R-05-04

Description of climate, surface hydrology, and near-surface hydrogeology

Simpevarp 1.2

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April 2005

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ISSN 1402-3091
SKB Rapport R-05-04

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Abstract

This report presents and evaluates the site investigations and primary data on meteorology, surface hydrology and near-surface hydrogeology that are available in the Simpevarp 1.2 "data freeze". The main objective is to update the previous Simpevarp 1.1 description of the meteorological, surface hydrological and near-surface hydrogeological conditions in the Simpevarp area. Based on the Simpevarp 1.2 dataset, an updated conceptual and descriptive model of the surface and near-surface water flow conditions in the Simpevarp area is presented. In cases where site investigation data are not yet available, regional and/or generic data are used as input to the modelling. GIS- and process-based tools, used for initial quantitative flow modelling, are also presented. The objectives of this initial quantitative modelling are to illustrate, quantify and support the site descriptive model, and also to produce relevant input data to the ecological systems modelling within the SKB SurfaceNet framework.

For the Simpevarp 1.2 model, the relevant site investigations include the establishment of one local meteorological station and surface-hydrological stations for discharge measurements, delineation and description of catchment areas, manual discharge measurements in water courses, slug tests in groundwater monitoring wells, and manual groundwater level measurements. In addition, other investigations have also contributed to the modelling, providing data on geometry (including topography), data from surface-based geological investigations and boreholes in Quaternary deposits, and data on the hydrogeological properties of the bedrock.

The conceptual and descriptive modelling includes an identification and basic description of type areas, domains and interfaces between domains within the model area. The surface and near-surface flow system is described, including the assignment of hydrogeological properties to HSDs (Hydraulic Soil Domains) of Quaternary deposits based on a combination of site investigation data and generic/regional data. Furthermore, the use of data from other disciplines and models as supporting evidence is discussed and exemplified.

The quantitative flow modelling is performed using two different tools, a GIS-based hydrological model and the process-based MIKE SHE model. The GIS model simulates steady-state flow conditions, and uses the specific discharge (must be estimated separately) and the Digital Elevation Model (DEM) as the only inputs. The MIKE SHE model simulates the whole transient hydrological cycle, including unsaturated flow and saturated groundwater flow, as well as surface water flow. The GIS-based flow modelling is performed for the whole regional model area. The results illustrate the overall surface and near-surface water flow pattern in the model area, as well as the distribution of recharge and discharge areas. The model is also used to compare model-calculated and real water courses, and model-calculated and field-checked catchment area boundaries.

The MIKE SHE modelling is focused on the catchment area "Simpevarp 7", where Lake Frisksjön is located. This is also the area considered in the ecological systems modelling. The model is applied to quantify the water balance of the catchment area and to illustrate the three-dimensional groundwater flow system, from a depth of 150 m below sea level up to the ground surface. The hydraulic properties of the fractured rock and the pressure at the bottom boundary are imported from the Simpevarp 1.1 modelling of groundwater flow in the rock. In addition, the MIKE SHE modelling results illustrate the variations in the distribution of recharge and discharge areas during the year, using transient, high resolution data for a selected "representative" year to describe the meteorological conditions.

Based on the results from the conceptual, descriptive and quantitative flow modelling, uncertainties in the present model version are identified and discussed. The main uncertainties are related to the geometrical description of the system (the DEM, the Quaternary deposits and the description of the water courses), the limited data on the hydrogeological properties of site-specific materials, and the limited data available for assessing the temporal variations of the hydrological and hydrogeological processes. The next "data freeze", Laxemar 1.2, will contain data from geological and hydrogeological investigations of Quaternary deposits within the Laxemar sub-area, and extended time series of locally measured meteorological and hydrological data. It is expected that these data will reduce the main uncertainties associated with the present model version.

Sammanfattning

Denna rapport ger en presentation och utvärdering av de platsundersökningar och primärdata för meteorologi, ythydrologi och ytnära hydrogeologi som ingår i ”datafrysen” Simpevarp 1.2. Det övergripande syftet är att uppdatera den tidigare modellversionen (Simpevarp 1.1) med avseende på de meteorologiska, hydrologiska och hydrogeologiska förhållandena vid och nära markytan inom Simpevarpsområdet.

Baserat på den datamängd som finns tillgänglig för Simpevarp 1.2-modelleringen, presenteras en uppdaterad konceptuell och beskrivande modell avseende de ytliga och ytnära flödesförhållandena i området. I de fall där platsundersökningsdata ännu inte finns tillgängliga, används regional och/eller generisk information som indata till modelleringen. GIS- och processbaserade modelleringsverktyg, som använts för kvantitativ flödesmodellering, presenteras också. Syftena med denna inledande kvantitativa modellering är att illustrera, kvantifiera och stödja den platsbeskrivande modellen, och även att producera relevanta indata till den systemekologiska modellering som utförs inom ramen för SKB-projektet SurfaceNet.

De platsundersökningar som är relevanta för modellversion Simpevarp 1.2 innefattar etablering av en lokal meteorologisk station och ythydrologiska stationer för avrinningsmätningar, avgränsning och beskrivning av avrinningsområden, manuella flödesmätningar i vattendrag, hydrauliska tester i grundvattