explain the higher potential evapotranspiration at that station compared to the others (cf above). From the limited comparisons that can be made on the basis of the data in Table 3-11, it appears that the SMHI station Gladhammar is best suited for providing long-term data the “regional” SMHI stations.

Relative humidity

Table 3-12 presents minimum-, maximum- and averaged values per month of relative humidity at the local stations Äspö and Plittorp, and the corresponding values at the regional SMHI stations Gladhammar and Ölands norra udde (relative humidity is not measured at the SMHI station in Oskarshamn). Local relative humidity data are available from the beginning of October 2003 up to June 2005 (Äspö) and from mid-July 2004 to the end of June 2005 (Plittorp). Table 3-12 also shows regional SMHI data for the years 2003 and 2004.

During the periods shown in Table 3-12, there were generally small differences between the (monthly average) relative humidity measured at Äspö and Plittorp and the SMHI stations. Hence, either SMHI station may be considered suitable in terms of providing regional long-term data.

Table 3-12. Comparison of relative humidity (monthly minimum, maximum, and mean values, %) measured at the local stations Äspö and Plittorp, and the SMHI stations in Gladhammar and Ölands norra udde (data provided by SMHI). "–" means that no data are available.

Year/month	Äspö			Plittorp			Gladhammar			Ölands norra udde		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
2003												
January	–	–	–	–	–	–	70.4	91.3	82.7	74.3	93.4	84.7
February	–	–	–	–	–	–	62.1	92.0	81.5	72.0	94.8	87.7
March	–	–	–	–	–	–	35.6	86.3	69.7	39.1	92.1	77.8
April	–	–	–	–	–	–	45.1	93.1	71.7	66.3	95.8	82.5
May	–	–	–	–	–	–	45.6	90.5	70.0	55.3	91.1	76.1
June	–	–	–	–	–	–	54.0	84.4	69.5	64.3	91.4	77.1
July	–	–	–	–	–	–	64.0	92.4	80.9	75.1	95.8	86.7
August	–	–	–	–	–	–	58.9	90.5	73.6	64.1	91.0	77.0
September	–		–	–	–	–	60.9	87.5	75.9	69.0	97.0	82.7
October[1]	39.1	98.0	79.4	–	–	–	62.3	92.3	80.5	63.9	95.5	78.0
November	71.0	98.7	91.3	–	–	–	81.8	94.9	89.4	83.6	98.8	92.5
December	44.9	97.6	84.9	–	–	–	65.0	93.3	84.1	71.3	96.4	87.1
2004												
January	52.7	98.1	85.1	–	–	–	73.8	94.8	86.7	71.4	96.8	86.6
February	28.4	98.6	81.0	–	–	–	55.6	94.0	81.1	71.0	98.5	85.1
March	35.4	97.4	78.8	–	–	–	63.4	93.9	78.0	68.9	97.4	84.6
April	19.8	98.7	73.0	–	–	–	49.5	93.1	73.4	59.8	97.6	81.2
May	27.7	99.4	73.8	–	–	–	54.9	92.5	71.2	63.8	93.5	78.3
June	29.0	97.7	68.6	–	–	–	47.6	91.4	70.9	54.3	88.3	74.4
July[2]	25.1	97.6	78.3	30.6	98.7	80.2	60.5	94.8	80.4	60.0	95.8	79.3
August	33.1	98.1	78.3	35.7	99.5	81.2	61.5	96.6	79.0	60.0	94.1	79.4
September	37.1	97.1	77.9	41.7	99.1	81.5	64.0	95.9	79.8	63.3	88.4	78.8
October	51.4	97.8	88.7	54.2	99.3	91.2	83.3	97.6	90.1	73.9	95.0	86.5
November	47.1	97.0	87.2	48.1	98.4	89.3	70.6	97.9	89.3	69.5	93.3	85.3
December	46.6	97.1	87.0	48.4	98.3	88.4	61.4	97.9	87.6	71.3	92.9	85.2
2005												
January	38.6	96.8	80.3	39.8	97.6	82.1						
February	36.0	96.5	82.1	41.2	98.4	84.5						
March	30.9	97.3	73.2	27.9	98.3	73.4						
April	22.3	97.5	70.1	15.4	97.6	67.4						
May	23.9	97.9	71.9	28.1	99.0	71.6						
June	29.8	97.5	71.3	33.4	98.8	73.6						

[1] Äspö from October 4.
[2] Plittorp from July 14.

Air pressure

Table 3-13 presents monthly minimum, maximum, and average values of air pressure at the local stations Äspö and Plittorp, and the corresponding values at the SMHI station at Ölands norra udde; air pressure is not measured at the SMHI stations in Oskarshamn and Gladhammar.

Table 3-13. Comparison of air pressure (monthly minimum, maximum, and mean values, kPa) measured at the local stations Äspö and Plittorp, and the SMHI station at Ölands norra udde (data provided by SMHI). "–" means that no data are available.

Year/month	Äspö			Plittorp			Ölands norra udde		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
2003									
January	–	–	–	–	–	–	986.3	1,030.4	1,008.0
February	–	–	–	–	–	–	988.2	1,042.0	1,024.9
March	–	–	–	–	–	–	1,001.8	1,042.5	1,022.6
April	–	–	–	–	–	–	992.4	1,037.7	1,018.9
May	–	–	–	–	–	–	1,000.5	1,024.4	1,014.7
June	–	–	–	–	–	–	996.3	1,021.2	1,012.7
July	–	–	–	–	–	–	993.8	1,021.3	1,013.3
August	–	–	–	–	–	–	993.7	1,023.5	1,012.2
September	–	–	–	–	–	–	997.8	1,029.5	1,018.2
October[1]	987.8	1,035.3	1,009.8	–	–	–	989.6	1,034.4	1,010.6
November	992.8	1,045.4	1,016.3	–	–	–	996.2	1,044.9	1,016.8
December	977.1	1,030.3	1,009.2	–	–	–	980.5	1,029.2	1,009.5
2004									
January	978.8	1,028.5	1,008.4	–	–	–	982.6	1,026.5	1,008.8
February	985.6	1,031.9	1,010.2	–	–	–	991.7	1,030.4	1,010.6
March	973.1	1,040.5	1,018.0	–	–	–	979.9	1,039.1	1,018.4
April	998.5	1,034.6	1,015.5	–	–	–	1,003.3	1,033.8	1,016.9
May	995.3	1,026.7	1,011.0	–	–	–	997.0	1,026.3	1,011.3
June	996.6	1,026.0	1,013.0	–	–	–	998.3	1,024.5	1,010.8
July	991.0	1 021.7	1,011.0	–	–	–	993.7	1,021.5	1,011.4
August	1,000.7	1 024.1	1,011.5	–	–		1,003.1	1,023.6	1,011.9
September[2]	986.3	1 032.4	1,010.9	997.3	1,021.2	1,007.0	988.5	1,030.1	1,011.4
October	983.5	1 037.7	1,011.8	980.5	1,034.9	1,009.1	990.0	1,036.9	1,012.2
November	976.6	1 032.2	1,012.2	974.1	1,029.5	1,009.6	983.0	1,029.4	1,012.6
December	976.0	1 028.0	1,008.7	973.4	1,025.2	1,006.0	984.2	1,027.6	1,009.2
2005									
January	967.4	1 030.5	1,005.7	964.9	1 027.9	1,003.0			
February	971.9	1,037.7	1,017.2	969.1	1,034.9	1,014.5			
March	979.8	1,032.3	1,014.7	977.1	1,029.6	1,012.0			
April	993.6	1,032.5	1,016.1	1,013.4	1,029.8	990.7			
May	997.0	1,026.0	1,012.8	994.3	1,023.2	1,010.1			
June	998.7	1,030.8	1,013.4	996.0	1,027.8	1,010.8			

[1] Äspö from October 9.

[2] Plittorp from September 27.

Local air pressure data are available for the period mid-October 2004–June 2005 (Äspö), and from the end of September 2004 up to the end of June 2005 (Plittorp). Regional SMHI data for the years 2003–2004 are shown in Table 3-13. Similar to the relative humidity (see previous section), there were generally small differences between the (monthly average) air pressure measured at the stations during the periods shown in the table. Hence, the SMHI station Ölands norra udde may be used to provide long-term "regional" data.

3.2 Hydrological data

The delineation, size and land-use description of catchment areas presented in SDM S1.1 /SKB 2004a/ were only preliminary. For that model version, there were no site-specific data available on lakes, watercourses or wetland areas. Moreover, discharge data were only available from hydrological stations installed elsewhere within the region, prior to the site investigations.

For SDM S1.2, a detailed delineation and land-use description of the catchment areas within the regional model area was available (Section 3.2.1). The relative areas of different types of wetlands were also calculated for each of the identified catchments areas in the Simpevarp regional model area (Section 3.2.3). Main watercourses and lakes within the catchment areas were also identified (Sections 3.2.2 and 3.2.4), although no complete set of morphologic data (cross sections, bottom and surface water levels) was available. In addition, a set of data from manual discharge measurements in some of the watercourses was reported to SICADA (Section 3.2.6).

For L1.2, cross-section data (bottom levels and a set of points describing the cross-section geometry) are available from field measurements along the main watercourses in catchment areas 6 ("Mederhultsån"), 7 ("Kåreviksån"), and 9 ("Ekerumsån") /Strömgren et al. 2006/. Further, data are available from continued manual discharge measurements in some of the watercourses. There are also data on automatically measured water levels in some of the lakes and in the sea. However, there are yet no data on automatically measured water levels or calculated discharges in watercourses reported to the SICADA database. This is because rating curves (a station-specific empirical relationship between water level and discharge) for these automatic hydrological stations must be established before the data are stored in the database; the water level data from the hydrological stations are not stored separately, but will be stored when the discharge data are ready. It should be noted that once the rating cuves are established it will be possible to calculate discharges for the whole measurement period (i.e. also for the time prior to the establishment of the rating curves).

The bottom stratigraphy of wetlands, peat areas and lakes in the Simpevarp area was investigated by /Nilsson 2004/. These types of areas are not included in the "regular" mapping of Quaternary deposits /Rudmark 2004, Rudmark et al. 2005/. Referring to the terminology used in the investigation, it included "true wetlands", "true peat areas" (fens and bogs), areas on "dry land" (with just a thin layer of peat or water-laid sediments overlying the till or bedrock), and shallow/young as well as deep/old lakes.

3.2.1 Catchment areas

The L1.2 description of catchment areas is the same as that presented already in the S1.2 model version /Werner et al. 2005/; it is repeated here for completeness. In 2004, an updated Digital Elevation Model (DEM), air photographs and field studies resulted in a detailed delineation of 26 catchment areas (CA, for short) in the Simpevarp area, as shown in Figure 3-13 /Brunberg et al. 2004/. These 26 catchment areas are further divided into totally

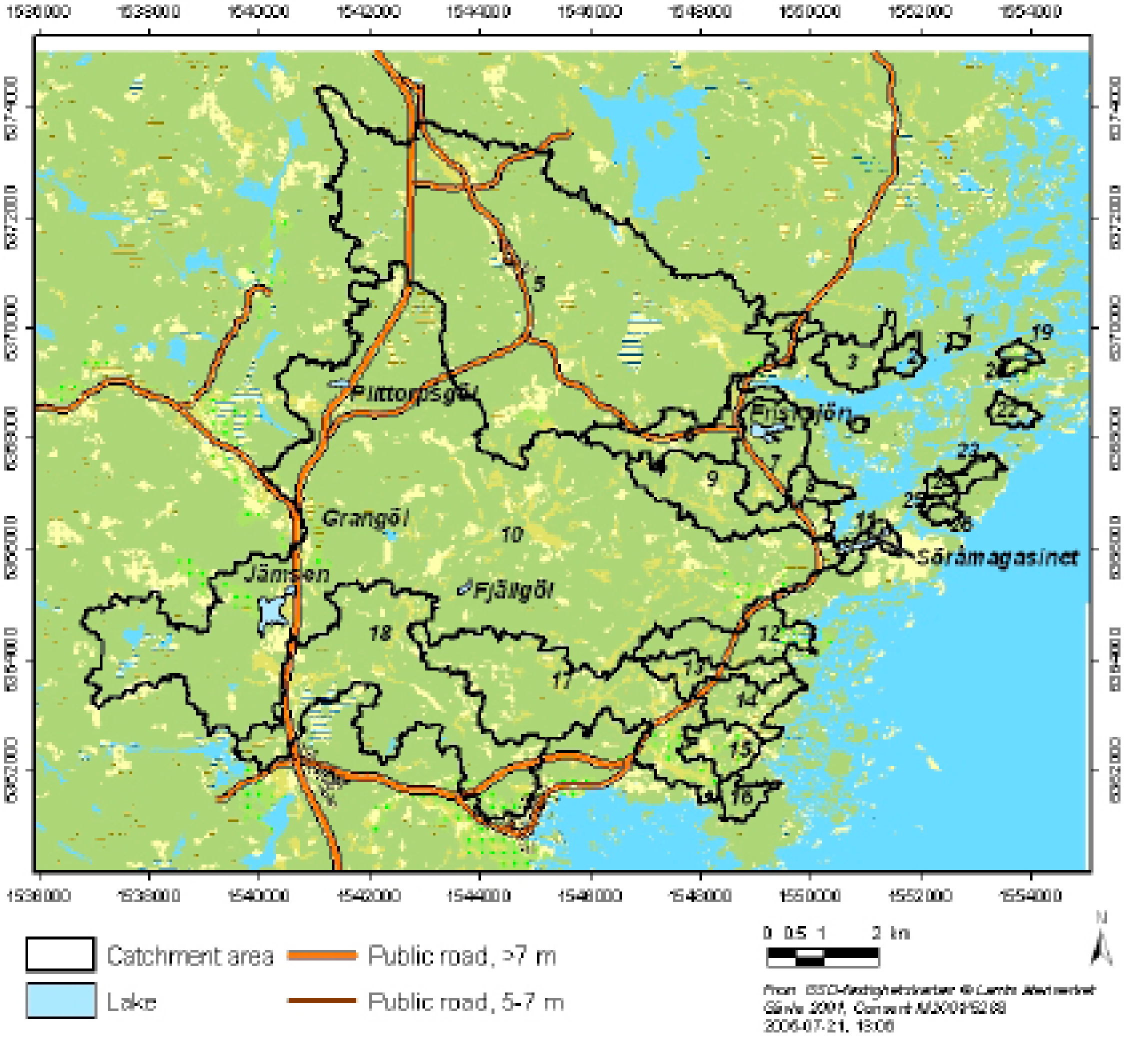

Figure 3-13. Delineation and numbering of the 26 catchment areas in the Simpevarp regional area. The map also shows the locations of the six lakes in the area (Section 3.2.2).

96 subcatchment areas /Brunberg et al. 2004/. All 26 catchment areas are located within the SMHI catchment area no. 72/73. Basic data, including watercourses, sizes of catchment areas and land use distributions, for each catchment area are provided in Table 3-14. The notations for the land-use types (MA) are explained in Table 3-15.

Table 3-14. Basic data for the 26 catchment areas (CA) identified within the Simpevarp area /Brunberg et al. 2004/. The numbering system for all CA is shown in Figure 3-13.

CA no	Watercourse[1] (or lake)	CA area (km^2)	MA1 (%)	MA2 (%)	MA3 (%)	MA4 (%)	MA5 (%)	MA6 (%)	MA7 (%)	MA8 (%)	MA9 (%)	MA10 (%)	MA11 (%)	MA19 (%)
1	"Långbonäs-bäcken"	0.070	0	81	0	0	1	0	0	0	18	0	0	0
2	"Bodvikebäcken"	0.380	20	78	1	0	0	0	0	0	0	0	1	0
3	"Sörviksån"	1.000	0	95	1	3	1	0	0	0	0	0	0	0
4	"Bjurhidebäcken"	0.632	0	94	1	4	1	0	0	0	0	0	0	0
5	Kärrviksån	27.154	0	86	1	4	3	2	0	1	0	0	2	1
6	"Mederhultsån"	2.003	0	83	0	12	5	0	0	0	0	0	0	0
7	"Kåreviksån"/Frisksjön	2.062	6	86	0	5	2	0	0	0	0	0	1	0

CA no	Watercourse[1] (or lake)	CA area (km^2)	MA1 (%)	MA2 (%)	MA3 (%)	MA4 (%)	MA5 (%)	MA6 (%)	MA7 (%)	MA8 (%)	MA9 (%)	MA10 (%)	MA11 (%)	MA19 (%)
8	“Pistlanbäcken”	0.499	1	95	0	0	1	0	0	3	0	0	0	0
9	“Ekerumsån”	2.834	0	81	0	12	4	3	0	0	0	0	0	0
10	Laxemarån/Fjällgöl, Jämsen, Plittorpsgöl	40.976	1	84	1	5	5	2	0	1	0	0	0	1
11	No watercourse/ Söråmagasinet	0.523	65	18	65	0	0	17	0	0	1	0	0	0
12	“Glostadsbäcken”	2.054	0	76	0	3	3	0	0	1	0	0	4	12
13	“Stålglobäcken”	1.033	0	79	0	14	5	2	0	1	0	0	0	0
14	“Stekebäcken”	1.338	0	81	0	6	7	1	0	5	0	0	0	0
15	“Södra Uvöbäcken”	0.967	0	55	0	6	12	0	0	9	0	0	0	18
16	Svartebäck	0.504	0	96	1	1	2	0	0	0	0	0	0	0
17	“Uthammarsån”	7.019	0	76	1	10	8	0	0	0	0	0	0	5
18	“Släthultebäcken”	8.958	0	81	2	5	7	0	0	0	0	0	1	3
19	“Flakvarpe-bäcken”	0.184	8	46	0	0	0	0	0	1	0	0	14	31
20	“Jössesbäcken”	0.111	0	0	0	0	17	0	0	0	0	0	0	83
21	“Äspöbäcken”	0.063	0	92	8	0	0	0	0	0	0	0	0	0
22	“Stekflage-bäcken”	0.359	7	86	0	0	2	0	0	0	0	0	6	0
23	“Vadvikebäcken”	0.307	0	99	1	0	0	0	0	0	0	0	0	0
24	“Lindströmme-bäcken”	0.192	0	96	0	0	4	0	0	0	0	0	0	0
25	“Gloebäcken”	0.131	97	0	97	0	0	3	0	0	0	0	0	0
26	“Skölkebäcken”	0.165	0	96	0	0	4	0	0	0	0	0	0	0

[1] Quotation marks (“ ”) indicate that the watercourse is given an unofficial name within the framework of SKB’s site investigations in the Simpevarp area. In the remainder of this report, all watercourses are referred to without quotation marks.

Table 3-15. Explanations of the land-use types in Table 3-14 /Brunberg et al. 2004/.

Column	English	Swedish
MA1	Water surface	Vattenyta
MA2	Coniferous- and mixed forest	Barr- och blandskog
MA3	Wetland normal – coniferous forest	Sankmark normal – barrskog
MA4	Agriculture land	Åkermark
MA5	Remaining open land	Övrig öppen mark
MA6	Cut forest	Hygge
MA7	Wetland normal – decidous forest	Sankmark normal – lövskog
MA8	Wetland normal – remaining open land	Sankmark normal – annan öppen mark
MA9	Wetland difficult – coniferous forest	Sankmark svår – barrskog
MA10	Wetland difficult – decidous forest	Sankmark svår – lövskog
MA11	Wetland difficult – remaining open land	Sankmark svår – annan öppen mark
MA19	Decidous forest	Lövskog
MA3 and MA7–11	Wetland	Våtmark

3.2.2 Lakes

The L1.2 geometrical description of the lakes in the Simpevarp area is the same as in the S1.2 stage /Werner et al. 2005/, and is repeated here for completeness. There are six lakes in the regional model area, see /Brunberg et al. 2004/ for a detailed description:

- Frisksjön (catchment area 7:2).
- Fjällgöl (catchment area 10:16).
- Grangöl (catchment area no. 10:19).
- Plittorpsgöl (catchment area 10:26).
- Jämsen (catchment areas 10:30–32).
- Söråmagasinet (catchment area 11:1).

In this description, 7:2 above denotes subcatchment area no. 2 in main catchment area no. 7. Morphometry parameters for five of the above lakes are presented in Table 3-16. The table also shows the ID numbers of SKB's hydrological stations in these lakes (stations installed up to November 2004). No morphometry parameters are available for Lake Grangöl, as it was not included in the field investigation programme /Brunberg et al. 2004/.

Moreover, on the topographic map there are four additional lakes in the upstream parts of catchment area no. 10. These were not included in the field investigations, partly because they are judged to be completely dry from IR photos (i.e. they are former lakes), but also due to unclear hydrological conditions (see /Brunberg et al. 2004/ for details). The locations of the lakes described in Table 3-16 are shown in Figure 3-13.

It should be noted that Lake Söråmagasinet originally was a natural bay, which was bounded by a dam wall and thereby was transformed to a lake. Söråmagasinet is used as a reserve water supply by OKG (pers. comm. with Kenneth Gustafsson, OKG). Occasionally, on the order of a few days each year or every second year, water is pumped from Ström on the watercourse Laxemarån into Söråmagasinet in order to maintain the available water storage in the lake (see also Section 3.4).

The bottom stratigraphy of the lakes Söråmagasinet, Frisksjön, Jämsen and Plittorpsgöl was investigated by /Nilsson 2004/. Söråmagasinet and Frisksjön are relatively shallow and recently isolated from the Baltic Sea, whereas Jämsen and Plittorpsgöl are fairly deep and considerably older. The investigation shows that a typical top-down stratigraphy in the shallow lakes consists of deep layers of gyttja and clay, whereas the bottom stratigraphy of the deeper lakes at some sampled locations is more complex. At many locations, also the latter stratigraphy consists of deep layers of gyttja and clay, but in places interchanging layers of silty-clayey gyttja, silty clay, and in some cases sandy clay and/or thin layers of sand also can be found. The thickness of the gyttja and clay layers is on the order of 1–5 metres. Hence, the investigation indicates that the bottom of lakes consists of low-permeable layers, limiting the contact between groundwater and surface water in these areas.

Table 3-16. Morphometry parameters[1] for the main lakes in the Simpevarp area /Brunberg et al. 2004/.

Catchment area	Simpevarp 7	Simpevarp 10	Simpevarp 10	Simpevarp 10	Simpevarp 11
Lake	Frisksjön	Fjällgöl	Plittorpsgöl	Jämsen	Söråmagasinet
Lake catchment/ Lake no.	7:2	10:16	10:26	10:30–32	11:1
Water elevation (m.a.s.l.)	1.37	–	24.79	25.11	2.07
Area (km^2)	0.13	0.03	0.03	0.24	0.10
Max. depth (m)	2.8	2.0	7.2	10.9	4.9
Mean depth (m)	1.7	1.1	3.7	3.7	2.0
Volume (Mm^3)	0.223	0.029	0.124	0.877	0.199
Shore length (m)	2 632	864	933	4,036	2,992
Mean discharge (m^3·s^{-1})[3]	0.0098	0.0016	0.0036	0.0369	0.0028
Retention time (days) [3]	264	218	399	275	829
Fetch (m)	705	116	349	959	936
Width (m)	248	55	119	603	184
Dynamic sediment ratio	0.21	0.14	0.05	0.13	0.16
Depth ratio	0.61	0.57	0.50	0.34	0.40
Relative depth ratio	9.89	15.29	49.31	28.02	19.22
Shoreline development factor	2.06	1.51	1.43	2.35	2.66
SKB hydrological station	PSM000347[2] PSM000348[2]	–	PSM000344	PSM000342	PSM000359

[1] The terms used are defined as follows /Brunberg et al. 2004/: *Fetch:* Maximum length; the longest straight line over the water surface. *Width:* Maximum width; the longest straight line perpendicular to the maximum length line. *Dynamic sediment ratio:* The square root of the area divided by the mean depth. *Depth ratio:* The mean depth divided by the maximum depth. *Relative depth ratio:* The ratio of maximum depth to mean diameter represented by the square root of the lake area. *Shoreline development factor:* Shore length divided by circumference of a circle with an area equal to that of the lake.

[2] PSM000347 is located in the inlet and PSM000348 in the outlet of the lake.

[3] Calculated using SMHI's estimate of the specific discharge in the area, see /Brunberg et al. 2004/.

3.2.3 Wetlands

SDM S0 and S1.1 presented a general description of different types of wetlands, but included no site-specific data except for the information given on the general maps of the area. In SDM S1.2, the relative areas of different types of wetlands were calculated for each of the identified 26 catchments areas in the Simpevarp regional area /Brunberg et al. 2004/. This was done by adding the land-use classes MA3 and MA7–11 in Table 3-14. The relative coverage (in %) of wetland areas thus represents varying parts of the other calculated land-use classes. The relative and total wetland area for each catchment area are summarised below. The total wetland area has been calculated based on the data in /Brunberg et al. 2004/. The different types of wetlands used in the classification are described in Table 3-18.

As can be seen in Table 3-17, there are wetland areas in almost all catchments, except for catchments 6, 9, 20, and 24–26. Wetlands can be divided into bogs, fens, and marches, see e.g. /Kellner 2004/. In the Simpevarp area, no marshes are identified. The results from the investigations of QD show that many of the wetlands in the Simpevarp regional model area contain peat, and that the peat layer is often thinner than one metre /Rudmark 2004, Rudmark et al. 2005/. At two of the groundwater monitoring wells in the Simpevarp subarea (SSM000020 and SSM000022), sand and gravel is covered by peat. The thickest observed peat layer is 1.5 metre (SSM000022). The wetlands that contain peat have been drained. It is therefore likely that drying and oxidation have made the peat coverage thinner. In the Simpevarp area, most wetlands have been above the sea level long enough for a distinct peat layer to form. Histosol (a soil type formed from materials with a high content of organic matter) is therefore the dominating soil type in the wetlands. This soil type is probably common also in drained wetlands.

Table 3-17. Basic data for wetlands in the Simpevarp area /Brunberg et al. 2004/.

Catchment area no.	Relative wetland area (%)	Total wetland area (km^2)	% coverage of total catchment area per type of wetland					
			MA3	MA7	MA8	MA9	MA10	MA11
1	18	0.070	0	0	0	18	0	0
2	2	0.0076	1	0	0	0	0	1
3	1	0.01	1	0	0	0	0	0
4	1	0.00632	1	0	0	0	0	0
5	4	1.08616	1	0	1	0	0	2
6	0	0	0	0	0	0	0	0
7	1	0.02062	0	0	0	0	0	1
8	3	0.499	0	0	3	0	0	0
9	0	0	0	0	0	0	0	0
10	2	0.81952	1	0	1	0	0	0
11	1	0.00523	0	0	1	0	0	0
12	5	2.054	0	0	1	0	0	4
13	1	0.010033	0	0	1	0	0	0
14	5	1.338	0	0	5	0	0	0
15	9	0.967	0	0	9	0	0	0
16	1	0.00504	1	0	0	0	0	0
17	2	7.019	1	0	0	0	0	1
18	3	0.26874	2	0	0	0	0	1
19	15	0.184	0	0	1	0	0	14
20	0	0	0	0	0	0	0	0
21	8	0.00504	8	0	0	0	0	0
22	6	0.02154	0	0	0	0	0	6
23	1	0.00307	1	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0

Table 3-18. Explanations of the land use types in Table 3-17 /Brunberg et al. 2004/.

Column	English	Swedish
MA3	Wetland normal – coniferous forest	Sankmark normal – barrskog
MA7	Wetland normal – decidous forest	Sankmark normal – lövskog
MA8	Wetland normal – remaining open land	Sankmark normal – annan öppen mark
MA9	Wetland difficult – coniferous forest	Sankmark svår – barrskog
MA10	Wetland difficult – decidous forest	Sankmark svår – lövskog
MA11	Wetland difficult – remaining open land	Sankmark svår – annan öppen mark

The bottom stratigraphy of wetlands and peat areas in the Simpevarp area was investigated by /Nilsson 2004/. Similar to the sea and lake sediments, these types of areas are not included in the "regular" QD mapping. The investigation included "true wetlands" (overgrown by reed, and with gyttja as the predominant type of QD), "true peat areas" (fens and bogs), and areas on "dry land", with just a thin layer of peat or water-laid sediments overlying the till or bedrock /Nilsson 2004/. The investigation shows that a typical top-down stratigraphy in wetlands and peat areas are peat (when present), clay gyttja and gyttja, silt-sand-gravel, postglacial clay, and glacial clay. The individual layers are on the order of 0.5–2 metres, except from the silt-sand-gravel layer, which generally is very thin. Hence, the investigation results indicate that the bottom layers of the wetlands and peat areas consist of low-permeable materials, which would correspond to limited interactions between groundwater and surface water in these areas.

3.2.4 Watercourses

A description of the main watercourses was presented in the S1.2 model version /Brunberg et al. 2004/. The names and locations of the main watercourses are presented in Table 3-19 and Figure 3-14. Table 3-19 also provides the ID codes of the hydrological stations in the watercourses, as of November 2004. /Brunberg et al. 2004/ presented estimated mean discharges for each main watercourse. These discharges were calculated as the estimated average specific discharge (5.7 $l{\cdot}s^{-1}{\cdot}km^{-2}$) times the size of each catchment area. In SDM S1.2, only X- and Y-coordinates for the main watercourses were stored in SKB's GIS database.

Additional, more detailed information, primarily X- and Y-coordinates, cross sections, and a characterisation of the bottom, from field investigations of some of the watercourses in the regional model area was presented by /Carlsson et al. 2005/ as a part of the L1.2 dataset. During 2005 (after the L1.2 data freeze), measurements of cross sections were performed along the main watercourses in catchment areas 6, 7 and 9 /Strömgren et al. 2006/. The general characteristics of diverted and/or "missing" watercourses, and areas that have been drained as a consequence of various water/land management operations are briefly presented in Section 3.4.3.

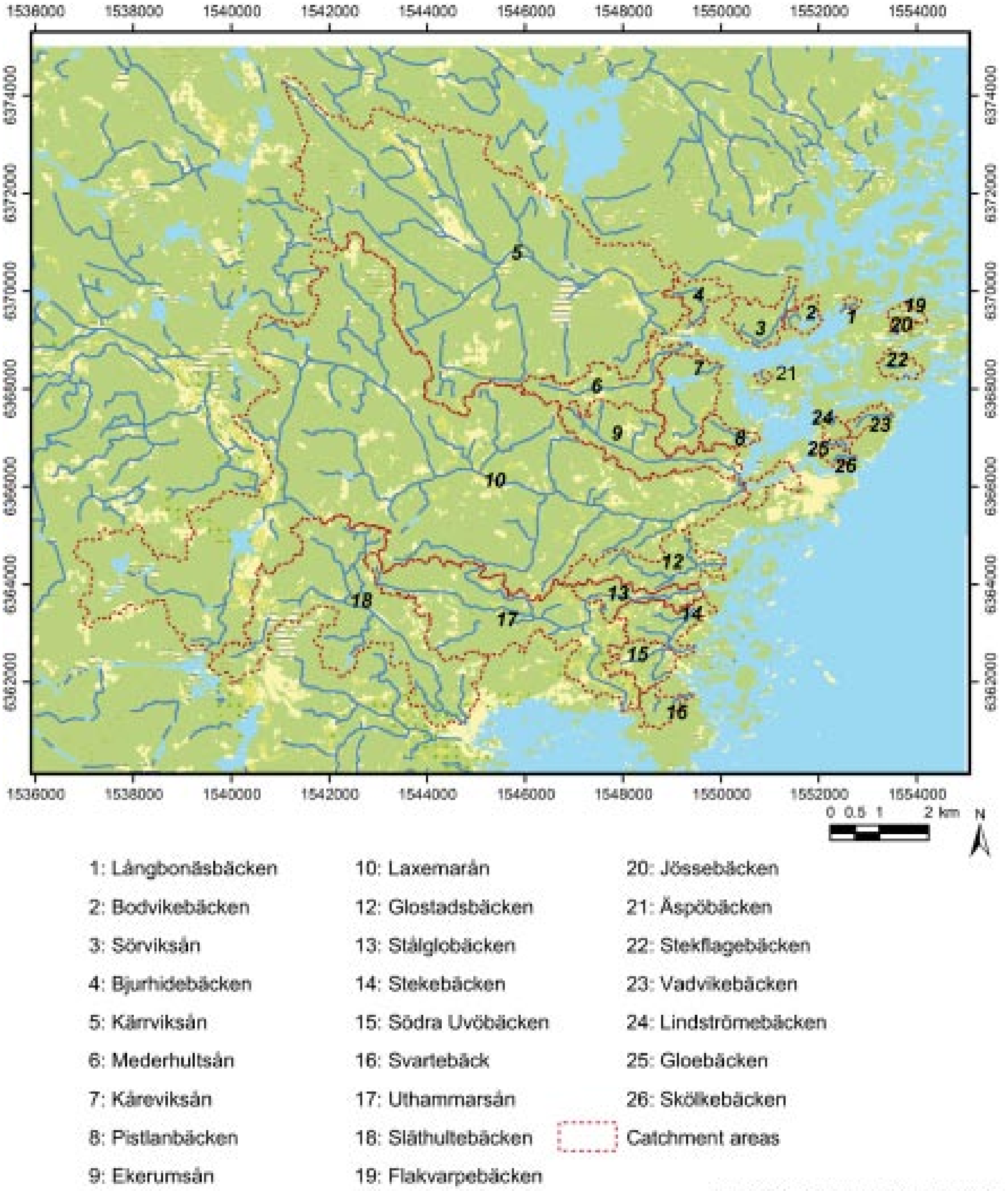

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Figure 3-14. *Names and locations of the main watercourses in the Simpevarp regional model area /Brunberg et al. 2004/.*

Table 3-19. Main watercourses in the Simpevarp area and estimated mean discharges /Brunberg et al. 2004/.

CA (cf Figure 3-13)	Watercourse	Mean discharge ($m^3 \cdot s^{-1}$)	SKB hydrological station
1	Långbonäsbäcken	0.0004	
2	Bodvikebäcken	0.0020	
3	Sörviksån	0.0053	
4	Bjurhidebäcken	0.0034	
5	Kärrviksån	0.1439	PSM000368
6	Mederhultsån	0.0106	
7	Kåreviksån	0.0109	
8	Pistlanbäcken	0.0026	
9	Ekerumsån	0.0150	PSM000365
10	Laxemarån	0.2171	PSM000353 PSM000364
11	No watercourse	–	
12	Glostadsbäcken	0.0109	
13	Stålglobäcken	0.0055	
14	Stekebäcken	0.0071	
15	Södra Uvöbäcken	0.0051	
16	Svartebäck	0.0027	
17	Uthammarsån	0.0372	
18	Släthultebäcken	0.0475	
19	Flakvarpebäcken	0.0010	
20	Jössesbäcken	0.0006	
21	Äspöbäcken	0.0003	
22	Stekflagebäcken	0.0019	
23	Vadvikebäcken	0.0016	PSM000341
24	Lindströmmebäcken	0.0010	
25	Gloebäcken	0.0007	PSM000343
26	Skölkebäcken	0.0009	PSM000345

3.2.5 Surface water levels

SDM S0 and S1.1 did not contain site investigation data (time series) on surface water levels in lakes, watercourses or the sea. In SDM S1.2, "snapshots" of the surface water levels (i.e. no continuous time series) were available for five of the lakes in the regional area, see Table 3-20. This table also shows the hydrological stations installed in the lakes (as of November 2004).

Table 3-20. Surface water levels in lakes in the Simpevarp area /Brunberg et al. 2004/.

Catchment	Simpevarp 7	Simpevarp 10	Simpevarp 10	Simpevarp 10	Simpevarp 11
Lake	Frisksjön	Fjällgöl	Plittorpsgöl	Jämsen	Söråmagasinet
Lake catchment	7:2	10:16	10:26	10:30–32	11:1
Elevation (m.a.s.l.)	1.37	–	24.79	25.11	2.07
SKB hydrological station	PSM003471 PSM003481		PSM00344	PSM00342	PSM00359

[1] PSM000347 is located in the inlet and PSM000348 in the outlet of the lake.

The planning and construction of the hydrological stations, and the time series measured up to November 2004 at the stations (in watercourses, lakes, and the sea) in the Simpevarp area are presented in /Lärke and Hillgren 2003, Lärke et al. 2005/. Table 3-21 summarises the status of the hydrological stations as of November 2004. It is evident that a significant amount of hydrological information will be available when these stations have been in operation for some time, and when the rating curves for the stations in the watercourses have been established. The locations of the stations are shown in Figure 3-15.

Figures 3-16 to 3-19 show time series of automatically measured lake and sea water levels. Figure 3-16 compares the sea level variations with the water level variations in the two lakes with water levels only slightly above the sea level, i.e. Lake Frisksjön and Lake Söråmagasinet. It is seen that the two lakes show some similarities, but also that the variations are somewhat larger in Lake Frisksjön than in Lake Söråmagasinet. This probably reflects the fact that Lake Söråmagasinet is a man-made reservoir with a small catchment area, to which surface water is sometimes transferred in order to maintain the water volume stored. Lake Söråmagasinet was originally a natural bay, now bounded by a dam wall and thereby transformed to a lake. It is used as a reserve water supply by OKG for drinking water and process water (see further description in Section 3.4). Conversely, the water level in Lake Frisksjön can be expected to respond to the "natural" variations in the discharge from its catchment area.

A comparison of the lake and sea water levels in Figure 3-16 indicates very little co-variation; the lake levels show no similarities to the various peaks and the period of more or less consistent decrease in sea level from January to March 2005. Similar conclusions concerning the lack of co-variation between sea and lake water levels can be drawn when comparing the results in Figure 3-17. This figure shows the time series measured in the lakes in the western part of the regional model area, i.e. Lake Jämsen and Lake Plittorpsgöl. The water levels in these lakes are much higher than those in the lakes discussed above; this is why the sea level is shown on a separate vertical scale in Figure 3-17 (note that the intervals on the two y-axes have the same length).

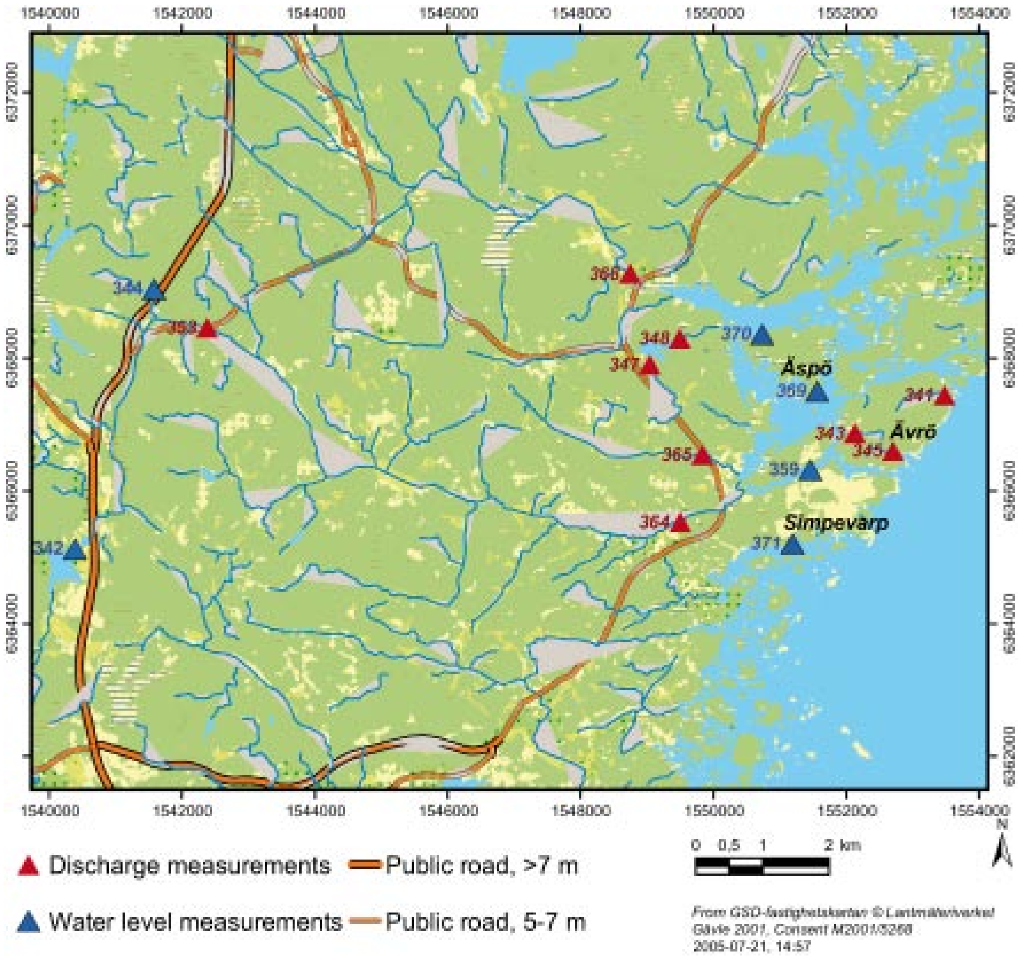
Another observation that can be made in Figure 3-17 is that the level variations in the two lakes are very similar, both in magnitude and with regard to the times when the peaks appear. The similarities between the natural lakes in the area are even more apparent in Figure 3-18, which includes all three natural lakes where automatic measurements are made. Again, the differences in absolute levels require two y-axes (with intervals of the same length) to be used. It is obvious that variations follow very similar patterns, although there are some differences when the maximum levels appear in the different time series.

There are two annual peaks in all water level curves shown in Figure 3-18, one during the autumn 2004 (associated with autumn rains) and another during the spring of 2005 (the snow melt period). There is also a smaller peak during June 2005, which may be due to heavy summer rains. The water level variation (maximum minus minimum level) during the one-year period is small, c 0.3–0.4 metre in Lake Jämsen and Lake Plittorpsgöl and c 0.5 metre in Lake Frisksjön. As expected, the sea water levels measured at the three stations coincide, see Figure 3-19, with a few exceptions that appear to be related to loss of data delivery from one of the stations. The variation in the sea water level during the period was about one metre (from –0.4 to +0.6 metre above sea level).

Table 3-21. Hydrological stations in the Simpevarp area.

Station no.	Location	Types of measurements	[1] Size of catchment area, km²	Period with automatically measured water level data
PSM000341	Ävrö – Vadvikebäcken, catchment area 23	Water level and discharge in watercourse (V-notch weir), electric conductivity, temperature	0.25	–
PSM000342	Laxemar – Lake Jämsen, catchment area 10	Lake water level	–	2004-07-24–2005-07-01
PSM000343	Ävrö – Gloebäcken, catchment area 25	Water level and discharge in watercourse (V-notch weir), electric conductivity, temperature	0.09	–
PSM000344	Laxemar – Lake Plittorpsgöl, catchment area 10	Lake water level	–	2004-07-24–2005-07-01
PSM000345	Ävrö – Skölkebäcken, catchment area 26	Water level and discharge in watercourse (V-notch weir), electric conductivity, temperature	0.14	–
PSM000347	Laxemar – inlet to Lake Frisksjön, catchment area 7	Under construction	0.80	–
PSM000348	Laxemar – outlet of Lake Frisksjön, catchment area 7	Water level and discharge in lake outlet (natural section)	1.8	2004-07-24–2005-07-01
PSM000353	Laxemar – Laxemarån, catchment area 10	Water level and discharge in watercourse (natural section)	13.5	–
PSM000359	Simpevarp peninsula – Lake Söråmagasinet, catchment area 11	Lake water level	–	2004-05-28–2005-07-01
PSM000364	Laxemar – Laxemarån, catchment area 10	Water level and discharge in watercourse (natural section)	40	–
PSM000365	Laxemar – Ekerumsån, catchment area 9	Under construction	2.4	–
PSM000368	Laxemar – Kärrviksån, catchment area 5	Water level and discharge in watercourse (natural section)	27.2	–
PSM000369	Äspö	Sea water level	–	2004-05-28–2005-07-01
PSM000370	Äspö	Sea water level	–	2004-05-28–2005-07-01
PSM000371	Simpevarp peninsula	Sea water level	–	2004-05-28–2005-07-01

[1] From /Lärke and Hillgren 2003, Lärke et al. 2005/.



From GSD-fastighetskartan © Lantmäteriverket Gävle 2001, Consent M2001/5268
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Figure 3-15. *Map showing the locations of hydrological stations in watercourses, lakes and the sea.*

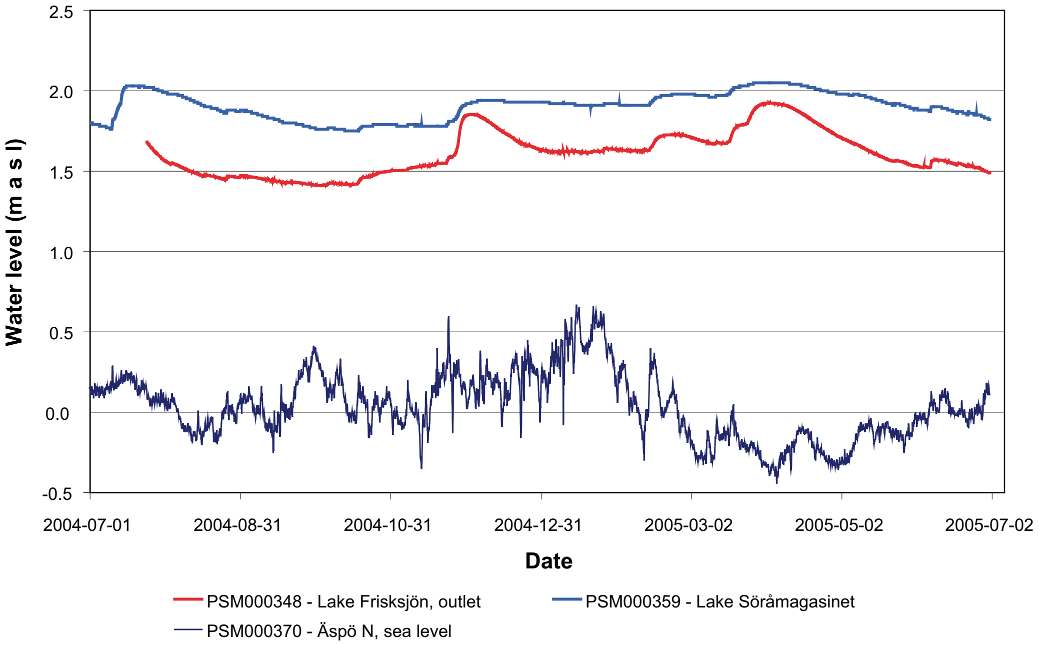

Figure 3-16. *Automatically measured surface water levels at the hydrological stations in the outlet of Lake Frisksjön (PSM000348) and in Lake Söråmagasinet (PSM000359), and the sea level measured on the northern shore of Äspö (PSM000370).*

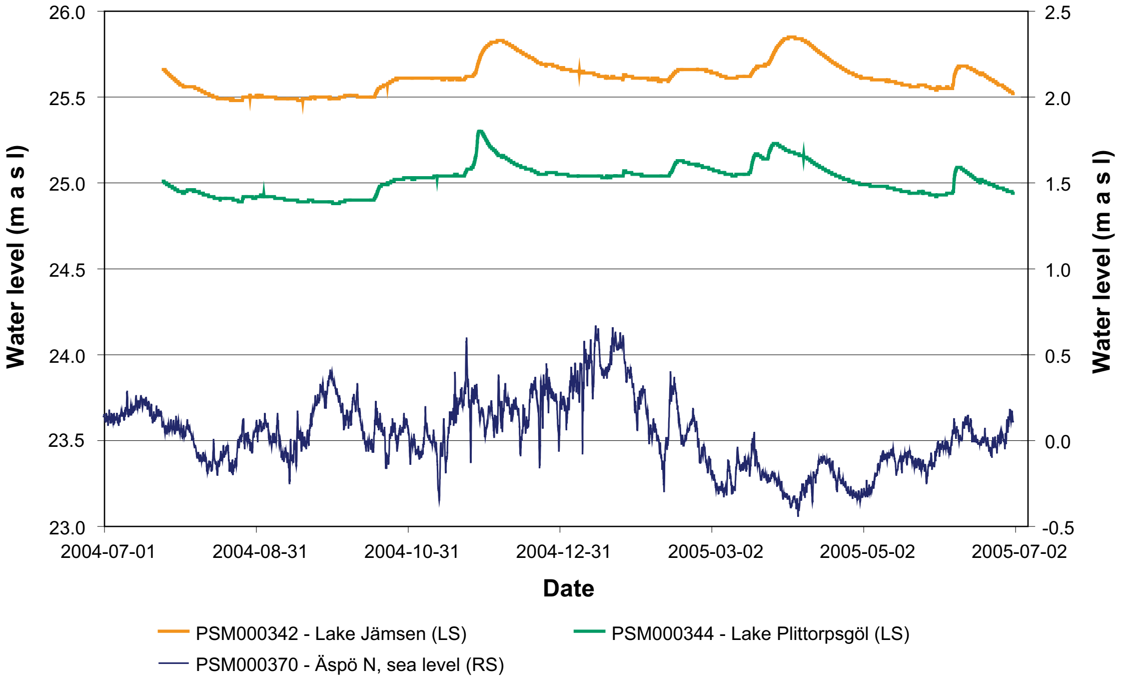

***Figure 3-17.** Automatically measured surface water levels at the hydrological stations in Lake Jämsen (PSM000342) and Lake Plittorpsgöl (PSM000344), and the sea level measured on the northern shore of Äspö (PSM000370); LS = left y-scale, RS = right y-scale.*

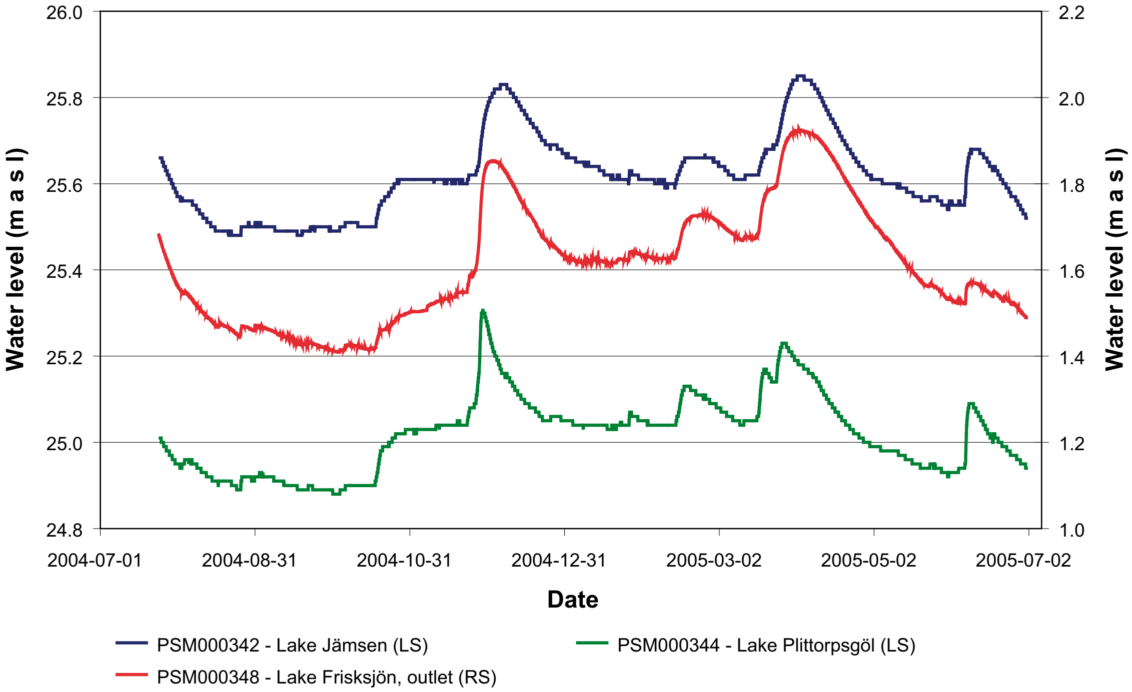

***Figure 3-18.** Comparison of automatically measured surface water levels in three lakes in the Simpevarp area (Figure 3-15); LS = left y-scale, RS = right y-scale.*

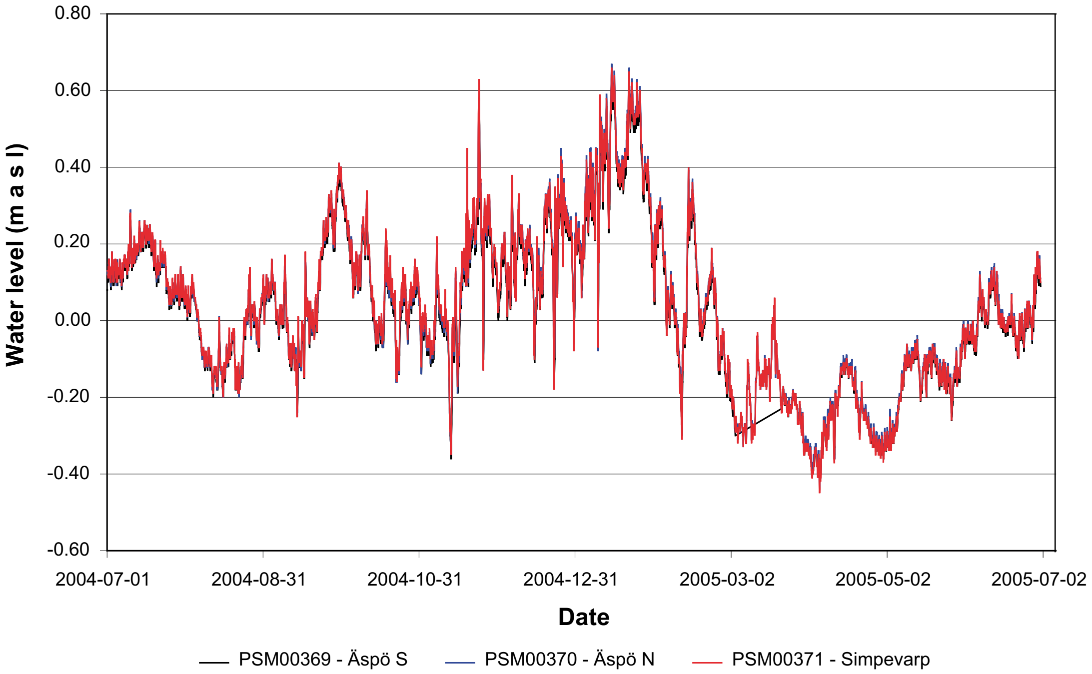

Figure 3-19. *Comparison of automatically measured sea levels at the three stations in the Simpevarp area; two are located on Äspö and one on the Simpevarp peninsula (Figure 3-15).*

3.2.6 Discharge data

Regional discharge data

Long-term discharge data from the hydrological station Forshultesjön nedre were used by /Larsson-McCann et al. 2002/ to estimate the specific discharge in the Simpevarp regional model area. Using these data, the regional long-term average specific discharge was estimated to 5.7 $l \cdot s^{-1} \cdot km^{-2}$, which corresponds to approximately 180 $mm \cdot year^{-1}$. Using the HBV model /Bergström 1992/ and regional meteorological data, they also simulated the average daily discharges at two other locations, the (sea) outlets of Gerseboån (denoted GE1) and Laxemarån (denoted LA1).

The calculated average specific discharges at these locations are 4.7 and 5.4 $l \cdot s^{-1} \cdot km^{-2}$, respectively, corresponding to discharges of c 150 and 170 $mm \cdot year^{-1}$. Calculated discharge characteristics (MLQ, MQ, and so forth) for the three locations Forshultesjön nedre (based on measured data), GE1 and LA1 (based on simulations) are shown in Table 3-22.

Note that the long-term average of annual specific discharge (MQ) is used as the "best estimate" of the regional average specific discharge, which according to the table is estimated to be in the range 4.7–5.7 $l \cdot s^{-1} \cdot km^{-2}$ /Larsson-McCann et al. 2002/. The discharge characteristics shown in the table are based on mean daily values. All the HHQ50 and HHQ100 values are based on calculations /Larsson-McCann et al. 2002/. The other results for GE1 and LA1 are all based on calculations, whereas those for the Lake Forshultesjön are based on measurements. Monthly discharge values for the station Forshultesjön nedre are shown in Figure 3-20. The mean daily discharges in the watercourses Gerseboån (GE1) and Laxemarån (LA1) were simulated by SMHI /Larsson-McCann et al. 2002/. The results are summarised in Figures 3-21 and 3-22, which show calculated characteristic daily values for each month during the year.

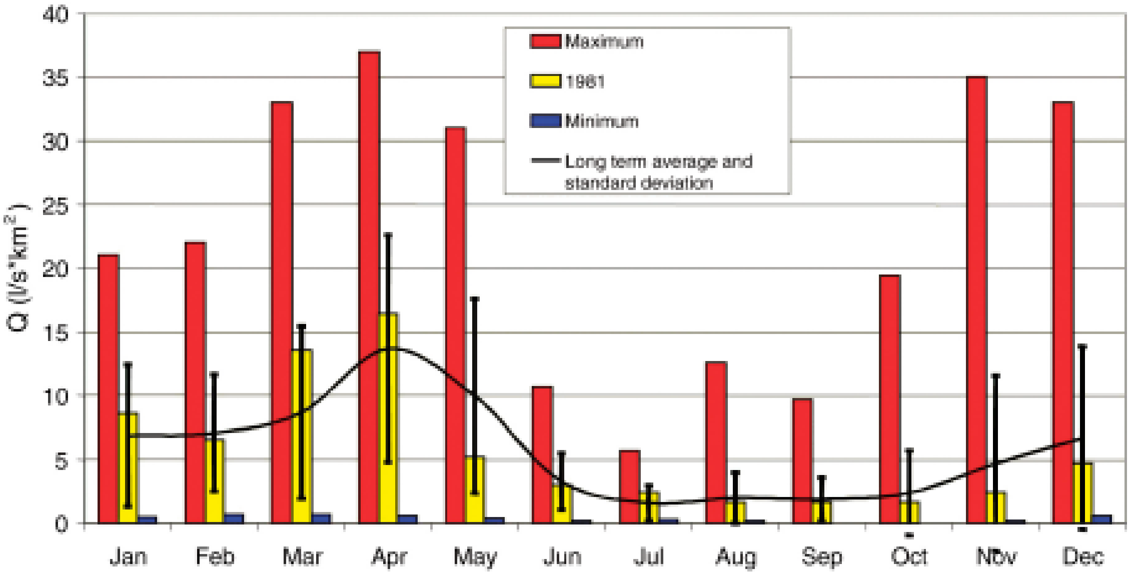

__Figure 3-20.__ Monthly discharge at hydrological station Forshultesjön nedre, 1955–2000; maximum and minimum daily mean, long term average and standard deviation (l·s^{-1}·km^{-2}). The year 1981 was selected by /Larsson-McCann et al. 2002/ as a "representative year".

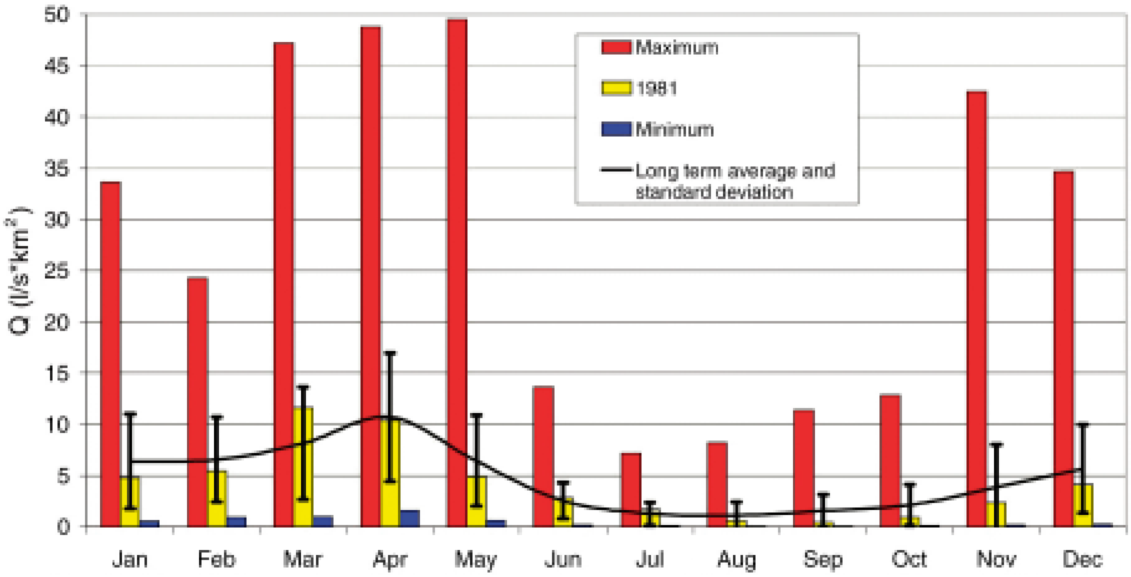

__Figure 3-21.__ Monthly simulated discharge at GE1 Gerseboån, 1962–2001; maximum and minimum daily mean, long term average and standard deviation (l·s^{-1}·km^{-2}). The year 1981 was selected by /Larsson-McCann et al. 2002/ as a "representative year".

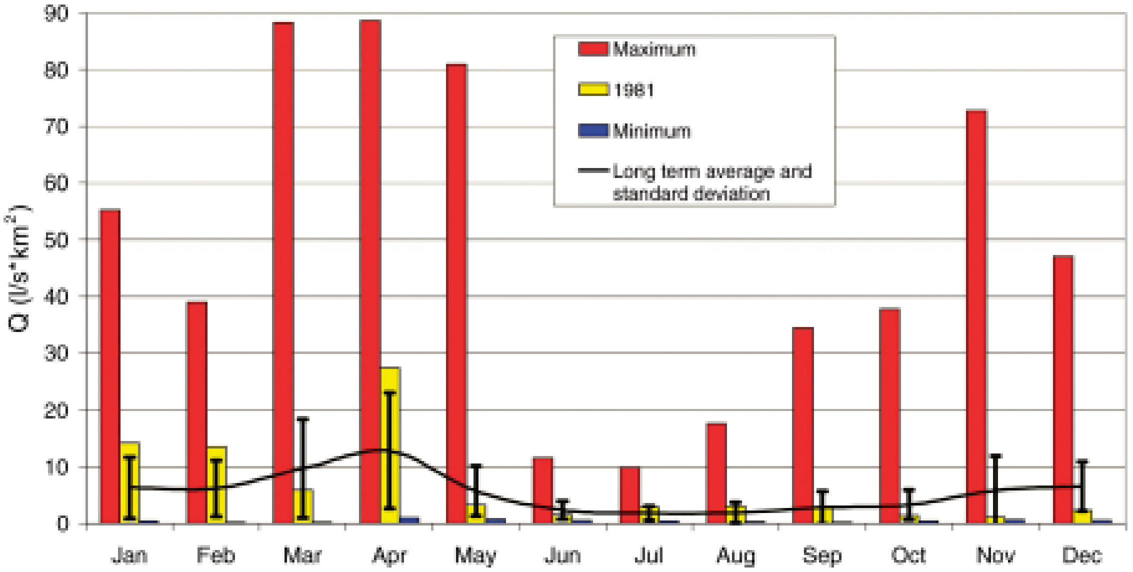

Figure 3-22. *Monthly simulated discharge at LA1 Laxemarån, 1961–2001; maximum and minimum daily mean, long term average and standard deviation (l·s^{-1}·km^{-2}). The year 1981 was selected by /Larsson-McCann et al. 2002/ as a "representative year".*

It can be seen in Figures 3-20 to 3-22 that the year can be subdivided into a "summer period", characterised by small discharges, and a "winter period" with much larger discharges. The summer period extends from June to September, with some differences among the stations. For Laxemarån, which is within the Simpevarp regional model area (and also within the Laxemar subarea), the discharges calculated for September and October are much larger than those for the period June–August. It can also be noted that the monthly discharges are constantly large throughout the "winter period" (from September–October to May).

Table 3-22. Measured (Forshultesjön) and calculated (Gerseboån, GE1, and Laxemarån, LA1) specific discharge characteristics (l·s^{-1}·km^{-2}) for three locations in the region around Simpevarp /Larsson-McCann et al. 2002/.

Station no.	Name/notation	Specific discharge characteristic[1]						Period
		Obs. min. Q	MLQ	MQ	MHQ	HHQ50	HHQ100	
1619	Forshultesjön nedre	0	0.58	5.7	26	59	66	1955–2000
	GE1		0.46	4.7	21	52	56	1962–2001
	LA1		0.24	5.4	43	99	111	1962–2001

[1] The characteristics are explained as follows /Larsson-McCann et al. 2002/: *MLQ:* Long-term average of annual minimum specific discharge. *MQ:* Long-term average of annual specific discharge. *MHQ:* Long-term average of annual maximum specific discharge. *HHQ50:* Highest maximum specific discharge, with a return period of 50 years. *HHQ100:* Highest maximum specific discharge, with a return period of 100 years.

Site investigation data

Discharge data are not yet available from the automatic hydrological stations in the area (see Section 3.2.5). In connection with surface water sampling, manual discharge measurements have been performed in some watercourses since the summer of 2003 /Ericsson and Engdahl 2004ab/. Hydrological stations are planned or constructed at three of the locations where manual discharge measurements are carried out (PSM0000347, -362, and -365).

As the catchment areas for these stations have been estimated /Lärke and Hillgren 2003, Lärke et al. 2005/, rough estimates of the specific discharge ($l \cdot s^{-1} \cdot km^{-2}$) can be obtained from these manual discharge measurements. As shown in the table, these estimates yield larger specific discharges than the range estimated from "regional" data (c 8–11 $l \cdot s^{-1} \cdot km^{-2}$ compared with 4.7–5.7 $l \cdot s^{-1} \cdot km^{-2}$). This discrepancy is probably due to incomplete time series and inaccurate measurements, rather than a reflection of the actual site conditions. The locations of the manual discharge measurements are shown in Figure 3-23.

The results of the manual discharge measurements are shown in graphs in Appendix 1. These figures show that surface water discharge in the watercourses is a highly transient process during the year. There are many measurements with zero discharge, but also short periods with relatively large discharges. Even though the measurements are sparse, they indicate that the discharge in the watercourses mainly occurs in the form of "peaks" in connection with precipitation events and/or snow melt periods, and that the discharge is low or zero during long periods between such events.

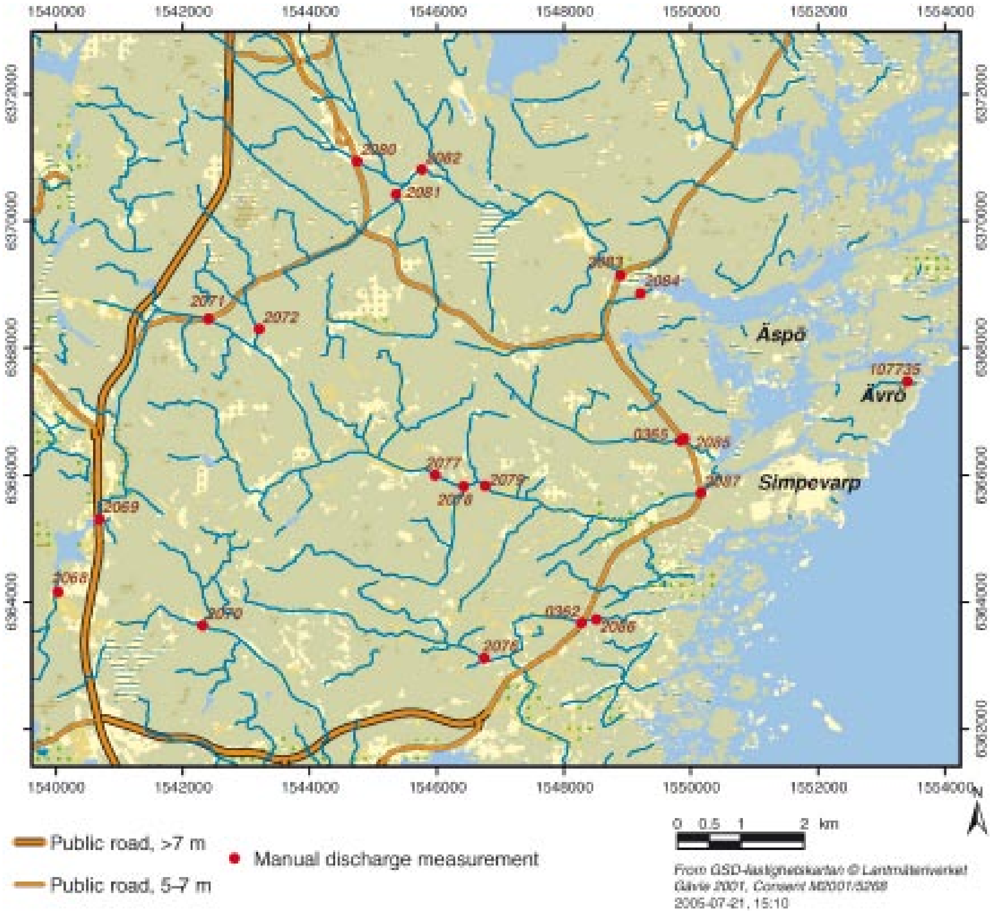

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Figure 3-23. *Map showing the locations of manual discharge measurements in watercourses. Note that all ID codes start with "PSM" and have six figures, e.g. "2077" is short for "PSM002077 ".*

Table 3-23. Manual discharge measurements in watercourses /Ericsson and Engdahl 2004ab/.

Station	Location, size of catchment area for measurement station	Average discharge ($m^3 \cdot s^{-1}$)	Average specific discharge ($l \cdot s^{-1} \cdot km^{-2}$)	Period with discharge data (YYYY-MM-DD) up to Jan. 2005	No. of measurements
PSM000347	Inlet to Lake Frisksjön (catchment area 7), 0.80 km^2	–	–	[2]2005-03-01–	–
[1]PSM000362	Stålglobäcken (catchment area 13), 1.0 km^2	$1.09 \cdot 10^{-2}$	10.9	2004-03-17– 2004-10-01	16
PSM000365	Ekerumsån (catchment subarea 9:1), 2.4 km^2	$1.89 \cdot 10^{-2}$	7.9	2003-10-29– 2005-01-14	23
PSM002068	Tributary to Laxemarån, catchment subarea 10:30	$4.96 \cdot 10^{-2}$	–	2002-11-20– 2005-01-14	40
PSM002069	Watercourse at Lake Jämsen (border between catchment subareas 10:25 and 10:30)	$4.96 \cdot 10^{-2}$	–	2002-11-20– 2004-12-09	45
PSM002070	Tributary to Släthultebäcken (border between catchments subareas 18:1 and 18:6)	$7.68 \cdot 10^{-2}$	–	2002-12-02– [4]2003-12-15	16
PSM002071	Tributary to Laxemarån (catchment subarea 10:25)	$9.74 \cdot 10^{-2}$	–	2002-12-02– 2005-01-14	40
PSM002072	Tributary to Laxemarån (catchment subarea 10:20)	$4.04 \cdot 10^{-2}$	–	2002-12-02– [4]2003-12-19	15
PSM002075	Släthultebäcken/Norrån (border between catchment subareas 18:1 and 18:2)	$8.69 \cdot 10^{-2}$	–	2002-11-18– [4]2003-12-02	21
PSM002076	Uthammarsån (catchment subarea 17:1)	$4.34 \cdot 10^{-2}$	–	2002-12-02– 2004-08-25	26
PSM002077	Laxemarån (catchment subarea 10:1)	$1.94 \cdot 10^{-1}$	–	2002-11-18– [4]2003-12-17	23
PSM002078	Tributary to Laxemarån (border between catchment subareas 10:1 and 10:8)	$3.54 \cdot 10^{-2}$	–	2002-11-18– 2004-11-12	34
PSM002079	Tributary to Laxemarån (border between catchment subareas 10:1 and 10:7)	$1.70 \cdot 10^{-1}$		2002-11-18– 2005-01-14	42
PSM002080	Kärrviksån (catchment subarea 5:1)	$5.69 \cdot 10^{-2}$	–	2002-12-02– [4]2003-12-19	10
PSM002081	Tributary to Kärrviksån (catchment subarea 5:8)	$2.11 \cdot 10^{-1}$	–	2002-11-19– 2004-11-11	13
PSM002082	Kärrviksån (catchment subarea 5:1)	$3.19 \cdot 10^{-1}$	–	2002-11-19– 2004-11-11	22
[3]PSM002083	Mederhultsån (catchment area 6)	$1.95 \cdot 10^{-1}$	–	2002-10-29– 2005-01-14	47
PSM002084	Kärrviksån (catchment subarea 5:1)	$5.76 \cdot 10^{-2}$	–	2002-10-29– 2004-11-11	39
PSM002085	Ekerumsån (catchment subarea 9:1)	$2.79 \cdot 10^{-2}$	–	2002-10-29– 2005-01-14	38
[1]PSM002086	Stålglobäcken (catchment area 13)	$8.14 \cdot 10^{-2}$	–	2002-10-29– 2004-09-24	20
[3]PSM002087	Laxemarån (catchment subarea 10:1)	$2.20 \cdot 10^{-1}$	–	2002-10-29– 2005-01-14	42
PSM107735	Vadvikebäcken (catchment area 23)	$1.46 \cdot 10^{-2}$	–	2003-12-10– 2004-10-19	12

[1] These locations are in the same watercourse (see Figure 3-23).

[2] Data are neither presented nor analysed, as measurements started after the data freeze for L1.2.

[3] During the period November 2003–May 2004, measurements were performed the same dates at the nearby locations PSM0000368/PSM002083 and PSM000364/PSM002087. In the SICADA database, data for these two pairs of locations are incorporated in the data files for points PSM002083 and PSM002087, respectively, as measurements now are made at these specific locations (pers. comm. with Mansueto Morosini, SKB). In cases where there is a difference in the reported values for "simultaneous" measurements, average values are calculated and used to represent single measurements.

[4] Measurements have been terminated.

3.3 Hydrogeological data

3.3.1 Hydrogeological properties

In the S0 and S1.1 stages, no site-specific hydrogeological data (hydraulic conductivity and storage parameters) were available for the QD or the interface between QD and near-surface bedrock. These previous model versions therefore included literature data and expected ranges for the hydraulic properties for different types of QD typical for Swedish geological conditions. In the S1.2 data freeze, results from so-called slug tests /Johansson and Adestam 2004ab/ were reported to SICADA for 13 groundwater monitoring wells (11 wells in the Simpevarp subarea and 2 wells in the Laxemar subarea). The purpose of slug tests is to provide estimates of the hydraulic conductivity (K) of the QD and/or the QD/bedrock interface (depending on where the well screen is). It is also possible to obtain an approximate value of the storativity (S) from slug tests; however, storativity data from these slug tests were not reported to the SICADA database.

Data from slug tests in 12 additional groundwater monitoring wells (all located in the Laxemar subarea) are included in the L1.2 data freeze /Johansson and Adestam 2004cd/. In the L1.2 data freeze, data from grain-size analyses (particle-size distribution curves) from QD samples are also available and used in order to obtain supplementary hydraulic conductivity data on the QD.

Hydraulic parameters from slug tests

Between the S1.2 and L1.2 data freezes, slug tests have been performed in 14 additional groundwater monitoring wells in the Laxemar subarea /Johansson and Adestam 2004cd/. However, in two of the wells (SSM000028 and 32), the water level was not recovered within a reasonable time frame during the tests, and therefore no hydraulic conductivity data were obtained from these wells. The standpipe of the tested wells has an inner diameter of 50 mm, and the lengths of the well screens are 1 or 2 metres. The diameter of the boreholes where the standpipe is installed is 82 or 120 mm. The results of all performed slug tests are presented in Appendix 2. The locations of the slug-tested wells are shown in Figure 3-24. This figure also shows the locations of wells with data from manual and/or automatic groundwater level measurements. It should be noted that the screens are located in till in almost all groundwater monitoring wells.

In the parameter evaluation, the transmissivity T obtained from a slug test is defined as $T = K \cdot B$, where B is the smallest of the screen length and the thickness of the tested QD layer /Johansson and Adestam 2004bd/. In cases where more than one slug test has been performed, the K-value corresponding to the T-value reported to SICADA is marked with a *-symbol in the table in Appendix 2.

A statistical analysis of the data from wells with their screens installed in till shows that the arithmetic mean value of K is c $2.7 \cdot 10^{-5}$ m·s^{-1} (geometric mean c $1.2 \cdot 10^{-5}$ and median c $1.9 \cdot 10^{-5}$ m·s^{-1}). The standard deviation is c $3.2 \cdot 10^{-5}$ m·s^{-1}, and the 95% confidence interval for the geometric mean value is $5.5 \cdot 10^{-6} < 1.2 \cdot 10^{-5} < 2.5 \cdot 10^{-5}$ m·s^{-1}. From slug tests in wells with the screen in stony-gravelly sand, sand and fine sand, the arithmetic mean value is c $5.3 \cdot 10^{-5}$ m·s^{-1}, and the geometric mean value and the median is c $2.8 \cdot 10^{-5}$ m·s^{-1}. For the remaining types of QD (silty-sandy clay, clayey-gravelly sand, clayey till, peat/sandy clay/clayey-sandy till, and sandy-clayey silt) the arithmetic mean value is c $1.3 \cdot 10^{-5}$ m·s^{-1}, the geometric mean value is c $9.6 \cdot 10^{-6}$ m·s^{-1}, and the median is c $6.8 \cdot 10^{-6}$ m·s^{-1}. Note that the type of QD at the screen depth is uncertain for some wells. Data from the slug tests in SSM000015 ("boulders"; uncertain QD classification) and SSM000018 (unusually high K-value for clayey till) are not included in the calculations.

Hydraulic parameters from particle-size distribution curves

Grain-size analyses (sieving) have been performed on a number of QD samples from boreholes, pits and trenches drilled/excavated in connection with various hydrogeological and geological investigations of the QD. Data from the resulting particle-size distribution curves (PSD) are used here in order to obtain supplementary hydraulic conductivity data on the QD. The PSD-based analysis is performed using two alternative methods, the Hazen method and the Gustafson method /Andersson et al. 1984/; see Appendix 3. Both these methods require the d_{10} value; this value can usually not be quantified for very fine-grained (clayey) soils. Table A-2 in Appendix 3 presents values of the hydraulic conductivity K for the soil samples for which the d_{10} value are available.

An analysis with sandy till and gravelly till defined as a single QD class gives an arithmetic mean value of K based on the Hazen method of c $4.9\cdot10^{-5}$ $\text{m}\cdot\text{s}^{-1}$ (geometric mean c $1.2\cdot10^{-5}$ and median c $1.1\cdot10^{-5}$ $\text{m}\cdot\text{s}^{-1}$). The arithmetic mean value based on the Gustafson method is c $6.2\cdot10^{-6}$ $\text{m}\cdot\text{s}^{-1}$ (geometric mean c $3.3\cdot10^{-6}$ and median c $3.1\cdot10^{-6}$ $\text{m}\cdot\text{s}^{-1}$). The slug tests in wells with their screens in till (see previous section), give arithmetic and geometric mean values of c $2.7\cdot10^{-5}$ and $1.2\cdot10^{-5}$ $\text{m}\cdot\text{s}^{-1}$, respectively, whereas the median is c $1.9\cdot10^{-5}$ $\text{m}\cdot\text{s}^{-1}$. It follows that the slug tests and the Hazen method provide approximately similar

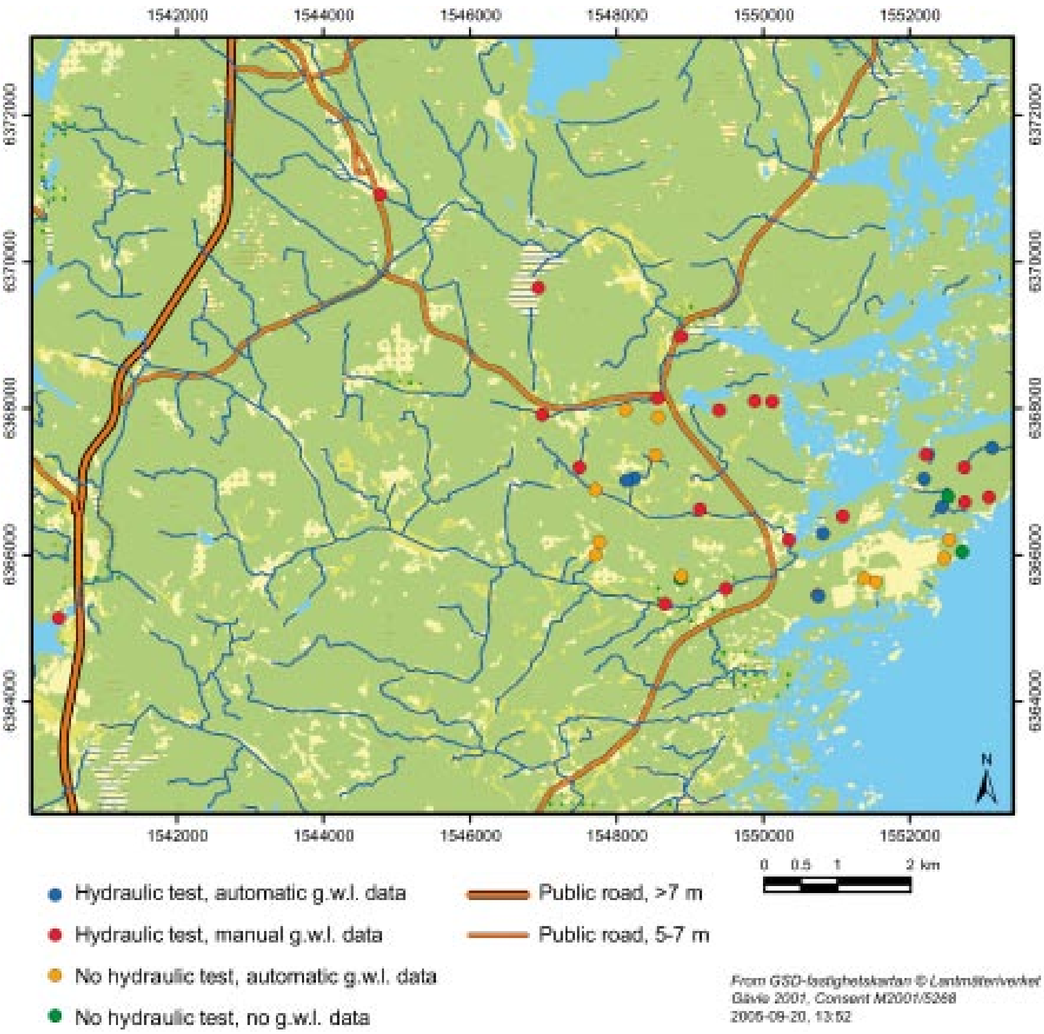

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Figure 3-24. *Locations of groundwater monitoring wells installed by SKB in the Simpevarp regional model area and data available from each monitoring well. Note that the data/measurements symbols refer to the L1.2 dataset. After the L1.2 data freeze automatic groundwater level measurements have started in several of the wells marked "manual g.w.l. data".*

mean/median values for the hydraulic conductivity of the till (in the range c $1–5 \cdot 10^{-5}$ m·s^{-1}), whereas the Gustafson method gives somewhat lower *K*-values (c $3–6 \cdot 10^{-6}$ m·s^{-1}). Table 3-24 summarises the average *K*-values obtained for sandy (gravelly) till from the slug tests and the analyses of PSD curves.

Table 3-24. Summary of average *K*-values for sandy (gravelly) till obtained from slug tests and PSD analyses.

Type of test/analysis method (no. of tests/samples)	Hydraulic conductivity K (m·s^{-1})
Slug tests (15 monitoring wells)	
Arithmetic mean	$2.7 \cdot 10^{-5}$
Geometric mean	$1.2 \cdot 10^{-5}$
Median	$1.9 \cdot 10^{-5}$
PSD (29 till samples)	
Hazen method:	
Arithmetic mean	$4.9 \cdot 10^{-5}$
Geometric mean	$1.2 \cdot 10^{-5}$
Median	$1.1 \cdot 10^{-5}$
Gustafson method:	
Arithmetic mean	$6.2 \cdot 10^{-6}$
Geometric mean	$3.3 \cdot 10^{-6}$
Median	$3.1 \cdot 10^{-6}$

3.3.2 Groundwater levels in QD

Summary of groundwater level measurements

Up to December 2004, a total of 42 groundwater monitoring wells have been installed by SKB in the QD of the Simpevarp regional model area. For the L1.2 modelling, data on automatically measured groundwater levels are available from 18 of these wells. Measurements have been terminated in nine of these wells, as measurements were performed as short-term groundwater level monitoring in connection to drilling in the bedrock. Further, data are available from manual groundwater level measurements in 29 wells. Out of these 29 wells, there are data from both automatic and manual measurements in 10 wells. In five wells, including one dry well, no groundwater level measurements have been made.

The locations of groundwater monitoring wells from which groundwater level data are available for the L1.2 modelling are shown in Figure 3-24 in Section 3.3.1. The table in Appendix 4 summarises the available time series data from automatic and manual groundwater level measurements in wells in QD in the Simpevarp area, as of December 2004. The ID codes of the wells from which automatically measured groundwater level data are obtained in the L1.2 stage are shown in Figure 3-25. During 2005 (i.e. after the L1.2 data freeze), automatic groundwater level measurements have started in several additional wells in Laxemar, most of which are indicated as manually measured in Figure 3-24 and 3-25. Thus, these wells will also provide detailed groundwater level data that can be used in future model versions.

The general impressions from the manually measured groundwater level data (Appendix 4) are that the groundwater table is shallow and that the temporal variations, with some exceptions, are relatively small. Specifically, the total variations in the groundwater level, i.e. the differences between the measured maximum and minimum levels, are usually in the range 0.5–1 metre. However, it must be observed that the manual measurements have been performed at a limited number of occasions, and that the actual variations therefore likely are larger than the measured ones.

Figure 3-26 shows a map with groundwater levels in the QD (metres above sea level), measured manually during September 2004. As expected, wells located in higher-altitude areas have higher absolute groundwater levels (cf the elevation map in Figure 4-2). The highest groundwater levels are found in the central and northern parts of the Laxemar subarea. As shown in Figure 3-26, the data points are very sparse, which is the reason why no interpolation and presentation in terms of isolines is presented. The data points are somewhat denser around Lake Frisksjön, and in particular on the island of Ävrö.

These areas of denser data points show that there are relatively large differences in groundwater levels between nearby monitoring wells in QD. In turn, this observation illustrates that there are rather small catchment areas, having local near-surface groundwater flow systems with small distances between groundwater recharge and discharge areas. A groundwater recharge area is defined as an area where the groundwater flow has a downward component; a groundwater discharge area is defined as an area where the groundwater flow has an upward component.

It is also clear from Figure 3-26 that there is a large number of groundwater monitoring wells in the vicinity of surface waters, i.e. watercourses, wetland areas and lakes; these are generally located in low-altitude areas, with a relatively large thickness of QD. Hence, the figure indicates that there are few monitoring wells that can be used for characterisation of groundwater flow in exposed or shallow bedrock areas, which cover some 35% of the regional model area (cf Section 4.1.3).

Automatic groundwater level measurements

Figure 3-27 and 3-28 show plots of all automatically measured groundwater levels in the monitoring wells in QD within the regional model area. Figure 3-27 shows the groundwater levels expressed in terms of metres above sea level, whereas Figure 3-28 shows the same data expressed in metres below the ground surface. Thus, Figure 3-27 displays absolute groundwater levels and Figure 3-28 “groundwater depths”. The locations of the wells are shown in Figure 3-25 above.

The figures show that the variations in the groundwater level, with some exceptions, can be regarded as small. In most wells, the difference between the highest and lowest levels recorded during period is in the interval 0.5–1 metre, which is similar to that obtained in the manual groundwater level measurements. Further, it is seen in Figure 3-28 that the groundwater table is generally located approximately 0.5–1.5 metre below the ground surface. The exceptions are the wells SSM000004 and -011, which show a deeper groundwater table (depth c 2–2.5 metres); especially SSM000004 demonstrates a “deep” groundwater table during most of the measurement period.

Figures 3-27 and 3-28 also show that the available time series are very short, with the exception of those from three wells (SSM000002, -04 and -05). However, these three wells have been used for short-term monitoring at core-drill sites, and the measurements in all three have been terminated. More detailed analyses would require groundwater level data, and associated meteorological and hydrological data, for a period of at least one (hydrological) year. This means that such analyses must be postponed to future model versions, when longer time series are available.

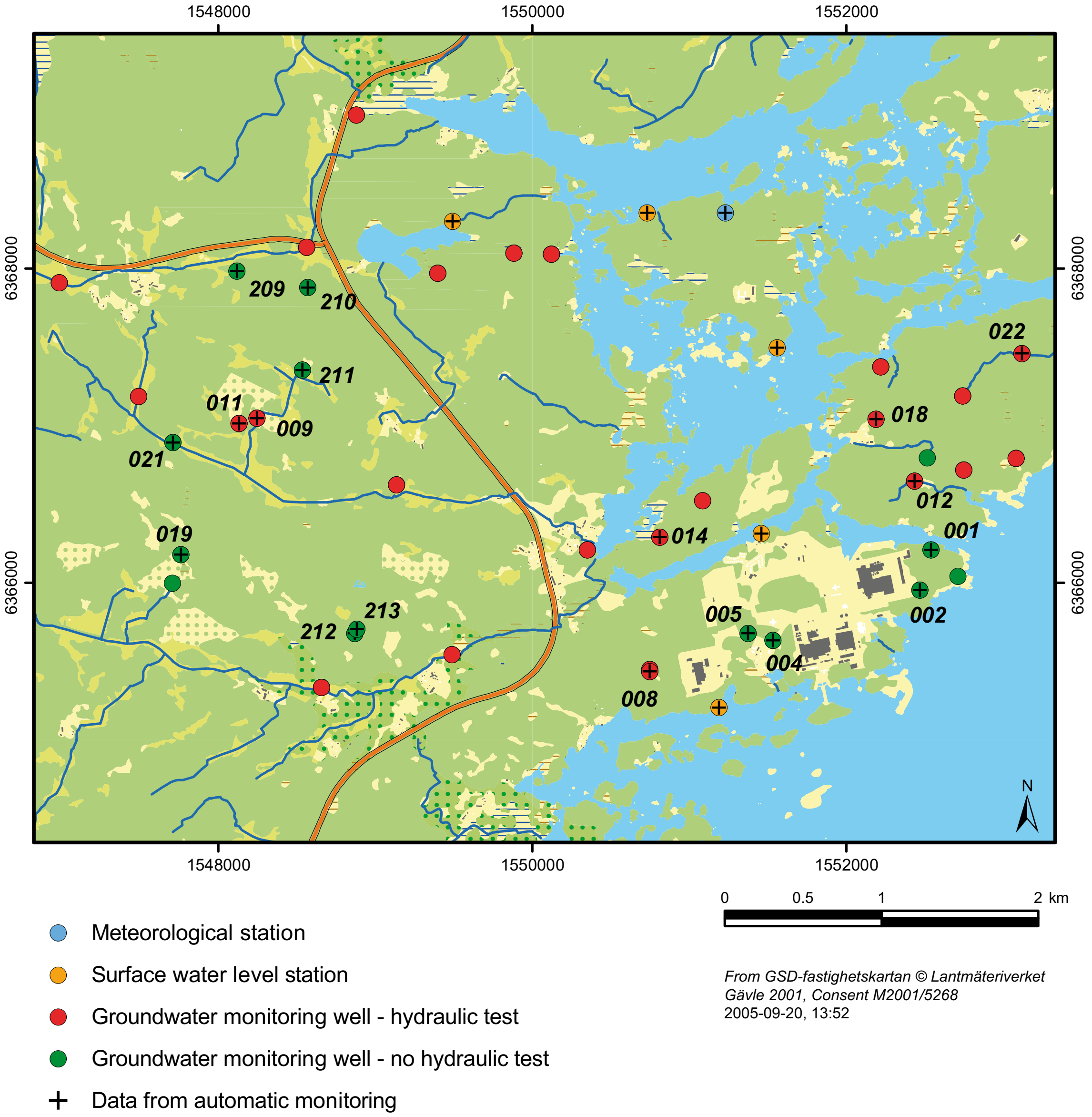

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Figure 3-25. *Locations of groundwater monitoring wells and meteorological and hydrological stations used to produce data for the L1.2 modelling. Stations providing time series data from automatic measurements are marked with "+". Simplified ID codes (e.g. 011 = SSM000011) of groundwater monitoring wells included in Figure 3-27 and 3-28 are also shown.*

As described above, measurements are no longer performed in the monitoring wells that have the longest time series in Figures 3-27 and 3-28. In order to focus on the results from monitoring wells with ongoing automatic measurements, i.e. the wells that will produce the long-term records to be used in forthcoming model versions, Figure 3-29 shows time series measured in such wells during the period August to December 2004. Note that not all monitoring wells with ongoing measurements are included; some wells are excluded for readability of the graph.

It can be seen in Figure 3-29 that many wells show similar seasonal patterns, with decreasing levels during September and a large increase in mid-October. After a period of more or less constant groundwater levels during most of November, the levels increase, or show a short-term peak, late in that month. In December, the general trend is that the

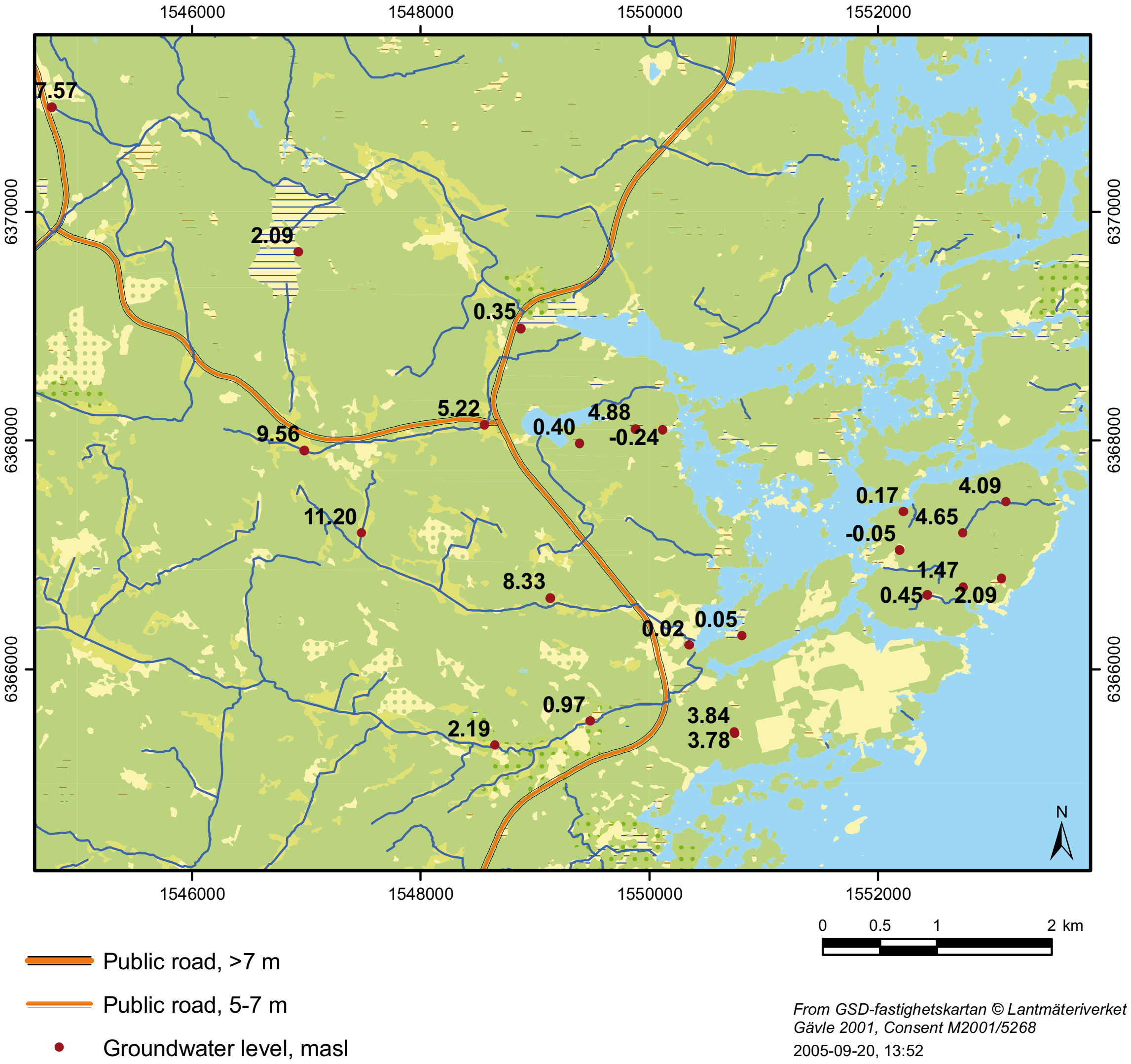

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Figure 3-26. *Absolute groundwater levels obtained from manual level measurements in QD during September 2004.*

groundwater levels decrease slightly. However, some differences among the monitoring wells can also be noted. The largest variations, more than two metres between the maximum and minimum levels during the period, were recorded in SSM000011, whereas the groundwater level in SSM000017 showed very small variations. Interesting is also to note that monitoring wells in both subareas, i.e. Laxemar (e.g. SSM000011 and –213) and Simpevarp (e.g. SSM000012 and -022), respond similarly during periods of changing groundwater levels (mid-October and late November–early December)

Figure 3-30 shows groundwater levels measured in selected monitoring wells in the Laxemar subarea during the period September to December 2004 (absolute levels, metres above sea level). For comparison, the sea level and the water level in Lake Frisksjön (cf Figure 3-16) are also shown in the figure; since these water levels are much lower than the groundwater levels in Laxemar, they are plotted on a separate y-axis. Comparing the surface water and groundwater level variations in Figure 3-30, it is seen that the groundwater levels do not appear to be affected by the sea level. However, the water level variations in Lake Frisksjön show some similarities with the groundwater levels, although the variations are smaller in the lake than in most of the monitoring wells.

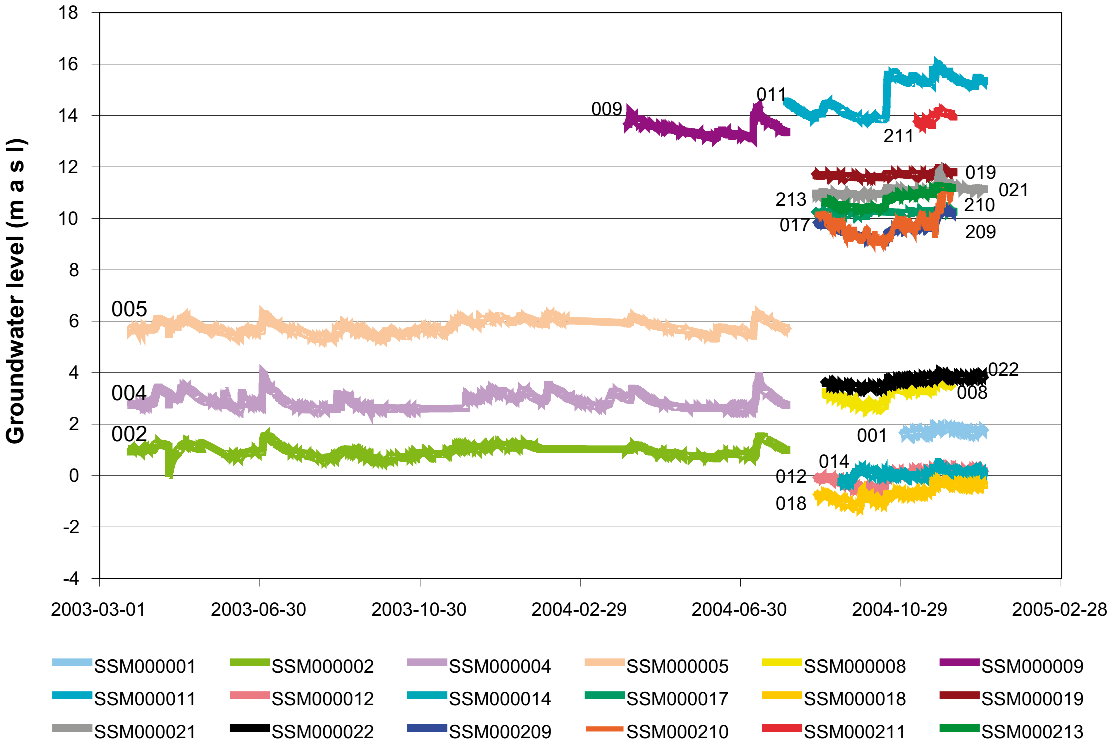

Figure 3-27. *Automatically measured groundwater levels in the monitoring wells in the Simpevarp area, expressed as absolute levels (in metres above sea level, m.a.s.l.).*

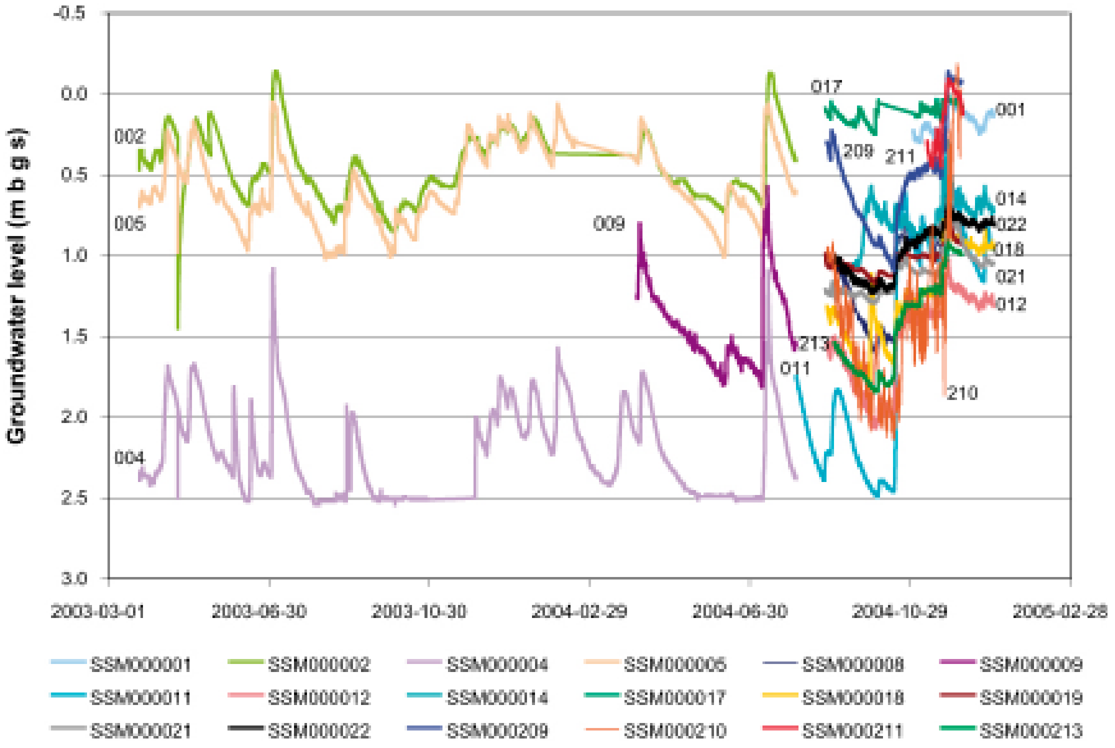

Figure 3-28. *Automatically measured groundwater levels in the monitoring wells in the Simpevarp area, expressed in terms of depths below ground (in metres below ground surface, m.b.g.s.).*

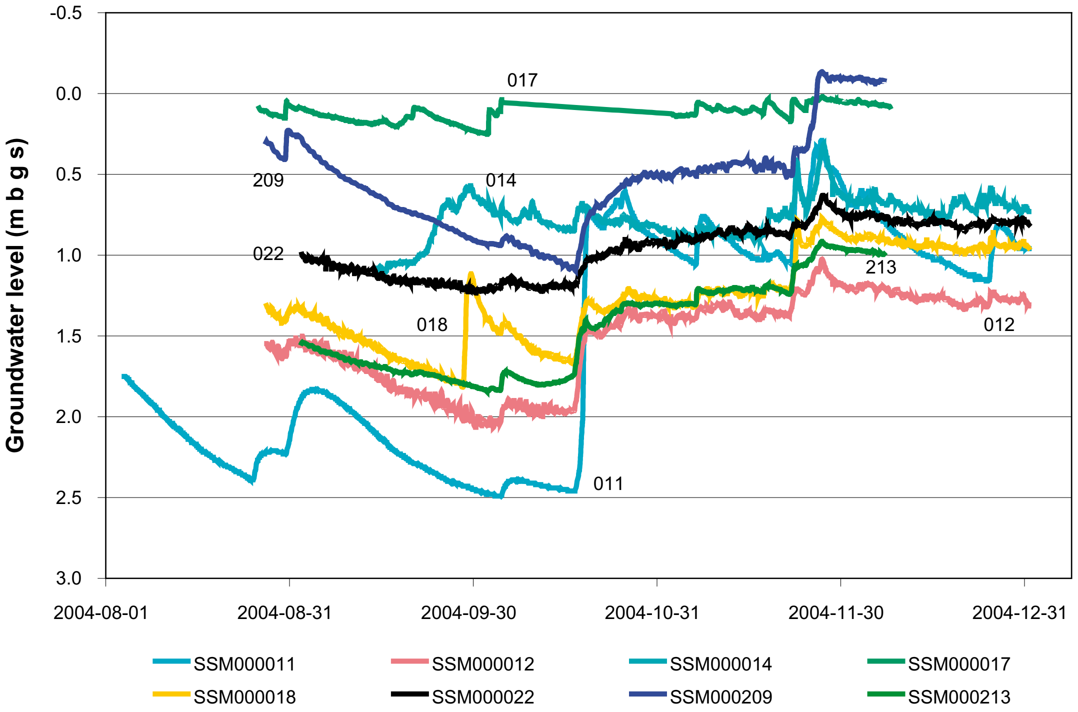

Figure 3-29. *Groundwater levels relative to ground (metres below ground surface) during the period from August to December 2004 in selected monitoring wells in the Simpevarp and Laxemar subareas.*

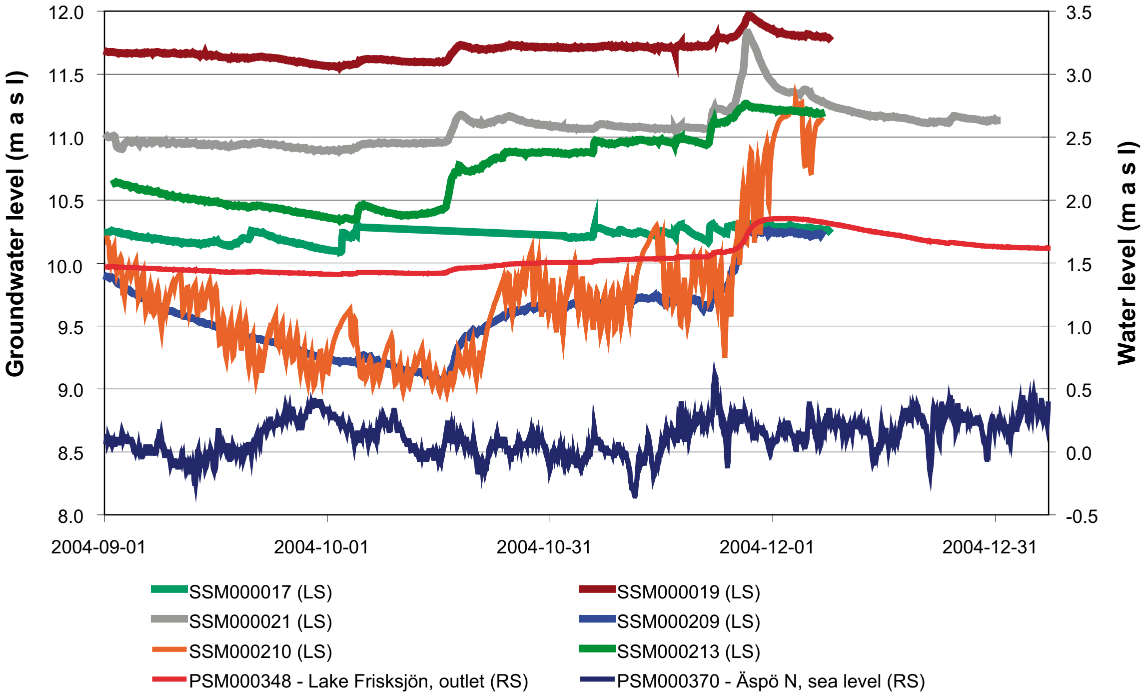

Figure 3-30. *Comparison of selected groundwater levels in the Laxemar subarea and the water levels in Lake Frisksjön and the sea, expressed as absolute levels (metres above sea level) using different y-intervals for groundwater and surface water levels (LS = left y-scale, RS = right y-scale).*

A similar comparison between groundwater levels measured in some of the monitoring wells in the Simpevarp subarea and the sea water level is shown in Figure 3-31. The groundwater level in one of the monitoring wells, SSM000014 on the Hålö island, appears to be closely related to the sea level variations, whereas there are no obvious co-variations between the sea level and the other Simpevarp monitoring wells. Actually, the period of relatively high sea water levels in September–October 2004 coincides with the lowest groundwater levels in many monitoring wells. This is also the case with many groundwater level time series measured in the Laxemar subarea (Figure 3-30).

A shallow groundwater table generally implies a strong interaction between the precipitation/evapotranspiration and the groundwater level variations. This interaction is illustrated in Figure 3-32, which shows the effects of diurnal (repeating daily) potential evapotranspiration cycles on the groundwater level in monitoring well SSM000009 during the period from 2004-07-01 to 2004-07-05. During this period, the groundwater level in SSM000009 is at a depth of about 1.7 metres below ground (cf Figure 3-28). It is clearly seen in the figure that an increased potential evapotranspiration (during day time) is associated with a decrease of the groundwater level; the opposite phenomenon is observed when the potential evapotranspiration decreases (during the nights).

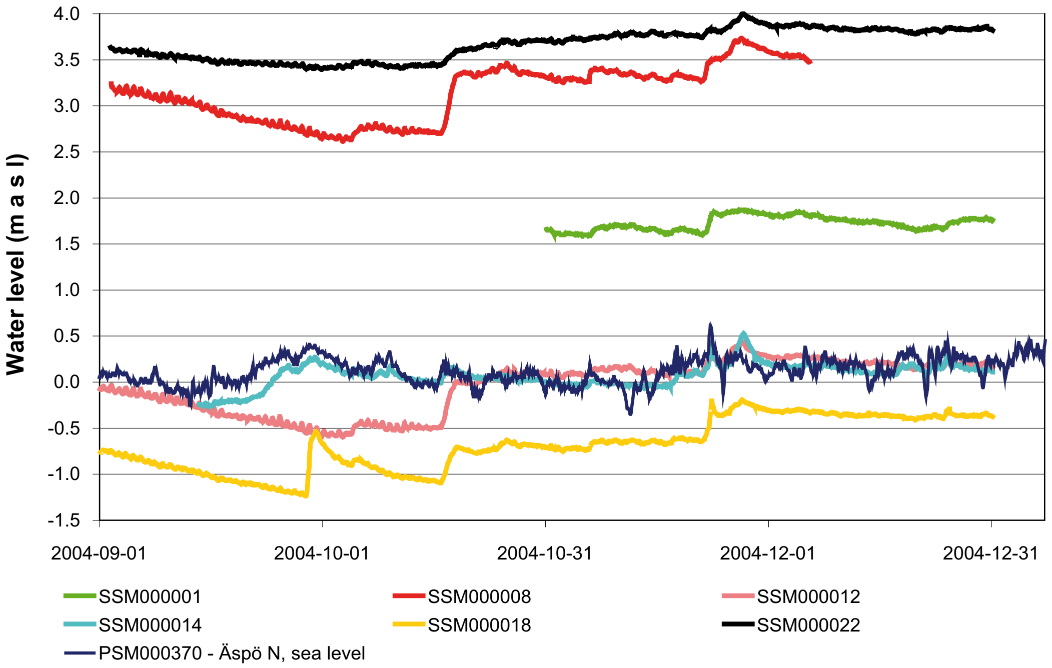

Figure 3-31. *Comparison of selected groundwater levels in the Simpevarp subarea and the sea level, expressed as absolute levels (metres above sea level).*

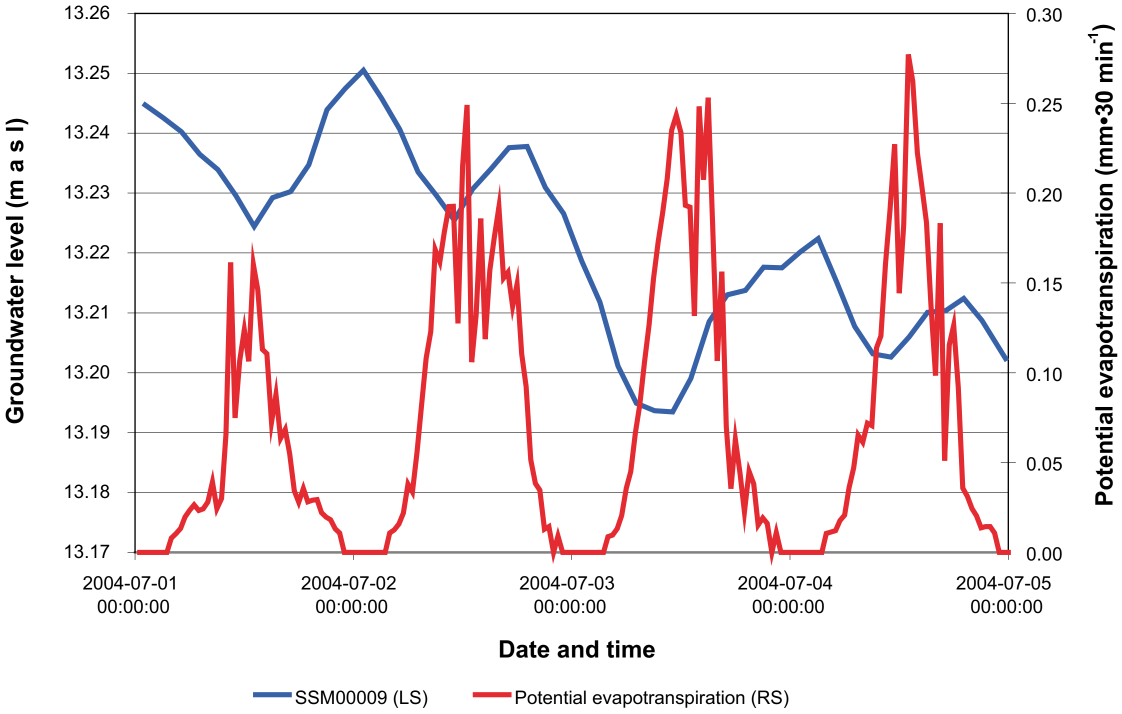

Figure 3-32. *Comparison of diurnal potential evapotranspiration cycles and the groundwater level in monitoring well SSM000009 during the period from 2004-07-01 to 2004-07-05.*

3.4 Private wells and other water-related activities

3.4.1 Private wells

The private wells in the Simpevarp regional model area were investigated and described by /Morosini and Hultgren 2003/. The locations of the wells found in the inventory are shown in Figure 3-33. For a list of the wells and collected basic data on them, see /Morosini and Hultgren 2003/ or /Werner et al. 2005/.

There are totally 218 private wells identified in the Simpevarp regional area, of which 213 have been checked in the field /Morosini and Hultgren 2003/. The well capacity is not reported, but the pumped discharge, Q_p, is reported for 6 wells. For these 6 wells, Q_p is between 0.24 and 5 $m^3 \cdot h^{-1}$ ($2.10 \cdot 10^3$ and $4.38 \cdot 10^4$ $m^3 \cdot y^{-1}$), with a mean value of $1.57 \cdot 10^4$ $m^3 \cdot y^{-1}$. The standard deviation of Q_p is large, $1.61 \cdot 10^4$ $m^3 \cdot y^{-1}$.

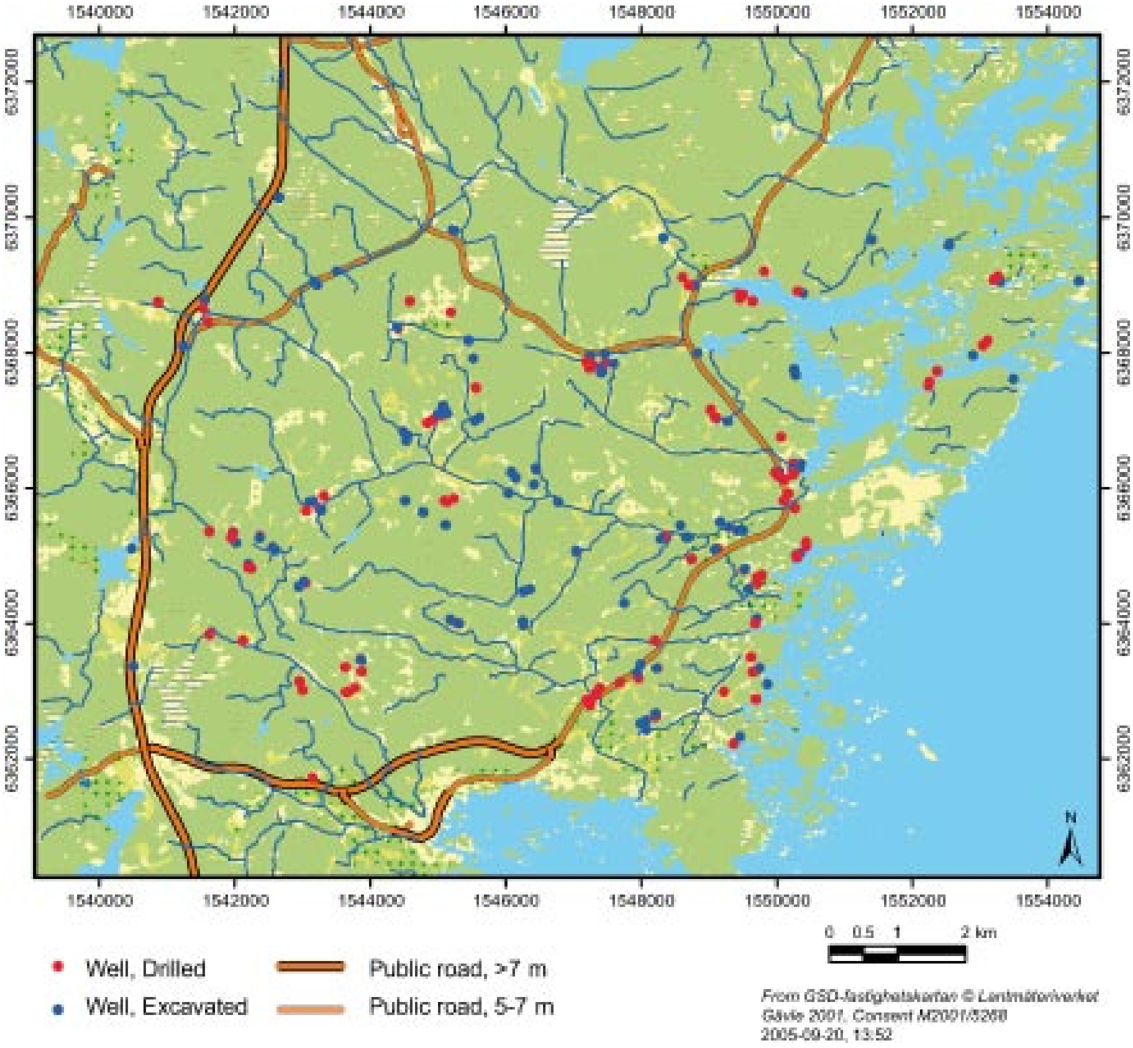

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***Figure 3-33.** Locations of private wells in the Simpevarp regional model area.*

3.4.2 Water handling at OKG

Activities involving artificial handling of water (pumping, drainage, discharge, recharge and so forth) are relevant for the overall understanding of the water systems in the regional model area. In particular, OKG, the owner and operator of the nuclear power plant on the Simpevarp peninsula, is responsible for most of the water-handling activities in the area. Therefore, this section provides a brief overview of the water handling at OKG.

It should be noted that the description does not contain any presentation and/or evaluation of site investigation data, and that more detailed data will be presented in connection with future model versions. For instance, data on surface water levels and pumping rates measured from 1972 until present are available in a paper log-book at OKG. During 2005, all these data will be stored in a digital database, which means that they will become accessible for analyses in connection with forthcoming site descriptive modelling.

The historical and present pumping of drinking, process and cooling water at OKG can be briefly summarised as follows (pers. comm. with Kenneth Gustafsson, OKG):

- Up to the end of the 1980's, water was pumped from Lake Trästen (situated west of the Laxemar subarea, upstream of Lake Fårbosjön) into Lake Jämsen, which has its natural outlet in the watercourse Laxemarån. Drinking and process water for OKG was during this period pumped from Ström in Laxemarån. The purpose of the pumping from Lake Trästen to Lake Jämsen was to compensate for the pumping from Laxemarån.
- Since 1983, drinking and process water for OKG is pumped from Lake Götemaren (situated north of the Laxemar subarea) in a pipeline to a water supply plant operated by OKG. At present, approximately 150,000–200,000 m^3 of water is pumped each year (information found at OKG's internet home page, www.okg.se).
- At present, Lake Söråmagasinet is used as reserve water supply for drinking and process water for OKG. Occasionally, on the order of a few days each year or every second year, water is pumped from Ström on the watercourse Laxemarån into Lake Söråmagasinet, in order to maintain the available water storage in the lake (see Figure 3-34).
- Cooling water for the nuclear power plant is pumped from the sea.

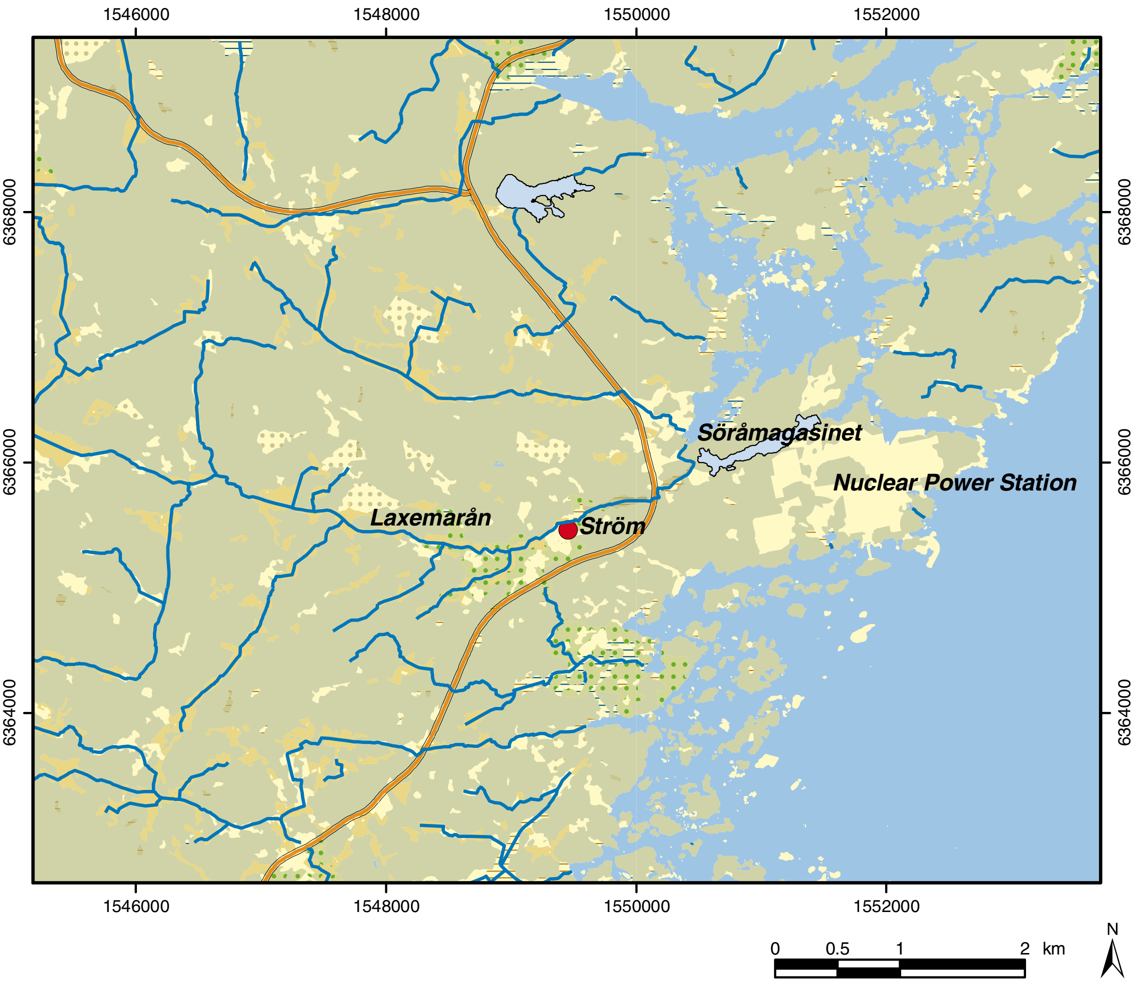

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Figure 3-34. *Map showing the location of Ström on the watercourse Laxemarån, from where water occasionally is pumped by OKG into Lake Söråmagasinet.*

The stormwater and wastewater handling at OKG can be summarised as follows:

- The sea is the recipient for storm water from the OKG industrial area (pers. comm. with Pär Grahm, OKG). Most of the storm water is discharged into Hamnefjärden, where it is mixed with the cooling water from the power plant. The storm water from the areas south and east of the O2 reactor building (including the central workshop and some oil tanks) is treated locally and discharged into a pond ("Spegeldammen"), located south east of the central restaurant "Simpan". The pond also receives sea water from the cleaning plant of O2. In the pond, some sedimentation and nutrient uptake take place. It is connected to the sea via an open ditch. The pond does not have any artificial sealing layer at the bottom that would reduce the contact with surrounding natural waters (pers. comm. with Kenneth Gustafsson, OKG).
- The Sörå village is situated in a previous march area, and therefore has a ground drainage system. This drainage is collected in a well and pumped into the sea (Hamnefjärden).
- The storm and waste water networks at OKG are separated. All waste water is treated in OKG's own waste water treatment plant. After treatment, the waste water is discharged into the sea (Hamnefjärden). Similar to other waste water, the main remaining chemical constituents of this water are nitrogen, phosphorous and oxygen-consuming substances.

3.4.3 "Missing" watercourses and drained areas

Many watercourses in the Simpevarp area are diverted and/or flow in conduits, and therefore diverge from the "natural" topography-controlled flow conditions /Carlsson et al. 2005, Svensson 2005/. Parts of watercourses are "missing" in the SKB GIS database, in some cases because the watercourses flow in conduits /Svensson 2005/. The Simpevarp area is generally characterised by many drained areas /Nyborg et al. 2004/, which probably would be lakes or wetlands without these drainage operations. Ditches, drainages, and "missing" watercourses that have been characterised /Carlsson et al. 2005, Svensson 2005/, but not included in the Laxemar 1.2 model version, will be considered in future modelling efforts.

3.4.4 Groundwater monitoring programmes at Clab and Äspö

In parallel to the site investigations in the Simpevarp area, there are ongoing groundwater monitoring programmes for Clab (OKG) and the Äspö Hard Rock Laboratory (SKB). This monitoring involves groundwater sampling and analyses for chemical and microbiological parameters, as well as measurements of groundwater levels. The monitoring programmes include both private wells (in soil and bedrock) and a number of boreholes in bedrock, drilled for other purposes than the site investigations in Simpevarp.

4 Modelling of surface water and near-surface groundwater flow

4.1 Conceptual-descriptive model

4.1.1 Modelling framework and objectives

This section presents an updated conceptual-descriptive model of the surface and near-surface water flow system in the Simpevarp area. One important purpose of the conceptual-descriptive modelling in the present section is to provide a basis for the quantitative water flow modelling, which is presented in Section 4.2. According to the definitions given by /Rhén et al. 2003/, the *conceptual model* should define the framework in which the problem is to be solved, the size of the modelled volume, the boundary conditions, and the equations describing the processes. The *descriptive model* defines, based on a specified conceptual model, geometries of domains and parameters assigned to these domains.

The present modelling integrates these aspects, and no subdivision is made here into conceptual and descriptive models. It should also be noted that the present conceptual-descriptive modelling concerns the whole regional model area, whereas the quantitative water flow modelling is focused on the catchment areas 6, 7, 8 and 9 (see Figure 3-13), including near-coastal parts of land (i.e. areas with direct runoff to the sea) and the most adjacent parts of the Baltic Sea.

The present model is an update of the previous S1.2 model, based on the site investigation data included in the previous model versions and the additional data collected between the S1.2 and L1.2 data freezes. Specifically, the objectives of the conceptual-descriptive modelling, common to the Simpevarp and Laxemar subareas, are to describe

- the boundaries and the topography of the model area,
- type areas, flow domains and interfaces relevant for the surface water and near-surface groundwater flow system, including parameters required for quantitative modelling of water flow in the model area, and
- other conditions of importance for the surface water and near-surface groundwater flow in the model area.

The confidence and uncertainties associated with the L1.2 modelling are discussed in Chapter 5.

The presentation and evaluation of meteorological, hydrological and hydrogeological site investigation and regional data (see Chapter 3) provide the basis for the updated conceptual-descriptive model. This model is then evaluated by application of a quantitative water flow model, which in turn serves two main purposes:

- To evaluate the conceptual-descriptive model, in order to further develop the overall understanding of the hydrological, meteorological and hydrogeological conditions in the Simpevarp area, and to provide a basis for future model versions.
- To produce output data necessary for other models and applications (i.e. modelling of groundwater flow in the bedrock, ecosystems modelling, Environmental Impact Assessment, and so forth).

In the S1.1 model version, the disciplines of meteorology, hydrology and hydrogeology were treated separately, whereas the previous S1.2 and the present L1.2 models integrate them. In addition, S1.1 was regional in character. As far as possible, depending on the available site investigation data, (see Chapter 3), S1.2 and L1.2 aim at local-scale modelling. Due to the still limited amount of data (especially time series), the conceptual-descriptive modelling is to a large extent based on the general knowledge of the regional-scale meteorological, hydrological, and hydrogeological conditions.

Figure 4-1 illustrates SKB's systems approach to hydrogeological descriptive modelling of groundwater flow. There is a division into three types of hydraulic domains, namely overburden materials (Hydraulic Soil Domains, HSD), rock mass (Hydraulic Rock Domains, HRD) and conductors in bedrock, i.e. larger deformation zones that are handled deterministically in the modelling (Hydraulic Conductor Domains, HCD). This division constitutes the basis for the quantitative models. From a hydrogeological perspective, the geological data and related interpretations constitute the basis for the geometrical modelling of the different hydraulic domains. Thus, the investigations and documentation of the Quaternary deposits (in this report abbreviated QD), and the upper part of the bedrock, provide input to

- the distribution of QD, including genesis, composition, stratification, thickness and depth,
- the geometry of deterministic fracture zones (or lineaments, if needed) (HCD) and the bedrock in between (HRD).

As mentioned in Section 1.2, a complete descriptive model of the hydrological and hydrogeological conditions at a site involves a description of the integrated (continuous) hydrogeological-hydrological system. The focus of the present description is on the surface- and near-surface conditions. In the present context, where the Hydraulic Soil Domains (HSD) are investigated in more detail, a further division is made of the near-surface hydrogeology (in terms of type areas, flow domains and interfaces, as explained below) than that shown in Figure 4-1.

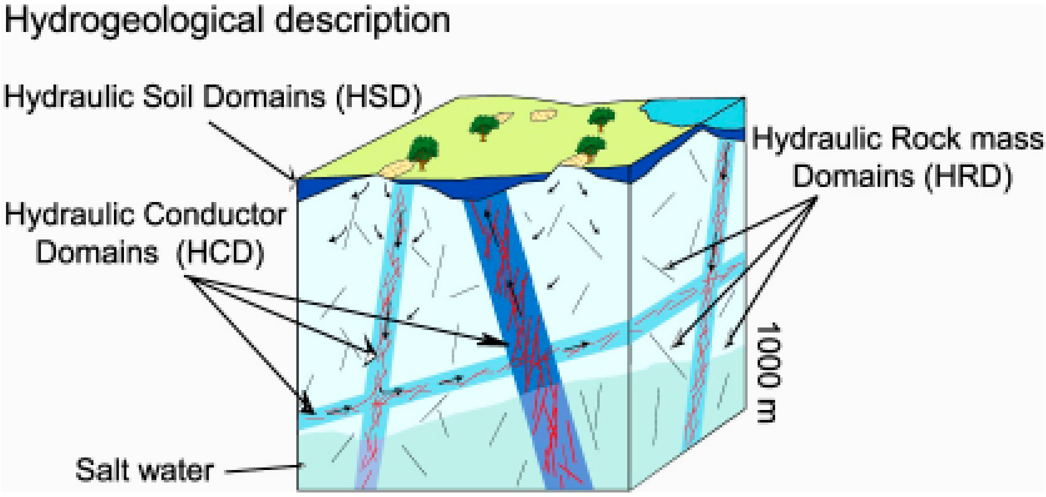

***Figure 4-1.** Division of the overburden and the bedrock into hydraulic domains, representing the Quaternary deposits (HSD), and the rock domains (HRD) between deformation zones modelled as hydraulic conductor domains (HCD) /Rhén et al. 2003/.*

4.1.2 Boundaries and topography

The model area is characterised by a relatively small-scale topographical undulation, see Figure 4-2, and by relatively shallow QD. Almost the entire area is below 50 metres above sea level, and the whole Simpevarp regional model area is located below the highest coastline.

The conceptual-descriptive model area is the same as that covered by the detailed catchment area mapping /Brunberg et al. 2004/, cf Figure 3-13. It should be noted that the quantitative water flow model discussed in Section 4.2 covers only four of the totally 26 catchment areas (i.e. catchment areas 6-9), and also near-coastal parts of land (i.e. areas with direct runoff to the sea) and the Baltic Sea (see Section 4.2). Due to shallow groundwater in the QD, it is assumed that the water divides for surface water and near-surface groundwater coincide. Hence, the boundaries between the catchment areas in Figure 3-13 are assumed to be no-flow boundaries for both surface and near-surface water flow. The boundary towards the sea is a prescribed head boundary, either constant or time-varying, depending on the considered time scale.

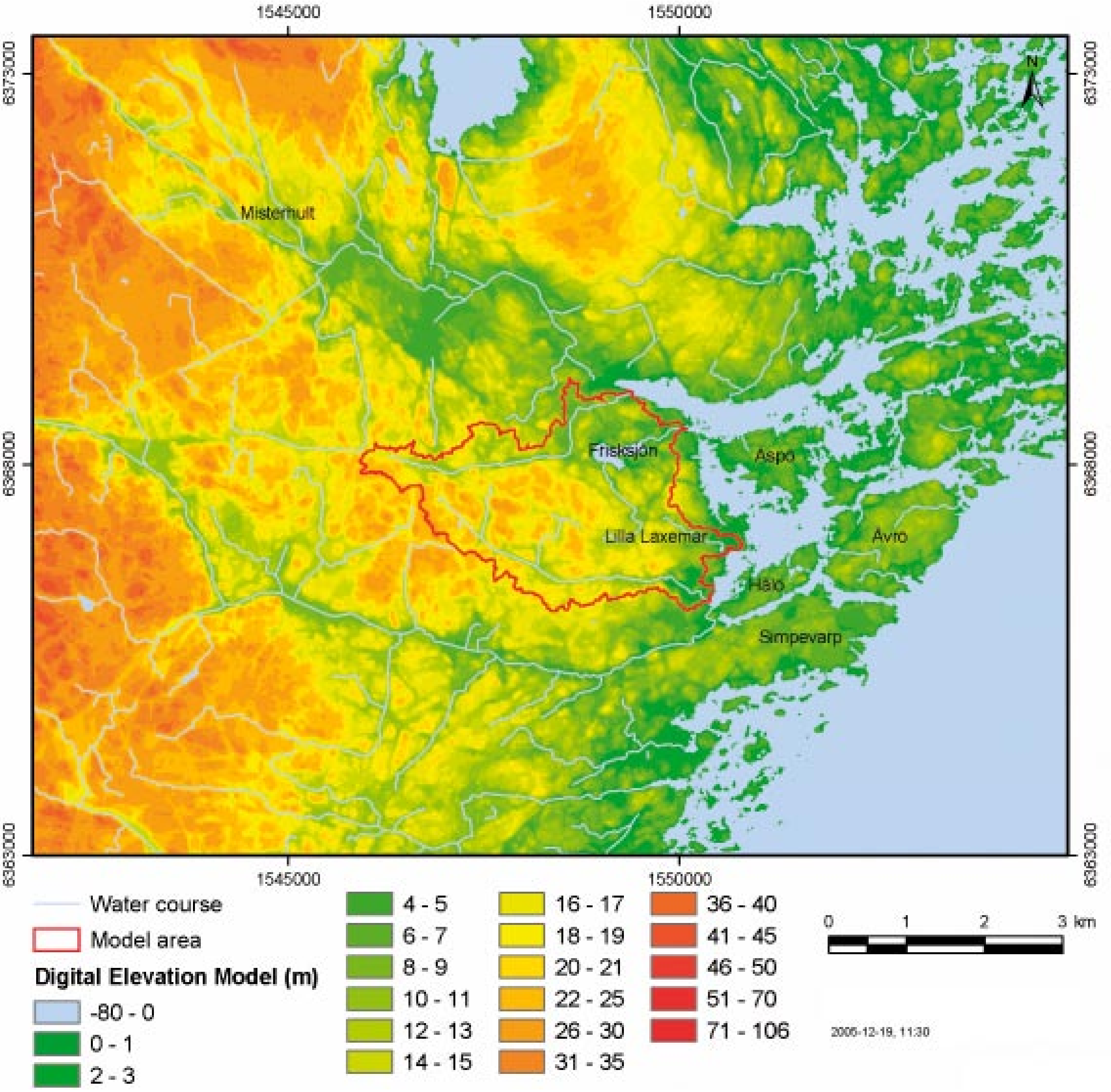

Figure 4-2. *Digital elevation model (DEM; metres above sea level) of the regional model area. The red line shows the outer boundary of the catchment areas (CA 6-9) included in the quantitative water flow modelling; note that the model area considered in this work also includes the adjacent coastal land and sea areas, see Section 4.2.*

4.1.3 Type areas, flow domains and their interfaces

In order to create a suitable framework for the conceptual-descriptive modelling, one can identify a number of alternative ways to divide the modelled area into “subareas”. Examples on such divisions include (specific or generic) *biosphere objects* or *hydrological-hydrogeological elements* (e.g. catchments, sub-catchments, lakes, watercourses, wetlands, groundwater wells, and so forth). For instance, in Chapter 3 different hydrological elements (watercourses, lakes and wetlands) and their characteristics are presented on a catchment-area basis. For each such object or area, the geometry and hydrological-hydrogeological parameters and other quantities (e.g. water residence time and water balance components) can be described.

The present conceptual-descriptive model is based on three other types of “elements”:

- **Type areas.** These are areas considered to be more or less similar units in a geological, hydrological and hydrogeological perspective.
- **Flow domains.** The overall SKB approach (Figure 4-1) is to divide the system into bedrock (HRD and HCD) and overburden (HSD). The focus in the present context is on the Hydraulic Soil Domains (HSD), which are divided into several types of QD. These QD types are identified and described, based on currently available site investigation data. In cases where no such data are available, generic (literature) data are used. In addition, flow domains relevant for the surface/near-surface system include lakes, watercourses and wetlands, which are not discussed in detail in the modelling strategy report /Rhén et al. 2003/. An overview of the latter flow domains is given in Section 3.2; a detailed description is provided in /Brunberg et al. 2004/.
- **Interfaces between flow domains.** The interfaces between different parts of the hydrological-hydrogeological system (the flow domains) are identified and described, as these to a large extent control the flow of water between different subsystems (i.e. the flow domains).

Type areas

Compared to the S1.2 model version, more data on the QD (surface distribution and stratigraphy) are available from the Laxemar subarea for the L1.2 model version /Rudmark 2004, Rudmark et al. 2005/. Figure 4-3 shows the detailed QD map of the Simpevarp area. The most striking characteristic is that large parts (c 35%) consist of areas of exposed bedrock or very thin QD (i.e. red areas on the map; the mapping depth is c 0.5 metre). However, there is a smaller fraction of exposed bedrock and more abundant QD in the Laxemar subarea than in the Simpevarp subarea (cf Figure 1-1).

Exposed/very shallow bedrock is predominantly found in high-altitude areas, where there is usually a thin layer of till and/or organic material. As shown in Figure 3-28, the groundwater table in the QD is generally shallow; it should be noted that these measurements for the most part are made in lower-lying areas, i.e. in the valleys.

The average depth of QD within the area in Figure 4-3 is c 2 metres with the exposed/shallow bedrock areas (the red areas in the figure) included, and c 3 metre with those areas excluded /Nyman 2005/. The QD mainly consist of till, covering c 43% of the land surface within the regional model area. The till is characterised as sandy (at some locations sandy-gravelly), with a high frequency of stones and boulders. The average depth of the till is c 2 metre on land, c 1 metre below the sea, and c 3–4 metre in clay/peat areas /Nyman 2005/. With a few exceptions, the maximum depth of the till is on the order of 3 metres. In the southern parts of the Laxemar subarea, the till thickness can be up to c 10 metres. In the valleys, in which the thickest QD layers are found, the bottom-up

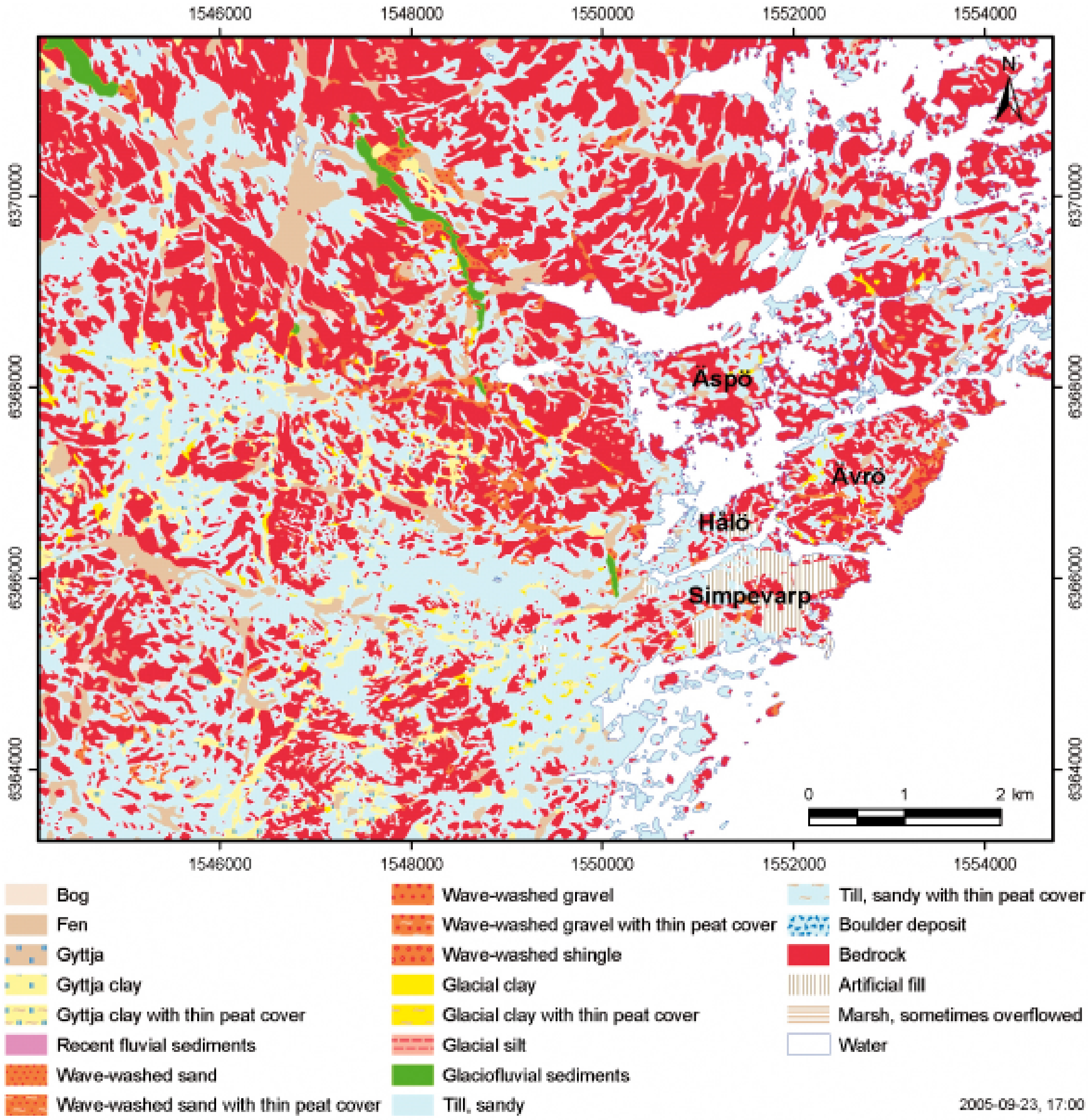

Figure 4-3. *Map of QD and exposed/shallow bedrock (red areas) in the Simpevarp and Laxemar subareas /Rudmark et al. 2005/.*

stratigraphy is till, glacial sediments (predominantly glacial clay) and postglacial sediments (gyttja clay, peat and/or fluvial outwash). At some investigated locations, a layer of silt or sand has been found between the till and the overlying glacial/postglacial sediments. At many locations, a layer of fen or bog peat is formed above the other postglacial sediments. Coniferous and deciduous forests are covering most of the regional model area, and wetlands are found in places.

Four glaciofluvial deposits (eskers) are located in the regional model area. The largest one is Tunaåsen (the Tuna esker), located in the western part of the regional model area. The three smaller eskers (Gässhultsåsen, Misterhultsåsen and a nameless esker) are located in the northern part of the regional model area. Artificial fill is found in the industrial area on the Simpevarp peninsula, where the nuclear power plant, Clab and other office and industrial buildings are located, and on Hålö (a rock deposit with material from the Äspö HRL tunnel). There are also gravelly areas with a fluvial-outwash surface layer, and some small fen areas on Ävrö and Hålö.

Based on presently available data on topography (the DEM; Figure 4-2) and QD (the detailed map of QD and exposed bedrock; Figure 4-3), four hydrogeological type areas are identified (no. 1-3 were identified and described already in the S1.2 model):

1: *High-altitude areas*, dominated by exposed or very shallow bedrock. In these areas, QD are absent or thin, but thicker layers of till and/or peat occur in local depressions. It should be noted that also in areas marked as exposed bedrock on the detailed map of QD /Rudmark 2004, Rudmark et al. 2005/, there may be a thin (< 0.5 metre) layer of soil and/peat, as the "mapping depth" (i.e. the depth at which the soil is classified) is approximately 0.5 metre. The dominating vegetation type in this type area is forest. The high-altitude areas can be assumed to be groundwater recharge areas.

2: *Valleys* with postglacial sediments at the surface (gyttja clay, peat and/or fluvial outwash). The postglacial deposits are usually underlain by glacial deposits (glacial clay and till). The thickness of the QD is several metres. Many valleys have been drained in order to create arable land. The QD in the submarine "valleys" close to the coast are dominated by sand and clay; the deepest parts are covered with gyttja clay. The valleys are assumed to be groundwater discharge areas.

3. *Glaciofluvial deposits*, of which Esker Tunaåsen in the western part of the regional model area is the largest. Three other small eskers (Gässhultsåsen, Misterhultsåsen and a nameless esker) exist in the northern part of the regional model area. The dominating vegetation type in this type area is forest. Generally, the glaciofluvial deposits are assumed to be groundwater recharge areas, but there are presently no field observations of groundwater levels in the eskers available.

4. *Hummocky moraine areas*, characterized by a coherent layer of till, thus with only a small fraction of exposed/shallow bedrock, and low-relief hummocks, i.e. small moraine hills that probably were formed by more or less stagnant ice during the deglaciation. This type area primarily exists in the south-western part of the regional model area and in the central part of the Laxemar subarea, where the QD thickness generally is larger than in type area 1 (high-altitude areas). Due to the small-scale topography, this type area is assumed to be characterised by small interchanging recharge-discharge areas.

To some extent, the sub-division into type areas may be expanded and/or more detailed in future model versions, when more site investigation data become available.

Flow domains

The description of flow domains is focused on the HSD (cf Figure 4-1), as the description of lakes, watercourses and wetlands mainly concern their interfaces to the HSD (see below). An overview of the flow domains lakes, wetlands and watercourses in the Simpevarp area is presented in Sections 3.2.2–4; detailed descriptions are provided in, primarily /Brunberg et al. 2004, Carlsson et al. 2005/.

Based on several types of data (e.g. data from boreholes, geophysical investigations, the QD mapping, and the DEM), a geometrical model of the HSD, in the following referred to as the "g-HSD", has been developed using the ArcGIS extension GeoEditor /Nyman 2005/. In the g-HSD, the HSD are divided into three QD layers, denoted Z1–Z3 (Z1 is the top layer and Z3 the bottom layer). The model also includes three additional QD layers, referred to as M1–M3. The latter layers represent peat (M1), glaciofluvial deposits (M2) and artificial fill (M3; not strictly QD). In the g-HSD, layer M1 replaces layer Z1 in peat areas, whereas layers M2 and M3 replace layers Z2 and Z3 in areas with glaciofluvial sediments and artificial fill, respectively.

In the g-HSD, each layer can locally have zero thickness. The total depth of QD and the thickness of each layer is assigned in grid cells, having the same spatial resolution as the DEM (10 metres). The assignment is done by interpolation of the various types of data used (see above). The thickness of each QD layer in the grid cells follow a set of "rules", depending on the total QD depth in each grid cell and the type of QD assigned to a grid cell. A "typical" cross section in the g-HSD is exemplified in Figure 4-4. The g-HSD is expected to be further developed in the future when more site investigation data are available.

The QD assigned to the layers Z1–Z3 and M1–M3 in the conceptual-descriptive model are based on the g-HSD /Nyman 2005/ and the detailed QD map /Rudmark 2004, Rudmark et al. 2005/. In Table 4-1, the QD assigned to layer Z1 is equal to the QD defined in the detailed QD map /Rudmark 2004, Rudmark et al. 2005/. Hence, the QD in layer Z1 is based on mapping of QD in the field. The QD assigned to layers Z2 and Z3 at a certain location also depends on the QD in layer Z1, based on the conceptual-descriptive model of the QD stratigraphy in the area. Hence, the QD assigned to layers Z2 and Z3 involves a higher degree of uncertainty, as the QD stratigraphy only has been observed in the field at a limited number of locations (points) by means of e.g. soil drilling.

Table 4-1. Assignment of QD in layers Z1, Z2 and Z3 in the g-HSD.

QD in the detailed QD map /Rudmark 2004, Rudmark et al. 2005/	QD in Z1 (layer thickness, m)	QD in Z2 (layer thickness, m)	QD in layer Z3[1]	Average total depth of QD (m)
1 – Gyttja (not on land)	Do not exist on land in the model area, assigned below open water (see 12 – Open water)			
2 – Clay gyttja, gyttja clay	Clay gyttja, gyttja clay (1.00)	2.80	Till	7.40
3 – Clay (glacial, postglacial)	Clay (1.00)	Clay (glacial 1.60, postglacial 2.80)	Till	Postglacial clay: 7.40 Glacial clay: 6.20
4 – Silt	Silt (1.00)	No Z2 layer	Till	–
5 – Till	Till (1.00)	No Z2 layer	Till	Till on land: 2.00 Till below sea: 1.00
6 – Till with thin surface layer of peat	Till (1.00)	No Z2 layer	Till	Till on land: 2.00
7 – Fluvial outwash, gravel	Gravel (1.00)	No Z2 layer	Till	–
8 – Fluvial outwash, sand	Sand (1.00)	No Z2 layer	Till	–
9 – Flood sediments, clay-gravel	Flood sediments, clay-gravel (1.00)	No Z2 layer	Till	–
10 – Peat (bog and fen)	Z1 is replaced by the additional layer M1 Peat (0.90)	Clay (3.80)	Till	8.30
11 – Bedrock (near-surface)	Thin soil layer, assumed to correspond to till (0.10)	No Z2 layer	No Z3 layer	0.10
12 – Open water (sea and lake)	Gyttja (0.50)	Clay (2.80 below lakes, no Z2 layer below the sea)	Till	Lake and some bays: 7.40 Sea (without QD data): 1.20
13 – Bouldery soil	Does not exist in the area considered in the flow modelling			
14 – Artifical fill	Artificial fill is assumed to correspond to till (1.00)	Z2–Z3 are replaced by the additional layer M3 Artificial fill is assumed to correspond to till		4.00

QD in the detailed QD map /Rudmark 2004, Rudmark et al. 2005/	QD in Z1 (layer thickness, m)	QD in Z2 (layer thickness, m)	QD in layer Z3[1]	Average total depth of QD (m)
15 – Fluvial outwash, stones-boulders	Does not exist in the area considered in the flow modelling			
16 – Glaciofluvial deposits	Glaciofluvial deposits (1.00)	Z2–Z3 are replaced by the additional layer M2		Tuna esker: 20.00 Fårbo esker: 15.00 Other eskers (incl. the Gässhult esker: 5.00
17 – Unclassified	Till (1.00)	No Z2 layer	Till	–

[1] In the g-HSD model, the thickness of layer Z3 below Z1 and Z2 depends on the "residual depth" down to the interpolated bedrock surface. The minimum thickness of layer Z3 is 1.00 metre on land and generally 0.50 metre below open water /Nyman 2005/.

Note that QD referred to as "Bouldery soil" and "Fluvial outwash, stones-boulders" in Table 4-1 are available in the QD database of the Simpevarp area. However, as they do not exist in the area included in the quantitative water flow modelling, these QD types are not included in the present conceptual-descriptive model.

The assigned hydraulic properties of QD in the L1.2 model version are shown in Table 4-2. Note that the hydraulic properties for "near-surface bedrock" shown in the table apply to the upper few metres of the bedrock. At larger depths in the bedrock, modelling results and the associated input data required for the quantitative flow modelling (see Section 4.2) are taken from the S1.2 model of the hydraulic properties of the bedrock, as presented by the DarcyTools modelling team /SKB 2005a, Follin et al. 2005/. However, these data comprise horizontal and vertical hydraulic conductivities and effective porosities only. Hence, data on the specific yield (S_Y) and the specific storage coefficient (S_S) is not included in the provided DarcyTools data set. As a rule of thumb, the approximate values $S_Y = 0.01$ (–) and $S_S = 1\cdot10^{-7}$–$1\cdot10^{-5}$ (m^{-1}) can be used for the bedrock in the area (pers. comm. with Ingvar Rhén, SWECO VIAK).

The S_Y of the "near-surface" bedrock is in the present modelling assumed to be equal to the effective porosity, whereas the specific storage coefficient S_S (m^{-1}) of the bedrock is calculated according to the empirical relationship

$$S_S = a\cdot K^b \tag{4-1}$$

between the hydraulic conductivity K ($m\cdot s^{-1}$) and S_S (m^{-1}) /Rhén et al. 1997/. In this equation, a fit to experimental data from the Äspö Hard Rock Laboratory has provided the values

$$a = 6.037\cdot10^{-5} \tag{4-2a}$$

$$b = 0.2312 \tag{4-2b}$$

Note that in equation (4-1), the horizontal hydraulic conductivity (K_H) is used to calculate S_S.

The hydraulic conductivity K of the till is assigned based on hydraulic tests and particle-size distribution (PSD) curves. The average value of K in till, obtained in the slug tests, is $3\cdot10^{-5}$ $m\cdot s^{-1}$, whereas the average K-value obtained by the Hazen method for analyses of PSD is $5\cdot10^{-5}$ $m\cdot s^{-1}$ (see Section 3.3.1). In the conceptual-descriptive model, the till is assigned the average of these two estimates, i.e. $K = 4\cdot10^{-5}$ $m\cdot s^{-1}$. For peat, a range of K-values obtained from field tests reported in the literature was presented by /Kellner 2004/. For all QD, the values of specific yield S_Y and specific storage coefficient S_S are taken from the literature.

Table 4-2. Assignment of hydraulic properties to QD.

QD no.	QD	Horizontal hydraulic conductivity, K_H ($m \cdot s^{-1}$)	K_H/K_V	Specific yield, S_Y (–)	Storage coefficient, S_S (m^{-1})
1	Gyttja (only present below open water)	[1]$1\cdot10^{-8}$	1	[1]0.03	[1]$6\cdot10^{-3}$
2	Gyttja clay, clay gyttja	[2]$1\cdot10^{-7}$	1	[1]0.03	[1]$6\cdot10^{-3}$
3	Clay (postglacial/glacial), silt		1	[3]0.03	[4]$6\cdot10^{-3}$
	Z1 (on land)	[4,5,6]1·10-6			
	Z2 (not in Z3)	[4,5,6]$1\cdot10^{-8}$			
4	Till, artificial fill, unclassified		1		[4]$1\cdot10^{-3}$
	Z1	[7]$4\cdot10^{-5}$		[8]0.15	
	Z2–Z3	[7]$4\cdot10^{-5}$		[8]0.05	
5	Fluvial outwash, gravel	[5,15]$1\cdot10^{-2}$	1	[3]0.25	[9]0.025
6	Fluvial outwash, sand	[5]$1\cdot10^{-3}$	1	[3]0.25	[9]0.025
7	Flood sediments, clay-gravel	[10]$1\cdot10^{-6}$	1	[1]0.03	[1]$6\cdot10^{-3}$
8	Peat	[11]$1.5\cdot10^{-6}$	1	[11]0.24	[11]$5\cdot10^{-2}$
9	Bedrock (near-surface)	[12]$1.05\cdot10^{-7}$	1	[12]0.005	[12]$1.5\cdot10^{-6}$
10	Glaciofluvial deposits (coarse sand, gravel)[2]	[13]$1\cdot10^{-4}$	1	[14]0.25	[9]0.025

[1] Assumed equal to the corresponding parameter for clay.
[2] Assigned 10 times the K_H-value for clay.
[3] Generic data from the literature /Domenico and Schwartz 1998/.
[4] Generic data from Blomquist-Lilja, 1999 (unpublished SKB report).
[5] Generic data from the literature /Knutsson and Morfeldt 2002/.
[6] K_H for near-surface clay assigned 100 times K_H for deeper clay.
[7] Site-specific data from slug tests /Johansson and Adestam 2004b, 2004d/and particle-size distribution curves.
[8] Based on the conceptual-descriptive model of till in the Forsmark 1.2 model /Johansson et al. 2005/.
[9] Assigned 1/10 of S_Y.
[10] Assumed to be 100 times the K_H-value for clay and 10^{-4} times the K_H-value for gravel.
[11] Generic data from the literature /Kellner 2004/.
[12] K_H and S_Y are the same as for the uppermost part of the bedrock in the DarcyTools data set (S1.2 model version), S_S is calculated based on an empirical relation between S_S and K_H in bedrock /Rhén 1997/ see also Chapter 5.
[13] Assigned a value equal to 1/10 of the K_H-value for gravel.
[14] Assumed to be equal to sand and gravel.
[15] The value was decreased by 1/10 in the quantitative water flow model (Section 4.2) due to numerical instability.

The occurrence of and reasons for anisotropic conditions (horizontal, K_H, and vertical, K_V, hydraulic conductivities not equal) in till have been investigated by e.g. /Lind and Nyborg 1988/. Further, field data indicate that K_H decreases with depth in peat, whereas the anisotropy ratio (the ratio K_H/K_V) increases with depth /Kellner 2004/. In the Simpevarp area, there are no data that support the occurrence of anisotropic conditions within the till or other individual QD layers. Further, the QD layers are generally thin (on average c 2–3 metres). Therefore, isotropic conditions are assumed as a base case in the L1.2 modelling, and the implications of this assumption are investigated by considering anisotropic conditions as sensitivity cases in the quantitative water flow modelling (Section 4.2).

Interfaces between flow domains

Relevant factors in the characterisation of surface water and groundwater flow are the interfaces between different flow domains, as these interfaces to a large degree control the flow of water between the domains. For instance, the interface to QD is the most important factor to consider in the development of the conceptual-descriptive model of surface waters (sea, lakes, watercourses and wetlands). In the L1.2 model, three important interfaces have therefore been identified.

- *The interface between "near-surface" bedrock and "deep" bedrock.* In the quantitative water flow modelling (Section 4.2), this interface is considered equivalent to the lower boundary of the model domain and is placed at 150 metres below sea level; this does not correspond to the "normal" definition of "near-surface bedrock", usually referring to, say, the upper 10 metres of the bedrock. It should therefore be noted that the distinction between near-surface and deep bedrock adopted here is solely due to the location of the bottom boundary of the considered flow domain; it is not based on differences in hydraulic properties.
- *The interface between QD and bedrock.* In the L1.2 modelling, the main exchange of water across this interface is assumed to take place at locations where bedrock fractures and deformation zones are in contact with QD. It should be noted that at present, there are no site investigation data available on this interface. For instance, no slug tests have yet been performed in wells with their screens placed across the QD/bedrock interface.
- *The interfaces between groundwater and surface water (sea, lakes, watercourses and wetlands/peat areas).* In the L1.2 model, the QD interface at the bottom of lakes is assumed to consist of low-permeable layers of gyttja and clay, whereas the QD interface below peat areas (wetlands) and the QD interface at the bottom of the sea are assumed to consist of gyttja (peat areas) and clay (the sea), respectively. The assignment of QD at these interfaces are based on site investigation data /Nilsson 2004/ and the conceptual-descriptive model of the QD in the Simpevarp area. The detailed QD investigations /Rudmark 2004, Rudmark et al. 2005/ provide input data on the QD along the watercourses; however, it should also be noted that a characterisation of the bottom conditions in the watercourses is presented by /Carlsson et al. 2005/. In the quantitative water flow modelling, the interface between groundwater and surface water in watercourses is modelled by a "leakage factor". This factor can be adjusted to influence the modelled exchange of water between groundwater and surface water in watercourses. It should be noted that apart from the geological investigations (e.g. boreholes and geophysical surveys), there are no site investigation data available on these interfaces. Thus, no field tests have been performed to investigate the exchange of water across lake/groundwater interfaces.

4.1.4 Interpretation of the surface and near-surface flow system

The model area is characterised by a relatively small-scale topographical undulation (see Figure 4-2) and by relatively shallow QD. Almost the entire area is below 50 metres above sea level, and the whole Simpevarp regional model area is located below the highest coastline. Hydrologically, the area consists of a large number of relatively small catchments, and it also contains a relatively large number of watercourses (most of them are very small). A crude water balance, based on approximate ranges of actual precipitation and evapotranspiration obtained from meteorological stations in surrounding areas, yields an average specific discharge in the range 150–180 mm·year^{-1} for the regional model area /Larsson-McCann et al. 2002/.

The conceptual-descriptive L1.2 model implies that near-surface groundwater flow and surface water flow mainly take place in the valleys between the higher-altitude areas with exposed or very shallow bedrock. In areas with exposed/shallow bedrock, there is generally a very thin QD layer, on the order of one or a few decimetres, of till and/or peat (the mapping depth is c 0.5 metre), or just a thin vegetation layer. Hence, the valleys act as large-scale “flow channels” for the near-surface groundwater and surface water. There is a large degree of surface runoff taking place in areas with exposed/shallow bedrock, which is diverted into the valleys, and further into watercourses, lakes and wetlands. Thin QD imply that the deposits can carry only little groundwater flow. Although the near-surface groundwater flow pattern has not yet been analysed in detail due to the scarcity of site investigation data, it can be assumed that this flow is characteristic for each catchment, directed towards local surface waters and near-surface drainage systems.

A regional-scale water balance calculation can be performed, based on selected “representative” precipitation P (Section 3.1.1) and discharge R (Section 3.2.6) data from measurements at “regional” stations. The water balance equation for a catchment area during a certain time period is written, $P = E+R+\Delta S$ where E is the loss of water due to evapotranspiration, and ΔS denotes the water storage change during the time period. Assuming that $\Delta S = 0$, the above equation simplifies to $P = E+R$. The error introduced by assuming zero storage change is usually small when considering a time period of one year.

The average (corrected) precipitation in the Simpevarp area (P) is c 600–700 $\text{mm}\cdot\text{y}^{-1}$ (Section 3.1.1), whereas the average specific discharge is estimated to be in the interval 4.7–5.7 $\text{l}\cdot\text{s}^{-1}\cdot\text{km}^{-2}$ (Section 3.2.6). The latter corresponds to a discharge R in the interval 150–180 $\text{mm}\cdot\text{y}^{-1}$. Hence, the evapotranspiration E can be estimated to be in the interval 420 (600 minus 180) to 550 (700 minus 150) $\text{mm}\cdot\text{y}^{-1}$.

It should be noted that the specific groundwater recharge in recharge areas is larger than the specific discharge (or runoff) calculated for a catchment area; the specific discharge (the runoff) is calculated for the whole catchment area, including both groundwater recharge and discharge areas. Recharge areas are generally found in high-altitude areas, whereas discharge areas are located in low-altitude areas (valleys and other depressions). The degree of surface runoff (overland flow) may be large, as there are large areas with exposed bedrock or very thin QD. However, there is often a thin QD or vegetation layer present also in the exposed bedrock areas, which may act to reduce the degree of surface runoff. The impact of these thin soil layers on the surface runoff is still somewhat unclear.

The small-scale topography implies that there are many small catchments with local, shallow groundwater flow systems in the QD. Even though there is yet no field evidence that precipitation and snow melt are the only sources of groundwater recharge, the Laxemar 1.2 modelling (which includes Lake Frisksjön) indicates that the lakes do not contribute to groundwater recharge even during dry periods when groundwater levels are low. Many of the watercourses in the areas are dry during long time periods. However, they are considered to be permanent discharge areas. As the groundwater table generally is located close to the ground surface, evapotranspiration-precipitation cycles have a strong effect on the groundwater level variations in the QD, see Figure 3-32.

The whole system is transient due to the fact that the meteorological conditions (primarily precipitation and temperature) vary with time. Concerning seasonal variability, Sweden can be divided into four regions based on the “typical” variations of the groundwater level during the year /Knutsson och Fagerlind 1977/. In the region where Simpevarp is located, the groundwater level in the near-surface groundwater is generally lowest during late summer/early autumn. During this period, most of the precipitation is consumed by the vegetation. The groundwater level increases during late autumn, and the levels are highest during spring. Hence, in order to understand, describe and predict the surface and near-surface hydrological-hydrogeological system, input data should include (preferably local) meteorological data, measured with as high temporal resolution as possible.

A descriptive model of the surface and near-surface water flow system is presented below, based on the identification of type areas, domains and interfaces in Section 4.3.1. From areas with exposed bedrock, a large part of the precipitation/snow melt is assumed to be diverted, in the form of surface runoff, into surrounding areas with Quaternary deposits or as overland flow into surface waters (watercourses, lakes or wetlands).

In general groundwater, recharge takes place in areas of relatively higher altitudes and discharge in lower-lying areas. However, the transient nature of the system (cf above) implies that the recharge and discharge areas may vary during the year. Considering near-surface groundwater flow in recharge areas (where the groundwater flow has a downward component), the soil-water deficit has to be filled before any major groundwater recharge can take place. By-pass flow in different types of macropores may take place, but can be assumed to be insignificant from a quantitative point of view. In discharge areas, defined as areas where the groundwater flow has an upward component, by definition no groundwater recharge takes place.

Some of the above concepts are illustrated in Figure 4-4. In a generalized form, the figure illustrates the conceptual-descriptive model of the surface-hydrological and near surface-hydrogeological conditions across a hypothetical valley in the regional model area. The figure illustrates three of the type areas and one of the identified interfaces between flow domains (the QD/bedrock interface, cf Section 4.1.3).

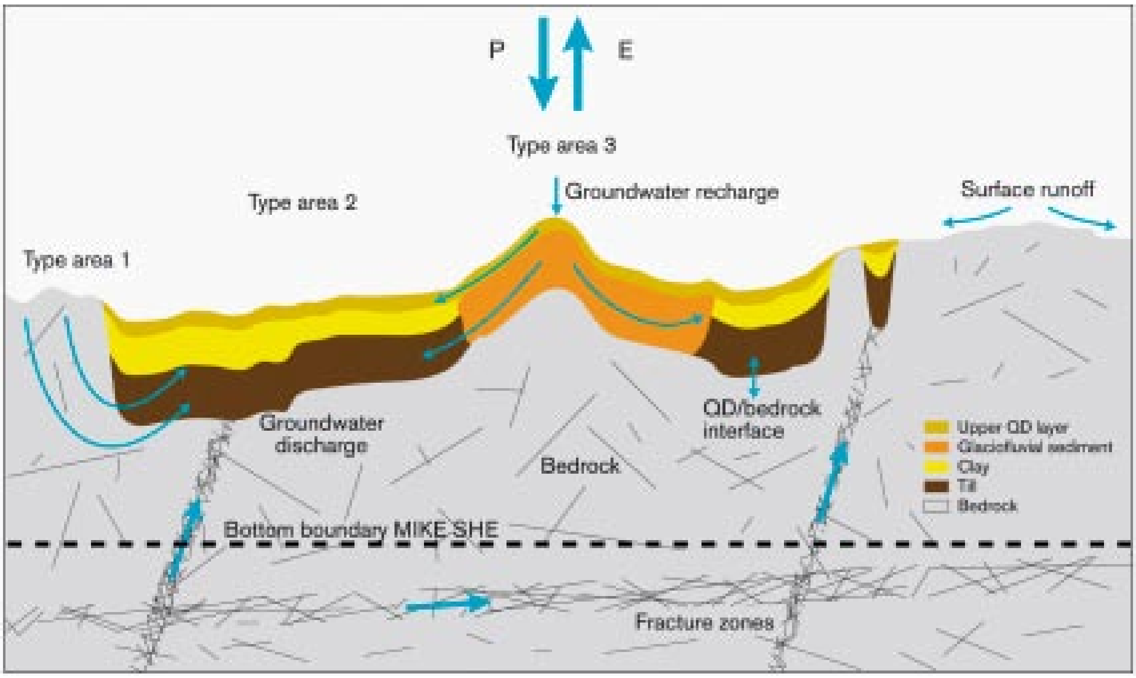

Figure 4-4. *Schematic cross section, illustrating the descriptive model of the near-surface/surface water flow system in the Simpevarp regional model area, including groundwater recharge and discharge, and surface runoff. The figure shows three of the identified hydrogeological type areas (1, 2 and 3), the QD/bedrock interface, and fracture zones in the bedrock. It also illustrates the principle of the geometrical model of the HSD /Nyman, 2005/, and the bottom boundary of the Laxemar MIKE SHE model. Note that the QD thickness is exaggerated in the figure. P and E denote precipitation and evapotranspiration, respectively.*

Not all groundwater discharge areas are saturated up to the ground surface, but water flows in the uppermost most permeable part of the profile. In unsaturated discharge areas, the soil water deficit is usually very small and these areas quickly respond to rainfall and snowmelt events. Generally, the absolute groundwater level is higher in high-altitude areas (presumably being groundwater recharge areas), and lower in low-lying areas (presumably being groundwater discharge areas). However, the depth to the groundwater table below the ground surface is usually smaller in the valleys, as compared to higher-altitude areas.

Watercourses are considered to be discharge areas. The manual discharge measurements in the watercourses (Section 3.2 6) indicate that there is no water flow in many of the watercourses during large parts of the year. The fact that there are many small catchment areas, imply that groundwater recharge as well as discharge of water into watercourses are highly transient during the year. In its simplest form, the conceptual model is that these processes mainly take place in connection to precipitation events and/or snow melt. Likewise, (relatively short) periods with large groundwater discharge and discharge in watercourses imply that simple averaging of a few individual measurements may lead to erroneous estimates of the total annual discharge. This implies that high-resolution (preferably automatic) measurements are needed to capture the temporal variations.

As mentioned above, lakes can, in principle, function as both discharge and recharge areas. A lake can be a recharge area during periods when near-surface groundwater levels are low, and shift to be a discharge area when near-surface groundwater levels are high /Johansson et al. 2005/. The hydraulic contact between lakes and near-surface groundwater is highly dependent on the hydraulic conductivity of the bottom sediments (see discussion on interfaces in Section 4.1.3). The effects of the hydraulic properties of the QD on the flow paths from great depth to the QD and further into a lake were investigated by /Holmén and Forsman 2004/ in a modelling study of Forsmark that was based on pre site-investigation data.

Wetlands (bogs and mires) can either be in direct contact with the groundwater and constitute typical discharge areas, or constitute separate hydrological systems with low-permeable bottom and little or no hydraulic contact with the groundwater zone (see /Kellner 2004/ and the discussion on interfaces in Section 4.3.1). Site investigation data indicate that QD at the bottom of wetlands consist of fine sediments with low permeability (cf Section 3.2.3). Interactions between near-surface groundwater flow in QD and near-surface flow in bedrock take place everywhere where bedrock is in contact with QD (see Section 4.3.1). Discharge from the bedrock into the QD will probably mostly take place in the topographically defined major discharge areas.

As mentioned above, the regional specific discharge has been estimated to be in the range 150–180 mm·year^{-1}. However, the actual sizes of recharge and discharge areas, and the magnitude of the groundwater recharge and discharge in these areas, need to be quantified by means of quantitative water flow models (see Section 4.2). The manual groundwater level measurements (Section 3.3.2) show that there is a small depth to the groundwater table (usually less than one metre). Note that no groundwater level data are available from eskers in the area; in eskers, the groundwater table is normally found at a larger depth. A shallow groundwater table indicates that the identified topographic boundaries of the catchment areas (see Figure 3-13) can be used as no-flow boundaries also for quantitative modelling of groundwater flow (i.e. surface water and near-surface groundwater divides coincide).

A shallow groundwater level also implies that the level can be assumed to follow the topography. In general, groundwater levels are usually less than a few metres below the ground level in recharge areas and less than one metre in discharge areas /Knutsson and Morfeldt 2002/. The annual groundwater level fluctuation is usually a few metres in recharge areas and about one metre in discharge areas /Knutsson and Morfeldt 2002/. As mentioned above, the extent of recharge and discharge areas may also vary during the year. The sea-water level fluctuations will probably have insignificant influence on the absolute groundwater levels and the groundwater level fluctuations in the more inland parts of the regional area.

In its most simple form, groundwater flow in eskers can be conceptualised as "channel flow", taking place parallel to the esker orientation. Depending on the hydraulic contact (interface) with their surroundings, and the difference in groundwater level between the eskers and their surroundings, the eskers can discharge groundwater to the surroundings, or groundwater recharge can take place from the surroundings into the eskers.

4.2 Quantitative water flow modelling

4.2.1 Introduction and objectives

As described by /Rhén et al. 2003/, quantitative water flow modelling is performed as an integrated part of the site descriptive modelling. Specifically, the quantitative water flow modelling serves three main purposes:

Model testing: Simulations of different major geometric alternatives or boundary conditions are carried out in order to try to disprove a given geometric interpretation or boundary condition, and thus reduce the number of alternative conceptual models of the system.

Calibration and sensitivity analyses: Flow modelling is also performed in order to explore the impact of different assumptions regarding, primarily, hydraulic properties, and boundary and initial conditions.

Description of flow paths and flow conditions: Model calculations are also useful for developing the general understanding of the surface water and groundwater systems at the site; in particular, analyses of flow directions and flow paths can be used to improve the site understanding (cf below).

Due to the limited data available and the "immature" state of the surface and near-surface flow modelling in general, only a limited modelling effort was made in S1.2. For instance, the model area for the process-based water flow modelling included catchment area 7 (where Lake Frisksjön is located) only. In the present L1.2 water flow modelling, the model area is enlarged compared to S1.2, now including catchment areas 6–9 and near-coastal parts of land and the Baltic Sea (to c 300 metres from the coastline). It can also be noted that the L1.2 conceptual-descriptive and quantitative modelling activities have been more integrated than in the S1.2 modelling, such that the quantitative modelling is fully based on the conceptual-descriptive model and to larger extent addresses issues identified in the modelling process.

The overall objectives of the L1.2 quantitative water flow modelling are to

- continue to develop the understanding of the water flow conditions in the Simpevarp area, by testing specific aspects of the conceptual-descriptive model,
- deliver specific output data to the integrated ecological systems modelling within SurfaceNet,
- continue the testing of modelling tools within the SKB environment.

The S1.2 model version included MIKE SHE-MIKE 11 process-based modelling of catchment area 7, and GIS-based modelling (using the Hydrological Modelling extension in ArcGIS 8.3) of all 26 catchment areas in the Simpevarp regional model area /Werner et al. 2005/. The present quantitative modelling does not include the above GIS-based modelling, which is because the main input data to this modelling, the DEM and the estimated "regional" value of the annual average specific discharge, have not been subject to major changes since the S1.2 model version. The L1.2 quantitative water flow modelling is focused on the process-based modelling, using the MIKE SHE-MIKE 11 software packages /DHI Software 2004/. A brief summary of MIKE SHE and MIKE 11 is provided in the following section. In addition, extended GIS-based hydrological modelling has been performed, applying the PCRaster-POLFLOW modelling approach /Jarsjö et al. 2005/, see Section 4.3.5.

The overall methodology in the setup and application of the L1.2 MIKE SHE-MIKE 11 model can be summarised as follows:

- Integrate generic data, pre site-investigation data (S0) and data from the previous SDM (S1.1 and S1.2) with the data in the L1.2 data freeze to establish an updated numerical water flow model of selected parts (catchment areas) of the Simpevarp regional model area.
- Define and simulate an "initial base case", which provides the basis for the sensitivity analysis (cf below). All the simulations use local meteorological data measured at the Äspö meteorological station during the year 2004.
- Define and simulate a series of "sensitivity cases", in order to investigate the sensitivity of the model output to, primarily, the hydraulic properties of the QD and the vegetation-related parameters that constitute a basic input to the modelling of evapotranspiration.
- Define an "updated base case" based on the results of the sensitivity analysis. The sensitivity cases and the resulting updated base case are used in a broader context to develop the understanding of the conditions for water flow in the Simpevarp area, and also to identify key data as a basis for planning of continued site investigations. Furthermore, the updated base case is used to produce output data to the ecological systems modelling within SurfaceNet.

4.2.2 Brief description of MIKE SHE and MIKE 11

This section provides a brief description of the MIKE SHE and MIKE 11 software packages. For details concerning these programs and their use in the present context, see the corresponding S1.2 background report /Werner et al. 2005/.

MIKE SHE /DHI Software 2004/ is a software package for physically based and spatially distributed modelling of the whole land-based hydrological cycle. This implies that MIKE SHE simulates water flow in the saturated (groundwater) and unsaturated zones, overland flow, and also simulates water losses due to interception, evaporation and transpiration. MIKE SHE is fully integrated and runs simultaneously with the 1D channel flow program MIKE 11 /DHI Software 2004/.

During the course of a simulation, there is a continuous exchange of water between the saturated zone (MIKE SHE) and surface waters (MIKE 11), which is controlled by the flow resistance through the interface and the head gradient. MIKE 11 requires that a so-called "river network" is defined, including the bottom level and the width (in a number of cross sections) of the considered watercourses. Table 4-3 lists the input data types required for MIKE SHE and MIKE 11.

Table 4-3. List of simulation modules and associated input data types in MIKE SHE and MIKE 11.

Compartment	Input data
Frame	Topography
	Model boundary (e.g. water divide)
Evapotranspiration/snow routine	Potential evapotranspiration
	Precipitation
	Snow melt constants
	Temperature
	Vegetation
	Leaf area index (LAI)
	Root depth
	Root distribution
	Kc-value (crop coefficient)
Overland flow/channel flow (MIKE 11)	River network
	Cross sections
	Permeability of bottom of watercourses and lakes
	Manning's number
Unsaturated flow	Map of QD
	Unsaturated zone-specific hydraulic parameters
Saturated flow	Geological model (map of QD, depth and stratigraphy of QD)
	Saturated zone-specific hydraulic parameters: K_H (horizontal hydraulic conductivity), K_V (vertical hydraulic conductivity), S_S (specific storage coefficient), and S_Y (specific yield)
Particle tracking	Kinematic (effective) porosity

In MIKE SHE, "geological layers" and "computational layers" can be separated. The latter need to be continuous throughout the model area (as is common in finite-difference models), but the thickness of a geological layer can be zero. Hence, it is possible to take into account a geological layer that exists only in part(s) of the model area. Further, the necessary initial and boundary conditions are defined for the computational layers. The main model simplifications concern unsaturated water flow and soil freezing/thawing. Unsaturated flow is assumed to be purely 1D (vertical), which in general can be considered a valid assumption. Further, the snow routine (cf Table 4-3) simulates snow accumulation and snow melt, but soil freezing/thawing is not accounted for.

A few notes should be made concerning the groundwater flow module, which in the case of MIKE SHE primarily is developed for modelling of groundwater flow in porous media. In the present modelling, groundwater flow in both QD and bedrock is modelled. In the bedrock, the dominant water flow paths consist of (discrete) fractures and fracture zones. For the bedrock, hydrogeological data were obtained from the DarcyTools model (the S1.2 model version /SKB 2005a, Follin et al. 2005/, see Section 4.1.3). In DarcyTools, data on the properties of "intact" rock from a so-called "discrete fracture network model" (DFN) are used to generate the hydrogeological properties for an "equivalent porous medium model" /Svensson et al. 2004/. Alternatively, a direct parameterisation of a continuum model can be made. In the present modelling, "gridded" hydrogeological properties are imported from the DarcyTools model to the corresponding grid cells in the MIKE SHE model.

4.2.3 Description of the model domain

The model area (model volume in 3D) includes catchment areas 6–9, and the associated coastal land and sea areas, i.e. areas with direct runoff to the sea and the sea bottom some distance into the adjacent bay of the Baltic, see Figure 4-5. The model area includes the catchment areas with the highest density of relevant site investigation data (cf Chapter 3). The MIKE SHE-MIKE 11 model area includes catchment areas 6–9 and adjacent coastal areas only. The part of catchment area 10 that was included in the terrestrial ecosystems modelling, see /Lindborg 2006/, was excluded from the hydrological modelling due to the lack of local input data. The hydrological input to the ecosystems modelling of this area was obtained from the results for catchments areas 6–9.

The horizontal spatial resolution of the model is 20 metres, whereas the vertical discretisation of the calculation layers follows that of the geological (QD) layers Z1–Z3 and M1–M3 in the g-HSD model (cf Section 4.1.3 and Table 4-4 below). Moreover, an additional calculation layer is introduced in the model, in order to be able to include the near-coastal parts of the sea. The grid resolution was determined based on experience from the previous Simpevarp /Werner et al. 2005/ and Forsmark /Johansson et al. 2005/ modelling. The sensitivity to the grid resolution has not been tested in L1.2; this should be done in forthcoming model versions (cf Section 4.2.8).

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Figure 4-5. *Catchment area boundaries (black lines) /Brunberg et al. 2004/ and the boundary of the MIKE SHE-MIKE 11 model area (red line). Note that the model area also includes the areas along the coastline, outside (downstream) of catchment areas 6-9.*

The upper boundary (the top surface) of the model follows the DEM /Brydsten and Strömgren 2005/, whereas the bottom of the model is located at a depth of –150 metres above sea level (i.e. in the bedrock). In the present modelling, no water flow is assumed to take place across the bottom boundary. The implications of this assumption, i.e. the effects of alternative boundary conditions, should be investigated in future model versions (see Section 4.2.8). Alternative cases that then could be tested include boundary conditions with a prescribed head or a prescribed flow rate at the bottom boundary, as well as different positions of the boundary; head values and/or flow velocities at selected depths in the bedrock could be obtained from the hydrogeological modelling of the rock.

The properties of the calculation layers, including external and internal boundary conditions, are summarised in Table 4-4. Note that the letter "C" is added in the table to emphasize that the data concern calculation layers and not geological layers. As mentioned above, MIKE SHE distinguishes between geological layers and calculation layers. The geological layers (cf Table 4-1) are the basis for the model parameterisation, which means that the hydrogeological parameters are assigned to the different geological layers. The calculation layers are the units considered in the numerical flow model. In cases where several geological layers are included in one calculation layer, the properties of the latter are obtained by averaging the properties of the former.

In general, the calculation layers coincide with the geological layers in the present model. However, one exception is the uppermost calculation layer. On land, the lower boundary of the uppermost calculation layer is placed at 1.0 metre below the ground surface (in areas with bedrock outcrops the lower level of the geological layer Z1 is at 0.1 metre). In the sea, the lower boundary of the uppermost calculation layer follows the sea bottom. The sea is described as a geological unit in the uppermost calculation layer; a constant-head internal boundary is used below the sea. For the calculation layers representing QD, no water flow is assumed to take place across the outer boundaries (i.e. across water divides). The outer boundary towards the sea is an exception, with a constant head assigned along that boundary.

Table 4-4. Description of the calculation layers in the MIKE SHE model. Note that the model layers in DarcyTools are numbered from the bottom and up (i.e. in reverse order compared to MIKE SHE); this numbering system is also adopted here for the bedrock.

Calculation layer	Domain	Bottom level (m.a.s.l.)	Outer boundary conditions	Internal boundary condition
C_1	QD and the sea	[1]g-HSD (upper boundary from [2]DEM)	Constant head towards the sea, otherwise no-flow along water divides (CA boundaries)	Constant head below the sea
C_2	QD	g-HSD	Constant head towards the sea, otherwise no-flow along water divides (CA boundaries)	None
C_3	QD	g-HSD	Constant head towards the sea, otherwise no-flow along water divides (CA boundaries)	None
C_4	QD	g-HSD	Constant head towards the sea, otherwise no-flow along water divides (CA boundaries)	None
C_5	Bedrock	~ 0	Constant head ([3]DT)	None
C_6	Bedrock	~ –10	Constant head ([3]DT)	None
C_7	Bedrock	~ –60	Constant head ([3]DT)	None
C_8	Bedrock	–150	No flow (including the bottom)	None

[1] According to the geometrical model of HSD (g-HSD) /Nyman 2005/.

[2] According to the DEM /Brydsten and Strömgren 2005/.

[3] Constant head supplied by the DarcyTools modelling team.

4.2.4 Hydraulic properties of QD and bedrock

The assignment of the hydraulic properties of QD follows that in the conceptual-descriptive model (see Table 4-2 in Section 4.1.3). Moreover, for the hydraulic properties of the bedrock, S1.2 model version data are used, provided by the DarcyTools modelling team. As these data do not include the specific yield (S_Y) or the specific storage coefficient (S_S), it is assumed that S_Y equals the effective porosity (which is included in the DarcyTools data set). Further, the specific storage coefficient (S_S) in the bedrock is calculated according to an empirical relationship between S_S and the hydraulic conductivity K (cf Section 4.1.3). The assigned spatial distributions of K in the upper (QD) layer and in the upper bedrock layer in the MIKE SHE model area are shown in Figures 4-6 and 4-7, respectively.

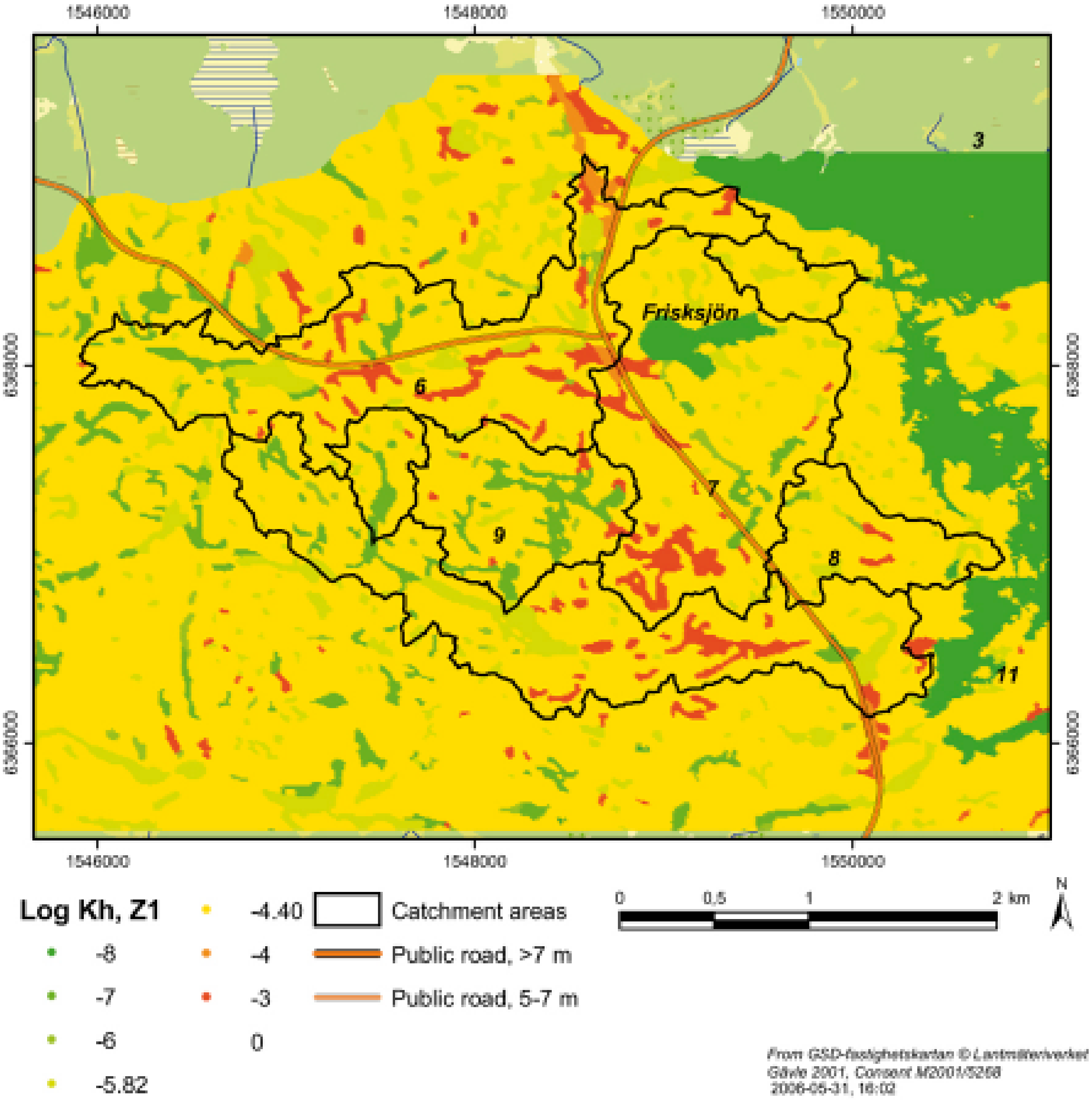

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***Figure 4-6.** Horizontal hydraulic conductivity (K_H) of QD in the upper layer (layer Z1) of the MIKE SHE model. The dark green areas in the various surface waters in the area refer to the uppmost, low-conductive sediment layer.*

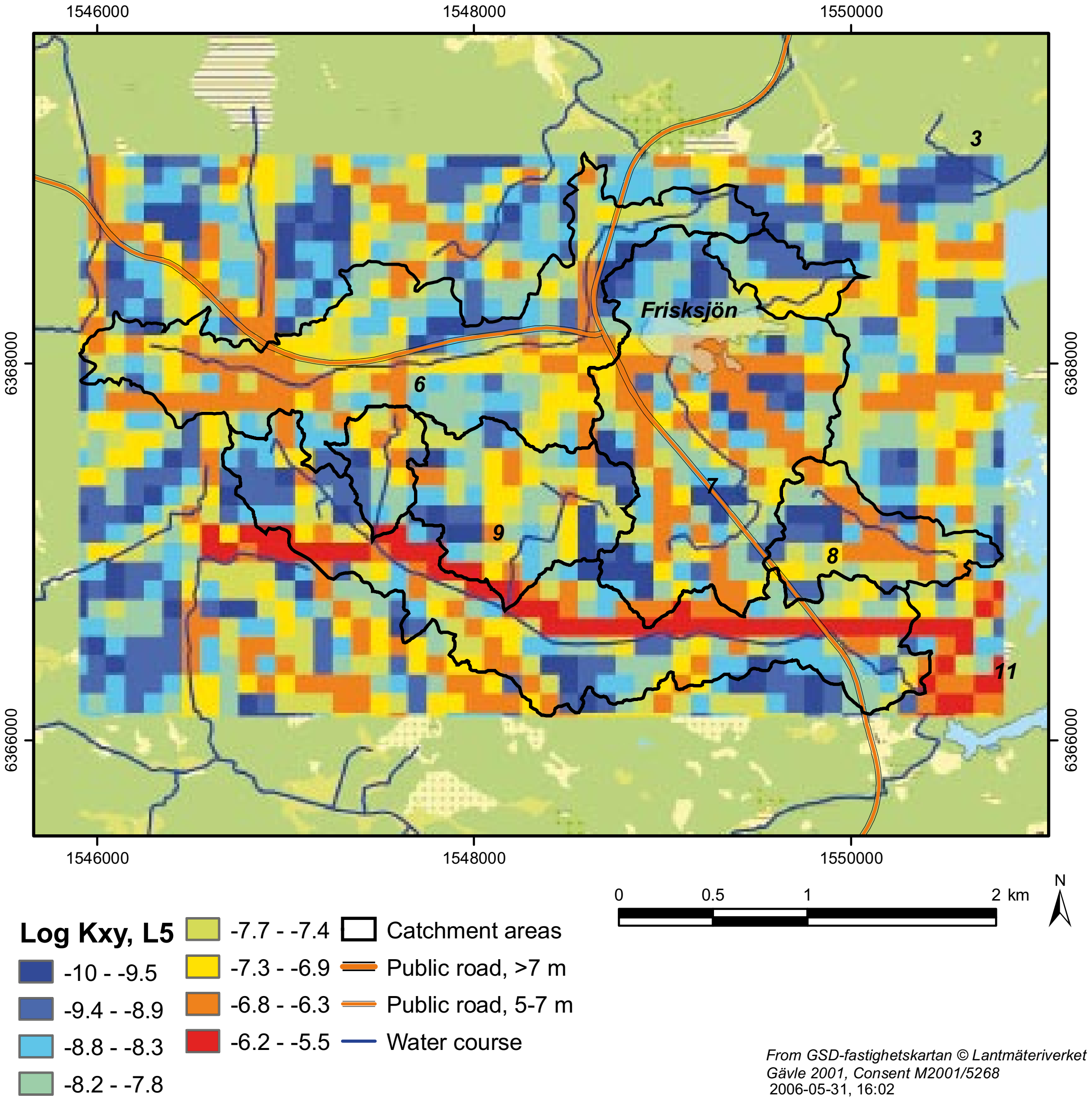

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Figure 4-7. *Horizontal hydraulic conductivity (K_H) in the upper bedrock layer (layer L5) of the MIKE SHE model, obtained from the DarcyTools modelling team. The figure also shows the catchment area boundaries (black lines) and the watercourses (blue lines).*

It can be noted that the conceptual-descriptive model includes a description of the hydraulic properties of "near-surface" bedrock (cf Table 4-2 in Section 4.1.3). In the process of creating calculation layers in MIKE SHE (which must be continuous throughout the model area), a minimum layer thickness of 1 metre is applied. In the g-HSD /Nyman 2005/, there are no (geological) Z2 and Z3 layers in areas with exposed bedrock. The definition of calculation layers above therefore implies that the hydraulic properties assigned to "near-surface bedrock" according to Table 4-2 are assigned to the upper 2 metres of the bedrock (adding the minimum thicknesses of calculation layers Z2 and Z3). Hence, in the exposed/shallow bedrock areas, the hydraulic properties of the bedrock are in accordance with the DarcyTools model below a depth of 2.1 metres (2 metres plus 0.1 metre, i.e. the thickness of QD layer Z1 in those areas).

In MIKE SHE, there is a separate module for modelling of unsaturated water flow (see Table 4-3). In order to reduce the simulation time, which generally is long when unsaturated water flow is to be calculated numerically, MIKE SHE performs the unsaturated zone calculations in a number of selected "UZ type areas". Each UZ type area represents different conditions in terms of depth to the groundwater table (divided into depth classes), type of QD, and land use (vegetation). The initial groundwater table (at the start of the simulated period) and the QD and vegetation maps are used to identify the UZ type areas.

For each type of QD, a "typical" (layered) vertical soil profile is defined and used in the calculations. Unsaturated zone-specific hydraulic parameters are also required for each QD type included in the defined profiles. These parameters include the relationships between water content and capillary pressure head, and between water content and (unsaturated) hydraulic conductivity. In the present modelling, an internal MIKE SHE database is used. This database includes these relationships for various soils in tabulated form. Based on the QD map, one typical soil profile is defined for each type of QD. Some QD types are lumped, resulting in totally six "type profiles". The soil profiles are described in Table 4-5 below (cf Table 4-1 in Section 4.1.3). The individual layers within each profile are referred to as "UZ layer" 1, 2, and 3. Note that the soil types in the table refer to their names in the internal MIKE SHE database.

Table 4-5. Soil type profiles defined for modelling of unsaturated water flow in MIKE SHE. There is one soil type profile for each type of QD in the QD map (note that some QD classes are lumped into a single soil type). The numbers within brackets denote the assigned vertical extension (m.b.g.s.) for each UZ layer in the soil type profiles.

Soil type profile (QD in QD map)	UZ layer 1 (vertical extension, m.b.g.s.)	UZ layer 2 (vertical extension, m.b.g.s.)	UZ layer 3 (vertical extension, m.b.g.s.)	Comments
1 – Gyttja				Areas with gyttja only exist below open water in the MIKE SHE model area (see 12 – Water)
2 – Clay gyttja, gyttja clay	Clay (0–2.5)	(Coarse) till (2.5–20)	No UZ layer 3	Part of the lumped soil type 20 (clay/gyttja)
3 – Clay	Clay (0–2.5)	(Coarse) till (2.5–20)	No UZ layer 3	Part of the lumped soil type 20 (clay/gyttja)
4 – Silt				No areas with silt exist in the MIKE SHE model area
5 – Till	(Coarse) till (0–20)	No UZ layer 2	No UZ layer 3	Part of the lumped soil type 21 (till)
6 – Till with thin peat cover	(Coarse) till (0–20)	No UZ layer 2	No UZ layer 3	Part of the lumped soil type 21 (till)
7 – Fluvial outwash, gravel	Gravel (0–1)	Clay (1–4)	(Coarse) till (4–20)	Part of the lumped soil type 22 (gravel)
8 – Fluvial outwash, sand	Sand (0–5)	Clay (5–7)	(Coarse) till (7–20)	
9 – Flood sediment, clay-gravel	Clay (0–5)	(Coarse) till (5–20)	No UZ layer 3	
10 – Peat	Peat (0–1)	(Coarse) till (1–20)	No UZ layer 3	
11 – Bedrock	Till (0–20)	No UZ layer 2	No UZ layer 3	Only till is defined in the profile
12 – Water	Clay (0–5)	(Coarse) till (5–20)	No UZ layer 3	
13 – Bouldery soil				No areas with bouldery soil exist in the MIKE SHE model area

Soil type profile (QD in QD map)	UZ layer 1 (vertical extension, m.b.g.s.)	UZ layer 2 (vertical extension, m.b.g.s.)	UZ layer 3 (vertical extension, m.b.g.s.)	Comments
14 – Artificial fill	(Coarse) till (0–20)	No UZ layer 2	No UZ layer 3	Part of the lumped soil type 21 (till)
15 – Fluvial outwash, stones/boulders				No areas with fluvial outwash, stones/boulders exist in the MIKE SHE model area
16 – Glaciofluvial deposits, coarse silt/boulders	Gravel (0–1)	Clay (1–4)	(Coarse) till (4–20)	Part of the lumped soil type 22 (gravel)
17 – Unclassified	(Coarse) till (0–20)	No UZ layer 2	No UZ layer 3	Part of the lumped soil type 21 (till)

Table 4-6 summarises the unsaturated zone-specific hydraulic properties assigned to the soil types in Table 4-5, according to the internal MIKE SHE database; the required parameters include K_s, θ_s, θ_{fc}, and θ_r (defined in Table 4-6). The table also shows values of the specific yield, S_Y, calculated from the database values of the water content at full saturation (θ_s) and the field capacity (θ_{fc}), by use of the commonly known expression $S_Y = \theta_s – \theta_{fc}$. Note that S_Y is shown in the table for comparison only; it is not used explicitly in the MIKE SHE calculations.

For (coarse) till, peat and gravel, the calculated S_Y-values in the table agree well with those used for the saturated (groundwater) zone, cf Table 4-2 in Section 4.1.3. The S_Y-values for the saturated zone are found in the literature. However, it can be noted that the S_Y-values for clay/gyttja ($S_Y = 0.31$) and sand ($S_Y = 0.43$) in the table are higher than those used for the saturated zone. For the saturated zone, the corresponding values are 0.03 and 0.25. In order to keep the model numerically stable, till is assigned in the whole "type profile" in areas with shallow/exposed bedrock.

Table 4-6. Unsaturated zone-specific hydraulic properties for the soil types in Table 4-5.

Soil type	Hydraulic conductivity at saturation, K_s ($m \cdot s^{-1}$)	Water content at saturation (θ_s)	Field capacity (θ_{fc})	Residual water content (θ_r)	$S_Y = \theta_s – \theta_{fc}$
Clay/gyttja	$1.0 \cdot 10^{-8}$	0.62	0.31	0.10	0.31
Sand	$4.2 \cdot 10^{-5}$	0.47	0.04	0.02	0.43
(Coarse) till	$4.0 \cdot 10^{-5}$	0.38	0.30	0.03	0.08
Peat	$1.5 \cdot 10^{-6}$	0.84	0.60	0.10	0.25
Gravel	$2.0 \cdot 10^{-3}$	0.30	0.09	0.02	0.21

4.2.5 Land use (vegetation) data

Land use is incorporated in the model by the vegetation map of the Simpevarp area /Boresjö et al. 2003/. Five land use (vegetation) types are defined in the model area: deciduous forest, mixed forest, coniferous forest, water, and grass areas. The classification is made based on tree-layer data extracted from the vegetation map; areas assigned the class "no tree layer" in that map are classified as grass areas. Each vegetation type is assigned vegetation-specific parameters, required for the interception-evapotranspiration calculations in MIKE SHE. The parameters required are the leaf area index (LAI), the crop coefficient (K_c), and the root depth.

The leaf area index (LAI) is defined as the fraction of leaf area per unit ground area ($m^2 \cdot m^{-2}$). Moreover, the Penman formula is considered to provide a realistic estimate of the "reference" potential evapotranspiration (PET_{ref}), valid for grass surfaces and short crops /Larsson-McCann et al. 2002/. Other vegetation types can have a "vegetation-specific" potential evapotranspiration (PET_{vs}), which is higher or lower than the "reference" potential evapotranspiration. This is considered by introducing a crop coefficient K_c, defined as $K_c = PET_{vs}/PET_{ref}$, i.e. the ratio between the potential evapotranspiration for a certain vegetation type, and the "reference" potential evapotranspiration calculated using the Penman formula.

In the MIKE SHE model, seasonal variations of the parameters LAI and K_c can be considered by dividing the year into a series of vegetation development periods of different lengths. The land-use (vegetation-) specific values of LAI, K_c and root depth for different vegetation types are assigned according to data based on experiences from previous MIKE SHE model applications (pers. comm. with Lars-Göran Gustafsson, DHI). The exception is for the vegetation type coniferous forest, for which the assigned K_c-values are modelling results for coniferous from the COUP-model /Gustafsson et al. 2006/. A series of sensitivity cases, involving the parameters LAI and K_c are analysed in Section 4.2.8.

4.2.6 Setup of the MIKE 11 channel-flow model

MIKE 11 /DHI Software 2004/ is a program for modelling of 1D channel flow. The MIKE 11 program is fully integrated and runs simultaneously with the MIKE SHE model; for details on the MIKE 11 program and its capabilities, see /Werner et al. 2005/. As previously mentioned, MIKE 11 requires that a so-called "river network" is defined, including the bottom level and width in a number of cross sections along the considered watercourses. In the Simpevarp model area (catchment areas 6–9), the main watercourses are Mederhultsån (catchment area 6), Kåreviksån (catchment area 7), Pistlanbäcken (catchment area 8), and Ekerumsån (catchment area 9).

For the main watercourses in catchment areas 6, 7 and 9, data are used from measurements of cross sections, performed during the spring of 2005 /Strömgren et al. 2006/. The surveying also included tributaries to Ekerumsån in catchment area 9. The surveyed watercourses are shown in Figure 4-8. For Pistlanbäcken in catchment area 8 (which has not been surveyed), a constant width of two metres and a depth of one metre are assumed. These measured or otherwise estimated data were used to define the river network in MIKE 11, and its associated cross sections. Additional parameters required for the modelling of flow in the watercourses, i.e. the those quantifying the flow resistance, were obtained from the MIKE SHE database.

Lake Frisksjön was also included in the MIKE 11 model, defined as a watercourse with a bottom level according to the DEM, and with a very large width (equal to the average width of the lake between its in- and outlets). In addition, in MIKE SHE, the option "Flood codes" is activated around Lake Frisksjön, in order to allow formation of a lake in the model during the course of simulations.

4.2.7 Definition of the initial base case

Using the MIKE SHE-MIKE 11 model setup described in Sections 4.2.3-6, an initial base case (BC) is defined, using meteorological data with a high temporal resolution (daily values) from the Äspö meteorological station during 2004 (cf Section 3.1.2). These data include precipitation, air temperature and potential evapotranspiration. Hence, the BC

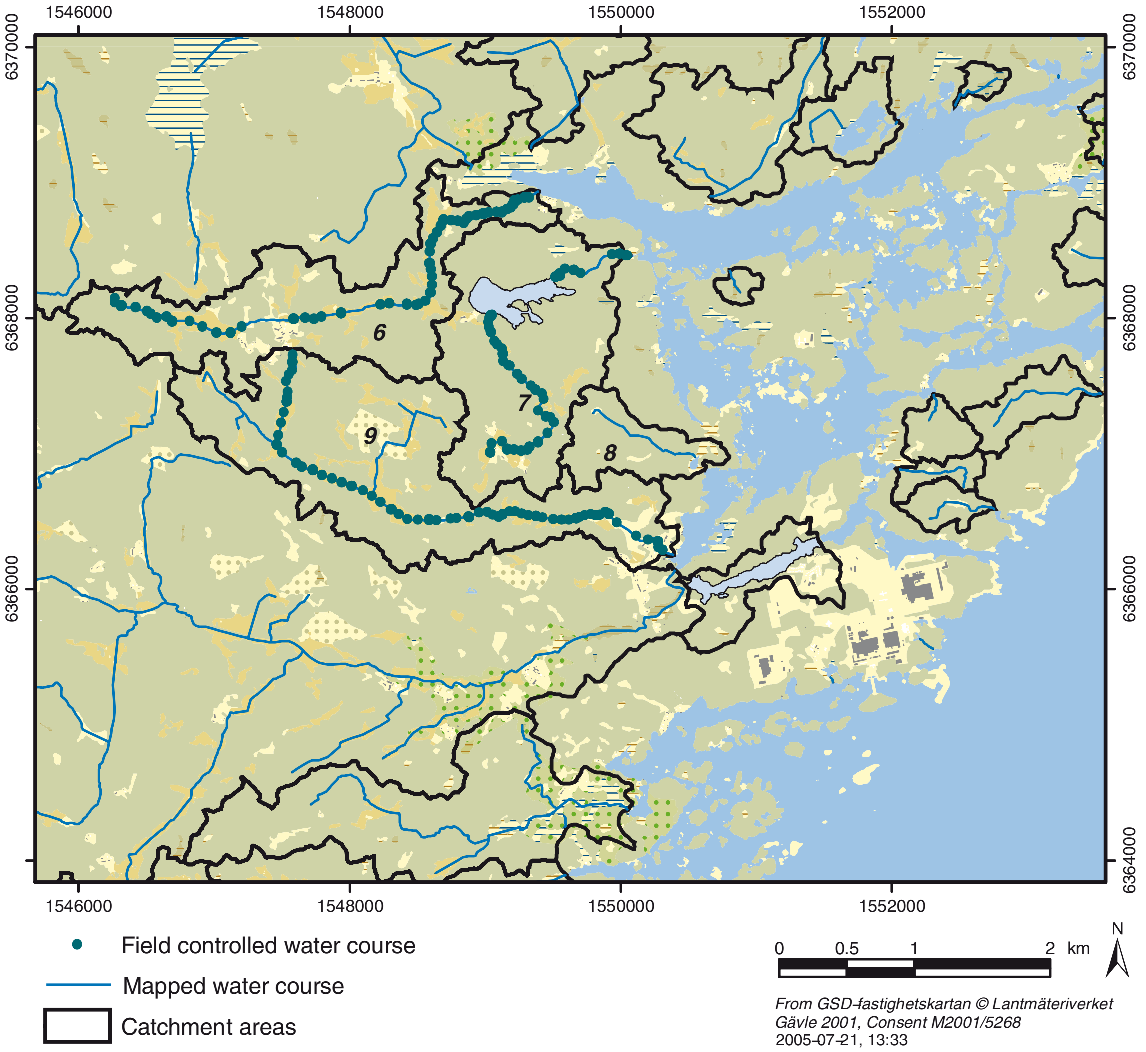

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Figure 4-8. *Map showing the surveyed main watercourses in catchment areas 6 (Mederhultsån), 7 (Kåreviksån) and 9 (Ekerumsån). The surveying also included a tributary to Ekerumsån /Strömgren 2006/. Pistlanbäcken in catchment area 8 has not been surveyed.*

implies that water flow in the model area is simulated for a one-year period, using locally measured meteorological data. The modelling methodology, which involves the use of initial conditions and "hot start" data, is briefly described below.

As a transient process is simulated, initial conditions are required. The modelling methodology implies that initial conditions for the MIKE SHE model are defined in terms of head in each grid cell. In the calculation layers representing QD (C_Z1 to C_Z4; see Table 4-4), the initial head is defined as the land surface from the DEM minus 1 metre. The bedrock calculation layers representing bedrock (C_L4 to C_L7) use values of head in grid cells, provided by the DarcyTools modelling team. Using these initial head values, a first simulation is run for a time period of several years. Subsequently, the model-calculated head values at the last time step in each grid cell are saved, and used as initial conditions for the following simulations, which include the sensitivity cases; see Section 4.2.8. Hence, the first simulation ("cold start") only aims at producing so-called "hot start" data (initial conditions).

It can be noted that the accumulated precipitation during 2004 at Äspö (c 660 mm) equals the corresponding value for the meteorological station in Oskarshamn during the representative year 1981 (a year "most equal" to the average conditions 1961–1990). Moreover, the accumulated potential evapotranspiration at Äspö during 2004 was c 434 mm, whereas it was c 460 and 490 mm during the representative year 1981 in Målilla and Västervik/Gladhammar, respectively (the potential evapotranspiration is not calculated by SMHI for the Oskarshamn station). During 2004, the accumulated potential evapotranspiration was c 455 mm in Gladhammar. Hence, the meteorological data used in the simulations are fairly similar to the long-term "average" conditions in the area. In the following, the response of the hydrological system to these meteorological conditions is investigated in a series of sensitivity cases and in a detailed analysis of the updated base case.

4.2.8 Definition of the sensitivity cases

Objectives and scope

The initial base case (BC) described in the previous section is used as a "benchmark" for other simulation cases, from which an updated base case (UBC) is identified. The UBC is later used to produce results to other models and applications, primarily the integrated ecological systems modelling within SurfaceNet /Lindborg 2006/. There are a number of uncertainties associated with the BC model, including factors related to assumptions and simplifications in the conceptual-descriptive model (and the numerical model itself), and/or scarce or missing site investigation data. This section defines a series of sensitivity cases (abbreviated SA), aiming to explore the impact on the model output of (1) the hydrogeological properties of the QD, and (2) the vegetation-related parameters LAI (Leaf Area Index) and K_c (crop coefficient). Of course, there are several other sources of uncertainty, and the present analysis is focused on a small subset of them. For instance, further sensitivity analyses could include analyses of the effects of

- the spatial discretisation of the model (e.g. across the QD/bedrock interface),
- heterogeneity in the hydraulic properties of the QD,
- the bottom boundary condition (e.g. a prescribed head or a prescribed flow velocity at the bottom boundary, instead of simply assuming a no-flow boundary),
- the magnitude of surface runoff for different assumptions concerning the description of the exposed bedrock areas (shallow QD versus no QD in such areas),
- temporal variability in the meteorological conditions (e.g. dry and wet periods/years, with specified return periods).

Hydraulic properties of QD

In near-surface groundwater flow modelling, the hydraulic properties (primarily hydraulic conductivity, specific yield, and specific storage coefficient) of the QD are generally subject to a relatively high degree of uncertainty. One potentially important type of uncertainty is that arising when upscaling data obtained in small-scale tests (e.g. slug tests) to the much larger elements in the numerical flow model. In the L1.2 modelling, the interaction between groundwater and surface water is also taken into account, through the MIKE SHE-MIKE 11 coupling; obviously, groundwater and surface water always interact to some extent in reality. Hence, uncertainties concerning the hydraulic properties of the QD do not only have an influence on model-calculated groundwater flow, but these uncertainties may to some extent also propagate to the model-calculated surface water flow.

This section defines sensitivity cases that aim at investigating the sensitivity of the model output to the hydraulic properties of QD. It should be noted that there are site investigation data (obtained from slug tests and grain-size distribution curves) on the hydraulic conductivity (*K*) of till in the Simpevarp area, whereas there are scarce site investigation data, or no site data at all, for the other hydraulic parameters and types of QD (cf Section 3.3.1). The following sensitivity cases are defined:

- ***Sensitivity cases SA_1a–n – Simultaneous variations in K_H and K_V with constant anisotropy ratio K_H/K_V:***
  - In cases SA_1a and SA_1b, both the horizontal and vertical hydraulic conductivity *K* (K_H and K_V) of all QD layers (Z1–Z3 and M1–M3) are increased to *K_SA*/*K_BC* = 10 (SA_1a) and decreased to *K_SA*/*K_BC* = 0.1 (SA_1b), where *SA* denotes sensitivity case and *BA* base case, respectively.
  - In cases SA_1c through SA_1n, the *K*-values are increased or decreased in one QD layer per case. Note that this increase/decrease in K_H and K_V corresponds to a variation interval of ±1 order of magnitude compared to the BC. In all these cases, the anisotropy ratio $K_H/K_V = 1$.

- ***Sensitivity cases SA_2a–n – Variations in K_H only (variable anisotropy ratio K_H/K_V):***
  - In cases SA_2a–b, the horizontal hydraulic conductivities, K_H, of all QD layers (Z1–Z3 and M1–M3) are increased to *K_SA*/*K_BC* = 10 (SA_2a) or decreased to *K_SA*/*K_BC* = 0.1 (SA_2b).
  - In cases SA_2c–n, K_H is increased or decreased in one QD layer per case. In all these cases, the vertical hydraulic conductivity (K_V) is kept unchanged compared to the BC, which implies that the cases represent different anisotropy ratios ($K_H/K_V = 0.1$ or 10).

- ***Sensitivity cases SA_3a–b – Variations in the specific yield:***
  - In cases SA_3a–b, the specific yield (S_Y) of all QD layers (Z1–Z3 and M1–M3) is changed ±50% compared to the BC.

- ***Sensitivity cases SA_4a–b – Variations in the storage coefficient:***
  - In cases SA_4a–b, the specific storage coefficient (S_S) of all QD layers (Z1–Z3 and M1–M3) is changed ±50% compared to the BC.
  - It should be noted that these sensitivity cases only involve the hydraulic properties in the saturated flow module in MIKE SHE (cf Section 4.2.2). Hence, the hydraulic properties in the unsaturated flow module are not changed compared to the BC.
    As shown in the definition of the sensitivity cases SA_3 and SA_4, the sensitivity analysis concerning the specific yield S_Y (SA_3) and the specific storage coefficient S_S (SA_4) is not as comprehensive as that delaing with the hydraulic conductivity *K* (SA_2). The reason for this prioritisation are partly due to the fact that the available computational resources limit the possibilities to perform extensive sets of simulations. However, the main reason is that S_Y and S_S generally demonstrate more narrow variation intervals, and that it also can be assumed a priori that these parameters have less impact on the model output, as compared to the hydraulic conductivity *K*. The definitions of the sensitivity cases SA_1 to SA_4 are summarised in the table below.

Table 4-9. Definition of sensitivity cases for investigation of the impact of the hydraulic properties of QD. In all defined cases, the remaining parameters are unchanged compared to the BC (denoted "–" in the table).

Case	Horizontal hydraulic conductivity (K_H); *K_SA/K_BC*		K_H/K_V	Specific yield (S_Y)		Specific storage coefficient (S_S)	
SA_1a/b	Z1–Z3, M1–M3[1]	10/0.1	1	–		–	
SA_1c/d	Z1[1]	10/0.1	1	–		–	
SA_1e/f	Z2[1]	10/0.1	1	–		–	
SA_1g/h	Z3[1]	10/0.1	1	–		–	
SA_1i/j	M1[1]	10/0.1	1	–		–	
SA_1k/l	M2[1]	10/0.1	1	–		–	
SA_1m/n	M3[1]	10/0.1	1	–		–	
SA_2a/b	Z1–Z3, M1–M3[1]	10/0.1	10/0.1	–		–	
SA_2c/d	Z1[1]	10/0.1	10/0.1	–		–	
SA_2e/f	Z2[1]	10/0.1	10/0.1	–		–	
SA_2g/h	Z3[1]	10/0.1	10/0.1	–		–	
SA_2i/j	M1[1]	10/0.1	10/0.1	–		–	
SA_2k/l	M2[1]	10/0.1	10 0.1	–		–	
SA_2m/n	M3[1]	10/0.1	10/0.1	–		–	
SA_3a/b	–			Z1–Z3, M1–M3[1]	±50%	–	
SA_4a/b	–			–		Z1–Z3, M1–M31	±50%

[1] Refers to the layer or layers where the properties are varied in the sensitivity case(s) described.

Vegetation properties

The vegetation-related parameters Leaf Area Index (LAI), crop coefficient (K_c) and root depth (see Section 4.2.5) are the main "process-specific" input parameters in the modelling of the interception, evaporation and transpiration processes. Thus, they are of importance also for the calculated water balance, and it needs to be tested whether the water balance is sensitive to variations in these parameters. In particular, LAI and K_c are key parameters used in the modelling of these processes in MIKE SHE; they are defined in Section 4.2.5. As there are no site-specific data on these parameters, LAI- and K_c-values from the literature are used in the present modelling.

An analysis of the land-use data in Table 3-14 (Section 3.2.1) for the 26 catchment areas in the Simpevarp area /Brunberg et al. 2004/ shows that coniferous forest covers some 85% of the total land area. This type of forest covers c 69% of land within the MIKE SHE model area. This section defines a series of sensitivity cases, which aim at investigating the sensitivity of the model output to the assigned values of the key parameters LAI and K_c of the coniferous forest; the coniferous forest parameters are the most important to study, since this is the dominating land-use (vegetation) type in the area (cf above). The sensitivity cases formulated are summarised in Table 4-10 below.

For the initial base case (BC) and the sensitivity cases SA_5c–d, the assigned K_c-values for coniferous forest are taken from the COUP-model simulations of the Simpevarp area /Gustafsson et al. 2006/. In this data set, the K_c-value is assumed to demonstrate seasonal variability, as follows: K_c is equal to 1.7 during November to February, 1.3 during March and October, 1 during April and September, and 0.7 during April to August. However, it should be noted that these values are actual outputs for coniferous forest from the COUP-model simulations (i.e. the calculated ratio of the actual and potential evapotranspiration), and hence is based on a different definition than the crop coefficient K_c as defined and used in the MIKE SHE model.

There are relatively few relevant literature values of the crop coefficient K_c available, mainly because it is a typical "agricultural" parameter usually reported for individual vegetables and crops only. Based on experiences from previous MIKE SHE model applications (pers. comm. with Lars-Göran Gustafsson, DHI), K_c-values of 1 or 1.3 are recommended for coniferous forest. In comparison, there is a somewhat larger amount of relevant literature data available for the leaf area index LAI. For instance, /Gustafsson et al. 2004/ report LAI to be in the range 3–5 for a coniferous forest in Sweden, dominated by spruce and pine.

In the sensitivity cases SA_5a–j (see Table 4-10), the leaf area index LAI of coniferous forest is assigned temporally constant values of 5, 7 or 9, whereas the K_c-value is assumed to be either temporally constant (SA_5a–b and e–h) or seasonally variable (initial base case, SA_5c–d and i–j). In the sensitivity analysis, the considered range of K_c-values is 0.7–1.3; note that K_c-values lower than 1 are considered only in the initial base case and in the sensitivity cases SA_5c–d. The sensitivity cases SA_5i–j consider seasonally variable K_c-values, with $K_c = 1.3$ during the growth season (mid April to mid September) and $K_c = 1$ during the rest of the year.

Table 4-10. Definition of sensitivity cases for investigating the impact of the crop coefficient K_c and the leaf area index (LAI) for coniferous forest. In all cases, the remaining parameters are unchanged compared to the initial base case (BC). A single K_c-value implies that this value is assumed to be constant during the year, whereas cases with several values imply seasonal variability. In all sensitivity cases, LAI is assumed to be constant during the year.

Case	Crop coefficient, Kc	Leaf area index, LAI
Initial base case (BC)	COUP[1]	7
SA_5a	1.3	7
SA_5b	1	7
SA_5c	COUP[1]	9
SA_5d	COUP[1]	5
SA_5e	1	5
SA_5f	1	9
SA_5g	1.3	5
SA_5h	1.3	9
SA_5i	1.3 mid April to mid Sept. 1 otherwise	7
SA_5j	1.3 mid April to mid Sept. 1 otherwise	5

[1] K_c-values from the COUP modelling of the Forsmark and Simpevarp areas /Gustafsson et al. 2006/, see text.

4.3 Modelling results for base case and sensitivity cases

4.3.1 Water balance and specific discharge

The first part of this section presents the results of the sensitivity analysis, which was performed to investigate the sensitivity of the total evapotranspiration and the relative distribution of the evapotranspiration components to the vegetation-related parameters LAI (Leaf Area Index) and K_c (crop coefficient) of coniferous forest. As discussed above, this is the dominant land-use (vegetation) type in the L1.2 model area (cf Section 4.2.8). Based on this sensitivity analysis, an updated base case is identified, which also is used to produce output data to the ecological systems modelling within SurfaceNet. Second, another sensitivity analysis is presented, concerning the hydraulic properties of QD. It should be noted that also in this sensitivity analysis, the intial base case (cf Section 4.2.7) is used as reference case.

Vegetation-related parameters and update of base case

The results of the sensitivity analysis concerning the vegetation-related parameters LAI and K_c (cf Table 4-10) are summarised in Table 4-11. Note that meteorological data from Äspö from 2004 are used in all these cases. To assess the most appropriate combination of vegetation-related parameters LAI and K_c in Table 4-11, these results are compared to those presented by /Gustafsson et al. 2004/. They used the COUP model to calculate the water and heat balance of a coniferous forest in Norunda, located c 30 km north of Uppsala in the mid-eastern part of Sweden. The dominating type of QD at the Norunda site is deep, boulder-rich sandy till. The LAI (leaf area index) of the forest is estimated to be in the range 3–5; in the COUP-Norunda simulations, LAI was assumed to demonstrate a seasonal behaviour, with an average value of 4.5.

It should be pointed out that the MIKE SHE-MIKE 11 model area includes many land-use (vegetation) types, whereas the study site in /Gustafsson et al. 2004/ mostly consists of coniferous forest. Further, the total evapotranspiration E_{tot} in Table 4-11 includes evaporation from the unsaturated zone, the saturated zone, and from overland water (open water surfaces), whereas soil evaporation in the COUP-Norunda simulations refers to “forest floor evaporation” /Gustafsson et al. 2004/. For the purposes of the present comparison, “forest floor evaporation” is assumed to correspond to evaporation from the unsaturated zone (soil evaporation) in the MIKE SHE-MIKE 11 simulations. In the L1.2 model area, there are areas with overland water (e.g. Lake Frisksjön) and areas with near-surface groundwater, from which water is more or less directly available for evaporation. The E_{tot} values in Table 4-11 include also these evaporation components, but they are not specified in the table.

In the COUP-Norunda case /Gustafsson et al. 2004/, the COUP model simulations were performed using soil hydraulic data, and meteorological and vegetation data for a 3-year period. Meteorological data for a 30-year period were used to calculate the annual average water balance of the Norunda forest. The calculated average annual evapotranspiration was 416 mm, of which evaporation (both soil and snow), transpiration, and interception constitute 62 mm, 230 mm and 124 mm, respectively. Hence, the average annual distribution of the evapotranspiration components was 55% transpiration, 30% interception, and 15% evaporation (including both soil and snow evaporation).

There are relatively large differences in the total evapotranspiration E_{tot} calculated by MIKE SHE-M11 for the cases in Table 4-11. The value of E_{tot} is between 78 mm lower and 69 mm higher than the annual average evapotranspiration (416 mm) calculated by the COUP model for the Norunda coniferous forest /Gustafsson et al. 2004/. In terms of E_{tot}, the best fit to

Table 4-11. Model-calculated annual values of the total evapotranspiration and its components (mm) for the initial base case and sensitivity cases SA_5a–j. Note that meteorological data from Äspö from 2004 are used in all cases.

Case	Total evapotranspiration, E_{tot}	Transpiration (% of E_{tot})	Interception (% of E_{tot})	Soil evaporation (% of E_{tot})
Initial base case	342	108 (32)	178 (52)	30 (10)
SA_5a	483	204 (42)	199 (41)	54 (12)
SA_5b	398	147 (37)	187 (47)	40 (11)
SA_5c	346	104 (30)	186 (54)	29 (9)
SA_5d	338	113 (33)	168 (50)	31 (10)
SA_5e	396	152 (38)	176 (44)	41 (11)
SA_5f	400	143 (36)	193 (48)	38 (10)
SA_5g	481	209 (43)	191 (40)	55 (12)
SA_5h	485	201 (41)	205 (42)	53 (12)
SA_5i	468	197 (42)	194 (41)	52 (11)
SA_5j	466	200 (43)	186 (40)	53 (11)

the COUP-Norunda results are for case SA_5b, e and f (c 20 mm lower). Considering the distribution of the evapotranspiration components, the best fit to the COUP-Norunda case is for cases SA_5g and j; for the soil evaporation, there are small differences between the cases in Table 4-11.

As a preliminary conclusion, the combination of vegetation-related parameters (LAI and K_c) associated with case SA_5j in Table 4-11 is considered to produce the most realistic distribution of the evapotranspiration components; this case will in the following be referred to as the updated base case. Case SA_5j is also associated with the most realistic input data for coniferous forest in terms of LAI and K_c; see the discussion associated with Table 4-10.

Figure 4-9 illustrates the model-calculated water balance (mm·year^{-1}) for the updated base case, and the exchanges of water between different compartments. Since the water balance during the first day of the simulated period (Jan. 1, 2004) is not included in the water balance, the annual precipitation shown in the figure (P = 654.5 mm) differs c 6 mm compared to the actual precipitation during 2004 (660.5 mm; see Section 3.1.2).

The water balance in Figure 4-9 considers all land areas within the model boundary, hence excluding the sea part of the model area but including near-coastal land areas with direct runoff to the sea. The boundaries of catchment areas 6–9 delimit the areas which contribute to the discharge into the watercourses (see the schematic watercourse in Figure 4-9). As shown in Figure 4-9, the model-calculated average specific discharge is 136 (from OL to M11)+24 (from SZ to M11)+14 (OL across boundary)+15 (SZ across boundary) = 189 mm·year^{-1} (corresponding to c 6 l·s^{-1}·km^{-2}) for the considered one-year period using Äspö meteorological data from 2004. The specific discharge includes overland and groundwater flow into the watercourses and the sea.

The water losses due to interception, transpiration, and evaporation (including evaporation from surface water, snow, and the unsaturated and saturated zones) are 186, 200 and 80 mm·year^{-1}, respectively (cf case SA_5j in Table 4-11), which means that the total average evapotranspiration is 466 mm·year^{-1}. With reference to the numbers displayed in Figure 4-9, the distribution of the evaporation on its different components is: 3 mm from snow, 19 mm from surface water, 53 mm from the unsaturated zone (i.e. upper soil layer), and 5 mm from the saturated zone during the one-year simulation period. Similar to the rest of the water balance components, these are averaged over the on-shore part of the model

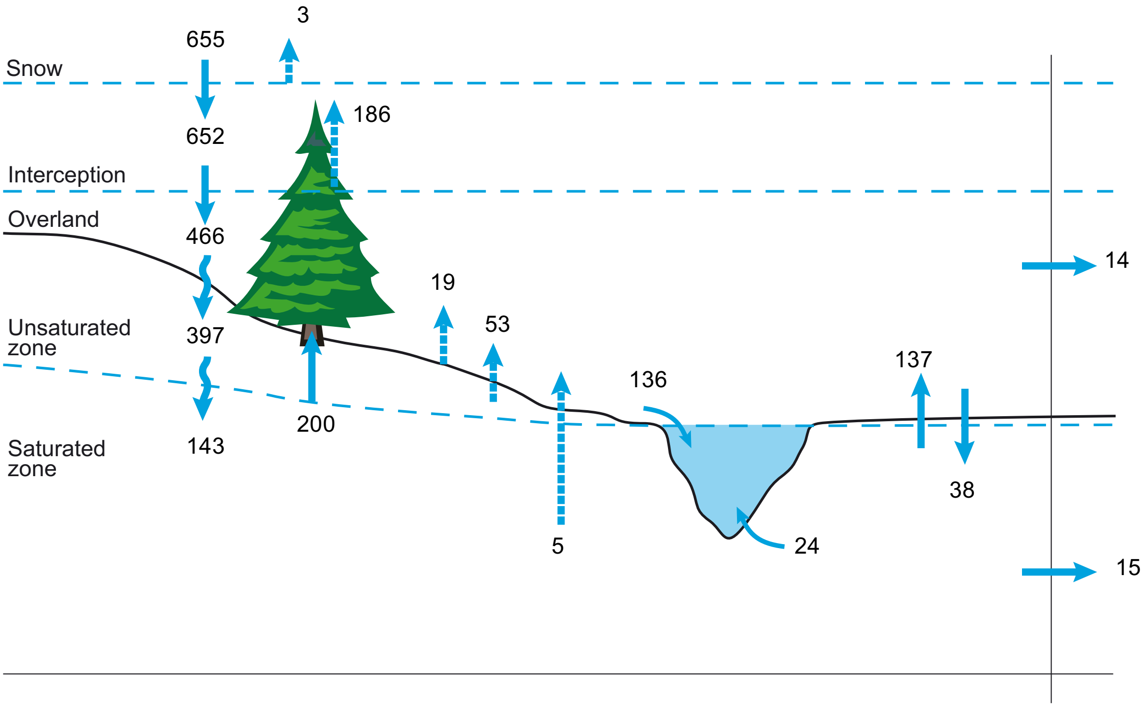

Figure 4-9. Summary of the calculated water balance for the land areas in the model area (mm·year^{-1}) for the updated base case.

area. This implies that the actual (specific) evaporation taking place in, for instance, areas with overland water is larger than that indicated by model area-averaged value.

For the updated base case summarised in Figure 4-9, Table 4-12 shows the model-calculated total annual discharges (l·s^{-1}) and the average specific discharges (l·s^{-1}·km^{-2}) for the catchment areas 6–9 and the coastal area with direct runoff to the sea. The average specific discharge for each "inner" catchment area is calculated as the ratio between the total annual discharge into the associated main watercourse (cf Figures 4-8 and 4-9), i.e. the discharge in the watercourse where it leaves the catchment, and the total area of the catchment area. The much smaller discharges through overland flow and groundwater discharge that take place due to differences between the field-controlled catchment boundaries /Brunberg et al. 2004/ and those calculated in the MIKE SHE model are also included. Conversely, discharges in the form of overland and groundwater flows are the dominant discharge components for the coastal area.

According to the table, there are some differences in specific discharge between the modelled catchment areas. The largest annual average specific discharges are those of catchment area 8 and the coastal area (just above 200 mm·year^{-1}), whereas the smallest one is that of catchment area 7 (approximately 180 mm·year^{-1}). An important difference between catchment area 7 and the others is that area 7 is the only one that contains a lake. In catchment area 7, which was the only catchment considered in the previous Simpevarp 1.2 modelling /Werner et al. 2005/, Lake Frisksjön may act as a reservoir, thereby increasing the evaporation and decreasing the discharge from the catchment.

It can be noted that the specific discharge calculated for catchment area 7 in the present L1.2 modelling (c 180 mm·year^{-1}) is somewhat larger than that reported in S1.2 (c 150 mm·year^{-1}). This is due to the fact that the precipitation measured at Äspö during 2004 is larger than that in the "reference dataset" considered in S1.2; however, part of the increased precipitation is compensated by a larger evapotranspiration in the L1.2 water balance.

Table 4-12. Calculated annual average discharges into the watercourses, and the associated specific discharges, for the updated base case.

Catchment area no.	Size of catchment area (km^2)	Accumulated total annual discharge (m^3·y^{-1})	[1]Average specific discharge (l·s^{-1}·km^{-2})	[1]Average specific discharge (mm·y^{-1})
6	2.119	398,300	6.0	188
7	2.006	363,000	5.7	181
8	0.520	105,600	6.4	203
9	2.732	516,300	6.0	189
Coastal area	0.988	200,500	6.4	203

[1] The average specific discharge for each catchment area is calculated as the ratio between the total annual discharge into the associated main watercourse plus other discharge terms (which are small, for all areas except the coastal/direct-runoff area), and the total area of the catchment.

Hydraulic parameters

Figure 4-10 shows the calculated specific discharge for the initial base case and all the sensitivity cases involving variations of the hydraulic conductivity *K* of the QD (SA_1a–n and SA_2a–n; see definitions in Section 4.2.8). Note that BC refers to the initial base case, which is used as reference in the sensitivity analysis of the hydraulic properties of QD. The specific discharge is calculated in the same way as in Figure 4-9, i.e. as the accumulated discharge (overland flow and groundwater flow) into the watercourses, and divided by the area of the land parts of the model area.

According to Figure 4-10, there is generally a relatively small impact of the hydraulic conductivity in the QD on the specific discharge. An analysis of the evapotranspiration also shows that there are small effects of the hydraulic conductivity on the evapotranspiration from the area. The smallest specific discharge among the cases reported in Figure 4-10 is calculated for sensitivity case SA_2c (c 7.1 l·s^{-1}·km^{-2}), whereas the largest one is obtained for SA_1b (c 7.7 l·s^{-1}·km^{-2}). In the SA_2c case (the case with the smallest specific discharge), the horizontal hydraulic conductivity (K_H) is increased 10 times relative the initial base case, whereas the vertical hydraulic conductivity (K_V) is as in the initial base case. In the case SA_1b (largest specific discharge), both the horizontal and the hydraulic conductivity are decreased to 1/10 relative the initial base case. The corresponding specific discharge for the initial base case is c 7.2 l·s^{-1}·km^{-2}.

The results also show that a change of the hydraulic conductivity in the QD has different effects on the specific discharge, depending on where (in which QD layer(s)) *K* is changed and also depending on the anisotropy ratio (K_H/K_V). For instance, for a anisotropy ratio of 1 ($K_H = K_V$), both increases and decreases of the hydraulic conductivity in all QD layers (sensitivity cases SA_1a and SA_1b) appear to yield a higher specific discharge compared to the initial base case.

In the sensitivity cases with a lower hydraulic conductivity *K*, the infiltration to the soil is reduced, which increases the amount of overland flow into the watercourses (MIKE 11). On the other hand, increased *K*-values in the QD increases the infiltration capacity of the soil. This implies that water in the soil layers in high-altitude areas more easily flows to watercourses in low-altitude areas. These cases lead to an increased discharge from the saturated (groundwater) zone into the watercourses. The conclusion is that even if the specific discharge increases for both cases with a higher and a lower hydraulic conductivity in QD, there are different impacts on the different parts of the water flow system. According to an analysis of the specific discharge for the individual catchment areas (not shown), the largest differences between the initial base case and the different sensitivity cases are obtained for catchment area 7 (the Lake Frisksjön catchment area).

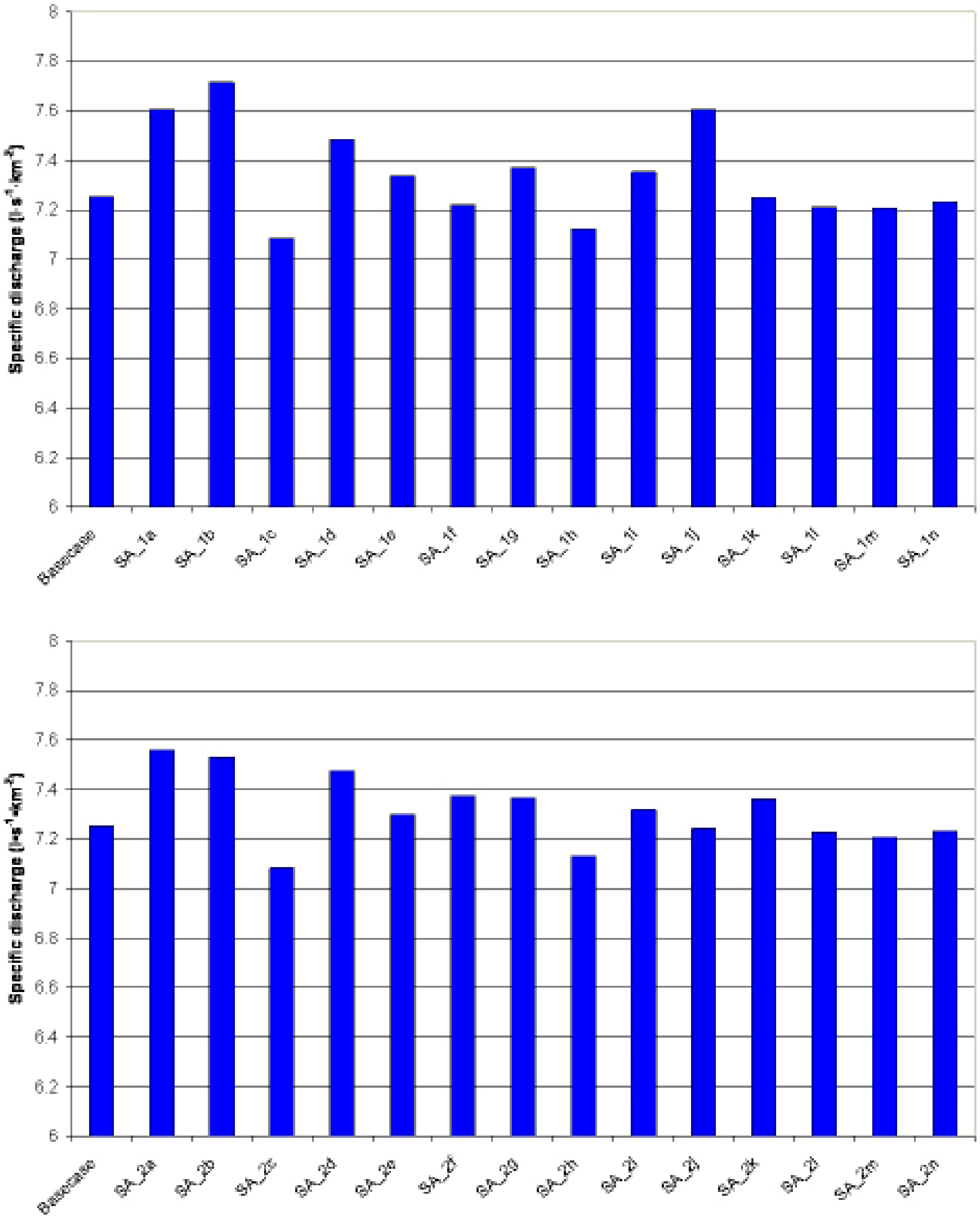

Figure 4-10. *Calculated specific discharge from the inner catchments, i.e. excluding the areas with direct runoff to the sea, in the initial base case and the sensitivity cases, SA_1a–n (top) and SA_2a–n (bottom); for a definition of the sensitivity cases, see Section 4.2.8.*

The model-calculated specific discharge for the updated base case summarised in Figure 4-9 and Table 4-12 can be compared to other independent estimates of the discharge. Based on long-term discharge observations (Forshultesjön nedre; 1955–2000) and discharge calculations based on long-term meteorological data (Laxemarån and Gerseboån; 1962–2001), the annual average specific discharge is estimated to be in the range 4.7–5.7 $l \cdot s^{-1} \cdot km^{-2}$ /Larsson-McCann et al. 2002/. Applying the PCRaster-POLFLOW approach (GIS-based hydrological modelling; see also Section 4.3.5) to the Simpevarp regional area, /Jarsjö et al. 2005/ calculated an annual average specific discharge of c 4.0 or 5.9 $l \cdot s^{-1} \cdot km^{-2}$, using two different methods to calculate the actual evapotranspiration.

For the modelling performed using meteorological data from Äspö for the year 2004, it can be noted that the average specific discharge calculated for all land areas in the model area (189 mm·year^{-1}) is slightly larger than other estimates /Larsson-McCann et al. 2002, Jarsjö et al. 2005/. However, it must be pointed out that the specific discharge is not a "static property" of the Simpevarp area, as the meteorological conditions demonstrate both large variations between years, and also vary from place to place /Werner et al. 2005/. For instance, using precipitation data from the Ölands norra udde SMHI station leads to an underestimation of the precipitation in the Simpevarp area; on average, the annual precipitation is c 100 mm less there than at the Oskarshamn station (cf Section 3.1.1).

Figure 4-11 (summarised in Table 4-13) details the effects of changing the hydraulic conductivity *K* in all QD layers (SA_1a–b) or in the upper QD layer only (SA_1c–d) on the overland and groundwater flow into the watercourses, and the groundwater flow into the sea. Again, note that BC refers to the initial base case. The figure shows that overland flow into the watercourses increases for all the sensitivity cases; the largest effects are observed when *K* is increased or decreased in all QD layers. The effect on the groundwater flow into the watercourses and to the sea are of the same order or higher; both these flows decrease with *K* in the QD. In general, changing *K* in the upper QD layer only (SA_1c and SA_1–d) has only a very small or no influence on the flow. In particular, these is no effect of a decrease in *K* in the upper layer on the groundwater flow into the sea. This may be due to that this outflow is dominated by deep groundwater flow paths, which are relatively insensitive to the hydraulic conductivity of the upper QD layer.

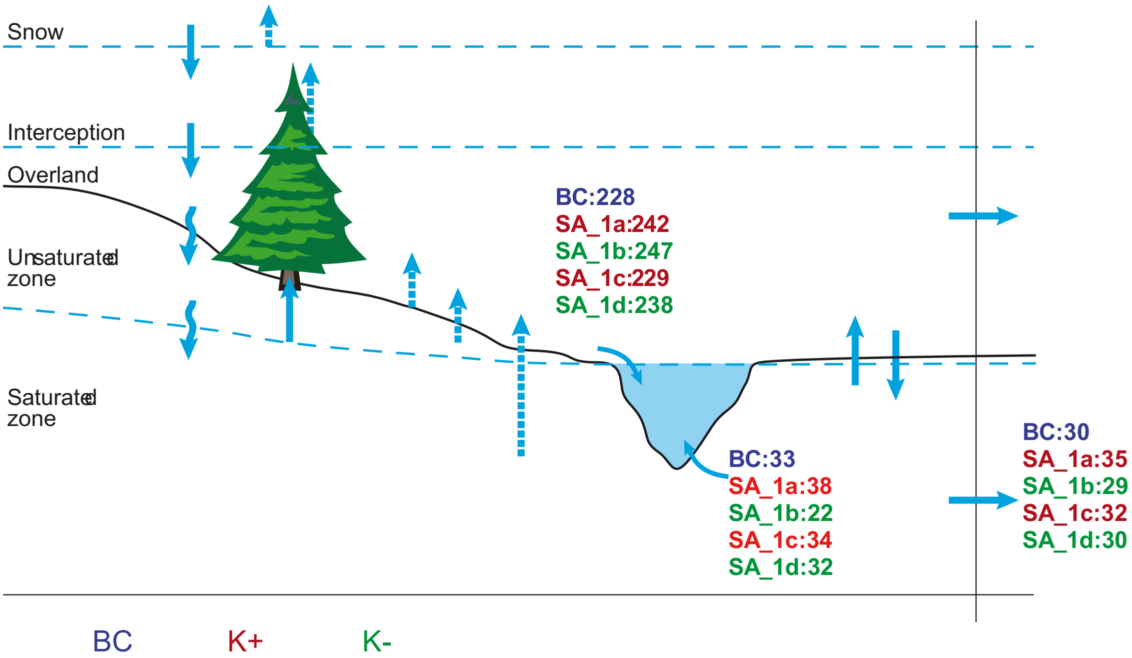

Figure 4-11. *Illustration of the effects of changing K in all QD layers (SA_1a–b) or in the upper QD layer only (SA_1c–d) on the overland and groundwater flow into the watercourses, and the groundwater flow into the sea. Note that BC refers to the initial base case, whereas SA_1a–d are sensitivity cases.*

Table 4-13. Comparison between the intitial base case and the sensitivity cases SA_1a–d in terms of model-calculated water flows expressed in mm·year^{-1} (cf Figure 4-11).

	Initial base case	SA_1a	SA_1b	SA_1c	SA_1d
Overland flow into watercourses					
	247	242	247	229	238
Diff. (%)	+8.3	+6.1	+8.3	+0.4	+4.4
Groundwater flow into watercourses					
	22	38	22	34	32
Diff. (%)	–33.3	+15.2	–33.3	+3.0	–3.0
Groundwater flow into the sea					
	29	35	29	32	30
Diff. (%)	–3.3	+16.7	–3.3	+6.7	0.0

Large differences are observed when comparing the discharge terms in Figure 4-11 with those in Figure 4-9. These differences, which essentially quantify the differences between the initial and updated base cases, are mainly due to changes in the vegetation parameters that determine the interception and transpiration processes (see summary of sensitivity analysis in Table 4-11). Thus, it can be seen that the parameters LAI and K_c have large effects on the results. The present sensitivity analysis indicates that uncertainties in the vegetation parameters are much more important for the overall uncertainty associated with the hydrological/hydrogeological model than uncertainties related to the hydraulic properties of the QD. However, the analysis of input data to and results from the sensitivity study shows that the values assigned to LAI and K_c in the initial base case were unrealistic, thereby probably over-estimating the sensitivity to these parameters compared to the intervals that would have been obtained for more "realistic" values.

4.3.2 Groundwater levels

Figure 4-12 shows the annual average depth to the groundwater table in the model area, as calculated for the updated base case. As can be seen in the figure, the groundwater table is shallow and located less than 2 metres below ground in the main part of the model area. The deeper groundwater levels are mainly found in high-altitude areas, associated with groundwater recharge. There are also areas with a groundwater table above the ground surface (surface water), including Lake Frisksjön and areas in the vicinity of the main watercourses, i.e. (local) low-altitude areas according to the DEM /Brydsten and Strömgren 2005/.

However, there are not lakes, wetlands and/or watercourses in all areas where the modelling results indicate surface water. In most cases, this is due to the fact that these areas have been drained, which is a general characteristic of the Simpevarp area (cf Section 3.4.3). Without these land-management operations, these areas would most likely be flooded at least during parts of the year, in accordance with the model. All ditches, drainages, and "missing" watercourses identified in the field /Carlsson et al. 2005, Svensson 2005/ are not included in the L1.2 model version, but will be considered in future model versions.

Figures 4-13 to 4-15 illustrate the simulated transient effects of time-varying meteorological conditions at the ground surface on the groundwater level in QD. Note that "base case" in these figures refers to the initial base case. For the base case and the sensitivity

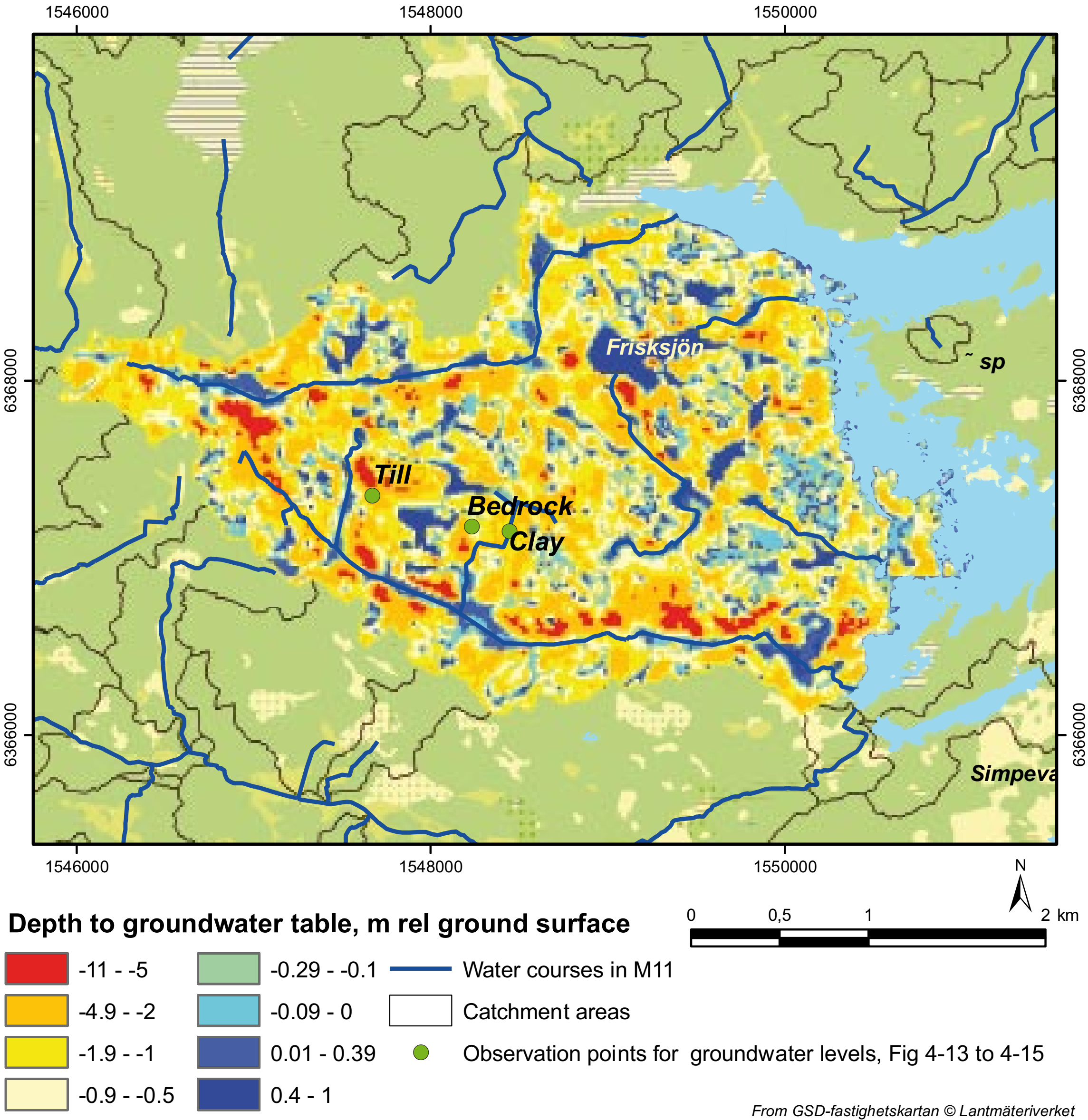

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Figure 4-12. *Annual average depth to the groundwater table (metres below ground surface). Results are shown for the updated base case. M11 is an abbreviation for MIKE 11. The figure also shows the locations of the three "observation points" analysed in Figures 4-13 to 4-15.*

cases, results are shown at three "observation points" located in areas characterised by different geological conditions: till (Figure 4-13), exposed bedrock (Figure 4-14), and clay (Figure 4-15). The geographical locations of the observation points are shown in Figure 4-12. These points reflect areas with different types of QD, but they also represent different topographical conditions.

The "till point" is located in a topographically intermediate area, i.e. an area that is neither a typical groundwater recharge or discharge area. According to the g-HSD model /Nyman 2005/, the local QD depth is c 2 metres. The "exposed bedrock point" is located in a high-altitude area, i.e. in a typical groundwater recharge area according to the topography. According to the g-HSD, the local QD depth is c 0.1 metre. The "clay point" is located in a low-altitude area, i.e. in a typical groundwater discharge area according to the topography. According to the g-HSD, the local QD depth is 7.4 metres at the "clay point".

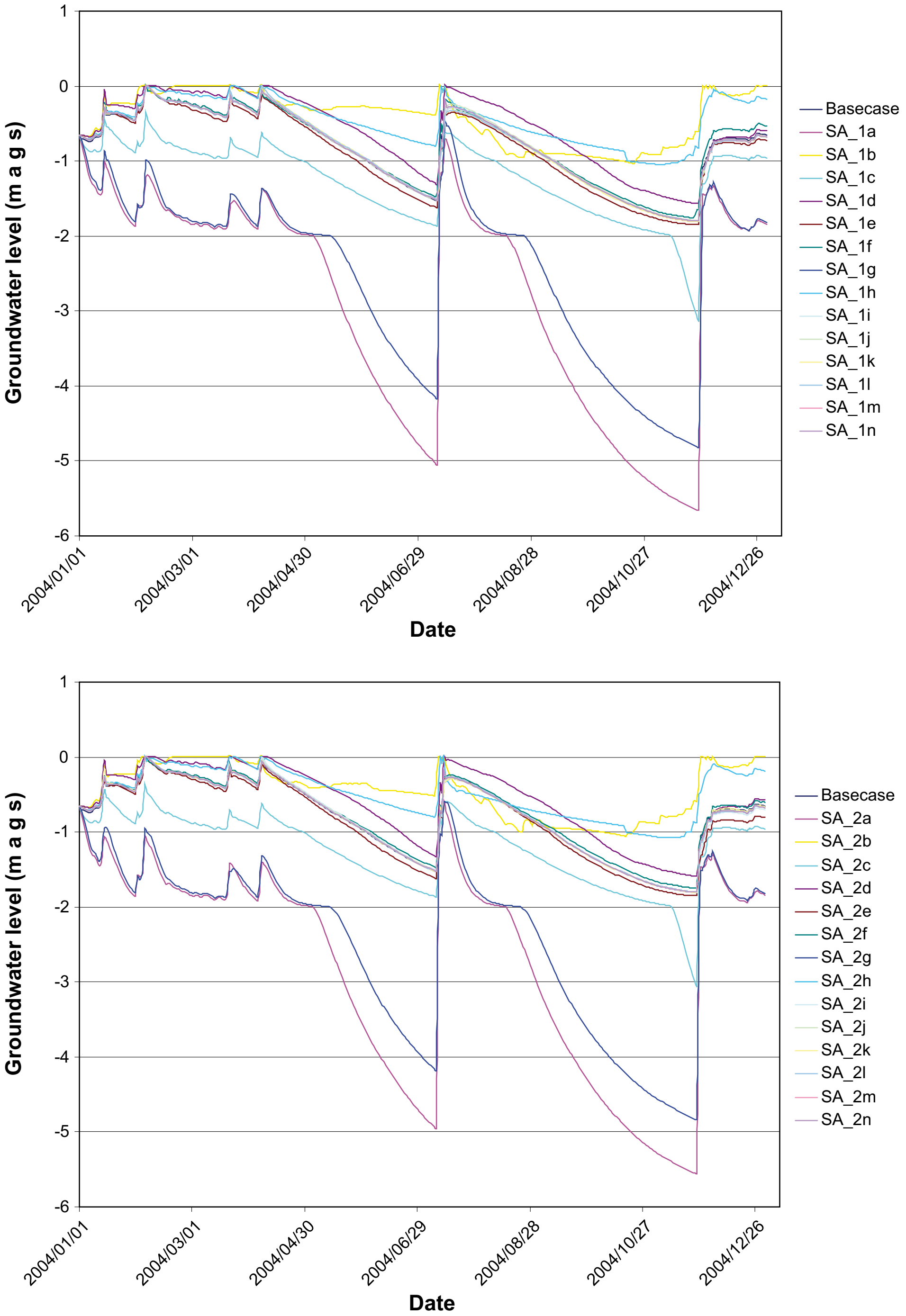


Figure 4-13. *Time series of the model-calculated groundwater level (metres above ground surface at the "observation point" in till for the initial base case and the sensitivity cases SA_1a–n (top) and SA_2a–n (bottom); for a definition of the sensitivity cases, see Section 4.2.8.*

In the base case, the groundwater level at the "till point" (Figure 4-13) is c 0.5 metre below the ground surface (m.b.g.s.; note that the levels are shown (negative) as metres above the ground surface in the figure) during the winter and the early spring. During the spring and the summer, the groundwater level decreases continuously down to a minimum of c 1.5 metres below ground surface. As an effect of a very wet July during the simulated year 2004 (cf Section 3.1.2), the groundwater level increases with approximately one metre during a relatively short period in July. Subsequently, the level decreases during the late summer and early autumn. The autumn rains lead to an increase of the groundwater level towards the "winter level" (c 0.5 metres below ground surface). Hence, the groundwater

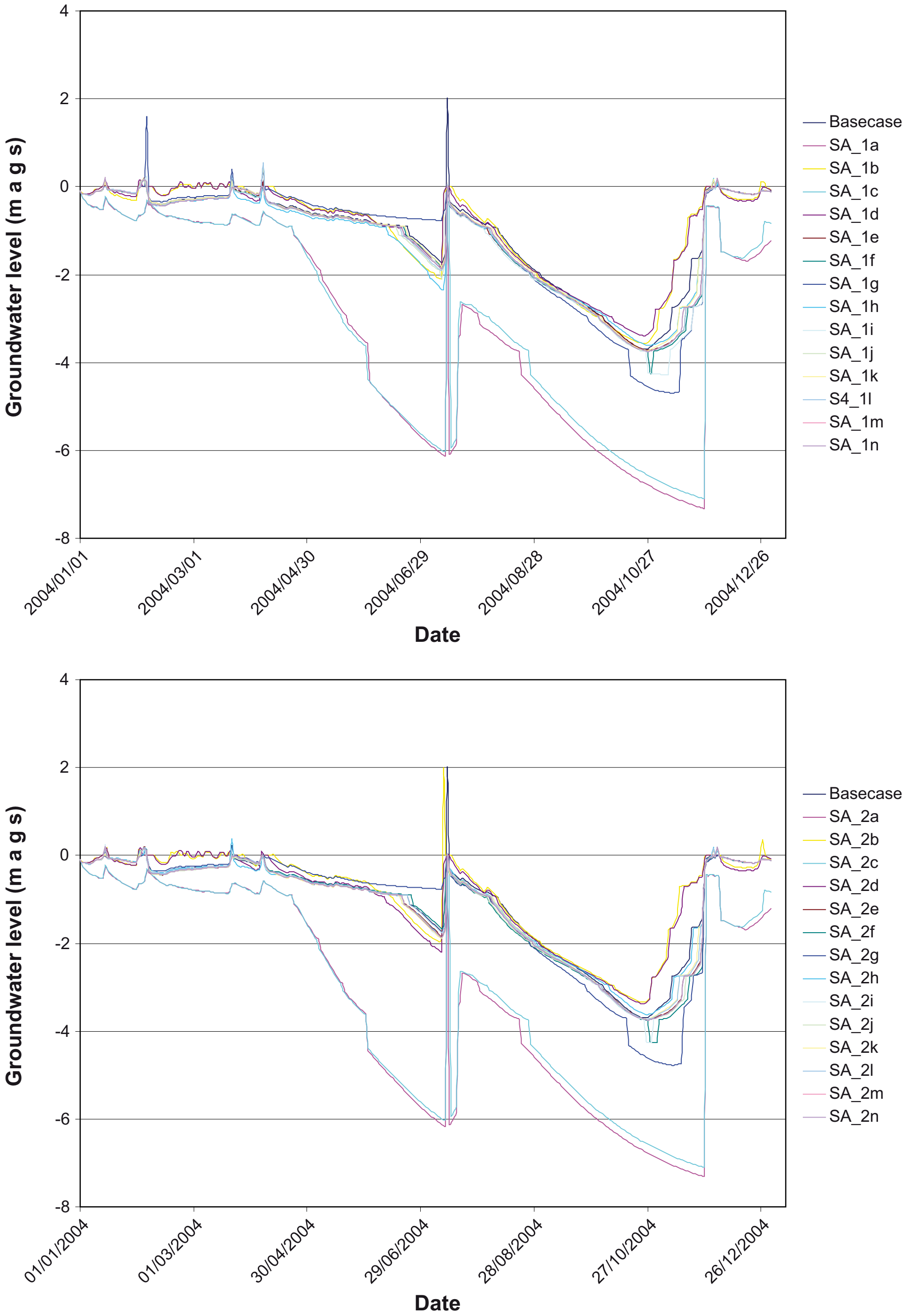
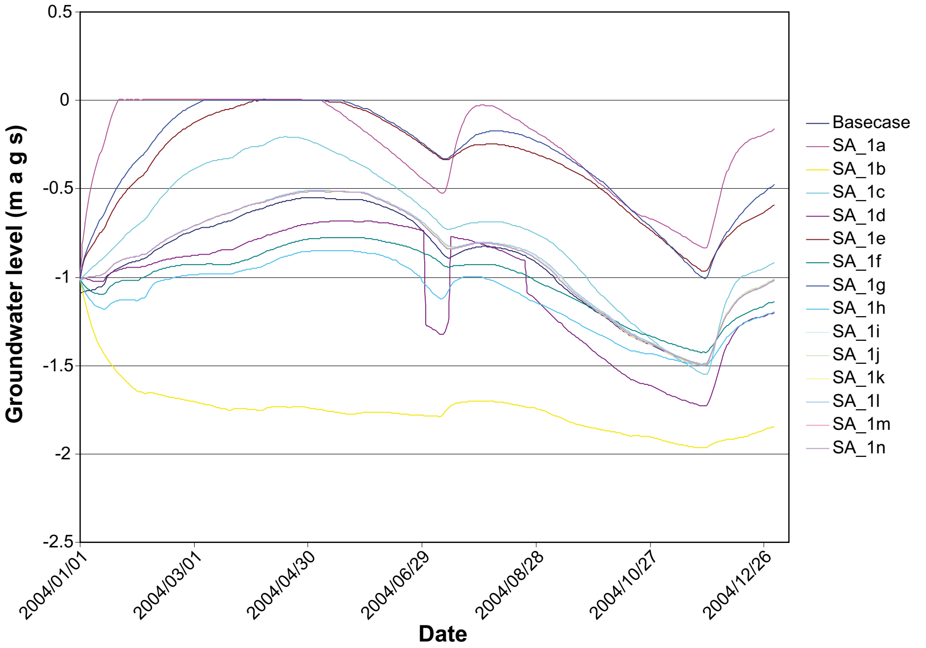


Figure 4-14. *Time series of the model calculated groundwater level (metres above ground surface) at the "observation point" in exposed bedrock for the initial base case and the sensitivity cases SA_1a–n (top) and SA_2a–n (bottom); for a definition of the sensitivity cases, see Section 4.2.8. Note that the peak of the groundwater level for the basecase and the sensitivity case SA_2b most likely are due to numerical instabilities in the model.*

flow at the "till point" possibly could reflect changes between groundwater recharge (periods with a groundwater table below the ground surface), and groundwater discharge (periods with a groundwater table at the ground surface).

Being within a typical recharge area, the groundwater level at the "exposed bedrock point" (Figure 4-14) demonstrates a rather large seasonal fluctuation of the groundwater level. In the base case, the groundwater level is relatively high (a few decimetres below ground)



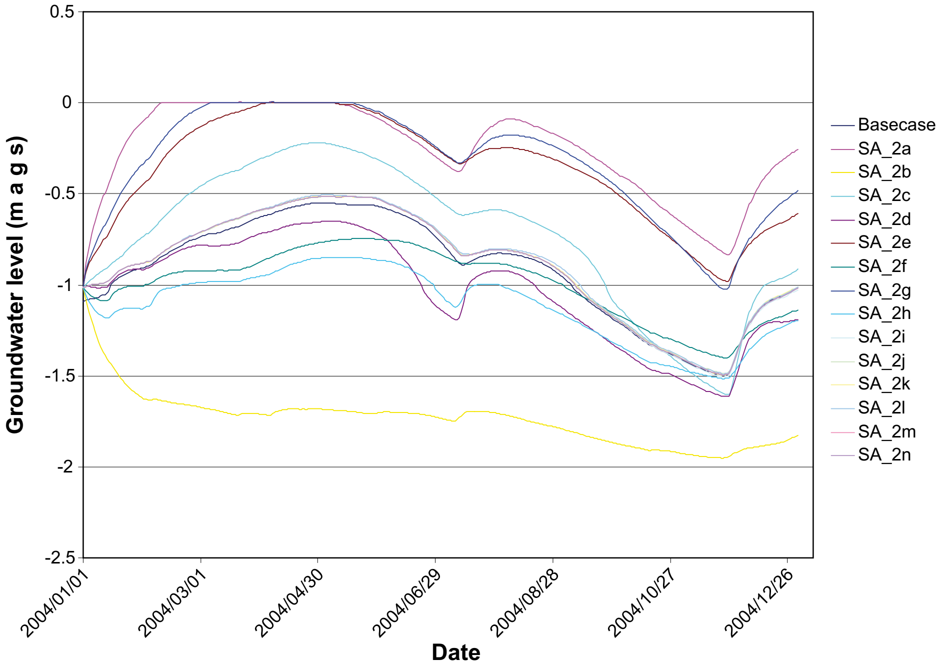


Figure 4-15. *Time series of the model calculated groundwater level (metres above ground surface) at the "observation point" in clay for the initial base case and the sensitivity cases SA_1a–n (top) and SA_2a–n (bottom); for a definition of the sensitivity cases, see Section 4.2.8.*

during the winter and the early spring. During the spring and the summer, the groundwater level decreases continuously down to a seasonal minimum of c 1.5 metres below ground surface. The calculated groundwater level increases with approximately one metre during a relatively short period in July (cf above); note that the peaks in the groundwater level for the basecase and the sensitivity case SA_2b most likely are due to numerical instabilities in the model. Subsequently, the level decreases during the late summer and early autumn down to an annual minimum of c 3.5 metres below ground surface. The autumn rains lead to an increase of the groundwater level towards the "winter level" (a few decimetres below ground).

Compared to the till and the exposed bedrock observation points (Figure 4-13 and Figure 4-14, respectively), the temporal variation of the groundwater level at the “clay point” (Figure 4-15) is smaller, and also of a more “continuous” character throughout the year; the variations of the groundwater level are not as abrupt as in the other observation points. In the base case, the groundwater level is c 1 metre below ground surface at the beginning of the year. The groundwater level increases during the whole spring up to an annual maximum of c 0.5 metre below ground surface. The level decreases continuously during the summer, except from the short period in July mentioned above, and it also increases during the autumn. However, the groundwater level in the “clay point” does not start to increase towards the “winter level” (c 1 metre below ground surface) until late autumn/early winter, i.e. later than at the till and exposed bedrock points.

The behaviour observed in the “clay point” can be considered typical for a discharge area, which is characterised by relatively small and dampened groundwater level fluctuations. The autumn rains cause a relatively quick groundwater level response in the till and exposed bedrock areas (these are recharge areas), whereas there is a slower response in the discharge (clay) area. By definition, no groundwater recharge takes place in discharge areas, and the groundwater level fluctuations in such areas depend on the recharge of groundwater in (upstream) recharge areas.

In most of the sensitivity cases reported in Figures 4-13 through 4-15, the effect of the hydraulic conductivity K on the groundwater level, and its temporal fluctuations, are relatively small. At the “till point” (Figure 4-14), the largest effects on the groundwater level are obtained for sensitivity cases SA_1a/g, and SA_2a/g, i.e. when both the horizontal (K_H) and vertical (K_V) hydraulic conductivity (SA_1a/g), and only the horizontal conductivity (SA_2a/g) are increased 10 times relative the base case (BC). Note that in the “a” cases, K is changed in all QD layers, whereas the “g” cases imply a higher K in the lowest QD layer only (layer Z3). In these sensitivity cases, the model-calculated groundwater level is located between 2 and 4 metres below the groundwater level for the BC. There is a similar but less pronounced effect in the sensitivity cases SA_1c and SA_2c, i.e. when K is changed in the upper QD layer only.

The opposite effect, i.e. a higher model-calculated groundwater level compared to the BC, is observed for the sensitivity cases corresponding to a decreased hydraulic conductivity relative to the BC. However, the difference relative to the BC is smaller in the reduced-conductivity cases. As expected, the sensitivity cases that involve the QD layers M1–M3 only (peat, glaciofluvial deposits and artificial fill) have no observable effect; such areas are not included in the selected set of observation points.

In the exposed/shallow bedrock areas, all QD layers are thin (0.1–2 metres) according to the g-HSD /Nyman 2005/. Consequently, there are generally small differences between the BC and the different sensitivity cases at the “exposed bedrock point” (Figure 4-15). The exceptions are SA_1a/c and SA_2a/c, i.e. cases where both K_H and K_V (SA_1a/c) and K_H only (SA_2a/c) are increased compared to the BC. In these cases, the model-calculated groundwater level is c 4 metres lower than in the BC. Again, note that in the “a” cases, K is changed in all QD layers, whereas the “c” cases imply a higher K in the uppermost QD layer only (layer Z1).

At the “clay point” (Figure 4-15), the effects of the sensitivity cases are reversed, as compared to the other observation points. The calculated groundwater level is lower than in the BC for a smaller hydraulic conductivity (e.g. SA_1b, which involves a 10 times smaller K in all QD layers). The general hydrogeological principle behind these observations is illustrated in Figure 4-16. “GWT” in the figure denotes the groundwater table. A simple case is considered, where, regardless of the hydraulic conductivity of QD, there is groundwater flow of a certain magnitude from a recharge area (the high-altitude area in the figure) to a discharge area (the low-altitude area).

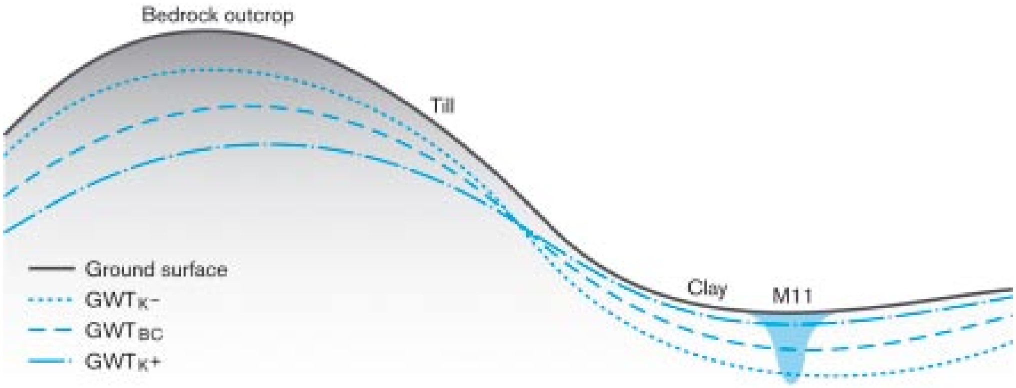


Figure 4-16. *Illustration of the effect of an uniform change of the hydraulic conductivity on the groundwater level in recharge and discharge areas.* K^+ *and* K^- *denote cases with a higher and a lower hydraulic conductivity, respectively, compared to a base case (BC). M11 is a short for MIKE 11; the blue area indicates a watercourse.*

A uniform increase of the hydraulic conductivity (denoted as K^+ in the figure) compared to a base case (BC) implies that a smaller head gradient is required for the groundwater flow from the recharge area to the discharge area. Accordingly, the groundwater level decreases in the recharge area, whereas it increases in the discharge area, provided it is not determined by, e.g. a "fixed" surface water level. The opposite phenomenon takes place if one considers a decreased hydraulic conductivity (K^-); this case requires a larger head gradient, compared to the BC. It should be emphasised that the example is a simplification; for example, a higher hydraulic conductivity close to the ground surface most likely leads to a larger infiltration, which in turn implies a larger groundwater flow rate and hence that a larger gradient is required.

Sensitivity cases SA_3a–b and SA_4a–b involve changing the specific storage coefficient S_S and the specific yield S_Y. An analysis of these cases shows that there is generally only a small effect on the groundwater level and its fluctuations in all the observation points (till, exposed bedrock, clay). The largest groundwater level difference, even between "extreme cases" (SA_3a versus SA_3b, and SA_4a versus SA_4b) is c 0.5 metre. The main influence of changing the storage parameters S_S and S_Y is noted in terms of the "response time" required for increasing/decreasing the groundwater level in response to changes in the meteorological conditions at the ground surface. These effects are possible to observe in the model, as the meteorological conditions are the same in the base case and all the sensitivity cases.

4.3.3 Surface-water levels and discharge

The MIKE 11 modelling results show large temporal variability of the discharge in the watercourses during the year. The results also show that there is a strong co-variation between the discharge variations and the temporal variations of the precipitation. There are long periods with very small or zero model-calculated discharges in the watercourses, and relatively short periods with large discharges. These model results agree with observations from manual discharge measurements (cf Section 3.2.6).

As an example, Figure 4-17 shows three model-calculated hydrographs (plots of the discharge versus time) for the watercourse Mederhultsån, located in catchment area 6, for the updated base case. Hydrographs are shown at three observation points at distances of 120, 1,800 and 4,110 metres from the upstream end of the watercourse in the model (see Section 4.2.6 for a description mapping of the watercourses).

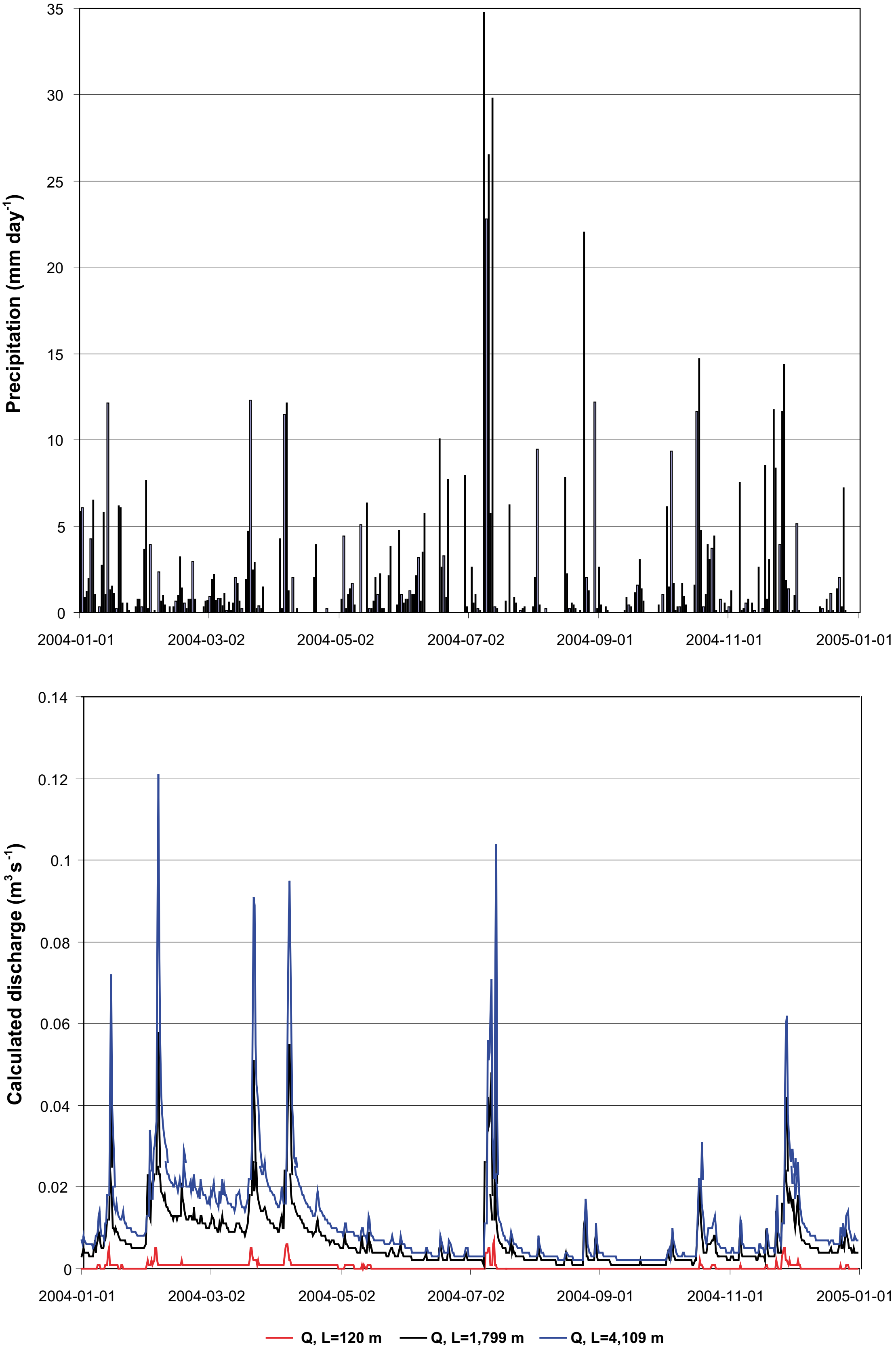


Figure 4-17. *Time series of the model calculated discharge at three positions (cf Figure 4-19) along the watercourse in catchment area 6 (Mederhultsån) for the updated base case (bottom). Also the actual precipitation at the Äspö meteorological station during the simulated time period is shown (top).*

As shown in the figure, the model-calculated discharge is larger at downstream observation points, which, of course, is because they have larger catchment areas. It can also be noted that the peaks in the discharge curves occur more or less simultaneously at the three observation points. This is due to that there are no lakes along Mederhultsån, which otherwise would reduce the peaks of the discharge at observation points downstream of the lakes. The peaks of the discharge are associated with precipitation events, for instance, the maximum discharge that occurs in the summer (mid July) during a period with heavy summer rains (cf Section 3.1.2). However, it can be noted that even though most of the more prominent precipitation events are reflected in the hydrographs, the discharge responses are generally not proportional to the associated precipitation events, at least not in an easily observable way.

For the updated base case, Figure 4-18 shows the model-calculated annual average depth of overland water, i.e. the average depth of water above the ground surface. These results can be compared to those for the depth to the groundwater table presented in Section 4.2.6, where it was observed that the model produces areas with the groundwater table above the ground surface, e.g. Lake Frisksjön and areas in the vicinity of the main watercourses.

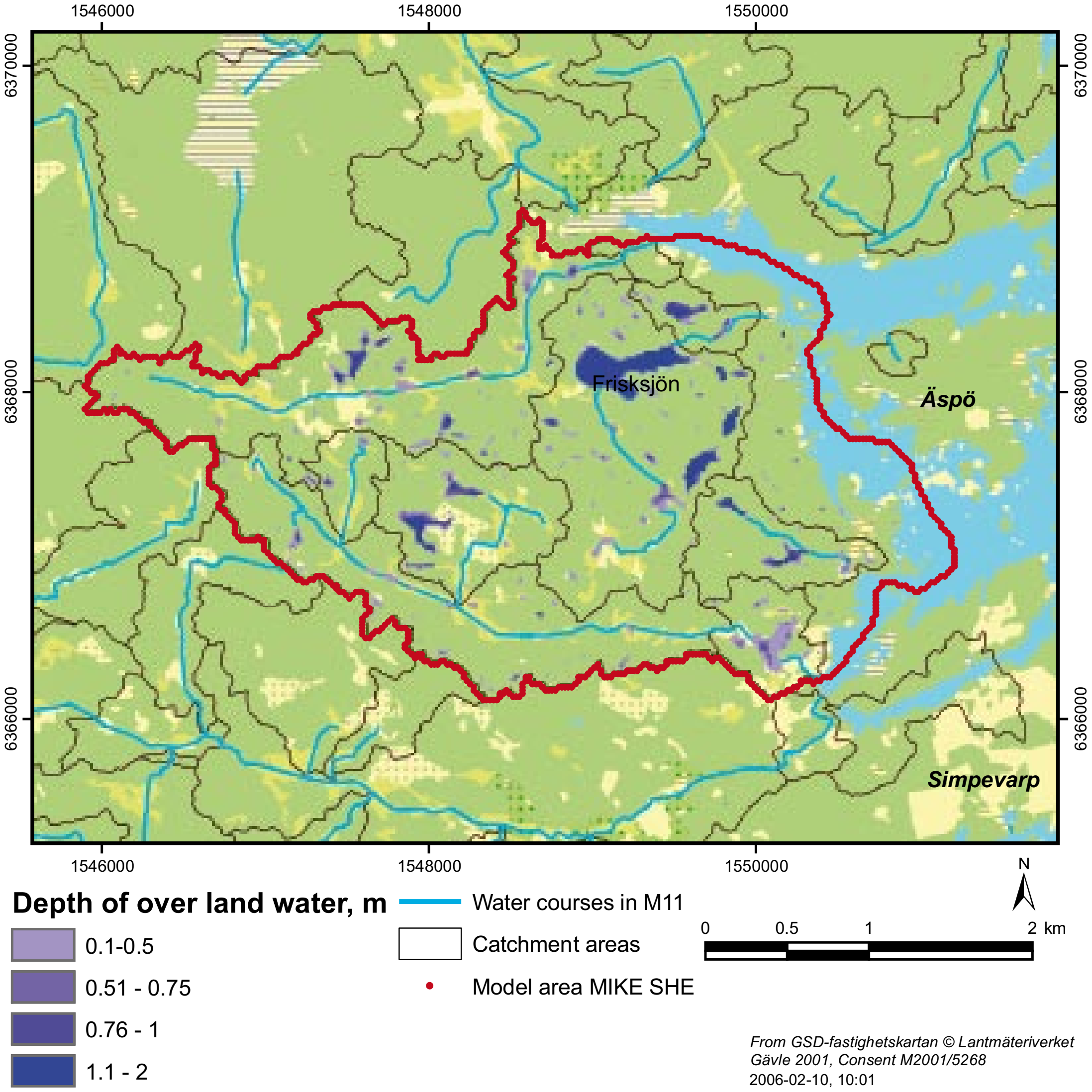


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Figure 4-18. *Annual average depth of overland water calculated for the updated base case. There are not actual flooded areas in all areas with overland water in the figure. M11 is an abbreviation for MIKE 11.*

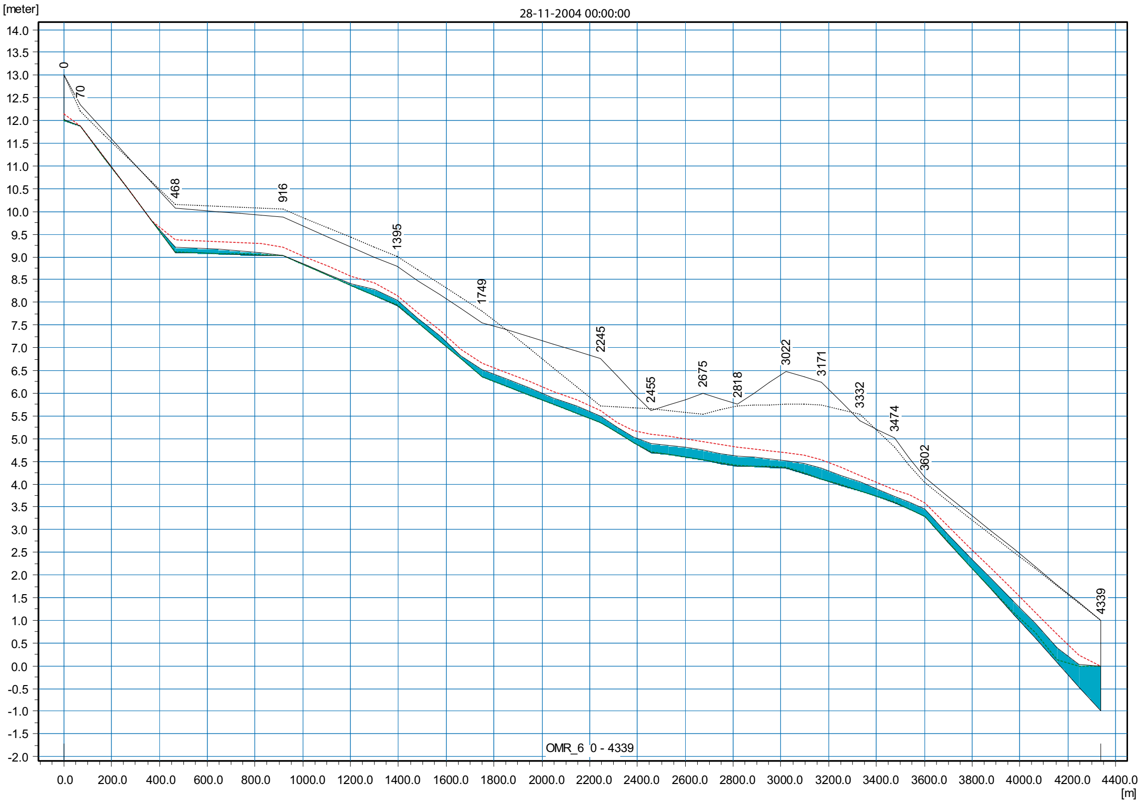

Figure 4-19. *Profile of the bottom level topography along Mederhultsån (catchment area 6), and the calculated surface water level in December 2004 (updated base case). The blue band illustrates the calculated water depth, and the numbers along the profile are length coordinates where bottom levels and cross sections have been measured /Strömgren et al. 2006/. The red dotted line indicates the maximum surface water depth during the whole simulation period (2004) and the two lines above the red line represent the bank levels on either side of the watercourse.*

In reality, there is not surface water in all areas where the modelling results shown in Figure 4-18 indicate presence of overland water. As mentioned in Section 4.2.6, this is due to the fact that these areas have been ditched and/or otherwise drained, which is a general characteristic of the Simpevarp area. Ditches, drainages, and “missing” (parts of) watercourses /Carlsson et al. 2005, Svensson 2005/ are not included in the L1.2 model version. Most areas with discrepancies between model-calculated and actual flooded areas in Figure 4-18 were checked in the field during the summer of 2005. It was observed that all the areas that were checked in fact are drained. These field observations will be included in future model versions.

Figure 4-19 shows the bottom-level topography along the whole stretch of Mederhultsån in catchment area 6. The figure also shows the calculated (MIKE 11) surface water level in the watercourse in the end of November 2004, as obtained from the updated base case. As shown in the figure, there is shallow surface water along the profile in December (on the order of one or a few decimetres). The maximum surface-water depth during the whole simulation period (2004) is illustrated by the red line. The maximum calculated depth during the period is c 0.75 metre (in a section at half the distance between the upstream to the downstream end). Where Mederhultsån discharges to the sea (at length coordinate c 4,350 metres), the water level in the downstream end is set to 0 metre above sea level.

4.3.4 Groundwater recharge and discharge areas

Each catchment area can be divided into recharge and discharge areas. In recharge areas, the groundwater flow has a downward component, whereas it has an upward component in discharge areas. By definition, no groundwater recharge takes place in the discharge areas. The conceptual-descriptive model of groundwater flow (cf Section 4.1) implies that groundwater recharge is generally associated with high-altitude areas, whereas discharge of groundwater takes place in low-altitude areas.

In the present context, the identification of groundwater recharge and discharge areas is an important issue. For instance, the (near-surface) discharge areas are areas where radionuclides from a deep repository may enter the surface system; the discharge areas of the deep rock groundwater likely constitute a subset of those associated with the surface system. For the updated base case, Figure 4-20 shows the model-calculated annual average of the difference in hydraulic head between the uppermost calculation layer and calculation layer 5, located c 8–10 metres below the ground surface. This head difference indicates the vertical (i.e. upward or downward) direction and magnitude of the groundwater flow between these planes at each location. The blue areas in the figure represent recharge areas (downward flow), and the yellow and red areas are the discharge areas (upward flow). The dark blue lines show the main watercourses in the area covered by the figure.

It can be seen in the figure that the (average) discharge areas are found in the vicinity of the main watercourses, in and around Lake Frisksjön, and also along the coastline towards the Baltic Sea. In general, discharge areas are associated with a shallow groundwater table, or a “groundwater table” above the ground surface (surface water). In some of the model-calculated discharge areas in Figure 4-20, the model produces “flooded” areas (cf Figure 4-18). As previously mentioned, many of these are affected by man-made drainage measures not been included in the present model. The annual average fractions of recharge and discharge areas in the land parts of the model area is 63% and 37%, respectively, as measured by the head difference displayed in Figure 4-20.

Due to the temporally variable meteorological conditions at the ground surface, the surface and near-surface water flow system is transient (in principle, transients can also be imposed by variations in other boundary conditions, but those at the upper boundary are by far the most important). One potentially important effect of a transient water flow system is that the locations of recharge and discharge areas may vary during the year. Figure 4-21 and 4-22 show the calculated (updated base case) vertical groundwater flow component in calculation layer 2 during a wet period (the end of October) and a dry period (the mid of August).

A comparison between the two figures shows that the distribution of recharge and discharge areas varies somewhat with time, due to (seasonally) variable meteorological conditions. Examples of areas where notable changes take place are indicated by the circles in Figure 4-21 and 4-22. It can be seen that there is a shift from yellow to blue within these circles, i.e. from recharge to discharge, when going from wet (Figure 4-21) to dry (Figure 4-22) conditions. However, there are permanent recharge and discharge areas; areas in the vicinity of the main watercourses and Lake Frisksjön are permanent discharge areas, whereas the high-altitude areas are permanent recharge areas.

Generally, the differences between the wet and dry periods can be regarded as very small. During both periods, the fractions of recharge and discharge areas, as measured by the flow direction in layer 2, are approximately 75% and 25%, respectively. Whether this similarity is an effect of some specific meteorological conditions prevailing during 2004 remains to be investigated. Considering CA 7 only, i.e. the catchment area where Lake Frisksjön is located, /Werner et al. 2005/ presented a comparison between flow directions during wet and dry periods in several calculation layers based on simulations using the “reference year” meteorological dataset.

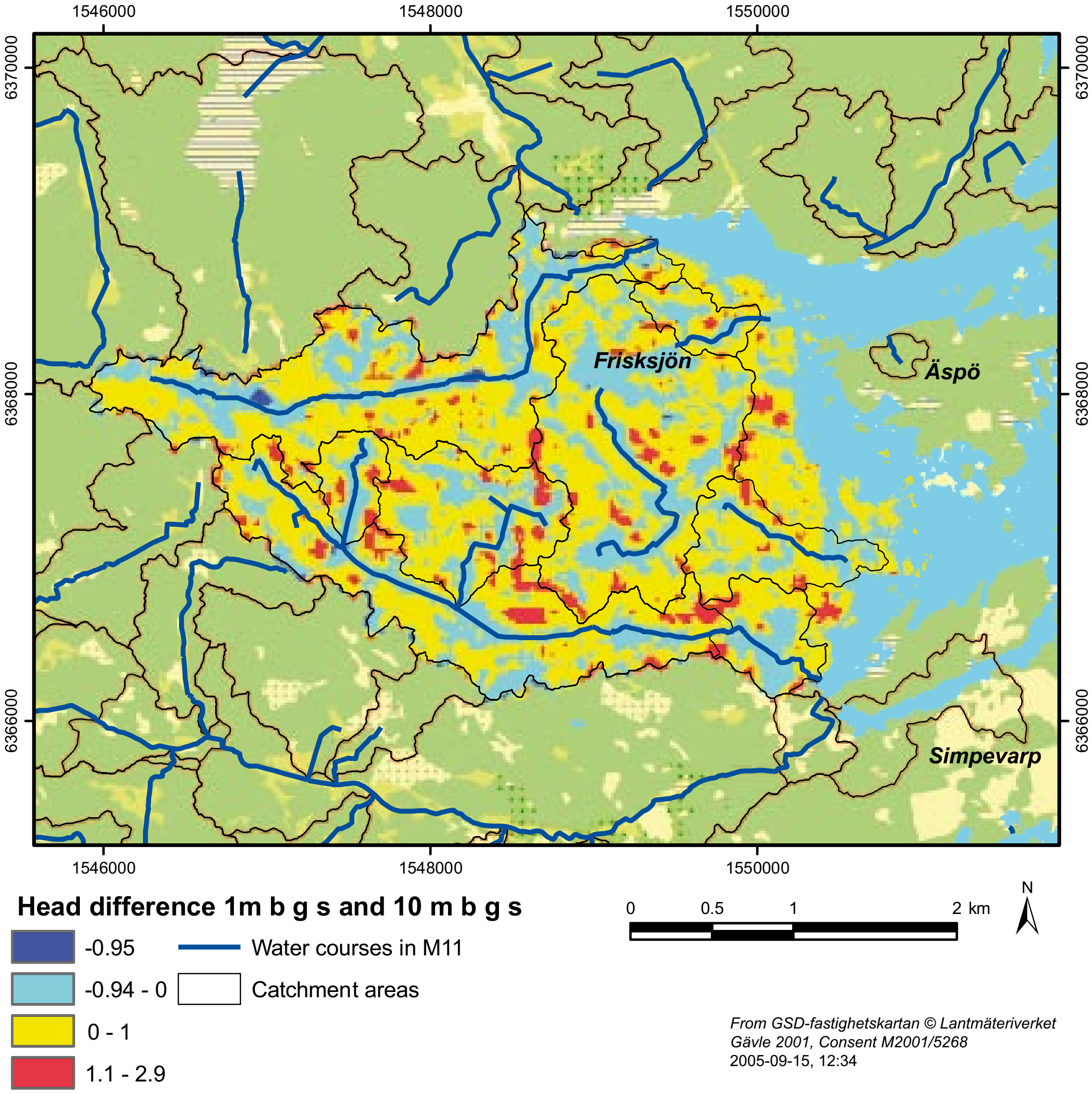

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Figure 4-20. *Annual average head difference between the uppermost calculation layer and calculation layer 5, located c 8–10 m.b.g.s. (metres below the ground surface). The blue areas in the figure are (average) recharge areas (downward flow), whereas the red and yellow areas are discharge areas (downward flow). The dark blue lines are the main watercourses in the area covered by the figure. Results are shown for the updated base case. M11 is an abbreviation for MIKE 11.*

The findings described above concerning the distribution of recharge and discharge areas are further illustrated in Figures 4-23 and 4-24. These figures show the direction and (relative) magnitude of the vertical (i.e. upward or downward) groundwater flow velocity component in a cross section across Lake Frisksjön. In order for the vectors below the lake to be visible when using velocity proportional vector sizes (which currently is the only way they can be presented), very large vectors are shown in other parts of the cross section. In particular, the vertical groundwater velocity components are large near the western catchment boundary and near the shoreline of Lake Frisksjön. For the updated base case, results are shown for a wet period (end of October; Figure 4-23) and a dry period (mid of August; Figure 4-24); these periods are the same as those in Figures 4-20 and 4-21. The location of the cross section is shown in Figure 4-23.

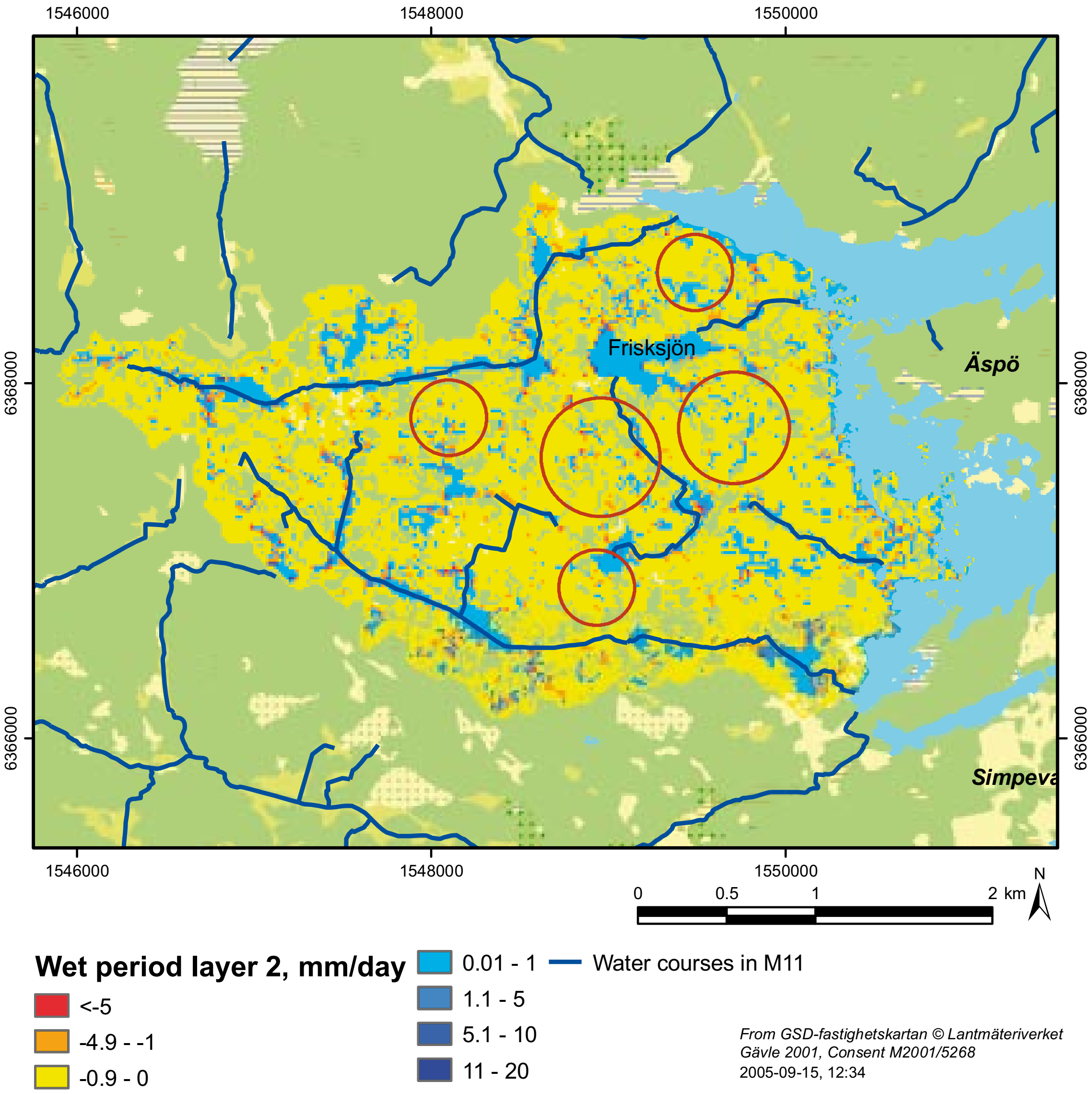

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Figure 4-21. *Vertical groundwater flow (mm·d^{-1}; positive upwards) in calculation layer 2 during a wet period (end of October). The results shown are for the updated base case. Areas within circles show large differences between wet and dry periods (cf Figure 4-22). M11 is an abbreviation for MIKE 11.*

These figures show that Lake Frisksjön is a permanent discharge area, i.e. the direction (and also the relative magnitude) of the vertical groundwater flow velocity component is the same during a wet and a dry period. The figures also show that the (relative) flow velocity from QD into the lake is rather low, which is in accordance with the conceptual-descriptive model (Section 4.1). The bottom of the lake consists of low-permeable QD (lake sediments), which reduces the exchange of water between groundwater in QD and the surface water in the lakes. The pattern with vertical arrows directed upwards below Lake Frisksjön (during both wet and dry periods) can be noted also at a large depth in the bedrock (–120 metres above sea level). All large vertical flows take place within a small area in the eastern part of the cross section.

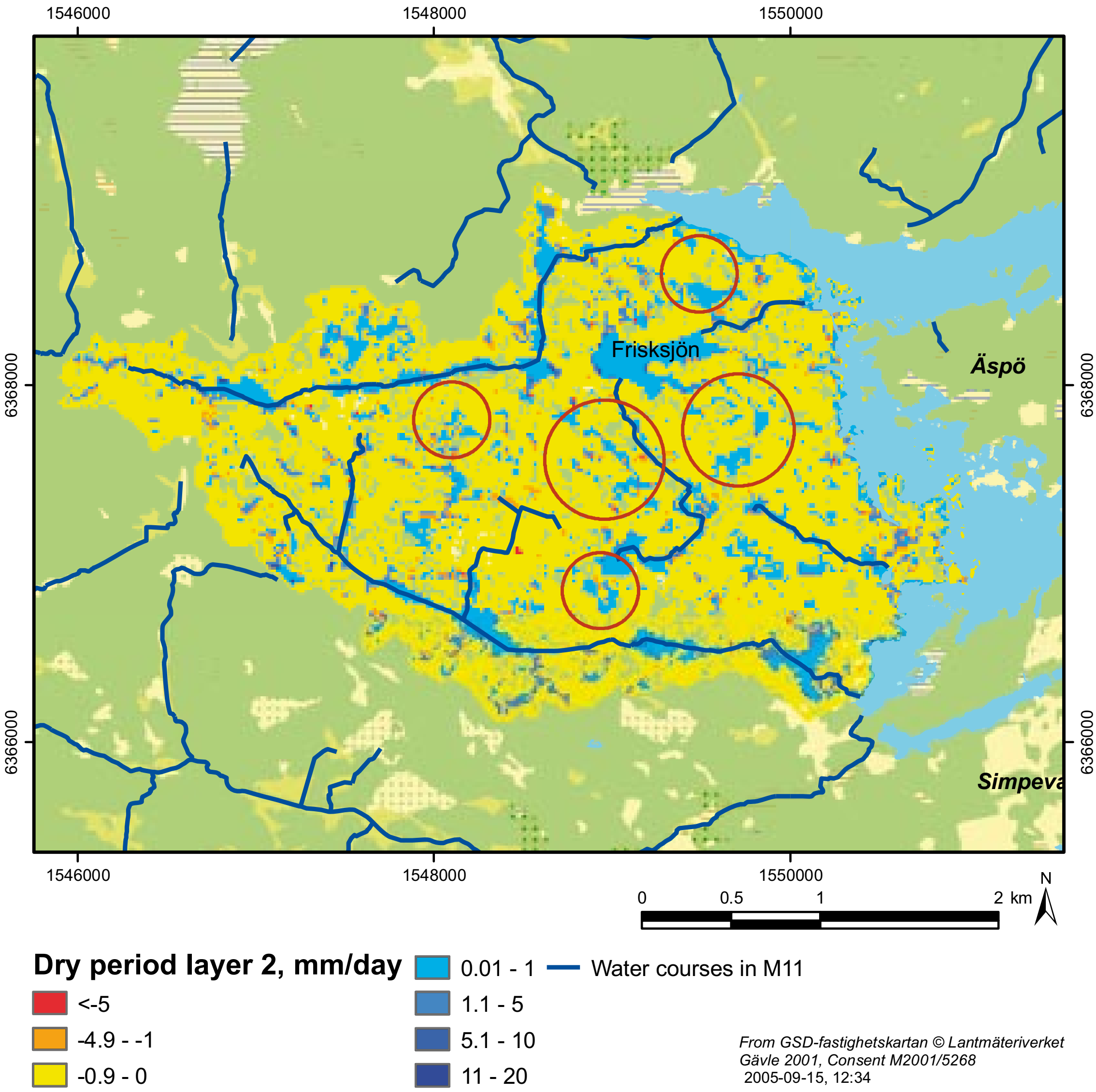

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Figure 4-22. *Vertical groundwater flow (mm·d^{-1}; positive upwards) in calculation layer 2 during a dry period (mid August). The results shown are for the updated base case. Areas within circles show large differences between wet and dry periods (cf Figure 4-21). M11 is an abbreviation for MIKE 11.*

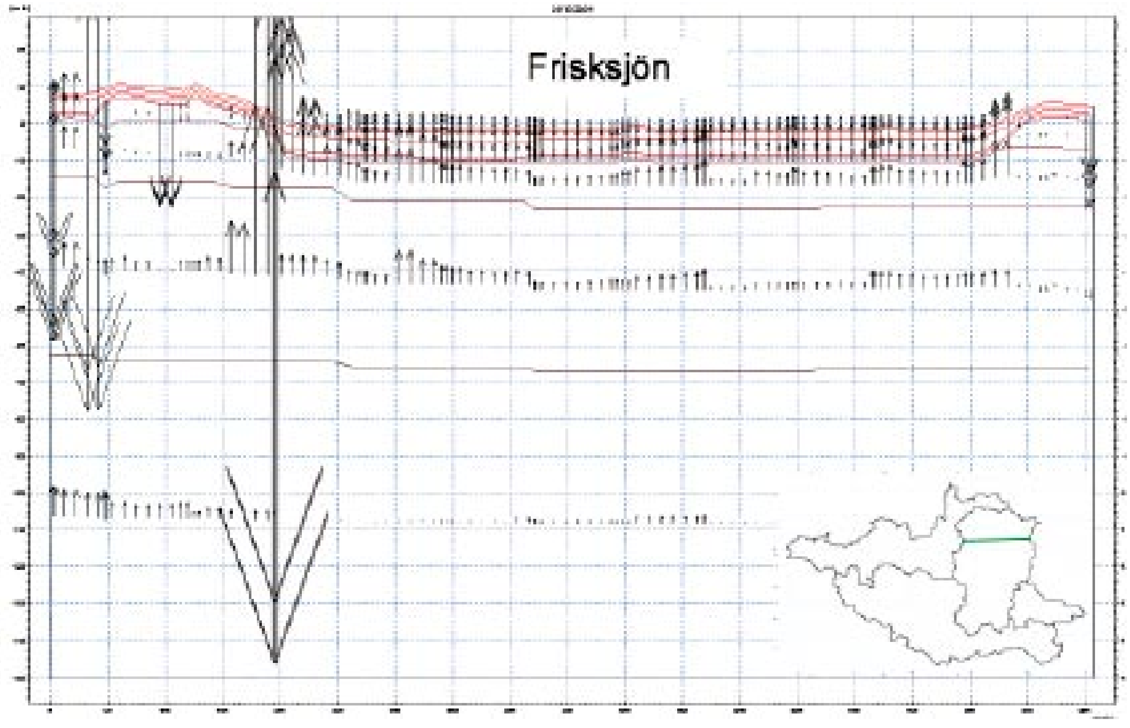

Figure 4-23. *Cross section across Lake Frisksjön, indicating the direction and relative magnitude of the vertical flow component in all calculation layers during a wet period (end of October). The inserted map shows the location of the cross section.*

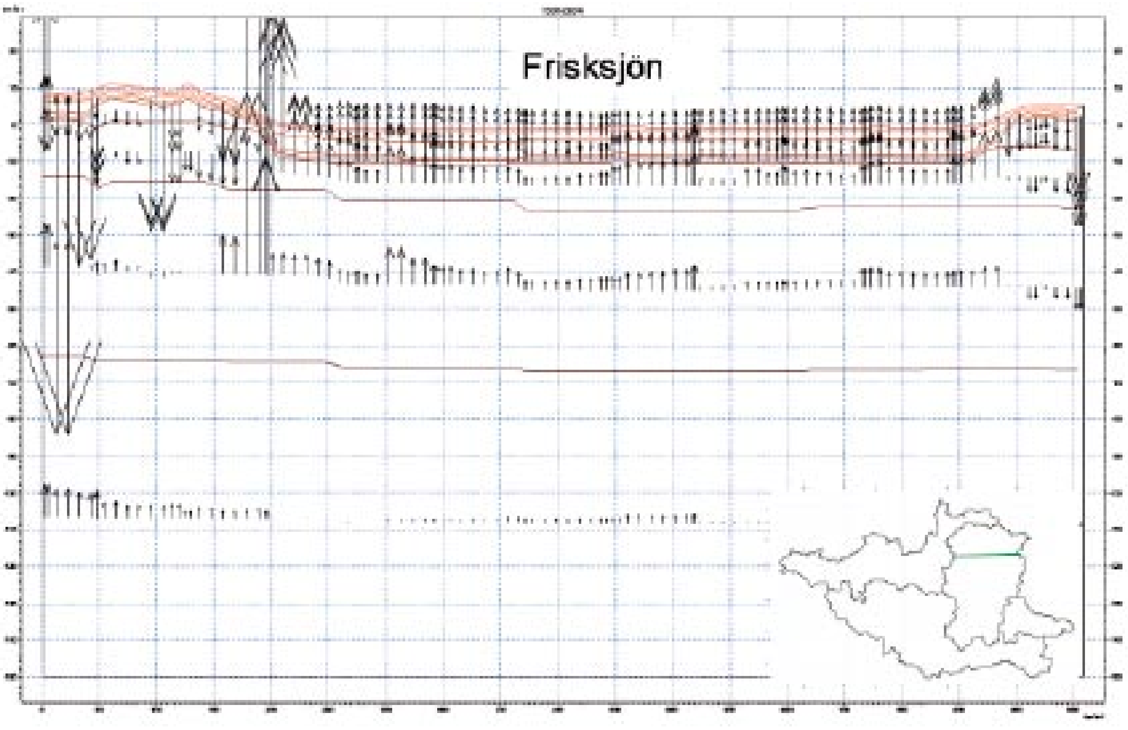

Figure 4-24. *Section across Lake Frisksjön, indicating the direction and relative magnitude of the vertical flow component in all calculation layers during a dry period (mid of August). Results are shown for the updated base case.*

4.3.5 GIS-based modelling with PCRaster-POLFLOW

Overview of the modelling approach

The PCRaster-POLFLOW approach provides extended capabilities compared to the GIS-based modelling reported in the Simpevarp 1.2 background report /Werner et al. 2005/. The GIS-based S1.2 modelling was based on the DEM and assumed a temporally and spatially constant specific discharge. The PCRaster-POLFLOW approach, which uses a single language for performing both GIS and process modelling operations, allows for analyses of temporally and spatially varying flow and transport processes within catchments on various spatial-temporal scales.

The PCRaster-POLFLOW approach has been applied to pre site-investigation and version 1.2 data from both the Forsmark and Simpevarp regional model areas. The basic principles behind the modelling approach are briefly described below. For further details concerning the modelling approach and the Forsmark and Simpevarp modelling results, the reader is referred to /Jarsjö et al. 2004, 2005, Johansson et al. 2005/. The main reason for considering PCRaster-POLFLOW, in addition to the other simulation tools used in the hydrological modelling, is that it offers possibilities to account for spatially distributed processes with much less computational effort than that associated with the MIKE SHE simulations.

In PCRaster-POLFLOW, a precipitation surplus (*PS*) is calculated for each grid cell (mm·year^{-1}) as $PS = P–E$, where *P* is actual precipitation and *E* is actual evapotranspiration. In /Jarsjö et al. 2005/, two different methods are used to calculate *E* (note that PCRaster-POLFLOW is flexible, and allows empirical relations to be modified as needed). Method 1 uses empirical expressions for *E* as a function of *P* and the potential evapotranspiration, *PET*). Method 2 implies that different soil texture/land-use classes are assigned different *E*-values.

The fraction of *PS* that adds to groundwater recharge (*GW*) is subsequently calculated, based on ground slope (the DEM) and land cover (the QD map and the vegetation map). The remaining fraction of *PS* is available for surface runoff from the grid cell. The total flow (the sum of groundwater and surface water flow) through each cell is calculated as the sum of the locally generated *PS*, and the inflow from upstream cells, calculated by use of the DEM. It can also be noted that in the present PCRaster-POLFLOW modelling, the ground surface level is lowered along the main watercourses, in order to account for the local depressions determining the surface runoff. Since the mapped watercourses represent the real flow system, this improves the similarity between the modelled and the real surface water flow pattern, as compared to a model that uses the DEM only.

Results

This section gives a brief summary of the main PCRaster-POLFLOW modelling results for the Simpevarp area. A detailed description of the Simpevarp results is presented in /Jarsjö et al. 2005/.

Using Method 1 for calculation of the actual evapotranspiration *E*, the spatial distribution of *E* and *PS* (see definitions above) shows relatively small variations within the model area, which is because they are based on interpolated temperature data from measurement stations located outside of the model domain. By contrast, Method 2 is based on a more detailed soil texture and land-use classification from within the model domain. We will therefore in the following present more details on the Method 2 results and variability. As mentioned above, Method 2 implies that different *E*-values are assigned according to the soil texture and land-use classes. In the Simpevarp modelling, these values consist of calibrated data from catchments in Germany. Hence, the classification into "*E*-classes" is based on site investigation data, whereas the values used to parameterise the classes are not.

Figure 4-25 shows the local values of the actual evapotranspiration E (mm·year^{-1}). There are large areas with relatively high E-values (> 460 mm·year^{-1}), which reflects that the parameterisation of the evapotranspiration classes is based on data from a warmer climate than in Simpevarp. However, there are also areas with lower evapotranspiration values (< 350 mm·year^{-1}), which indicates a relatively high degree of spatial variability due to the underlying combined soil type/land use classification.

Figure 4-26 shows the corresponding local values of the precipitation surplus $PS = P–E$ (mm·year^{-1}), i.e. the local contributions to the total runoff. As for the E-values in Figure 4-25, the precipitation surplus demonstrates a high degree of spatial variability within the Simpevarp regional model area; grid cells with high E-values have low values of precipitation surplus PS.

The precipitation map (not shown here) is constructed based on interpolation and extrapolation of the long-term annual average precipitation from the SMHI meteorological stations Målilla, Oskarshamn and Ölands norra udde (cf Section 3.1.1). The resulting P-map displays a NE-SW gradient, with values in the approximate range 500–600 mm·year^{-1} across the model area. This affects the PS-map in Figure 4-26 in terms of low PS-values in the NE, increasing towards SW.

Figure 4-27 shows local values of the groundwater recharge GW (mm·year^{-1}), which on average equals the locally generated groundwater discharge, considering time periods of several years. As can be seen in the figure, also this parameter displays some degree of spatial variability. The fraction of PS that adds to groundwater recharge (not shown here) displays values in the range 0.1–1, however being in the range 0.5–0.8 in the largest part of the model area, implying in other words that 50% to 80% of PS contributes to GW. As Figure 4-27 shows, this further implies that the largest part of the model area has a groundwater recharge GW of less than 100 mm·year^{-1}.

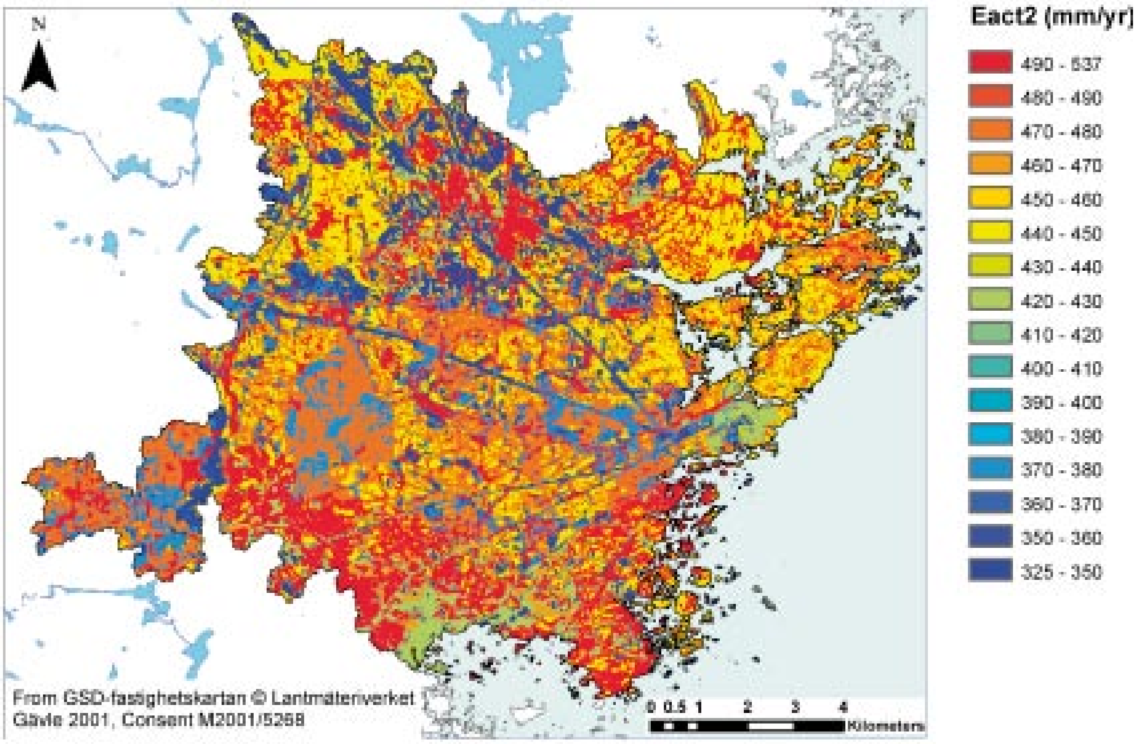

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Figure 4-25. *Actual evapotranspiration (mm·year^{-1}), calculated according to Method 2 /Jarsjö et al. 2005/.*

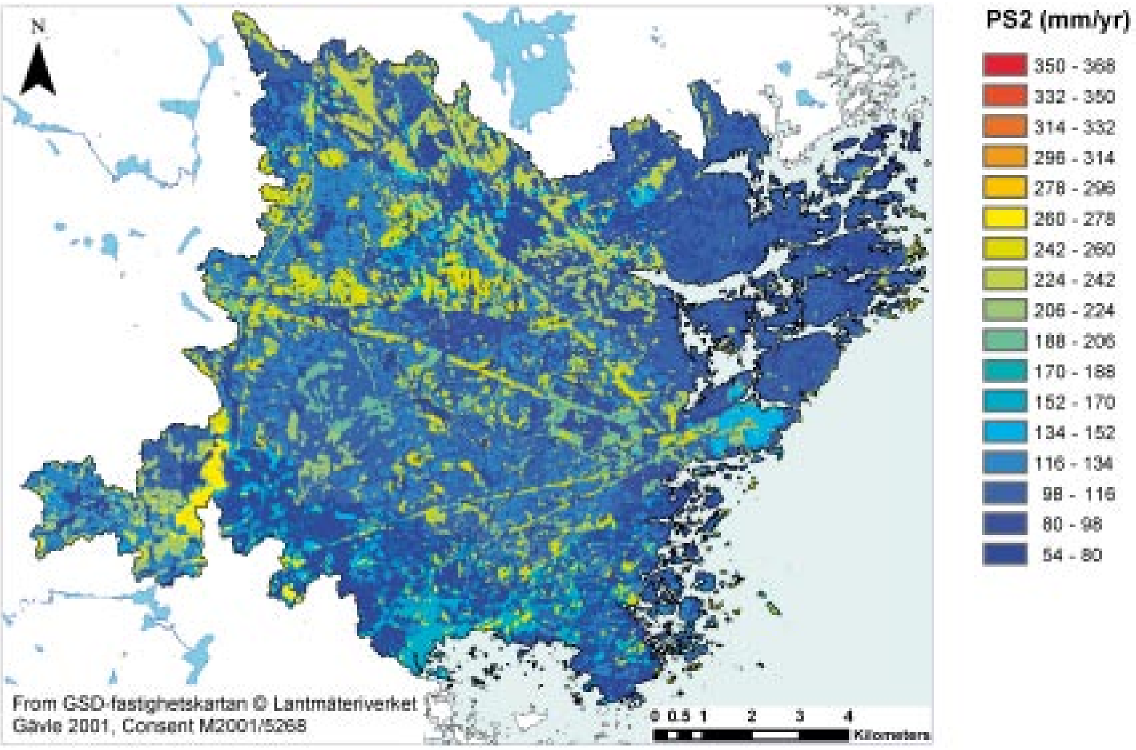

Figure 4-26. *Local precipitation surplus (mm·year^{-1}), which equals the total locally created discharge, calculated according to Method 2 /Jarsjö et al. 2005/.*

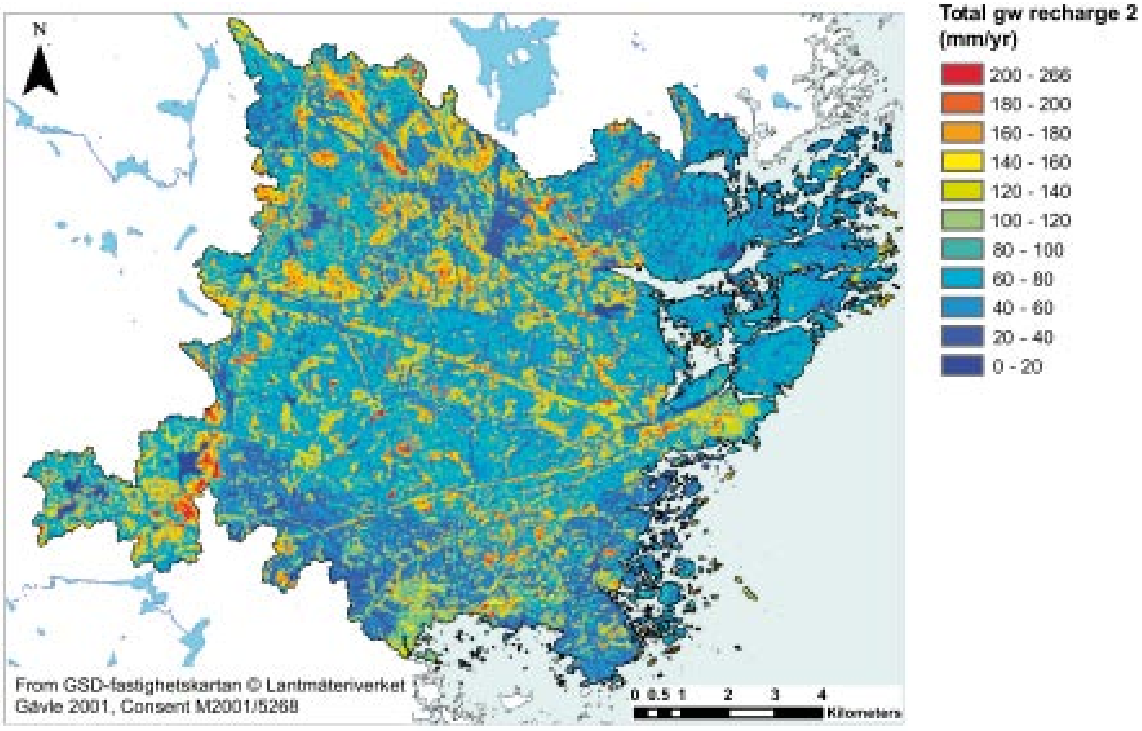

Figure 4-27. *Local groundwater recharge (mm·year^{-1}), and the locally created groundwater discharge, adding to local stream discharge, or flowing as groundwater and adding to stream discharge further downstream according to Method 2 /Jarsjö et al. 2005/.*

Based on long-term average data, the annual average specific discharge is estimated to be in the range 4.7–5.7 $l \cdot s^{-1} \cdot km^{-2}$ /Larsson-McCann et al. 2002/. Using the PCRaster-POLFLOW approach, /Jarsjö et al. 2005/ calculated an area-averaged specific discharge of c 5.9 and 4.0 $l \cdot s^{-1} \cdot km^{-2}$, using Method 1 and 2, respectively, to calculate the actual evapotranspiration. As previously mentioned, Method 2 predicts relatively high E-values, resulting in an average PS (= $P–E$; being equal to the average specific discharge) that is lower than implied by the independent, regional estimate of the specific discharge /Larsson-McCann et al. 2002/. Therefore, /Jarsjö et al. 2005/ developed a calibration procedure to avoid the systematic differences between the regional discharge estimate and the results implied by Figures 4-25 to 4-27. They also noted that the arithmetic average of the calculated annual average PS produced by Method 1 and 2 was consistent with these regional estimates.

Considering now local discharges /Jarsjö et al. 2005/ also calculated the average annual discharge at a number of existing or planned hydrological stations in watercourses in the Simpevarp area. At present, there are data from manual discharge measurements (see Section 3.2.6) at three of the locations considered in /Jarsjö et al. 2005/, namely PSM000364, -365, and -368; automatically measured discharge data are not yet available from the Simpevarp site investigations. A comparison shows that average values calculated from the manual discharge measurements agree reasonably well with the annual average discharge predicted by PCRaster-POLFLOW considering these stations (using the average PS computed by Methods 1 and 2). At PSM000364, -365, and -368, the PCRaster-POLFLOW model predicts discharge values of c 0.20, 0.013, and 0.14 $m^3 \cdot s^{-1}$, whereas the manual discharge measurements yield annual averages of c 0.22, 0.019, and 0.20 $m^3 \cdot s^{-1}$.

4.3.6 Concluding remarks on the quantitative modelling

To the degree of detail considered in the present evaluation, the quantitative modelling results support the conceptual-descriptive model of the hydrological and hydrogeological conditions in the Simpevarp regional model area. However, due to lack of time series data, the modelling does not include detailed comparisons between modelled and measured data. It is expected that such comparisons (and model calibration in general) will be important components of the continued model development during the next stage of the site descriptive modelling.

The integration of simulations and site data, in the form of site-specific time series of meteorological parameters, groundwater levels and discharges in watercourses, is important for improving the site understanding, thereby increasing the confidence in the modelling results. In addition to more and longer time series, some additional data on the hydraulic properties are expected that will improve the model parameterisation in future model versions; these data include water retention parameters of the QD, and an improved characterisation of the QD/bedrock interface.

Model calibrations/comparisons with site data (such as those indicated above) require that hydrological and hydrogeological data are available for the same time period as that for which local meteorological input data can be obtained. Since most of the automatic groundwater level measurements in the Laxemar subarea were initiated during 2005, it is the access to this type of data that will be the limiting factor. In the present modelling, site-specific meteorological data from Äspö for the year 2004 are used. However, in order to improve the site understanding, several alternative meteorological datasets and scenarios should be considered in future modelling efforts (e.g. site-specific average/typical conditions, long-term time seres, extreme dry/wet periods, and so forth). Depending on the definitions of these cases (they could consist of measured data or be defined according to some synthetic or extrapolated time series), actual data then could or could not be available for comparing simulation results with hydrological-hydrogeological measurements.

The present modelling includes a thorough sensitivity analysis, in terms of the hydraulic properties of QD and the vegetation parameters LAI and K_c. In future modelling work, further sensitivity analyses will be performed. Such analyses are important for identifying key processes and parameters, and simplifications of these. As an example, the bottom boundary in the present MIKE SHE-MIKE 11 model is simplified as a no-flow boundary at 150 metres below sea level. The implications of this assumption needs to be tested by studying the coupling between the groundwater in the rock and that in the QD.

The GIS-based hydrological modelling approach PCRaster-POLFLOW has proven to provide a suitable framework for analysing the effects of hydrological spatial variability with limited computational effort. Hence, this approach is probably most useful for investigating the uncertainties in flow and transport models of the surface system.

4.4 Hydrochemical data for interpretation of flow systems

Direct comparisons with spatial distributions of hydrochemical parameters (main elements and specific components such as isotopes) can be used to distinguish “water types” and to infer information on the flow pattern. Evaluations of the available hydrochemical data in the L1.2 data set are presented in /Tröjbom and Söderbäck 2006/ and in the background report from the hydrogeochemical modelling /SKB 2006b/. The following sections provide a summary of these reports, focusing on information and data of relevance for the present conceptual-descriptive modelling.

4.4.1 Chemical characteristics of shallow groundwater in the Simpevarp area

The shallow groundwater in the Simpevarp area is characterised by neutral or slightly acid pH-values, normal content of major constituents, and alkalinity ranging from high to very low. Groundwater in the area is influenced by marine relics, resulting in elevated contents of e.g. chloride and sulphate in samples from wells in the QD, and also in samples from surface waters (see Section 4.4.2). Several chemical parameters show large deviations when data from the Simpevarp area are compared with “normal” Swedish conditions. For instance, iron and manganese show markedly elevated concentrations of about an order of magnitude, and also fluoride, iodide and strontium show higher concentrations in the area than normal in Sweden.

Major and minor constituents

Table 4-14, taken from /Tröjbom and Söderbäck 2006/ Table 7-2, shows median values of major and minor constituents for individual groundwater monitoring wells, as well as for the categories “higher” and “lower” located soil tubes (explained below). The median values represent very different numbers of observations. The table was compiled to facilitate comparisons between several elements. For example, SSM000018, SSM000022 and SSM000034 show elevated concentrations of several marine ions, whereas e.g. SSM000008, SSM000010, SSM000020 and SSM000026 display markedly lower values for most of these ions. /Tröjbom and Söderbäck 2006/ present a detailed element-by-element evaluation.

The concentrations of calcium, magnesium, sodium and potassium in shallow groundwater are normal in comparison with typical shallow groundwater in Sweden. Concentrations of silicon, fluoride, manganese, and iron are elevated. However, the high manganese concentration could be due to methodological reasons /Tröjbom and Söderbäck 2006/.

Table 4-14. Summary of major and minor constituents of groundwater in the Simpevarp area, median values in mg/l /Tröjbom and Söderbäck 2006/. The columns correspond in order from left to right to identification code for the groundwater monitoring well, the catchment name, the subcatchment number, the classification in "higher" (H) and "lower" (L) located wells.

ID code	Catchment			Ca	Mg	Na	K	Sr	Li	Cl	HCO_3	SO_4	F	Br	I
SSM000001	Simpevarp Peninsula		L	30	11	11	4.2	0.081	0.013	7.1	110	4.1	0.48	< 0.2	
SSM000002	Simpevarp Peninsula		H	32	29	59	12	0.27	0.012	8.5	370	13	1.1	< 0.2	
SSM000005	Simpevarp Peninsula		H	91	18	10	9.3	0.26	< 0.004	17	220	4.5	5.4	0.91	
SSM000008	Simpevarp Peninsula		L	34	3.6	10	2.1	0.10	0.0050	3.9	100	8.5	0.35	< 0.2	0.012
SSM000009	Ekerumsån	9:2	L								2.0				
SSM000010	Simpevarp Peninsula		L	44	7.8	13	4.3	0.14	0.011	4.7	130	22	0.82	< 0.2	0.011
SSM000011	Ekerumsån	9:2	H								3.0				
SSM000012	Skölkebäcken	26:1	L	57	9.0	34	5.5	0.18	0.019	15	210	68	1.8	< 0.2	0.0060
SSM000014	Coastal area		L	25	13	23	6.8	0.099	0.041	12	69	61	3.0	< 0.2	0.016
SSM000016	Island of Ävrö		L	47	7.3	5.6	4.1	0.070	0.0090	6.2	110	18	2.1	< 0.2	0.0060
SSM000017	Laxemarån	10:5	L								42				
SSM000018	Lindströmmebäcken	24:1	L	42	17	69	41	0.16	0.026	120	59	100	0.99	0.77	0.020
SSM000019	Laxemarån	10:5	H								27				
SSM000020	Vadevikebäcken	23:1	H	35	6.5	5.8	3.7	0.10	0.015	5.3	45	51	1.4	< 0.2	0.0060
SSM000021	Ekerumsån	9:1	L								200				
SSM000022	Vadevikebäcken	23:1	L	22	8.7	230	7.6	0.28	0.023	150	280	130	3.9	0.64	0.015
SSM000024	Island of Ävrö		H	16	5.1	6.5	3.3	0.068	0.010	6.0	83	11	0.97	< 0.2	0.018
SSM000026	Island of Ävrö		H	31	5.1	7.7	2.2	0.070	0.0060	5.6	55	18	0.77	< 0.2	0.0040
SSM000027	Kärrviksån	5:1	L	6.1	1.3	6.2	1.1	0.025	0.0020	7.4	17	21	0.51	< 0.2	0.0030
SSM000029	Coastal area		L	23	14	98	11	0.15	0.029	86	190	22	2.9	1.0	0.050
SSM000030	Mederhultsån	6:1	L	69	8.3	29	2.5	0.27	0.010	16	260	46	2.3	< 0.2	0.010
SSM000031	Mederhultsån	6:1	L	12	3.3	7.5	1.3	0.044	0.0040	6.1	48	11	2.4	< 0.2	0.0050
SSM000034	Coastal area		L	100	45	72	12	0.54	0.025	140	550	< 0.2	0.38	1.5	0.033
SSM000035	Laxemarån	10:30	L								87				
SSM000037	Ekerumsån	9:3	L	55	11	34	5.7	0.22	0.031	16	220	24	2.2	< 0.2	0.0080
SSM000039	Ekerumsån	9:1	L	37	7.6	9.7	4.5	0.10	0.014	6.2	50	16	1.3	< 0.2	0.0050
SSM000040	Coastal area		L	28	21	82	9.6	0.20	0.019	120	160	13	1.8	0.92	
SSM000041	Laxemarån	10:1	L								120				
SSM000042	Laxemarån	10:1	L							65	180	91	1.1	0.78	
Monitoring wells at 'lower' levels			L	36	8.7	25	5.2	0.14	0.017	12	120	24	1.8	< 0.2	0.011
Monitoring wells at 'higher' levels			H	32	5.9	6.5	3.3	0.076	0.0090	5.9	58	18	1.1	< 0.2	0.0060
All monitoring wells				34	8.2	12	4.8	0.13	0.014	7.4	93	22	1.4	< 0.2	0.010

The contents of chloride and sulphate are slightly elevated, probably due to the marine relics and the proximity to the Baltic Sea. In addition to the marine sources, sulphate is also added through long distance deposition and by weathering of sulphur-containing minerals. There were too short time series of water chemistry observations of shallow groundwater (1–4 samples) to enable a meaningful evaluation of temporal variability /Tröjbom and Söderbäck 2006/. However, a long time series, available from a private well in the area, indicates decreasing content of non-marine sulphate in the shallow groundwater. This finding is consistent with the diminishing sulphate deposition during the last decades.

According to a preliminary classification based on the topographical location, /Tröjbom and Söderbäck 2006/ divided all QD wells in the ID series SSM000001-42 into "higher" and "lower" wells; these classes are indicated by "H" and "L", respectively in Table 4-14.

They also made a preliminary classification of pre-site investigation wells in the QD; all these wells were classified as "lower" wells. This preliminary classification is a first attempt in the direction of classifying the monitoring well locations in terms of their recharge/discharge characteristics. In this context, "higher" wells are likely to be within recharge areas and "lower" wells within discharge areas. However, more detailed studies of the local conditions at the monitoring well locations are required before a final recharge-discharge classification is established. This "physically based" classification could then be compared with the hydrochemical characteristics of the monitoring wells and the results of hydrological modelling, in order to find out whether a consistent description of the site conditions emerges.

Figure 4-28 shows a Piper diagram of the mean concentration of the major chemical constituents in QD wells in the Simpevarp area /Tröjbom and Söderbäck 2006/. It can be seen in the figure that the shallow groundwater in the area ranges from Ca-HCO_3 to Na-Cl types. The figure shows that all "higher" wells in the QD are of Ca-HCO_3 type, probably indicating recently infiltrated water and presumably groundwater recharge areas /Tröjbom and Söderbäck 2006/. "Lower" QD wells range from the Ca-HCO_3 type to the Na-Cl type.

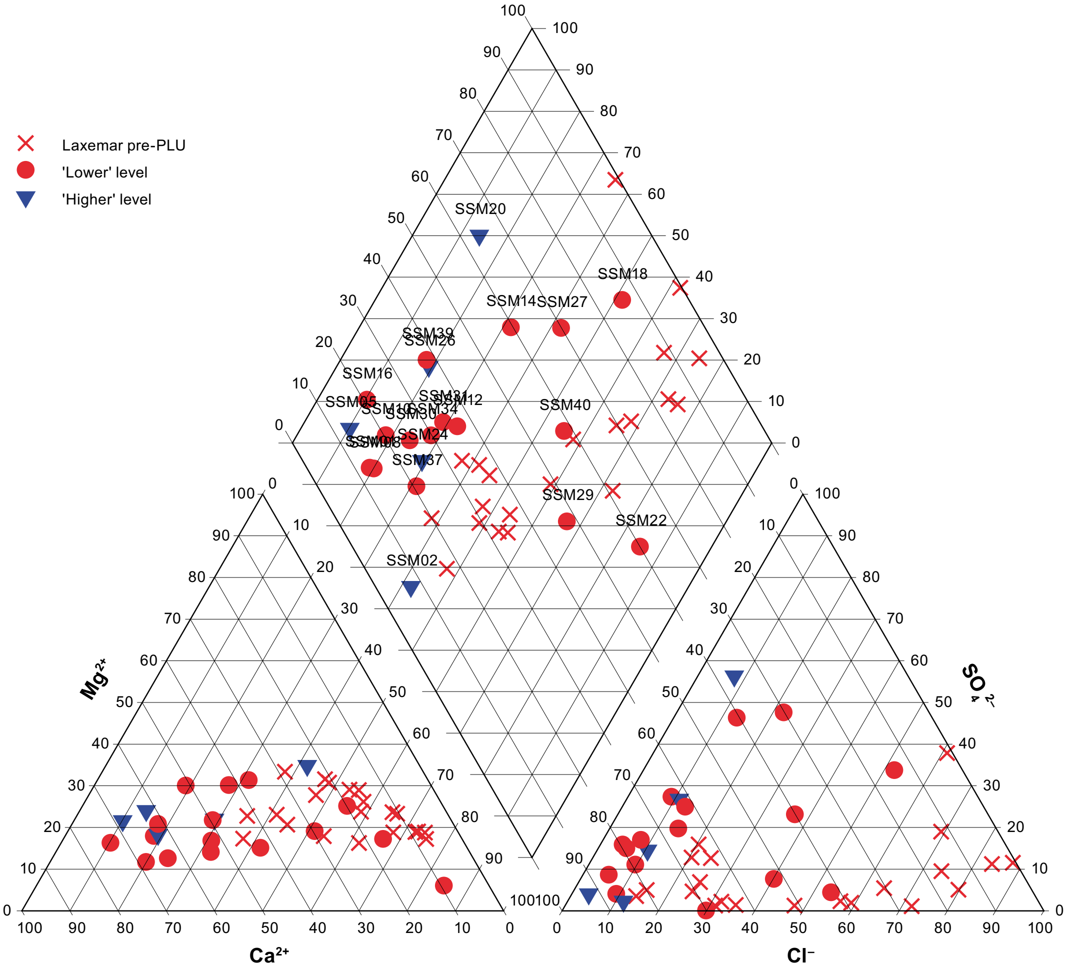

Figure 4-28. *Piper diagram of the mean concentration of the major constituents in QD wells in the Simpevarp area /Tröjbom and Söderbäck, 2006/. The QD wells are classified into the categories "higher" and "lower", based on the topographic location.*

There are also some QD wells in the middle of the Piper diagram, indicating intermediate characteristics with respect to the major constituents. Some wells classified as "lower" fall into the "recharge water area" on the left side of the Piper diagram, indicating that a relatively simple classification of QD wells into "higher" and "lower", as determined by the topography only, not necessariliy corresponds to the hydrochemical recharge and discharge characteristics of the groundwater /Tröjbom and Söderbäck 2006/.

All QD wells (also all sampled lakes and watercourses) demonstrate a significantly lower electrical conductivity than the sea water. The highest electrical conductivity is found on the island of Ävrö (SSM000022) and at the coast of Laxemar (SSM000034). These two QD wells, as well as SSM000018 (on Ävrö), are classified as "lower" QD wells and show elevated concentrations of several "marine" ions (e.g. natrium and chloride).

As an example of a spatial distribution of one of the more important main elements, Figure 4-29 shows the mean chloride concentrations in near-surface groundwater and surface water in the Simpevarp area. The monitoring wells SSM000022 and SSM000018 on the Island of Ävrö, as well as SSM000029, SSM000034 and SSM000040 located near the brackish basins of Granholmsjärden and Borholmsfjärden, show markedly elevated chloride concentrations. However, the chloride concentration in SSM000022 is less elevated than what is seen for some of the other elements (e.g. sodium). There is no obvious large scale gradient from inland to sea for chloride.

It can be seen in Figure 4-29 that the chloride concentrations in the shallow groundwater are usually comparable to that in both stream and lake water, and markedly lower than sea water. The chloride concentration in precipitation is usually about 1 mg/l. In streams concentrations of c 10 mg/l are usually measured, compared to 3 mg/l in the rest of Sweden.

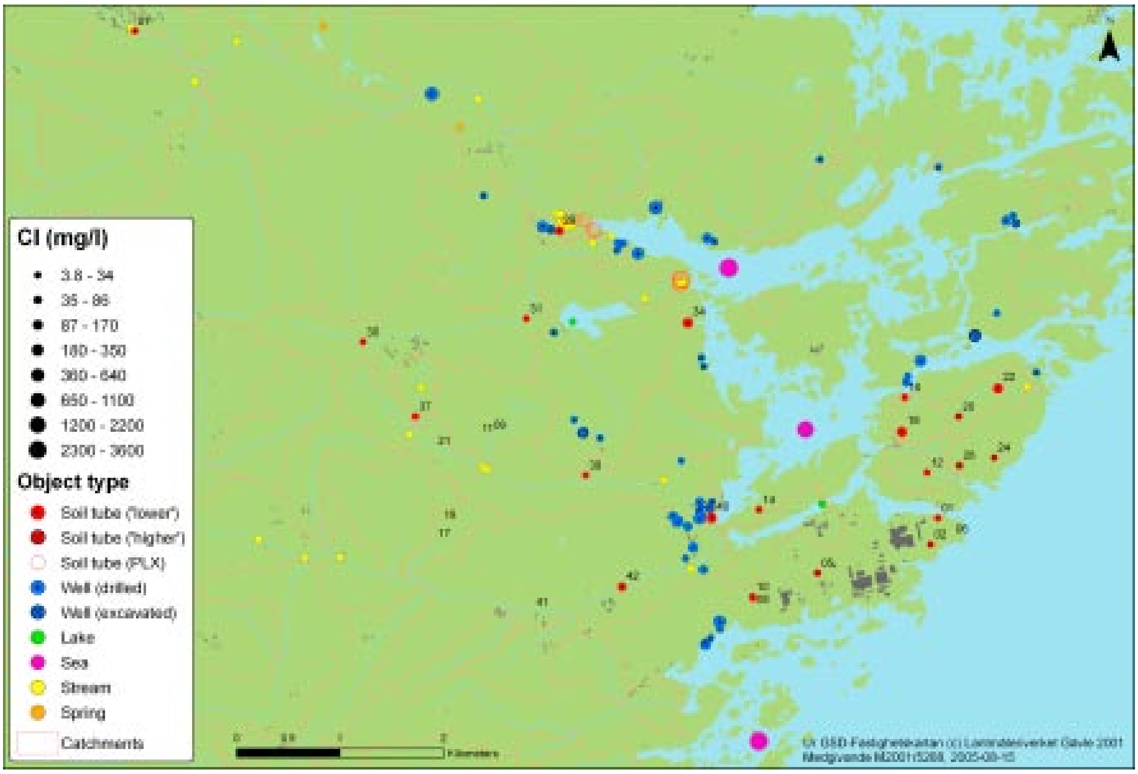

__Figure 4-29.__ Chloride concentrations in shallow groundwater and surface water in the Simpevarp area /Tröjbom and Söderbäck, 2006/. The dots represent mean values of available data from SKB groundwater monitoring wells, private wells and surface waters. The figures in black correspond to the last two digits of the ID-codes of the monitoring wells.

The concentrations found in sea water are markedly higher, about 3,400 mg/l. Typical chloride concentrations in shallow groundwater in the Simpevarp area are 6 mg/l in “higher” located monitoring wells and 12 mg/l in “lower” located wells.

Alkalinity, pH and redox potential

The shallow groundwater in the Simpevarp area is characterised by slightly acid pH-values, and the major part of the observations are in the range pH 6–7. The alkalinity ranges from “very high” to “very low”; most measurements are classified as “high”. There are examples of “higher” wells in the QD having “low” alkalinity, combined with low pH. This indicates low buffering capacity and ongoing acidification, promoted by thin QD or shallow/exposed bedrock with very low contents of calcite. The pH and alkalinity in private wells in the Simpevarp area are characterised as normal. The redox potential is “low” or “very low” in all wells in the QD.

The highest pH-values are found in SSM000002 near the nuclear power plant, and in SSM000012 and SSM000022 on the Island of Ävrö. The latter QD well shows deviating characteristics with respect to many parameters. SS000022 is situated in a small catchment dominated by bare bedrock on the topographical heights and by till in the lower areas, see Figure 4-30. The upstream located well, SSM000020, as well as the streaming water sampling site (PSM107735) at the outlet of the catchment of Vadevikebäcken, show markedly lower pH than SSM000022.

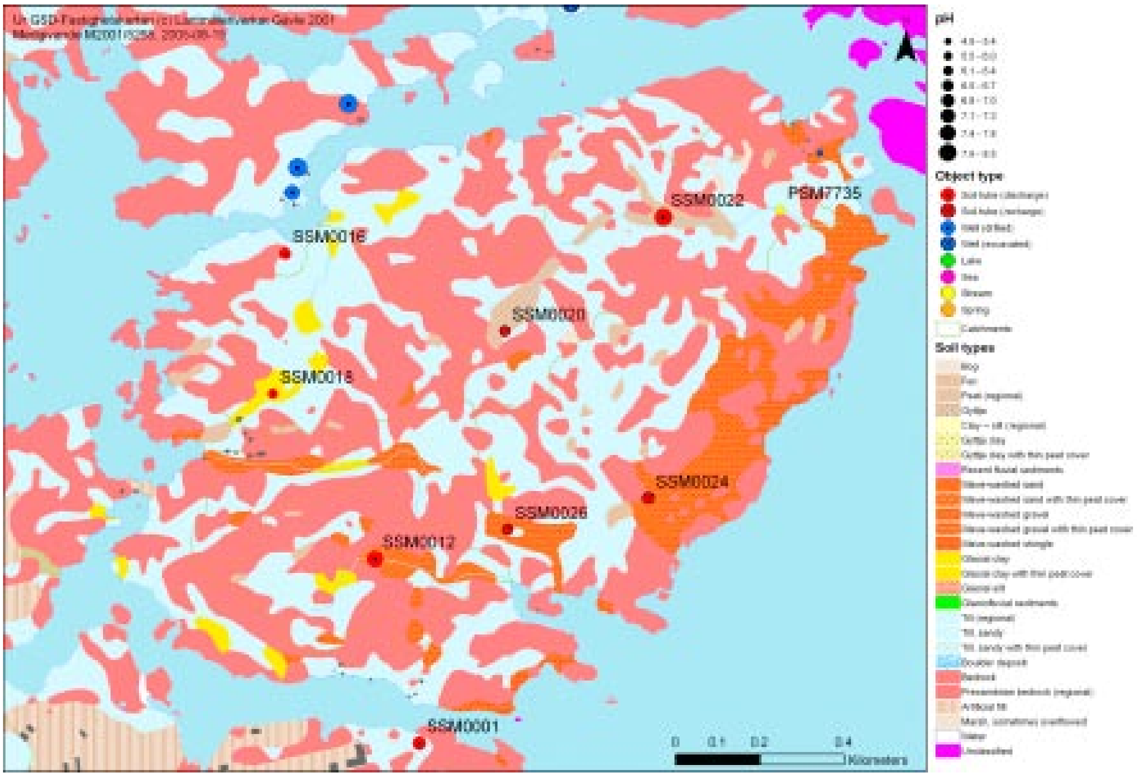

Figure 4-30. Median pH in shallow groundwater and surface water at the Island of Ävrö displayed on a detailed QD map /Tröjbom and Söderbäck, 2006/. Groundwater from SSM000022 shows deviating chemical composition with respect to several parameters.

Trace elements

About thirty trace elements have been measured in shallow groundwater and surface waters. The shallow groundwater concentrations of rare earth elements (e.g. lanthanum and ytterbium) and vanadium are elevated compared to the Forsmark area, whereas the concentrations of these elements in watercourses also are elevated compared to “normal“ Swedish conditions. Also other metals, e.g. chromium, copper, molybdenum, and nickel show elevated concentrations in the surface waters. Rubidium, zirconium, and thorium concentrations are elevated both in shallow groundwater and in surface waters.

Isotopes of hydrogen, oxygen and carbon

Median values for isotopes of hydrogen, oxygen and carbon are summarised in Table 4-15 /Tröjbom and Söderbäck 2006/ Table 7-6. Deuterium and oxygen-18 data from precipitation and most shallow groundwater observations from the Simpevarp area indicate a meteoric origin of most shallow groundwaters. Data from watercourses and lakes form an “evaporation line”, indicating enrichments of the heavier isotopes due to evaporation. There is also a gradual decrease of the deuterium deviations along the flow path from high-altitude (groundwater recharge) areas to watercourses, lakes and finally the Baltic Sea. The concentrations of oxygen-18 are lower in lakes and the sea compared to watercourses and shallow groundwater.

Table 4-15. Median values for isotopes of hydrogen, oxygen and carbon in shallow groundwater in the Simpevarp area /Tröjbom and Söderbäck 2006/.

ID code	Catchment			Tr TU	D ‰ SMOC	O-18 ‰ SMOC	D/O-18 ratio	C-13 ‰ PDB	C-14 pmC
SSM000001	Simpevarp Peninsula		L		–80.4	–11.3	7.11		
SSM000005	Simpevarp Peninsula		H	13.3	–85.2	–11.8	7.22		
SSM000008	Simpevarp Peninsula		L	12.0	–78.9	–11.0	7.17	–17.1	82.2
SSM000010	Simpevarp Peninsula		L	11.9	–77.3	–10.8	7.16	–17.5	81.1
SSM000012	Skölkebäcken	26:1	L	11.2	–76.3	–10.7	7.13	–13.7	54.9
SSM000014	Coastal area		L	14.5	–73.0	–10.6	6.89	–18.5	97.6
SSM000016	Ävrö		L	13.2	–79.8	–11.1	7.19	–17.9	
SSM000018	Lindströmmebäcken	24:1	L	12.9	–77.0	–10.9	7.06	–19.6	99.6
SSM000020	Vadevikebäcken	23:1	H	12.1	–76.3	–10.8	7.06	–18.8	
SSM000022	Vadevikebäcken	23:1	L	1.00	–77.1	–10.6	7.27	–10.8	45.4
SSM000024	Ävrö		H	12.6	–77.4	–10.5	7.37	–16.5	103
SSM000026	Ävrö		H	13.4	–74.5	–10.7	6.96	–12.7	
SSM000027	Kärrviksån	5:1	L	9.60	–84.3	–11.3	7.46		
SSM000029	Coastal area		L	11.0	–80.4	–10.9	7.38	–12.4	
SSM000030	Mederhultsån	6:1	L	8.70	–77.4	–10.9	7.10	–15.2	
SSM000031	Mederhultsån	6:1	L	12.1	–76.2	–10.7	7.12		
SSM000034	Coastal area		L	14.8	–78.5	–10.9	7.20	–10.7	
SSM000037	Ekerumsån	9:3	L	10.7	–77.4	–11.0	7.04	–14.6	
SSM000039	Ekerumsån	9:1	L	11.0	–77.8	–10.9	7.14	–12.4	
SSM000040	Coastal area		L	12.7	–79.7	–10.7	7.45		
‘Higher’ monitoring wells			S	13.0	–76.9	–10.7	7.19	–17.4	103
‘Lower’ monitoring wells			S	11.8	–77.4	–10.8	7.17	–16.9	81.7
All monitoring wells			S	12.0	–77.4	–10.8	7.17	–16.9	82.2

The tritium levels in shallow groundwater range from 8–15 TU, an interval which overlap the range of surface waters and precipitation of approximately 9–19 TU. In SSM000022 on the Island of Ävrö, low tritium values corresponding to submodern levels have been observed. The low fraction of modern carbon also indicates groundwater of relatively old origin; observed low carbon-14 values may also originate from dissolution of calcites, depleted in carbon-14.

Other isotopes

The boron-10/boron-11 ratios in the Simpevarp area are slightly lower than the natural abundance ratio. Boron-10 is most depleted in SSM000022, located on the Island of Ävrö; the highest enrichment is found in SSM000005, installed near the nuclear power plant on the Simpevarp peninsula. SSM000005 shows a deviating water chemical composition with respect to several parameters.

The chlorine-37/chlorine-35 ratios found in the Simpevarp area are normal for Swedish conditions. The recorded values of sulphur-34 in shallow groundwater demonstrates large variability. Three wells in the QD (SSM000022, -29 and -37) show enriched content of sulphur-34, corresponding to sea water. Strontium-87 is generally enriched compared to normal conditions. Strontium-87 is least enriched in SSM000002 and -34, whereas the highest enrichments are found for SSM000005 and -16. The radium-226 activities are significantly higher compared to normal Swedish conditions, whereas the radon-222 activities are normal.

Summary of groundwater chemistry per subarea

The following summarises the conclusions concerning groundwater chemistry, on catchment area level, for the Laxemar and Simpevarp subareas /Tröjbom and Söderbäck 2006/. They note that a summary per catchment area is appropriate for shallow groundwater, as the catchment area boundaries often coincide with the (near-surface) groundwater divides. They also note that measurements in watercourses and lakes may be considered as the integrated result of groundwater discharge in the area, especially when local recharge-discharge patterns dominate.

The Laxemar subarea

The Laxemar subarea extends over several catchment areas. The watercourses Mederhultsån, Kåreviksån, Pistlanbäcken, Ekerumsån and Laxemarån discharge into the brackish basins of Granholmsfjärden and Borholmsfjärden at the eastern border of the Laxemar subarea. The groundwater samples from different monitoring wells in the Laxemar subarea show very different chemical compositions, probably due to differences between subcatchment areas and the topographical locations of the wells.

In the subcatchment areas of Ekerumsån (9:1–3), the levels of calcium and bicarbonate are generally elevated in both surface waters and in shallow groundwater from topographically “lower” wells. The wells in this catchment also show elevated contents of potassium, silicon and barium, compared to the adjacent catchment of Mederhultsån (6:1). One possible explanation to the deviating water chemistry in the catchment of Ekerumsån could be agricultural activities in the area.

The subcatchment of Ekerumsån contains two “higher” located wells (SSM000009 and SSM000011). These show highly deviating water chemical characteristics by having very low alkalinity and low pH. These wells are presumably representative for wells located at topographical heights, dominated by exposed/shallow bedrock. To date, no other parameters have been analysed on samples from these wells, but it can be expected that several other parameters will deviate from most of the other wells in the area. There are a number of wells located close to the coast of the brackish basins of Granholmsfjärden and Borholmsfjärden (SSM000029, SSM000034 and SSM000040) that show elevated contents of several major and minor constituents, e.g. magnesium, sodium, potassium, chloride and bromide, and depleted contents of strontium-87.

The Simpevarp subarea

The Simpevarp subarea consists of the Simpevarp peninsula and the islands of Ävrö and Hålö, on which a few smaller catchments have been identified. The wells in the Simpevarp subarea are characterised by rather normal levels of most major and minor constituents. Sulphate and fluoride levels are lower at the Simpevarp peninsula compared to the rest of the Simpevarp area. Contrary to those on the Simpevarp peninsula, the wells on Ävrö show elevated levels of sulphate and fluoride.

The wells SSM000022 on Ävrö and SSM000005 on the Simpevarp peninsula show deviating characteristics with respect to many parameters. In particular, SSM000022, situated in the small catchment area of Vadevikebäcken (23:1) on Ävrö, shows high pH, elevated concentrations of uranium and fluoride, and low content of tritium and modern carbon, possibly indicating groundwater of older and probably deeper origin compared to most other wells /Tröjbom and Söderbäck 2006/.

The hydrochemistry in SSM000005 deviates by showing remarkably high iron and manganese concentrations in combination with high calcium and fluoride content. The isotopes boron-10, chlorine-37 and strontium-87 also show deviating characteristics in that well. A possible explanation to the deviating chemical characteristics of this well may be influences from the prevailing artificial landfills in the area close to the nuclear power plant /Tröjbom and Söderbäck 2006/.

Indications of groundwater recharge and discharge areas

Based on a limited water chemstry data set from groundwater sampling of monitoring wells in the QD and percussion boreholes in the bedrock, a preliminary analysis has been performed to identify potential groundwater recharge and discharge areas /SKB 2006b/. The data set included e.g. chloride, sulphate, pH, alkalinity, tritium and andcarbon-14. The identification of groundwater recharge and discharge areas is only preliminary, as the analysed data set did not include seasonal sampling; the chemistry tends to be more stable in groundwater discharge areas /SKB 2006b/. However, longer sample series were available for nine QD wells, of which three wells (SSM000012, -18 and -22) demonstrated stable chloride concentration and alkalinity, hence indicating groundwater discharge. For some wells in the QD, the results deviate from those obtained by considering the topography only /Werner et al. 2005/.

The analysis of water chemistry in percussion boreholes in the bedrock, including oxygen-18, tritium and chloride, shows that in many cases the sampling intervals along the boreholes were too long (0–100 or 0–200 metres) to allow firm conclusions concerning groundwater recharge and discharge areas to be drawn. However, using tritium data, some percussion boreholes were identified as potential areas of groundwater discharge from the bedrock, as these boreholes were judged to contain groundwater being recharged during the 1950s, influenced by nuclear test fallout.

The preliminary analysis showed that there were too few data to provide a clear identification of recharge and discharge areas. In particular, the analysis identified the need for longer time series data on chemistry (in order to capture seasonal variations) and the need to install packers in percussion boreholes in order to improve the classification /SKB 2006b/. Furthermore, it should be noted that joint evaluations of hydrochemical data from both QD and rock need to be performed also in fortcoming modelling stages.

4.4.2 Chemical characteristics of surface waters in the Simpevarp area

The lakes and watercourses in the area are important parts of the hydrological system, and hydrochemical information obtained from surface water sampling and analyses can provide imformation on, e.g. the interactions between groundwater and surface water. In general, lakes and watercourses in the Simpevarp area are classified as mesotrophic brown water types, with very high levels of dissolved organic carbon, low visual depths, and strained oxygen conditions at the bottom of the lakes.

Most sampling sites show moderately to slightly acid pH-values and a high buffering capacity /Tröjbom and Söderbäck 2006/. Thin QD and a large proportion of exposed/shallow bedrock give prerequisites for acidification in small watercourses; a few sampling sites along watercourses indicate occurrence of acidified waters. However, a contratictory result is that alkalinity and pH is higher at topographically higher sampling sites. This probably reflects several superimposed processes, e.g. acid precipitation, oxidation of sulphide bearing minerals in the QD, and liming of arable land and possibly also of lakes and watercourses.

The concentrations of major ions (e.g. calcium, sodium and chloride) seem to increase downstream along watercourses; the highest levels are observed at the sampling sites near the outlets. There is also a tendency for an increasing gradient from north-west to south-east, coinciding with increasing QD depths.

Temporal variations of the chemical composition of surface waters

Many chemical parameters demonstrate temporal variations, connected to temporally variable surface water discharge and/or primary production. For instance, in the lakes, the observed temporal variation of nutrients and carbon (in particular for the particulate species) is typical for seasonally variable primary production. The concentrations of most elements in the watercourses show some degree of temporal variation, due to both seasonal variations of, for instance, the primary production and variations in the surface water discharge. The temporal (seasonal) variations of dissolved ions are less accentuated and are probably primarily controlled by variations in the discharge.

The concentrations of dissolved oxygen in the bottom waters of the lakes in the area are low during late summer and early autumn. These anoxic conditions are caused by decomposition of organic matter, produced by primary production in the lakes and supplied by surface water discharge from watercourses.

The sea basins Granholmsfjärden and Borholmsfjärden show very large variations in most chemical parameters, attributed to variable mixing proportions between sea water and fresh water from watercourses, discharging into the sea; this dilution-derived variation is in most cases overshadowing other causes of variation. The “open sea” coastal sites show only minor variations, compared to the lakes and the brackish sea basins.

Spatial variations in the chemical composition of surface waters

The concentrations of dissolved ions in the surface waters show spatial patterns that probably are coupled to the characteristics (type and depth) of the QD. The north-western part of the Simpevarp area is dominated by thin QD and exposed/shallow bedrock, whereas the south-eastern part has thicker QD, more arable land and consequently higher levels of most dissolved ions. Total and dissolved organic carbon is relatively evenly distributed throughout the Simpevarp area. On the other hand, nitrogen demonstrates higher concentrations in downstream areas with a high proportion of arable land /Tröjbom and Söderbäck 2006/.

The Ekerumsån catchment area (CA 9) shows deviating high contents of calcium, high alkalinity and elevated pH-values. This catchment area contains a relatively high proportion of arable land; the deviating chemistry may be caused by agricultural activities (such as liming) or by a deviating chemistry of the QD. The small Vadevikebäcken catchment area (CA 23), on the island of Ävrö, demonstrates deviating concentrations of lithium, and probably also of calcium and bicarbonate supplied by calcite dissolution processes. This deviation may indicate either discharge of deep groundwater, or a deviating chemistry of the QD. It can be noted that observations of shallow groundwater in this catchment area also show deviating characteristics of, for example, tritium and carbon-14, which may indicate discharging groundwater of deeper origin.

4.5 Other supporting data and models

The conceptual-descriptive model of surface hydrology and near-surface hydrogeology can be supported by a number of different types of data and models, hydrological/hydrogeological data and models as well as those from other modelling disciplines. Examples of such data and models and how they can be used to support conceptual-descriptive and numerical flow models are discussed in /Werner et al. 2005, Johansson et al. 2005/. Important aspects that can be considered include the overall flow pattern, especially the spatial distribution of groundwater recharge and discharge areas, and residence times of water in different parts of the flow system.

In the present model version, Section 4.4 demonstrated the use of the L1.2 hydrochemical data set, considering samples from shallow groundwater and surface waters, to identify water types and to interpret water flow systems at the Laxemar site /Tröjbom and Söderbäck 2006, SKB 2006b/. However, except for this analysis and the data and models presented in the previous chapters in the present report, the use of other data and models as support for the conceptual-descriptive modelling has so far been focused on the Forsmark site /Johansson et al. 2005/.

For the Laxemar site, the main part of these analyses are postponed to future model versions, primarily due to the lack of time series data (see Sections 3.2.5, 3.2.6 and 3.3.2). Such studies have now been initiated, including classification of wells installed in the QD in terms of their spatial distribution on groundwater recharge and discharge areas. Preliminary results (see also /Tröjbom and Söderbäck 2006/) show that few wells are located in high-altitude areas, which indicates that the majority of the wells are located in groundwater discharge areas. These results will be supplemented by fields checks of the monitoring wells, preliminary during the summer of 2006.

It can also be noted that a so-called (aerial) laser scanning has been performed within the area prioritised for detailed investigations in Laxemar, providing topographical data on the area for the planned repository and its immidiate vicinity with a horizontal spatial resolution of 0.25 metre /Nyborg 2005/. The resulting DEM may be used as input to more detailed GIS-based hydrological modelling in future model versions, using ArcGIS tools and/or the PCRaster-POLFLOW approach (see Section 4.3.5). In addition, the high-resolution DEM will be very useful in the identification of "missing" water courses and ditches and other evidence of the drainage operations that occur frequently in Laxemar.

5 Resulting site description

5.1 Developments since the previous model version

Compared to the previous S1.2 model version, more site investigation data are available on meteorological, hydrological, and hydrogeological parameters for the present L1.2 model. In particular, the L1.2 data freeze contains much more data from the Laxemar subarea. The new meteorological data include additional time series from the Äspö station (measurements started in September 2003), and data from a new station in Plittorp, where measurements started mid-July 2004. These time series have allowed a simple comparison with data from "regional" SMHI stations for the same period (2003–2004). The regional SMHI stations have long measurement records (on the order of 30–40 years). For these stations, long-term average data (monthly and annual mean values, return periods, and so forth) are available or can be calculated. Work has been initiated during 2005 to perform a more detailed comparative analysis of local (short term) and "regional" (long term) meteorological data, which will be included in forthcoming site descriptive models.

The L1.2 data freeze includes hydrological data from additional manual discharge measurements in watercourses. There are also time series on automatically measured water levels in some of the lakes in the area and in the sea. However, there are still no automatically measured time series on water levels and discharges in watercourses. The reason is that the station-specific empirical rating curves must be established and/or improved before these data can be stored in the SICADA database. During the 2005 field season, cross sections were measured along the main watercourses in catchment areas 6, 7 and 9 (Mederhultsån, Kåreviksån, and Ekerumsån, the latter including a tributary). In addition, the bottom stratigraphy of some wetlands, peat areas and lakes in the Simpevarp has been investigated /Nilsson 2004/, which improved the knowledge on the properties and conditions governing the interactions between surface water and groundwater in the Simpevarp area.

Since the previous model version, additional measurements of the hydraulic conductivity have been carried out by slug tests in 12 groundwater monitoring wells; all of these wells are located in the Laxemar subarea. A number of particle-size distribution curves for QD samples are also available in the L1.2 data freeze. These are used to obtain supplementary hydraulic conductivity data on QD. Up to December 2004, a total of 42 groundwater monitoring wells have been installed in the QD of the Simpevarp regional model area. Groundwater levels have been automatically measured in 18 wells; the measurements have however been terminated in 9 of these wells. Groundwater levels have been measured manually in 29 wells; 10 of these wells were also monitored by automatic measurements.

The L1.2 data set has provided the basis for improvements of the conceptual-descriptive model of climate, surface hydrology, and near-surface hydrogeology in the Simpevarp regional model area. The local and regional meteorological data have provided a better knowledge of site-specific meteorological conditions (especially the precipitation), and this knowledge may be used when evaluating which SMHI station is most suitable for assessment of the long-term meteorological conditions in the Simpevarp area.

The surveying along watercourses has provided a key input, primarily to the quantitative water flow modelling. It has also been found that parts of many watercourses in the Simpevarp area are diverted and/or flow in conduits, and therefore differ from the "natural" topography-controlled flow conditions. Due to the conduits, there are some "missing" (parts of) watercourses in SKB GIS database. An important input to the conceptual-descriptive modelling is the finding that the Simpevarp area generally is characterised by many ditched/drained areas. Without the ditches/drainages, many areas would probably be lakes or wetlands.

A geometrical model of the HSD (Hydraulic Soil Domains) has been developed. This model and the new detailed map of QD and exposed bedrock have provided substantial inputs to the improvement of both the conceptual-descriptive model and the quantitative water flow model. The hydraulic conductivity of sandy till, which is the dominant type of QD in the Simpevarp area, is obtained from the slug tests and from the analysis of particle-size distribution curves. The field measurements have been focused on till; for other types of QD, generic (literature) data are used. This is also the case for the storage properties (also for till). In the L1.2 modelling, it has been possible to identify an additional main type area (hummocky moraine areas), and the description of the interface between lakes/wetlands and QD has been improved, based on investigations of the bottom stratigraphy of some wetlands, peat areas and lakes.

The model area of the L1.2 process-based water flow modelling, performed using the MIKE SHE-MIKE 11 software packages, is larger than that in the previous S1.2 model. The S1.2 modelling considered catchment area 7 only (i.e. the catchment where Lake Frisksjön is located), whereas the L1.2 modelling concerns catchment areas 6, 7, 8 and 9, including near-coastal parts of land and the bays of Baltic Sea. More importantly, for many types of site investigation data (e.g. the detailed map of QD and exposed bedrock, and groundwater levels in QD), the L1.2 data freeze is essentially the first batch of data available for description of the Laxemar subarea.

In the L1.2 quantitative flow modelling, Äspö meteorological data from 2004 are used. In the previous S1.2 modelling, the meteorological input was in the form of SMHI data from Ölands norra udde, for the "representative year" 1981. The analysis of meteorological data performed as part of the L1.2 modelling indicates that the use of precipitation and potential evapotranspiration data from Ölands norra udde (most likely) underestimates the discharge in the Simpevarp area.

By use of the MIKE SHE-MIKE 11 model, an "initial base case" was identified. After the initial simulations, the MIKE SHE-MIKE 11 model was used in a comprehensive sensitivity analysis that investigated the effects of alternative values of the hydraulic parameters of the QD and the vegetation-related parameters LAI and K_c. Based on the sensitivity analysis, an updated base case was identified. The results of the updated base case have been delivered to the ecological systems modelling.

The results of the base cases and the sensitivity cases have provided a basis for further development of the conceptual-descriptive model, in terms of the understanding of the surface water and near-surface groundwater flow system in general and for estimates of "reasonable" ranges for the input parameters in particular.

5.2 Summary of present knowledge

5.2.1 Conceptual-descriptive modelling

The present knowledge, as inferred from data evaluations and expressed in the conceptual-descriptive modelling, can be summarised as follows:

- The annual (corrected) precipitation in the Simpevarp area is 600–700 mm. The long-term (1961–1990) average precipitation at the SMHI station in Oskarshamn is 633 mm, whereas the corresponding value for Ölands norra udde is c 530 mm. During 2004, the precipitation on Äspö was 660 mm, as compared to only 441 mm at Ölands norra udde. Hence, the precipitation in the Simpevarp area is underestimated "on average" if inferred from data measured at Ölands norra udde. However, a comparison between the S1.2 and L1.2 results for catchment area 7 shows that the increase in precipitation is partly compensated by an increase in the evapotranspiration.

- Based on long-term "regional" data, the annual average specific discharge has previously been estimated to be in the range 150–180 mm /Larsson-McCann et al. 2002/; the annual average evapotranspiration has been estimated to be in the range 420–550 mm. However, the L1.2 modelling shows that there are large variations of the specific discharge between years (and, of course, also during years) due to variations in the meteorological conditions. There is also a spatial variability in the specific discharge, e.g. between different catchment areas, within the Simpevarp area. This variability is likely due to differences in, for example, the fractions of exposed bedrock and open water, the land use (vegetation) and other geological and vegetation-related factors. For the year 2004, the present modelling results show a slightly larger specific discharge (c 190 mm·year^{-1}) than the regional estimate given above. Further analyses, involving data analyses and sensitivity studies related to the meteorological input data, are required before any firm conclusions can be drawn concerning the water balance and the specific discharge in the Simpevarp area.
- The topography of the Simpevarp area is characterised by a relatively small-scale undulation. The area consists of a large number of catchment areas and small watercourses. Most watercourses have a low discharge and are dry during large parts of the year. Consequently, most of the annual discharge takes place during a few relatively short periods with large discharge, associated with heavy precipitation events and/or snow melt.
- In many areas, the surface hydrology is affected by human activities, primarily in the form of ditches and other drainage systems. This implies that actual flow directions in some areas deviate from those obtained from the DEM. It also implies that many areas most likely would have been lakes or wetlands without the ditches/drainages. In the SKB GIS database, there are also missing (parts of) watercourses, in some cases because the watercourses flow in conduits.
- There is a large fraction of areas with exposed or very shallow bedrock (c 35% of the land surface area of the regional model area), primarily in the high-altitude areas. Sandy (at some locations sandy-gravelly) till is the dominating type of QD; till covers c 43% of the land surface of the regional model area. The thickness of the QD is generally small, and the average depth of QD is c 2 metres with exposed bedrock areas included, and c 3 metres with those areas excluded. The thickest QD are located in the valleys.
- The measured groundwater level in the QD is generally shallow, on the order of 0.5–1.5 metre below the ground surface. The amplitude (the difference between the maximum and minimum levels) is also generally small, c 0.5–1 metre. However, there is likely a bias in the measured groundwater level data towards shallow groundwater levels, because most of the monitoring wells are located in the valleys. It follows from the shallow near-surface groundwater levels in the QD that the topographic surface water divides most likely to a large extent coincide with near-surface groundwater divides.
- As a framework for the conceptual-descriptive modelling, the following types of "hydrological elements" are identified:
  - ***Type areas:*** These are (i) high-altitude areas with exposed or very shallow bedrock, (ii) valleys with thicker QD, (iii) areas with glaciofluvial deposits, and (iv). hummocky moraine areas (which were not described in the S1.2 model version).
  - ***Flow domains:*** These are lakes, watercourses, wetlands and HSD. The HSD are conceptualized in the form of three basic QD layers, and three additional layers representing peat, glaciofluvial deposits, and artificial fill, in a geometrical HSD model.

- ***Interfaces between flow domains:*** These are the interfaces between (i) near-surface and deep bedrock, (ii) QD and bedrock, and (iii) near-surface groundwater and surface water.

These "elements" are described in detail in Section 4.1.3. In particular, the QD are assigned hydraulic properties in accordance with Table 4-2.

- Groundwater recharge from precipitation (and snow melt) is considered to be the dominant source of groundwater recharge. There is yet no field evidence indicating that the lakes in the Simpevarp area act as recharge areas during dry periods with low groundwater levels.
- The whole near-surface groundwater flow system is transient, due to the temporally variable meteorological conditions (primarily precipitation and temperature). In the region where Simpevarp is located, the groundwater level in the near-surface groundwater is generally lowest during late summer/early autumn. During this period, most of the precipitation is consumed by the vegetation. The groundwater level increases during late autumn, and the levels are highest during spring.
- Each catchment area can be divided into recharge areas and discharge areas. In general, recharge takes place in areas of relatively higher altitudes and discharge in lower-lying areas. However, the transient nature of the system (cf above) implies that the extents of the recharge and discharge areas may vary during the year.
- Investigations of the QD stratigraphy below some lakes, wetlands and peat areas indicate that the QD in the bottom of such areas typically consist of low-permeable layers, limiting the interaction between groundwater and surface water.
- In some areas, there are discrepancies between modelled and "actual" areas with surface water. During a field campaign in the summer of 2005, it was observed that these discrepancies generally are due to water management operations, changing the flow conditions from those associated with the natural topography.

5.2.2 Quantitative water flow modelling

The observations and conclusions from the quantitative flow modelling with the MIKE SHE-MIKE 11 modelling tool can be summarised as follows:

- The water balance and the specific discharge in the Simpevarp area are strongly dependent on the meteorological conditions. This implies that these quantities vary from year to year (and also during individual years), as controlled by the period-specific meteorological conditions. Hence, using meteorological data from a "non-representative" meteorological station and/or from a single year may lead to erroneous estimates of the "actual" and/or average water balance and specific discharge in the Simpevarp area.
- The model-calculated specific discharge for the land part of the model area is c 190 mm·year^{-1}), which is slightly above the range of the previously estimated regional interval of the average annual specific discharge (150–180 mm·year^{-1}). It should be noted that the accumulated annual precipitation during the simulated year (2004) was only c 20 mm larger than the long-term average value at the SMHI station Oskarshamn, which indicates that the dataset describes a fairly typical year. However, no attempt has been made to model the Laxemarån catchment (area no. 10), which is the largest catchment area in the regional modelling area.
- There are some differences in the water balance and the specific discharge among the modelled catchment areas. For the four modelled areas (no. 6, 7, 8 and 9), the specific discharge varies from 180 mm·year^{-1} (catchment area 7) to c 200 mm·year^{-1} (catchment area 8 and the coastal area).

- The sensitivity analysis performed as a part of the L1.2 modelling shows that, in particular, the vegetation-related parameters LAI (Leaf Area Index) and K_c ("crop coefficient") have large effects on the modelling results. For example, the average specific discharge of overland flow into the watercourses is c 230 mm·year^{-1} in the initial base case used in the sensitivity analysis and c 140 mm·year^{-1} in the updated base case, where the main update is that of vegetation parameters. Although the analysis of the input data showed that the values of the vegetation-related parameters in the initial base case could be considered unrealistic, it is clear that these parameters must be further analysed in the forthcoming modelling.
- For the updated base case, the model predicts a generally shallow groundwater table, which is in agreement with available site investigation data and the conceptual-descriptive model. However, in the present modelling, no well-by-well comparison between model-calculated and measured groundwater levels has been made, as there still are few (and short) time series on groundwater levels in QD available. This type of comparisons (and model calibrations in general) will be part of forthcoming modelling efforts. Furthermore, the representativity of the existing wells should be investigated; there is likely a bias in the present dataset, due to the fact that the wells are located primarily in lower-lying areas.
- In agreement with available site investigation data, the calculated discharges in the watercourses are characterised by long periods of small or zero discharges, interrupted by relatively short periods with discharge peaks; these short periods are associated with heavy precipitation events and/or snow melt periods.
- In the MIKE SHE-MIKE 11 model area, the groundwater discharge areas are found in the vicinity of the main watercourses, Lake Frisksjön, and also along the coastline towards the innermost bays of the Baltic Sea. In general, discharge areas are associated with a shallow groundwater table, or a "groundwater table" above the ground surface (surface water).
- The transient nature of the water flow system implies that there are somewhat larger discharge areas during a dry period, compared to a wet period (during a single year). As compared to the previous S1.2 modelling, the present modelling, which is based on a different meteorological dataset and covers a larger area, shows smaller differences between periods of wet and dry conditions. Parts of the model area are permanent recharge or discharge areas. For instance, areas in the vicinity of the main watercourses and Lake Frisksjön are permanent discharge areas, whereas the high-altitude areas are permanent recharge areas.

5.3 Evaluation of uncertainties

New data on, for example, local meteorological conditions, surface water levels (lakes and the sea), and hydrogeological properties have been obtained and analysed in the present model version. However, the limited amount of site data (primarily time series) is still the main source of uncertainty in the present model of surface hydrology and near-surface hydrogeology. For instance, time series on discharge in watercourses and groundwater levels in QD are required for model calibration. The present status concerning the main uncertainties, and the related types of data and inputs as identified in the S1.2 modelling /Werner et al. 2005/, are as follows:

- ***Uncertainties in the geometrical description of the system:*** In general, these uncertainties have been reduced in the L1.2 modelling, compared to the previous S1.2 model. There are still uncertainties in the DEM; there are discrepancies between the actual topography and the DEM in some areas, which affect the modelling. On the other hand, the geological description (the detailed map of QD and exposed bedrock), as well as the geometrical model of the HSD, now cover both the Simpevarp and Laxemar subareas. Further, cross-sections have been surveyed along the main watercourses in the L1.2 model area (catchment areas 6, 7, 8 and 9). There are some "missing" (parts of) watercourses in the SKB GIS database, and there are many ditched/drained areas that are not treated as such in the present quantitative water flow model. However, many of these areas have recently been investigated in the field, and the information from these complementary field studies will be considered in future model versions.

- ***Uncertainties in the description of hydrogeological properties of site-specific materials:*** There is a relatively large amount of hydraulic conductivity data for till, which is the dominating type of QD in the Simpevarp area. However, there are still no (or, in some cases, very limited) site data on hydraulic parameters available for other QD types in the conceptual-descriptive model. The L1.2 dataset has enabled an improved descriptive model of the QD types and the geometry of the HSD, although there still is a low potential for quantification of the uncertainty related to spatial variability (at least if the aim is to describe spatial correlations). Furthermore, the database is restricted to hydraulic conductivity data (with a few exceptions). The S1.2 dataset mainly included data from the Simpevarp subarea. Additional data have now been provided from hydraulic testing in the Laxemar subarea. However, there are still no data on unsaturated water flow parameters available for the modelling. The sensitivity analysis performed during the L1.2 modelling shows that variations in the parameters quantifying the interactions between water and vegetation have relatively large effects on the modelling results. The values of these parameters can be considered uncertain, making this uncertainty an important topic for further studies. Furthermore, in the present work no attempt was made to model the hydrogeological interactions between near-surface system and the deep rock (the modelling was performed with a no-flow boundary at c 150 metres depth in the rock). Thus, the uncertainties associated with the details of these interactions remain.
- ***Uncertainties in the description of temporal variability:*** The site investigation data indicate significant transients in the discharges in the watercourses. Still, there is no detailed quantitative information available on these transients; data are available from sparse manual discharge measurements only. The data situation is (almost) the same concerning groundwater levels in QD, i.e. most of the groundwater level time series are very short. Longer time series on meteorological parameters are available for the present model, as compared to the S1.2 data freeze. However, a combination of meteorological data and data on surface water levels/discharges and groundwater levels is crucial for the evaluation of the hydrological/hydrogeological temporal variability; time series of these data types from the same period are necessary for detailed model calibration.
- ***Uncertainties in the description of spatial variability of hydro-meteorological parameters:*** In the previous Simpevarp 1.2 MIKE SHE-MIKE modelling, the specific discharge was calculated to c 150 mm·year^{-1} for the Lake Frisksjön catchment area, using meteorological data from Ölands norra udde for the "representative year" 1981 /Werner et al. 2005/. Taking into account a larger model area in the present modelling, the specific discharge is calculated to c 190 mm·year^{-1}, using local meteorological data from Äspö for the year 2004. Hence, the difference between model versions is c 25%. In the present modelling, the largest difference in the specific discharge between individual catchment areas is c 10%. During the period with simultaneous meteorological data (August 2004–June 2005), the difference in precipitation between the Äspö and Plittorp meteorological stations (c 10 km apart) is c 20%. The spatial variability in the hydro-meteorological input parameters may be of the same order as, or larger than, the observed differences between model versions and catchment areas. In addition, a sensitivity analysis shows that the sensitivity of the specific discharge to the hydraulic conductivity of the QD is of the same order or smaller than the variability

of the precipitation. Depending on the size of the model area, it may be necessary to take spatially variable hydro-meteorological parameters into account in future model development.

The present conceptual-descriptive model of the surface-hydrological and near surface-hydrogeological system is considered to be acceptable in a qualitative sense. This means that the general description of the hydrological and hydrogeological driving forces and the overall water flow pattern is more or less the same as in S1.2, and it is likely that this general description will remain the same in future model versions. It should be noted that the investigated area is similar to many other areas in Sweden regarding its overall hydrological characteristics. This implies that there is some potential for "importing" generic knowledge, and even data, from other sites in Sweden.

As described above, however, significant uncertainties remain regarding the quantitative aspects of the model, especially time series for model improvement and calibration. In particular, prolonged time series of groundwater level data are expected to contribute significantly to the site understanding. The identified type areas, flow domains and interfaces between flow domains need to be further developed, detailed and parameterised with site-specific data. A thorough sensitivity analysis has been reported in this model version (see Chapter 4), primarily in terms of the hydraulic properties of QD and the vegetation-related parameters. In addition, updated statistics of measured hydraulic conductivities are presented, which give an indication of the uncertainty associated with spatial variability. However, although more elaborated compared to S1.2, no systematic or complete quantification of uncertainties has been performed in the L1.2 model version.

5.4 Implications for future site investigations

More time series data are judged crucial for improving the present model of the Simpevarp site. Such data are expected to be available as meteorological data, hydrological data (water levels and discharge), and groundwater levels in the QD (and in the bedrock). However, it is not expected that the continuing site investigation will add much more data or other information on the geological and hydrogeological properties of the near-surface system; the majority of the planned drillings and installations of groundwater monitoring wells in QD have been performed.

Complementary investigations will most likely be concentrated to a relatively small investigation area, i.e. the area prioritised for the location of the deep repository and the associated surface installations. Whether the additional data actually lead to significantly reduced uncertainties will be evaluated in future modelling activities. A detailed evaluation of the existing database and the need for further investigations are performed subsequent to the L1.2 modelling. The objective of that work is to formulate more detailed recommendations for complementary investigations.

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Appendix 1

Results of manual discharge measurements in watercourses

Results of “simple” discharge measurements performed in connection with surface water sampling are presented in Figures A1-1 to A1-20 below

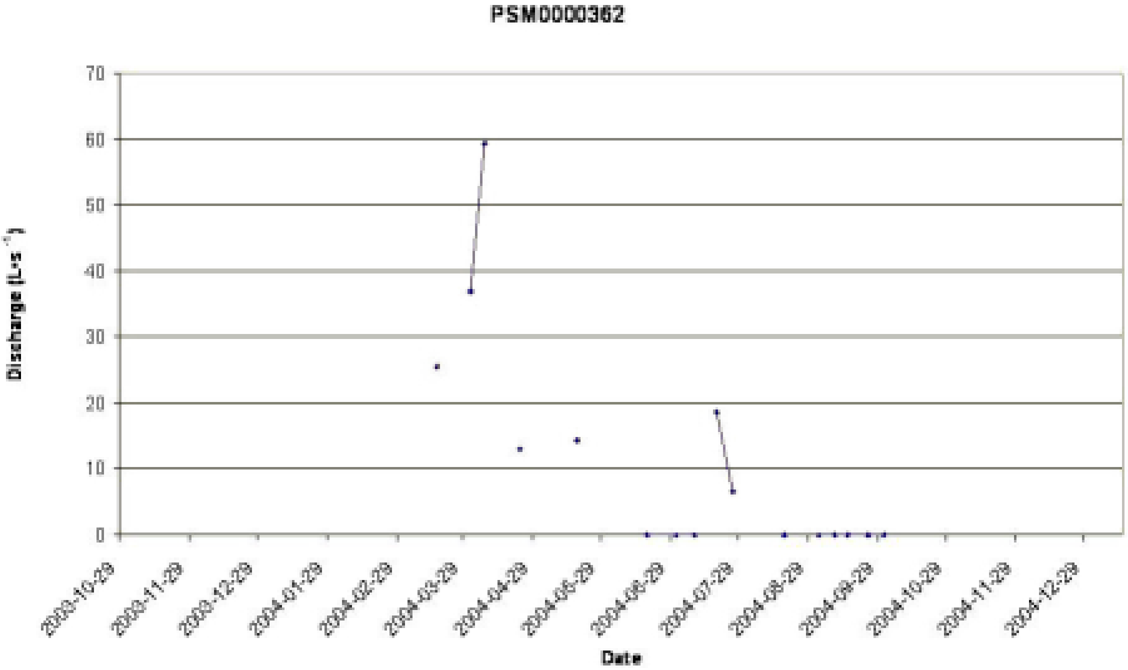

Figure A1-1. Results from manual discharge measurements at PSM000362.

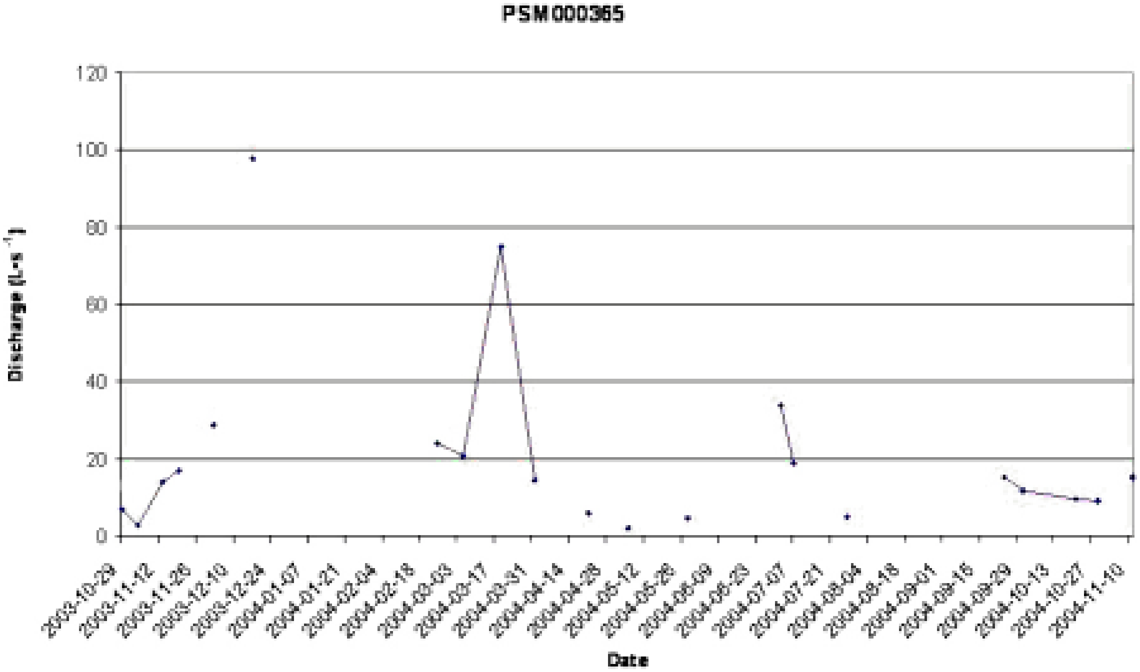

Figure A1-2. Results from manual discharge measurements at PSM000365.

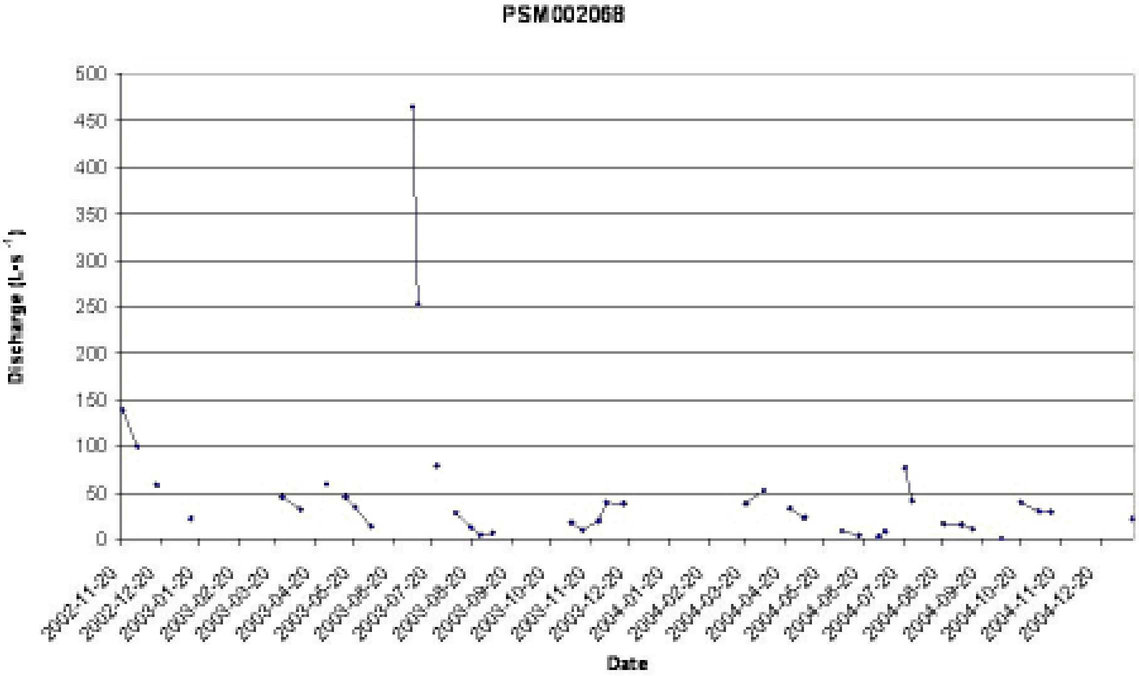

Figure A1-3. *Results from manual discharge measurements at PSM002068.*

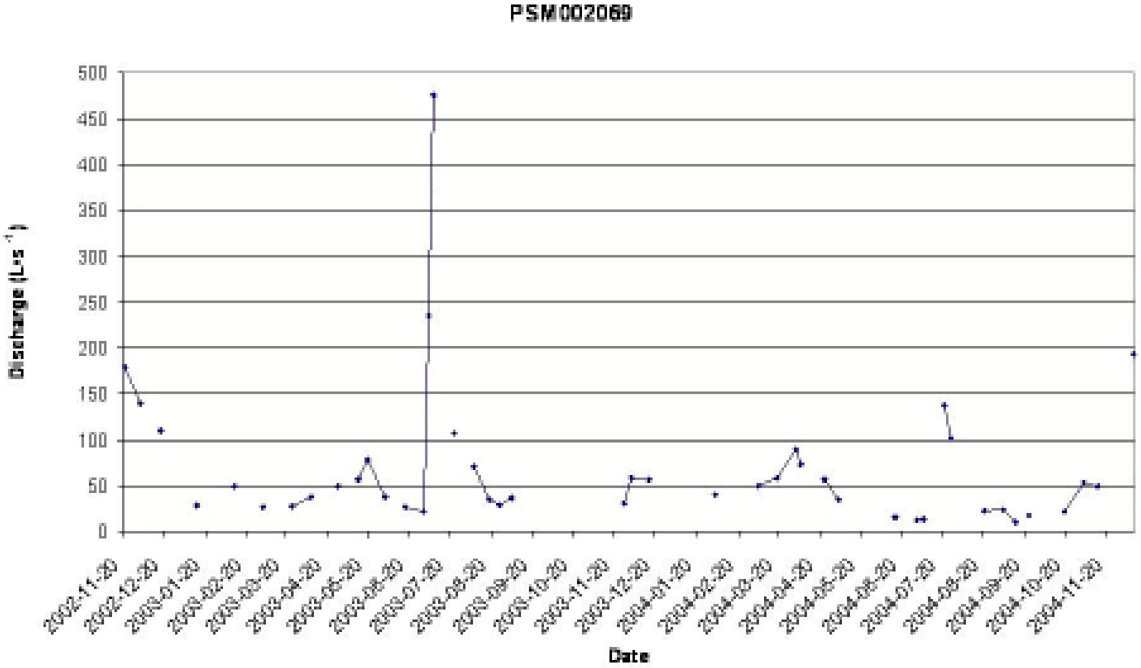

Figure A1-4. *Results from manual discharge measurements at PSM002069.*

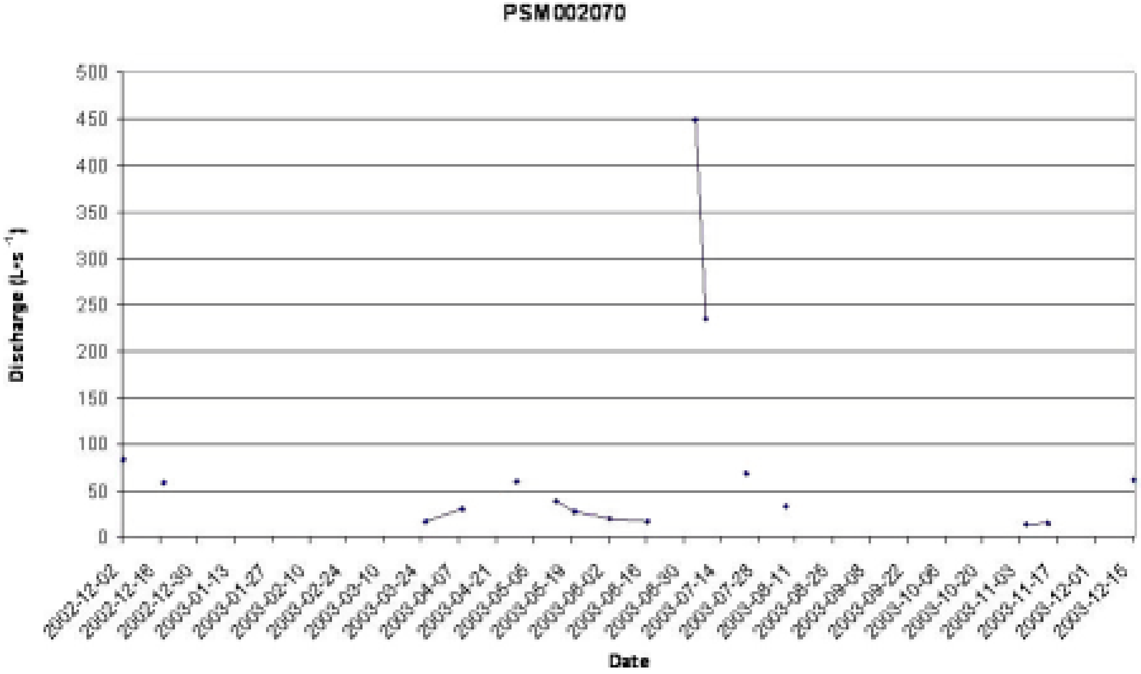

Figure A1-5. *Results from manual discharge measurements at PSM002070.*

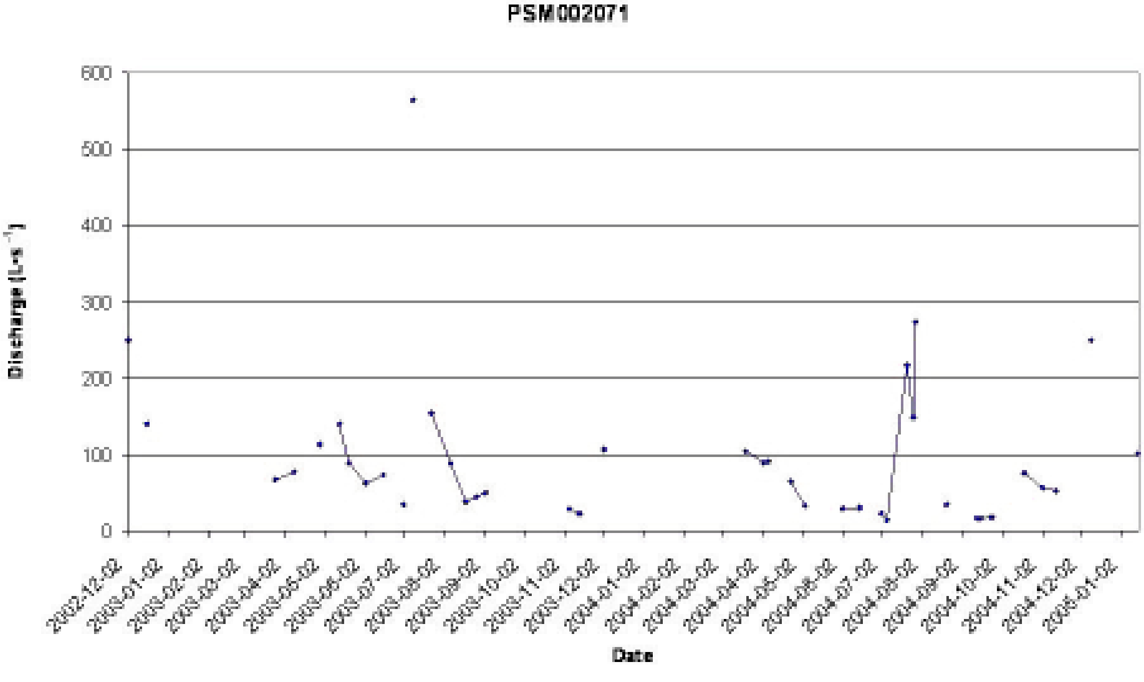

Figure A1-6. *Results from manual discharge measurements at PSM002071.*

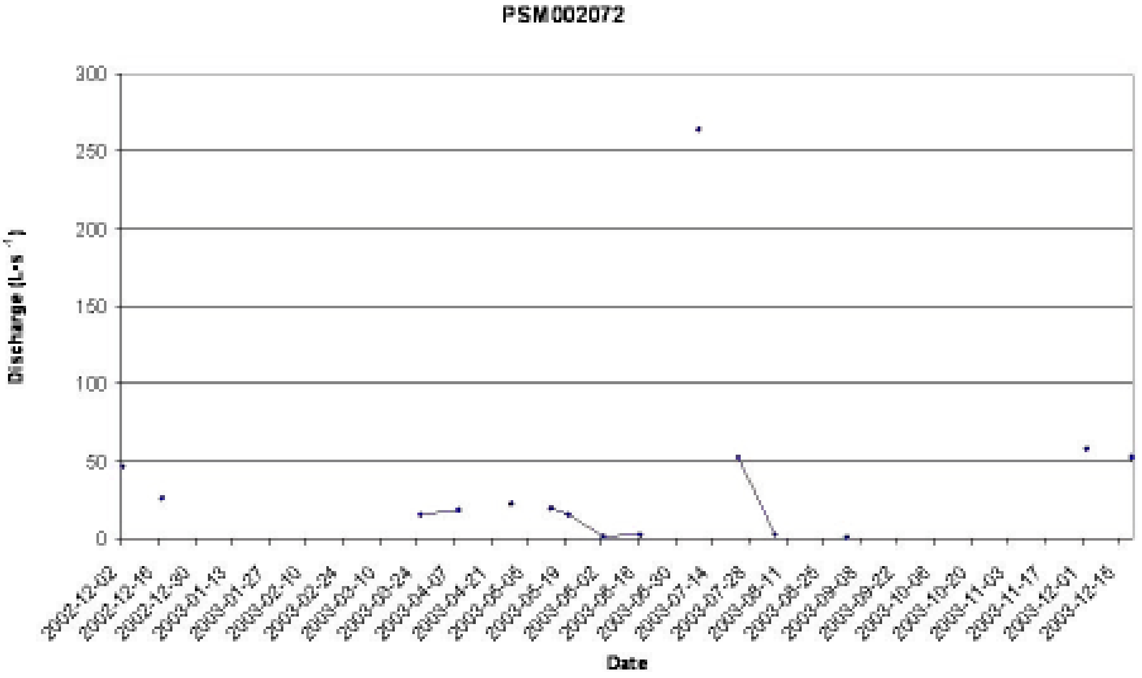

Figure A1-7. Results from manual discharge measurements at PSM002072.

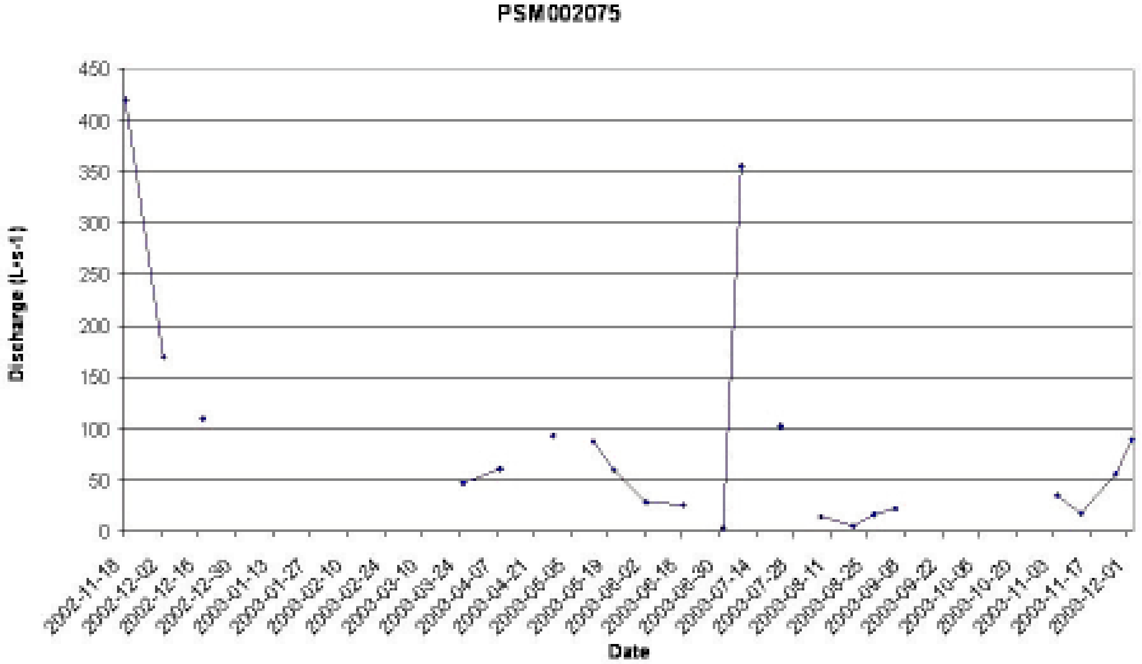

Figure A1-8. Results from manual discharge measurements at PSM002075.

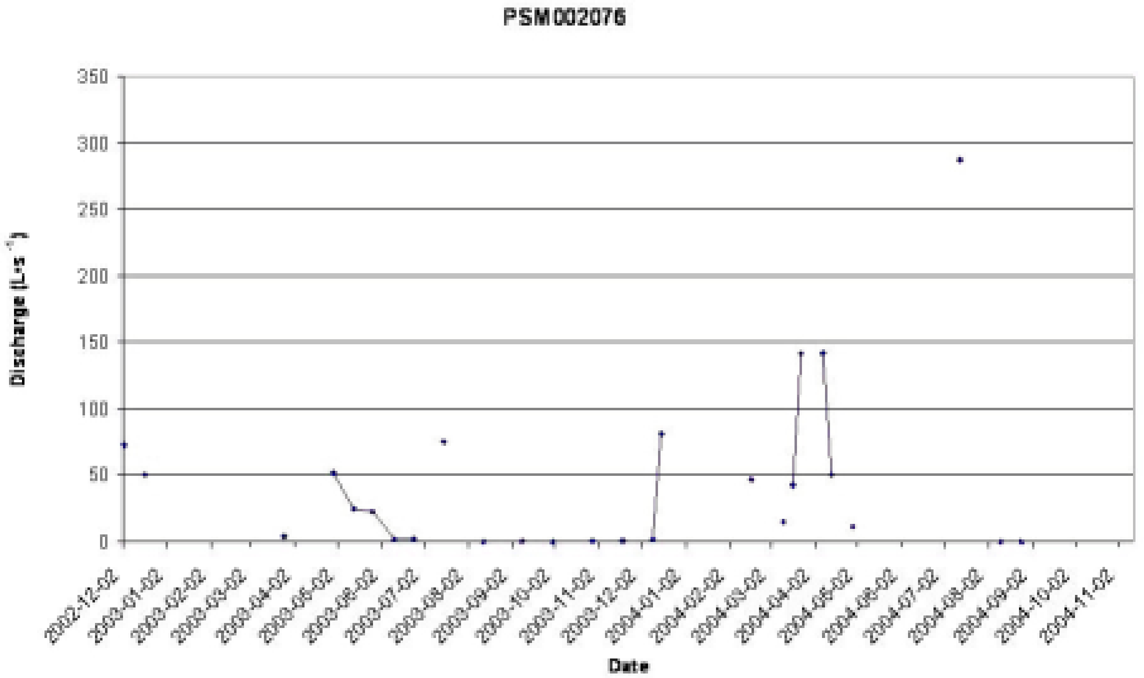

Figure A1-9. *Results from manual discharge measurements at PSM002076.*

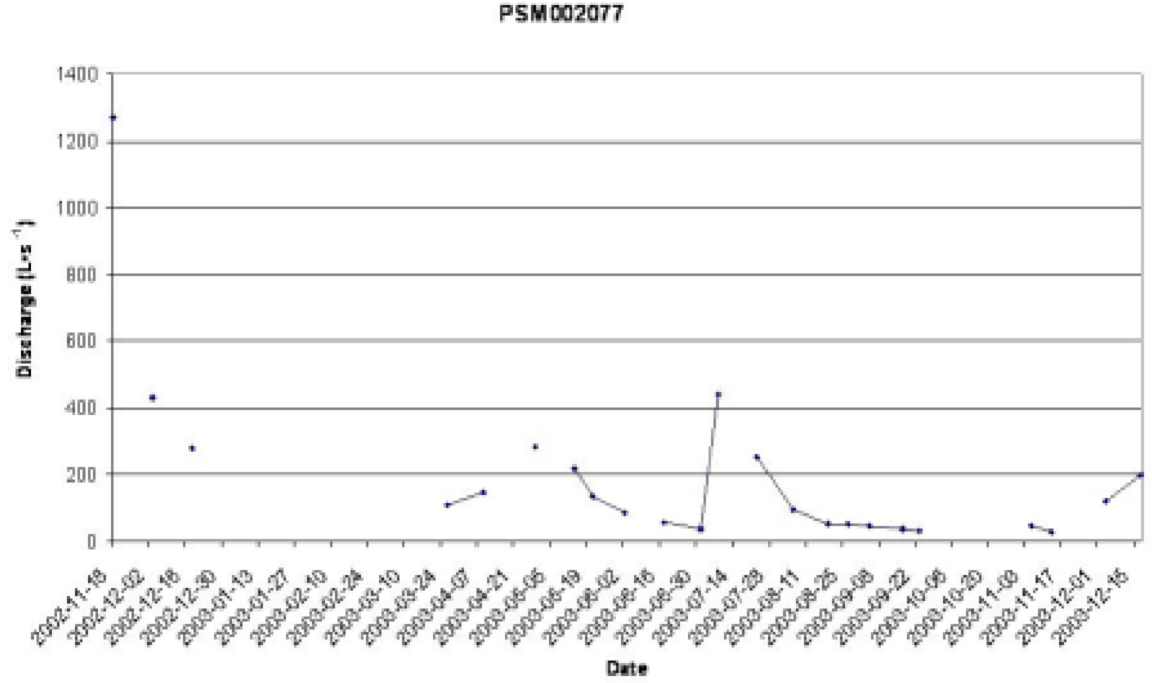

Figure A1-10. *Results from manual discharge measurements at PSM002077.*

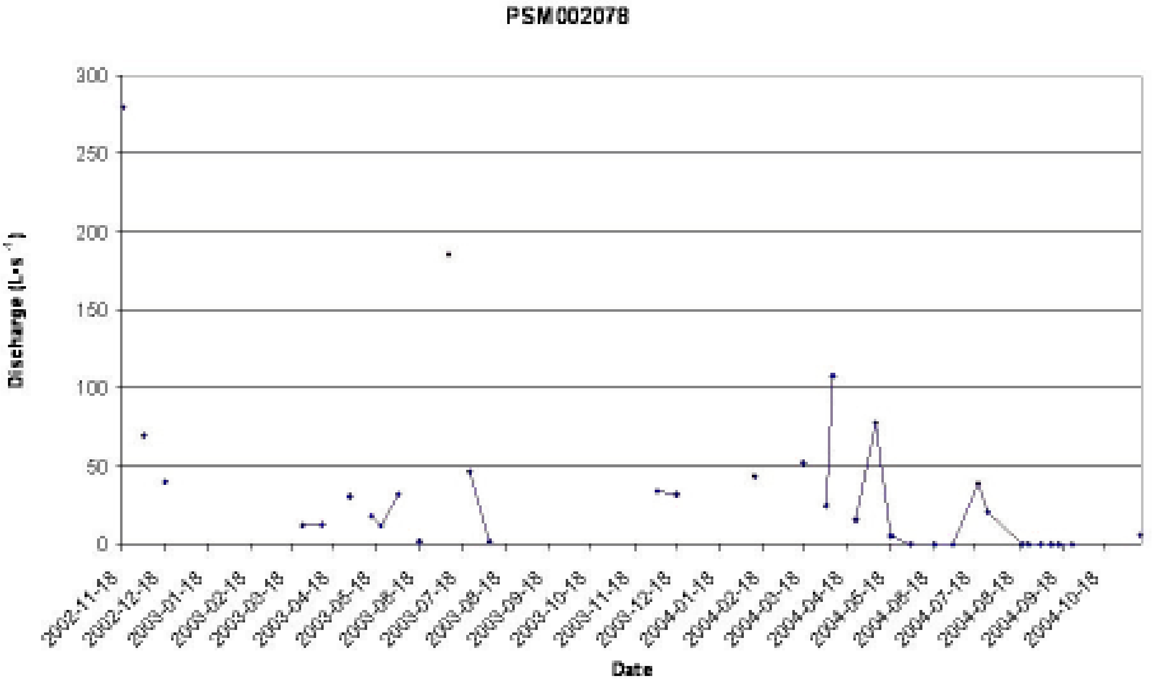

Figure A1-11. Results from manual discharge measurements at PSM002078.

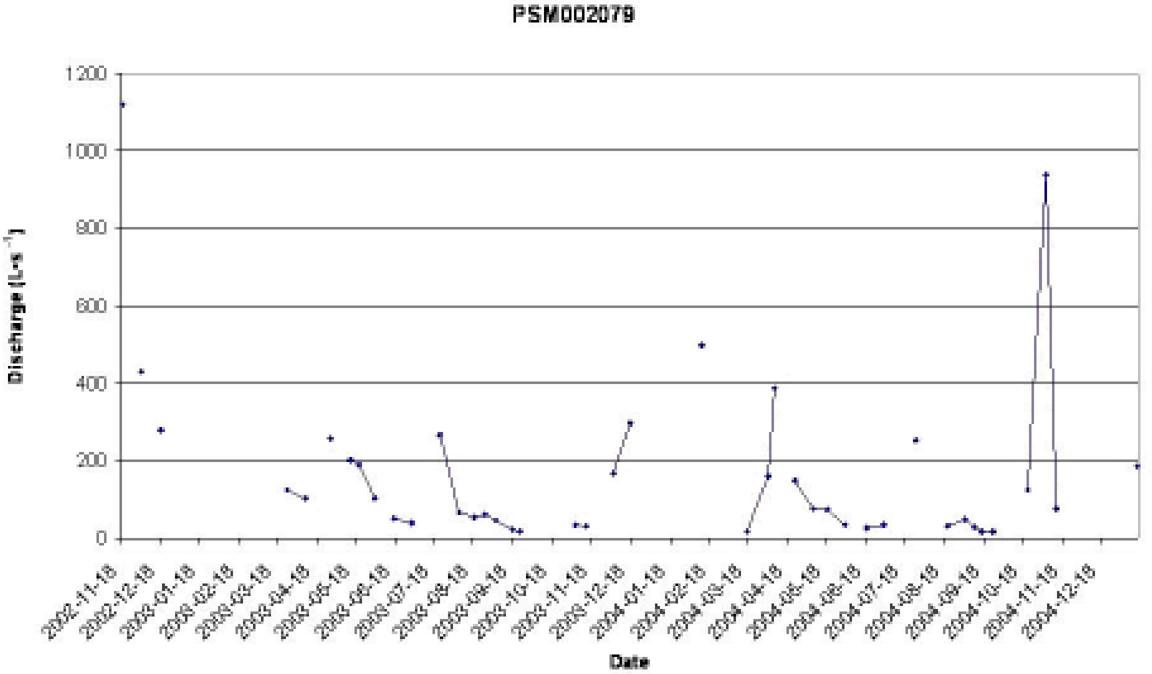

Figure A1-12. Results from manual discharge measurements at PSM002079.

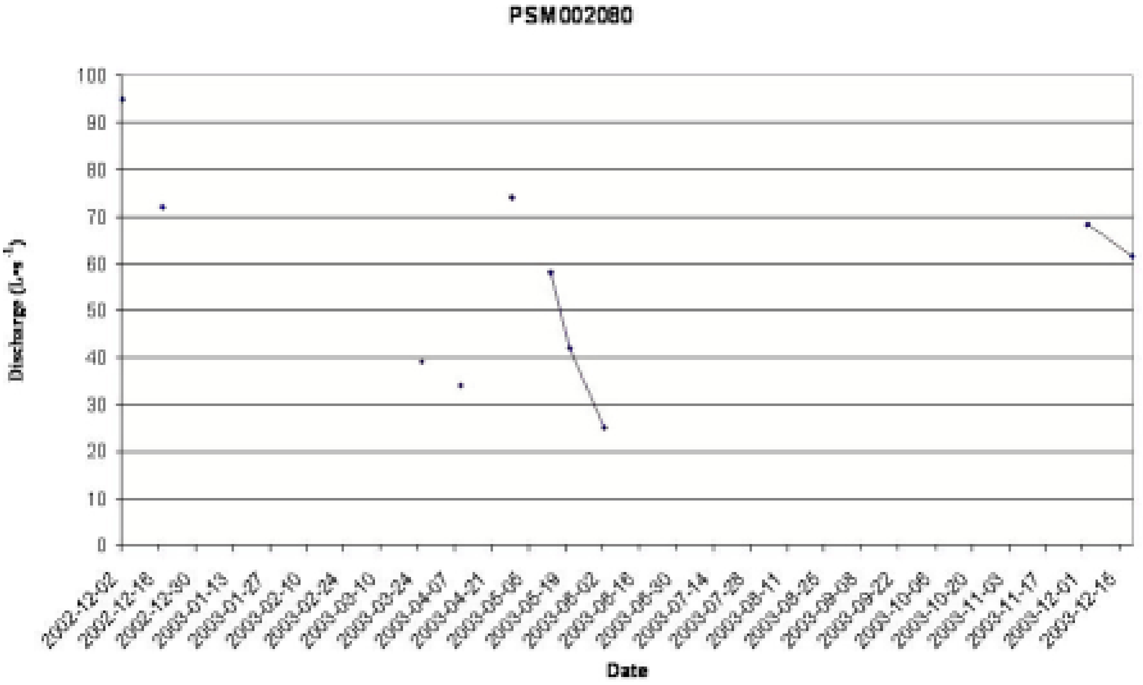

Figure A1-13. *Results from manual discharge measurements at PSM002080.*

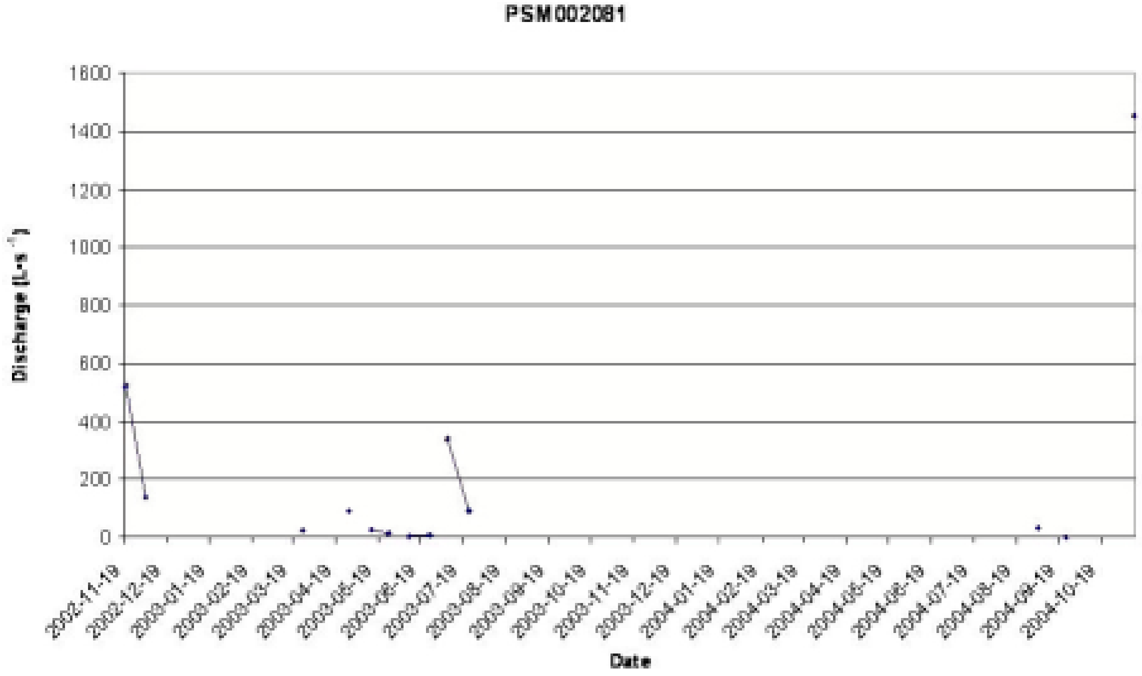

Figure A1-14. *Results from manual discharge measurements at PSM002081.*

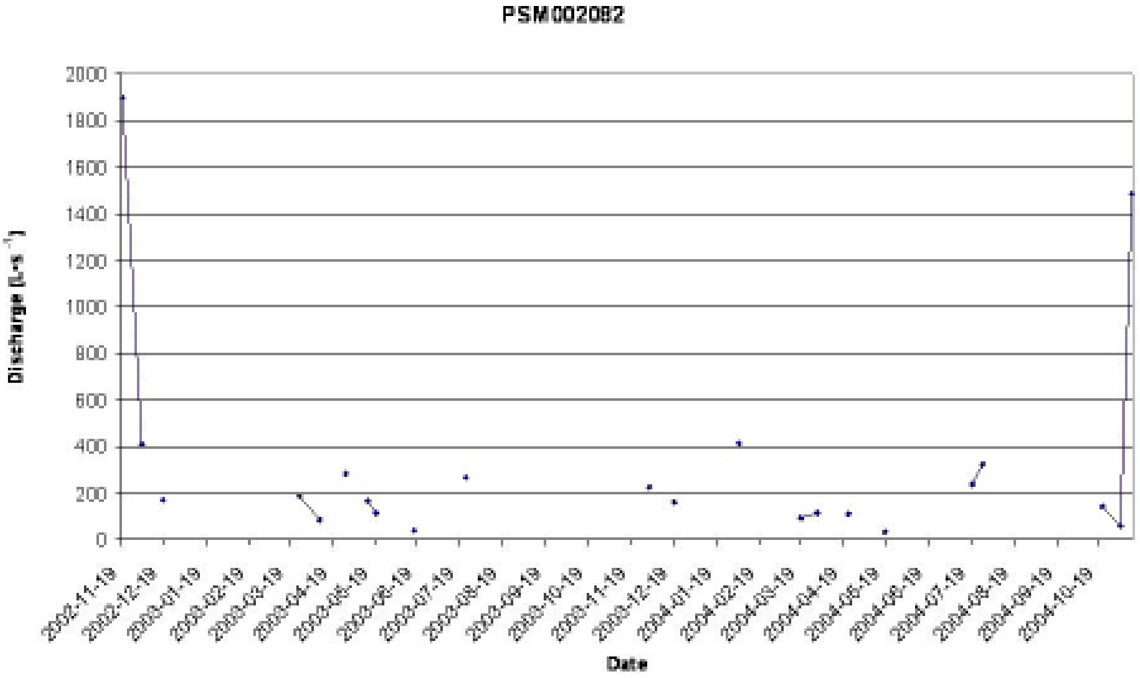

Figure A1-15. *Results from manual discharge measurements at PSM002082.*

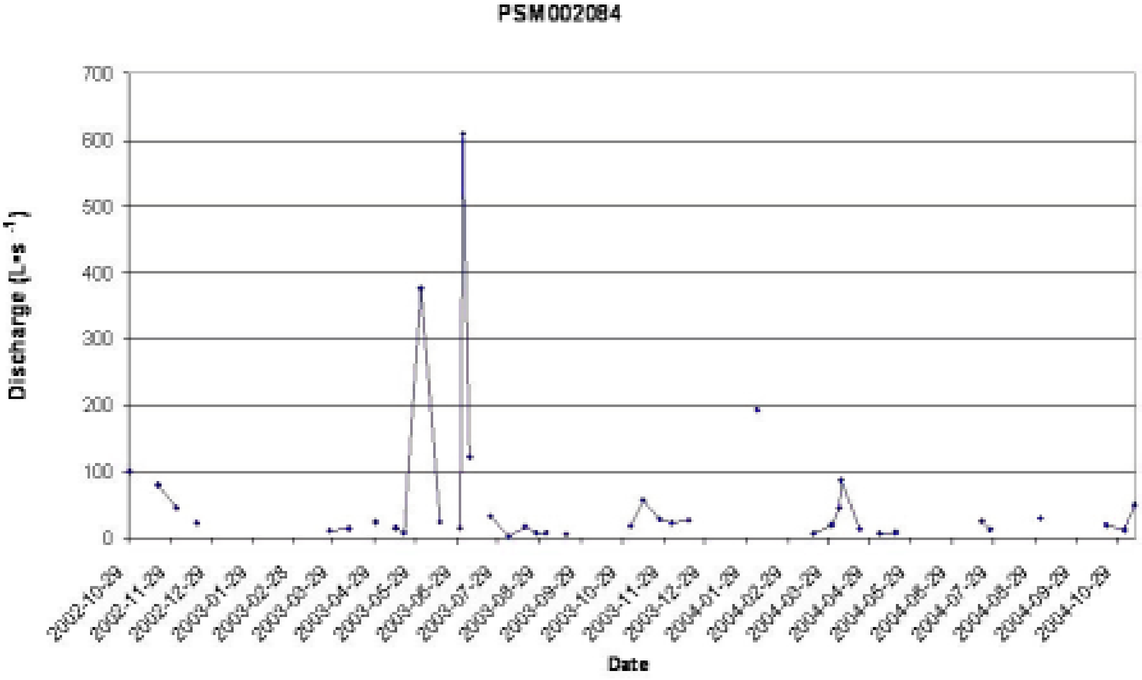

Figure A1-16. *Results from manual discharge measurements at PSM002084.*

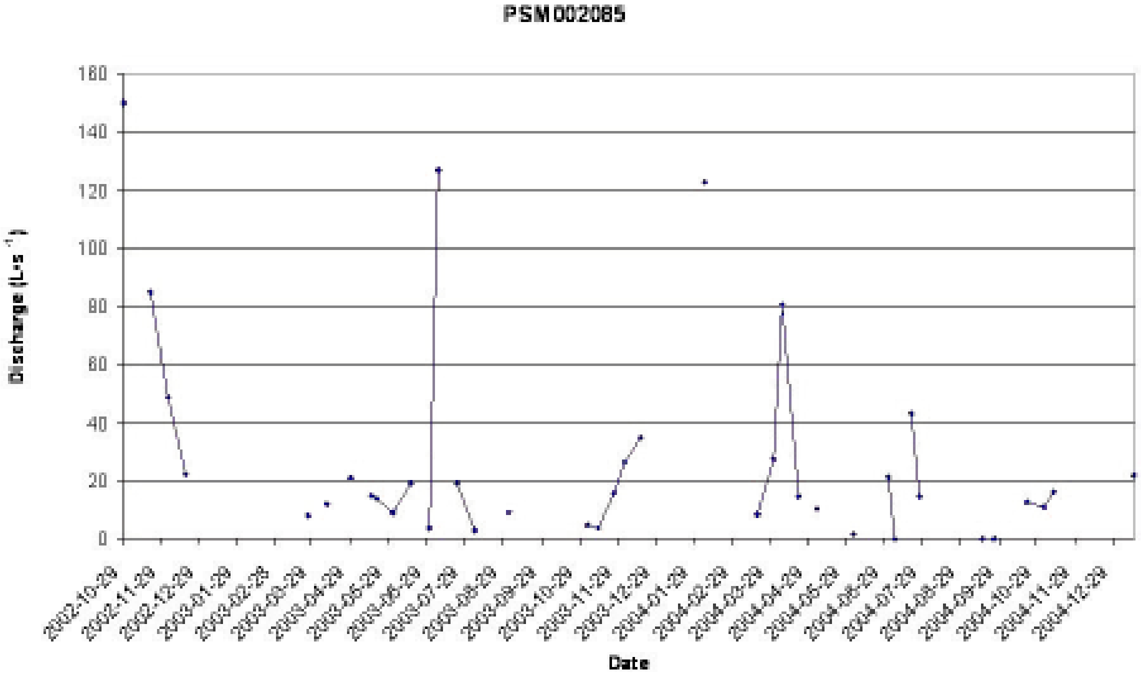

Figure A1-17. Results from manual discharge measurements at PSM002085.

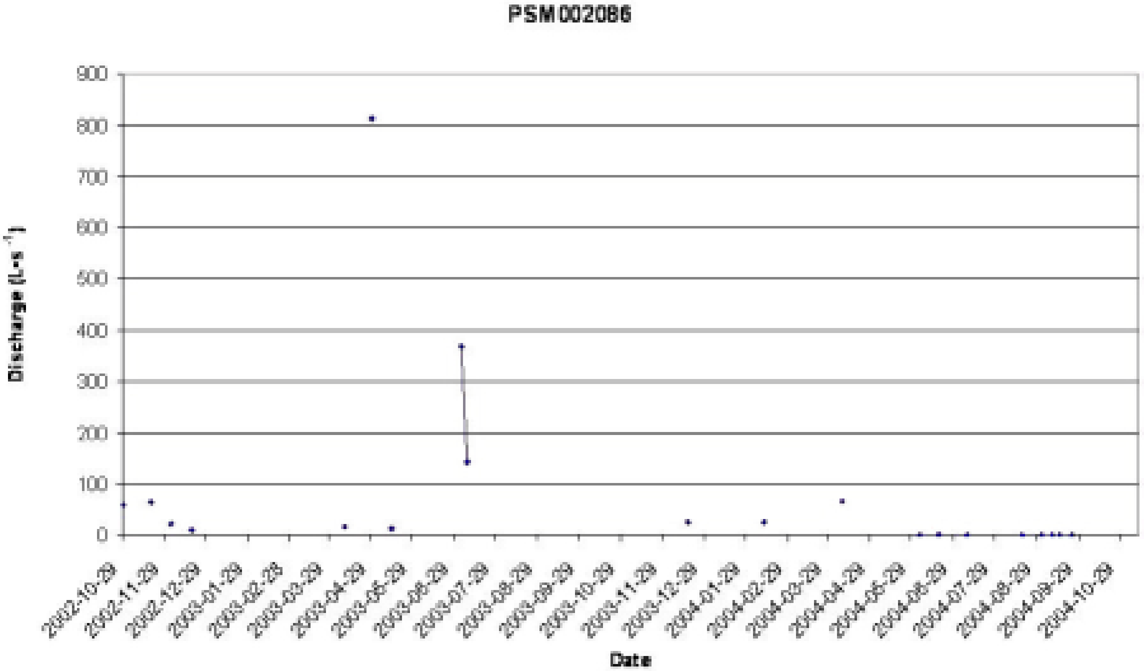

Figure A1-18. Results from manual discharge measurements at PSM002086.

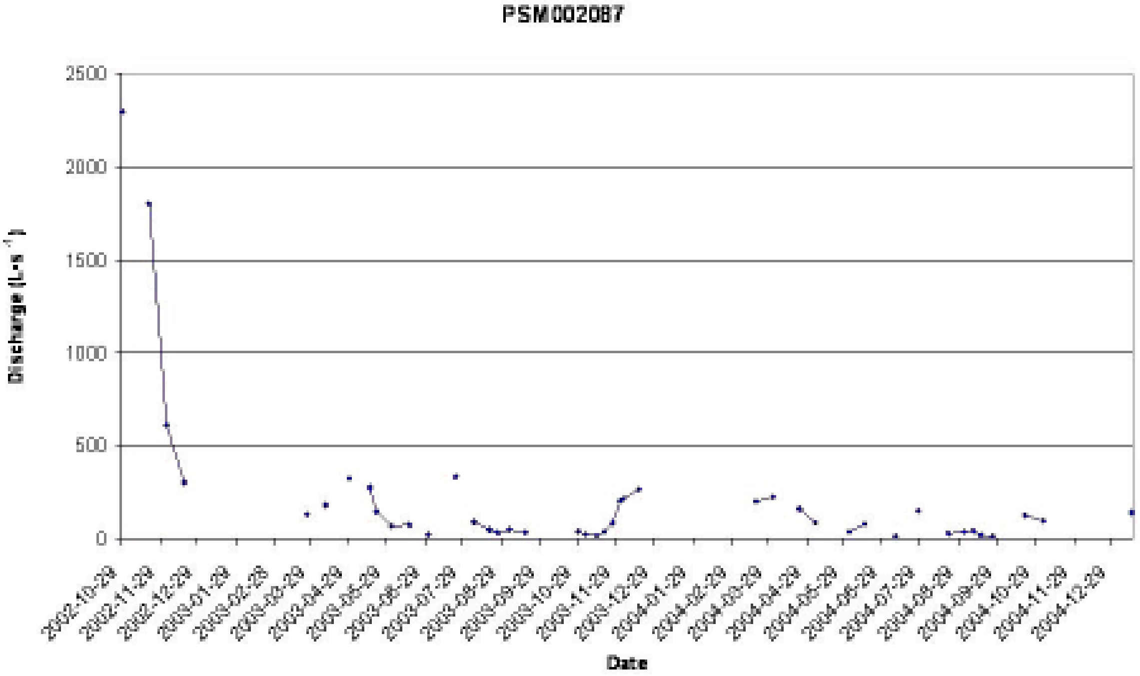

Figure A1-19. *Results from manual discharge measurements at PSM002087.*

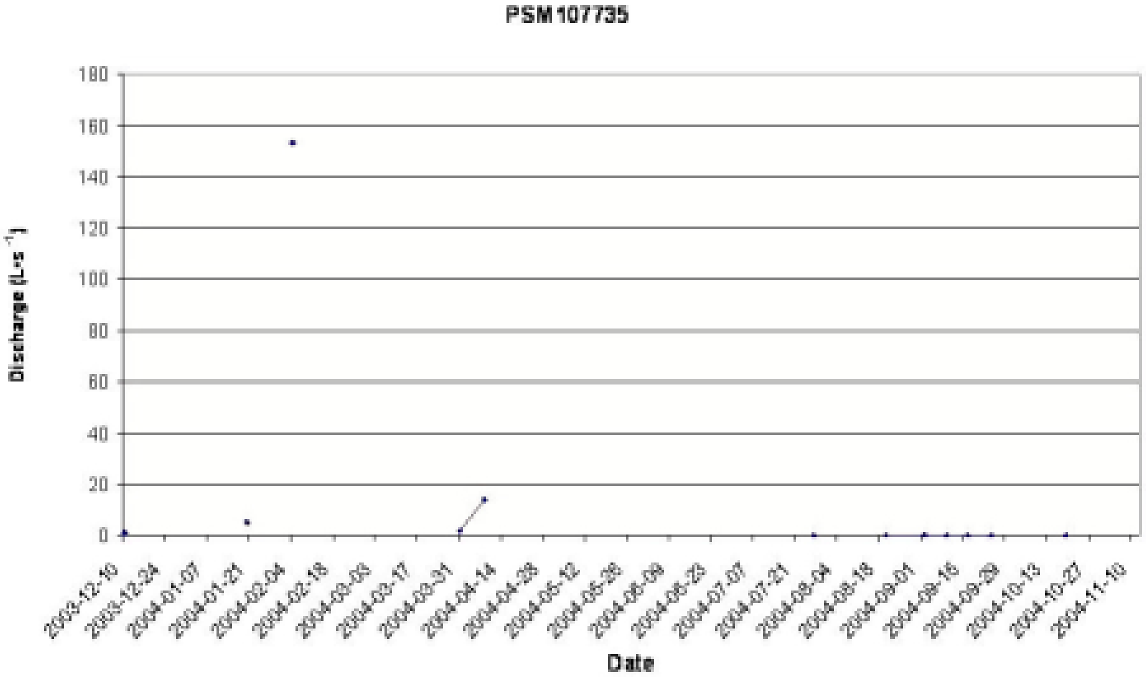

Figure A1-20. *Results from manual discharge measurements at PSM107735.*

Appendix 2

Results of slug tests in groundwater monitoring wells installed in QD

Hydraulic parameters determined from evaluations of slug tests in QD are summarised in Table A2-1. For some groundwater monitoring wells, more than one set of parameters are given (because different evaluation methods were applied to the same dataset). In these cases, the transmissivity value reported to SICADA is indicated in the table.

Table A2-1. Results of slug tests in wells installed in QD, 11 wells in the Simpevarp subarea and 16 wells in the Laxemar subarea /Johansson and Adestam 2004ab/. The abbreviation "m.b.g.s." denotes metres below ground surface.

Well ID (location)	Hydraulic conductivity K ($m\cdot s^{-1}$)	Transmissivity T ($m^2\cdot s^{-1}$), stored in SICADA	Storativity S (–)	Screen length B (m)	Screen depth (m.b.g.s.) Depth to bedrock surface (m.b.g.s.)	Soil type at screen depth (depth of bedrock surface)	Evaluation method
SSM000008 (Simpevarp peninsula)	$4.05\cdot10^{-5}$	$8.10\cdot10^{-5}$	–	2.00	2.6–4.6 4.6	Till	Hvorslev
SSM000009 (Laxemar)	$5.70\cdot10^{-6}$	$5.70\cdot10^{-6}$	–	1.00	2.6–3.6 4.2	Silty-sandy clay ("boulders below 3.0")	Bouwer & Rice
SSM000010 (Simpevarp peninsula)	$2.50\cdot10^{-5}$	$2.50\cdot10^{-5}$	–	1.00	1.4–2.4 2.0	Till	Hvorslev
SSM000011 (Laxemar)	$3.30\cdot10^{-6}$	$5.50\cdot10^{-6}$	–	2.00 (B = aq. thickness 1.66 m)	0.8–2.8 2.8	Bouldery-gravelly sand, silty-sandy till	Bouwer & Rice
SSM000012 (Ävrö)	$2.20\cdot10^{-6}$	$2.20\cdot10^{-6}$	–	1.00	4.7–5.7 6.1	Silty-sandy till	Hvorslev
SSM000014 (Hålö)	$3.30\cdot10^{-5}$	$3.30\cdot10^{-5}$	–	1.00	1.2–2.2 2.4	Clayey-gravelly sand	Bouwer & Rice
SSM000015 (Hålö)	$1.20\cdot10^{-4}$	$1.20\cdot10^{-4}$	–	1.00	3.8–4.8 4.8	"Boulders"	Hvorslev
SSM000016 (Ävrö)	$1.50\cdot10^{-4}$	$1.50\cdot10^{-4}$	–	1.00	1.5–2.5 2.6	Stony-gravelly sand ("boulders" below 1.8)	Bouwer & Rice
SSM000018 (Ävrö)	$1.80\cdot10^{-4}$	$*1.80\cdot10^{-4}$	–	1.00	1.8–2.8 3.2	Clayey till	Hvorslev
	$6.10\cdot10^{-4}$	$6.10\cdot10^{-4}$	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos

Well ID (location)	Hydraulic conductivity K ($m\cdot s^{-1}$)	Transmissivity T ($m^2\cdot s^{-1}$), stored in SICADA	Storativity S (–)	Screen length B (m)	Screen depth (m.b.g.s.) Depth to bedrock surface (m.b.g.s.)	Soil type at screen depth (depth of bedrock surface)	Evaluation method
SSM000020 (Ävrö)	$6.50\cdot10^{-5}$	$^*2.60\cdot10^{-5}$		1.00 (B = aq. thickness 0.40 m)	1.5–2.5 2.4	Clay, gravelly-sandy till	Hvorslev
	$2.75\cdot10^{-4}$	$1.10\cdot10^{-4}$	$1\cdot10^{-5}$				Cooper-Bredehoeft-Papadopulos
SSM000022 (Ävrö)	$1.85\cdot10^{-5}$	$^*3.70\cdot10^{-5}$	–	2.00	4.6–6.6 8.6	Silty clay, silty sandy till	Hvorslev
	$4.48\cdot10^{-4}$	$8.96\cdot10^{-4}$	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos
SSM000024 (Ävrö)	$2.00\cdot10^{-6}$	$2.00\cdot10^{-6}$	–	1.00	2.25–3.25 4.2	Sandy till	Bouwer & Rice
SSM000026 (Ävrö)	$1.50\cdot10^{-5}$	$^*3.00\cdot10^{-5}$	–	2.00	1.8–3.8 4.2	Sandy till	Hvorslev
	$1.86\cdot10^{-4}$	$3.72\cdot10^{-4}$	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos
SSM000027 (Laxemar)	$3.55\cdot10^{-5}$	$^*7.10\cdot10^{-5}$	–	2.00	2.8–4.8 Bedrock not reached	Sand, silty sand	Bouwer & Rice
	$1.25\cdot10^{-4}$	$2.5\cdot10^{-4}$	$5.0\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos
SSM000028 (Laxemar)	–	–	–	1.00	1.45–2.45 Bedrock not reached	Gyttja	Water level was not recovered
SSM000029 (Laxemar)	$2.05\cdot10^{-5}$	$^*4.1\cdot10^{-5}$	–	2.00	4.5–6.5 Bedrock not reached	Fine sand (no soil classification below 5.5)	Hvorslev
	$3.20\cdot10^{-5}$	$6.40\cdot10^{-5}$	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos
SSM000030 (Laxemar)	$2.75\cdot10^{-5}$	$2.20\cdot10^{-5}$	–	1.00 (B = aq. thickness 0.80 m)	2.8–3.8 Bedrock not reached	Gyttja, gravelly-sandy till	Hvorslev
SSM000031 (Laxemar)	$1.20\cdot10^{-4}$	$^*1.20\cdot10^{-4}$	–	1.00	2.4–3.4 Bedrock not reached	Silty-sandy till, gravelly-sandy till	Bouwer & Rice
	$6.30\cdot10^{-4}$	$6.30\cdot10^{-4}$	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos

Well ID (location)	**Hydraulic conductivity K ($m\cdot s^{-1}$)**	**Transmissivity T ($m^2\cdot s^{-1}$), stored in SICADA**	**Storativity S (–)**	**Screen length B (m)**	**Screen depth (m.b.g.s.)** **Depth to bedrock surface (m.b.g.s.)**	**Soil type at screen depth (depth of bedrock surface)**	**Evaluation method**
SSM000032 (Laxemar)	–	–	–	1.00	1.80–2.80	Gyttja, gyttja-bearing clay with sand layer	The water level was not recovered
SSM000033 (Laxemar)	$7.00\cdot10^{-6}$	$*5.6\cdot10^{-6}$	–	1.00 (B = aq. thickness 0.80 m)	0.3–1.3 Bedrock not reached	Peat, sandy clay, clayey sandy till	Bouwer & Rice
	$2.13\cdot10^{-5}$	$1.70\cdot10^{-5}$	$5\cdot10^{-4}$				Cooper-Bredehoeft-Papadopulos
SSM000034 (Laxemar)	$5.80\cdot10^{-6}$	$*5.80\cdot10^{-6}$	–	1.00	2.5–3.5 Bedrock not reached	Sandy clay, fine sand	Hvorslev
	$1.60\cdot10^{-5}$	$1.60\cdot10^{-5}$	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos
SSM000035 (Laxemar)	$2.60\cdot10^{-6}$	$2.60\cdot10^{-6}$	–	1.00	2.5–3.5 Bedrock not reached	Sandy-silty till	Bouwer & Rice
SSM000037 (Laxemar)	$2.00\cdot10^{-5}$	$2.00\cdot10^{-5}$	–	1.00	2.65–3.65 3.8	Sandy-gravelly till	Bouwer & Rice
SSM000039 (Laxemar)	$6.10\cdot10^{-5}$	$7.9\cdot10^{-5}$	–	2.00 (B = aq. thickness 1.30 m)	2.4–4.4 Bedrock not reached	Sandy till (no soil classification below 4.2)	Bouwer & Rice
SSM000040 (Laxemar)	$9.90\cdot10^{-7}$	$9.90\cdot10^{-7}$	–	1.00	1.1–2.1 Bedrock not reached	Peaty clay, silty-sandy till	Bouwer & Rice
SSM000041 (Laxemar)	$6.50\cdot10^{-6}$	$*1.30\cdot10^{-5}$	–	2.00	1.2–3.2 Bedrock not reached	Sandy-clayey silt, sandy-silty till	Bouwer & Rice
	$1.40\cdot10^{-5}$	2.7010^{-5}	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos
SSM000042 (Laxemar)	$3.80\cdot10^{-6}$	$*7.60\cdot10^{-6}$	–	2.00	2.2–4.2 Bedrock or bouder 3.5–4.5	Gravelly sand, silty-sandy till	Bouwer & Rice
	$4.60\cdot10^{-6}$	$9.20\cdot10^{-6}$	$5\cdot10^{-7}$				Cooper-Bredehoeft-Papadopulos

**T*-value reported to the SICADA database.

Appendix 3

Hydraulic conductivity estimates based on PSD curves

The PSD-based analysis in Section 3.3 is performed using two alternative methods, the Hazen method and the Gustafson method /Andersson et al. 1984/. According to the Hazen method, the hydraulic conductivity K (m·s^{-1}) can be calculated using the expression

$$K = 0.01157 \cdot d_{10}^{2} \qquad \text{(A-1)}$$

where d_{10} (mm) is the grain diameter for which 10% of the material in the sample (by mass) is finer. The expression for K (m·s^{-1}) in the Gustafson method is

$$K = E(U) \cdot d_{10}^{2} \qquad \text{(A-2a)}$$

where d_{10} is in m and $U = d_{60}/d_{10}$, with d_{60} having a definition similar to that of d_{10} (it is the grain diameter for which 60% of the sample is finer). The parameter $E(U)$ in equation (A-2a) is calculated as

$$E(U) = 10.2 \cdot 10^{6} \left(\frac{e^{3}}{1+e} \right) \left(\frac{1}{g^{2}(U)} \right) \qquad \text{(A-2b)}$$

where

$$e(U) = 0.8 \left(\frac{1}{2 \cdot \ln U} - \frac{1}{U^{2}-1} \right) \qquad \text{(A-2c)}$$

$$g(U) = \left(\frac{1.30}{\log(U)} \cdot \frac{U^{2}-1}{U^{1.8}} \right) \qquad \text{(A-2d)}$$

Hence, both these methods require the d_{10} value; this value can usually not be quantified for very fine-grained (clayey) soils. Table A3-1 presents values of the hydraulic conductivity K for the soil samples for which the d_{10} value are available.

Table A3-1. Estimated hydraulic conductivity *K* from PSD for which d_{10} values are available, i.e. samples of clayey soils are excluded from the analysis.

Sampling point	Soil type	Evaluated hydraulic conductivity K ($m \cdot s^{-1}$)	
		Hazen method	Gustafson method
PSM002642	Gravelly till	$1.53 \cdot 10^{-4}$	$6.36 \cdot 10^{-5}$
PSM002643	Sandy till	$4.18 \cdot 10^{-6}$	$1.38 \cdot 10^{-6}$
PSM002644	Gravelly till	$2.27 \cdot 10^{-6}$	$3.41 \cdot 10^{-7}$
PSM002683	Sandy till	$4.31 \cdot 10^{-5}$	$4.06 \cdot 10^{-5}$
PSM005370	Gravelly till	$2.45 \cdot 10^{-5}$	$5.07 \cdot 10^{-6}$
PSM005372	Gravelly till	$8.36 \cdot 10^{-5}$	$2.14 \cdot 10^{-5}$
PSM005373	Sandy till	$4.18 \cdot 10^{-6}$	$1.14 \cdot 10^{-6}$
PSM005374	Gravelly till	$1.58 \cdot 10^{-4}$	$9.82 \cdot 10^{-5}$
PSM005384	Gravelly till	$2.27 \cdot 10^{-6}$	$3.37 \cdot 10^{-7}$
PSM005399	Gravelly till	$7.23 \cdot 10^{-6}$	$1.83 \cdot 10^{-6}$
PSM005403	Gravelly till	$4.89 \cdot 10^{-5}$	$1.27 \cdot 10^{-5}$
PSM005404	Sandy till	$7.40 \cdot 10^{-7}$	$8.94 \cdot 10^{-8}$
PSM005406	Sandy till	$2.96 \cdot 10^{-6}$	$7.30 \cdot 10^{-7}$
PSM005408	Gravelly till	$2.67 \cdot 10^{-5}$	$7.70 \cdot 10^{-6}$
PSM005410	Gravelly till	$7.23 \cdot 10^{-6}$	$1.75 \cdot 10^{-6}$
PSM005412	Sandy till	$7.23 \cdot 10^{-6}$	$1.82 \cdot 10^{-6}$
PSM005489	Sandy till	$3.75 \cdot 10^{-6}$	$1.25 \cdot 10^{-6}$
PSM005503	Sandy till	$3.34 \cdot 10^{-6}$	$8.73 \cdot 10^{-7}$
PSM005505	Gravelly till	$7.82 \cdot 10^{-6}$	$1.52 \cdot 10^{-6}$
PSM005507	Gravelly till	$4.74 \cdot 10^{-5}$	$1.83 \cdot 10^{-5}$
PSM005508	Gravelly till	$4.17 \cdot 10^{-5}$	$1.52 \cdot 10^{-5}$
PSM005634	Gravelly till	$1.11 \cdot 10^{-5}$	$3.10 \cdot 10^{-6}$
PSM006943_0.6	Clayey-sandy till	$4.17 \cdot 10^{-5}$	$6.25 \cdot 10^{-8}$
PSM006944_1.0	Clayey-sandy silt	$1.85 \cdot 10^{-7}$	$1.53 \cdot 10^{-7}$
PSM006944_1.8	Sandy till	$1.16 \cdot 10^{-6}$	$4.77 \cdot 10^{-7}$
PSM006945_1.4	Gravelly till	$1.42 \cdot 10^{-5}$	$3.06 \cdot 10^{-6}$
PSM006946_1.0	Gravelly till	$2.14 \cdot 10^{-5}$	$5.38 \cdot 10^{-6}$
PSM006947_1.0	Gravelly till	$5.19 \cdot 10^{-5}$	$1.73 \cdot 10^{-5}$
PSM006948_1.4	Gravelly till	$1.58 \cdot 10^{-5}$	$5.50 \cdot 10^{-6}$
PSM006949_2.1	Sandy till	$1.96 \cdot 10^{-6}$	$2.92 \cdot 10^{-7}$
PSM006950_1.1	Sandy till	$2.45 \cdot 10^{-5}$	$1.94 \cdot 10^{-5}$

Appendix 4

Summary of groundwater level measurements

The groundwater level measurements providing data for the Laxemar 1.2 modelling are summarised in Table A4-1. It should be noted that automatic measurements have started in several wells that had not delivered such data by the end of the data period considered here (i.e. by 2004-12-31).

Table A4-1.Summary of manual and automatic groundwater level measurements at time of the L1.2 data freeze. All numbers are rounded off to two decimals. "–" implies that no data are available. Levels given in metres above sea level (m.a.s.l.) refer to the height system RHB 70. The abbreviation "m.b.g.s." means metres below ground surface.

Well ID	Automatic gw. level measurements (period with available data)	Manual gw. level measurements (YYYY-MM-DD)	ToSP (m.a.s.l.)	Ground level (m.a.s.l.)	Manually measured gw. level (m.a.s.l.) (average)	Manually measured gw. level (m.b.g.s.) (average)
SSM000001	2004-11-01– 2004-12-31	–	2.79	1.89		
SSM000002	[2]2003-03-24– 2004-08-03	–	2.40	1.40		
[1]SSM000003	–	–	–	–		
SSM000004	[2]2003-03-24– 2004-08-03	–	5.49	5.11		
SSM000005	[2]2003-03-24– 2004-08-03	–	6.98	6.33		
SSM000006	–	–	2.69	2.29		
SSM000007	–	–	7.01	5.91		
SSM000008	2004-09-02– 2004-12-06	2004-03-22 2004-03-23 2004-06-15 2004-09-02 2004-09-03	4.64	4.24	4.19 4.24 3.92 3.78 3.39	0.05 0.00 0.32 0.46 0.85
					(3.90)	(0.34)
SSM00009	[2]2004-04-05– 2004-08-03	2004-04-02 2004-04-05	15.32	14.92	13.72 13.70	1.20 1.22
					(13.71)	(1.21)
SSM00010	–	2004-03-22 2004-03-23 2004-06-16 2004-09-02 2004-09-03	5.09	4.49	4.26 4.29 3.98 3.85 3.84	0.23 0.20 0.51 0.64 0.65
					(4.04)	(0.45)
SSM00011	2004-08-04– 2004-12-31	2004-04-02 2004-04-05	16.50	16.30	15.45 15.45	0.85 0.85
					(15.45)	(0.85)
SSM00012	2004-08-27– 2004-12-31	2004-03-24 2004-03-25 2004-09-06 2004-09-07	1.77	1.47	3-3.98 0.94 0.50 0.45	0.50 0.53 0.97 1.02
					(0.63)	(0.84)

Well ID	Automatic gw. level measurements (period with available data)	Manual gw. level measurements (YYYY-MM-DD)	ToSP (m.a.s.l.)	Ground level (m.a.s.l.)	Manually measured gw. level (m.a.s.l.) (average)	Manually measured gw. level (m.b.g.s.) (average)
SSM00014	2004-09-14–	2004-03-22	1.64	0.84	0.24	0.60
	2004-12-31	2004-03-23			0.27	0.57
		2004-06-16			0.01	0.83
		2004-08-31			0.03	0.81
		2004-09-01			0.05	0.79
					(0.12)	(0.72)
SSM00015	–	–	3.74	3.54		
SSM00016	–	2004-03-22	2.37	1.87	1.02	0.85
		2004-03-23			1.27	0.60
		2004-08-31			0.07	1.80
		2004-09-01			0.17	1.70
					(0.63)	(1.24)
SSM00017	[2]2004-08-26–	2004-05-05	10.99	10.34	10.15	0.20
	2004-12-08	2004-05-06			10.15	0.20
					(10.15)	(0.20)
SSM00018	2004-08-27–	2004-03-22	0.78	0.58	0.41	0.17
	2004-12-31	2004-03-23			0.41	0.17
		2004-06-16			3–1.65	0.62
		2004-08-31			–0.04	0.63
		2004-09-01			–0.05	
					(0.18)	(0.40)
SSM00019	[2]2004-08-26–	2004-05-05	13.21	12.72	10.96	1.75
	2004-12-08	2004-05-06			10.94	1.77
					(10.95)	(1.76)
SSM00020	–	2004-03-22	6.12	5.62	5.17	0.45
		2004-03-23			5.20	0.42
		2004-06-16			4.12	1.50
		2004-09-02			4.65	0.97
		2004-09-03			4.65	0.97
					(4.76)	(0.86)
SSM00021	2004-08-26–	2004-05-05	12.63	12.18	11.06	1.12
	2004-12-31	2004-05-06			11.04	1.14
					(11.05)	(1.13)
SSM00022	2004-09-02–	2004-03-22	5.03	4.63	4.45	0.18
	2004-12-31	2004-03-23			4.45	0.18
		2004-09-06			4.09	0.54
		2004-09-07			4.09	0.54
					(4.27)	(0.36)
SSM00024	–	2004-03-25	2.90	2.36	2.24	0.11
		2004-09-06			2.05	0.30
		2004-09-07			2.09	0.26
					(2.13)	(0.22)
SSM00026	–	2004-03-24	2.67	2.47	2.17	0.30
		2004-03-25			2.19	0.28
		2004-09-06			1.47	1.00
		2004-09-07			1.45	1.02
					(1.82)	(0.65)
SSM00027	–	2004-09-27	9.21	9.01	7.59	1.42
		2004-09-28			7.57	1.44
					(7.58)	(1.43)

Well ID	Automatic gw. level measure-ments (period with available data)	Manual gw. level measurements (YYYY-MM-DD)	ToSP (m.a.s.l.)	Ground level (m.a.s.l.)	Manually measured gw. level (m.a.s.l.) (average)	Manually measured gw. level (m.b.g.s.) (average)
SSM00028	–	2004-09-15	4.09	3.54	3.46	0.08
		2004-09-16			2.09	1.45
					(2.78)	(0.77)
SSM00029	–	2004-09-15	1.26	0.76	0.47	0.29
		2004-09-16			0.35	0.41
					(0.41)	(0.35)
SSM00030	–	2004-09-26	11.19	9.99	9.56	1.63
		2004-09-27			9.59	1.60
					(9.58)	(1.62)
SSM00031	–	2004-09-08	6.32	5.72	5.22	0.50
		2004-09-09			5.21	0.51
		2004-12-08			5.52	0.20
		2004-12-09			5.49	0.23
					(5.36)	(0.36)
SSM00032	–	2004-09-13	2.81	1.62	1.52	0.09
		2004-09-14			0.40	1.21
					(0.96)	(0.65)
SSM00033	–	2004-09-13	5.82	5.12	4.88	0.24
SSM00034	–	2004-09-13	0.48	–0.02	–0.14	0.12
		2004-09-14			–0.24	0.22
					(–0.19)	(0.17)
SSM00035	–	2004-09-22	27.11	26.61	25.52	1.09
		2004-09-23			24.33	2.28
					(24.92)	(1.69)
SSM00037	–	2004-09-15	12.70	12.35	11.22	1.13
		2004-09-16			11.20	1.15
					(11.21)	(1.14)
SSM00039	–	2004-09-08	11.70	11.10	8.32	2.78
		2004-09-09			8.33	2.77
		2004-12-06			9.65	1.45
		2004-12-07			9.62	1.48
					(8.98)	(2.12)
SSM00040	–	2004-09-08	1.16	0.26	0.19	0.07
		2004-09-09			0.02	0.24
		2004-12-06			0.26	0.00
		2004-12-07			0.08	0.18
					(0.14)	(0.12)
SSM00041	–	2004-09-22	4.15	3.36	2.18	1.18
		2004-09-23			2.19	1.17
		2004-12-15			2.66	0.70
		2004-12-16			2.56	0.80
					(2.40)	(0.96)
SSM00042	–	2004-09-22	3.35	2.55	0.98	1.57
		2004-09-23			0.97	1.58
		2004-12-15			1.76	0.79
		2004-12-16			1.75	0.80
					(1.37)	(1.19)
SSM00209	[2]2004-08-27– 2004-12-07	–	10.85	10.15		
SSM00210	[2]2004-08-27– 2004-12-07	–	11.31	11.11		

Well ID	Automatic gw. level measurements (period with available data)	Manual gw. level measurements (YYYY-MM-DD)	ToSP (m.a.s.l.)	Ground level (m.a.s.l.)	Manually measured gw. level (m.a.s.l.) (average)	Manually measured gw. level (m.b.g.s.) (average)
SSM00211	[2]2004-11-11–2004-12-08	–	15.27	14.08		
SSM00212	–	–	13.58	13.28		
SSM00213	2004-09-02–2004-12-07	–	12.38	12.18		

[1] The well is dry.

[2] Automatic groundwater level measurements have been terminated.

[3] The measurement is an outlier and may be erroneous. Therefore, it is excluded in the calculation of the average groundwater level and depth.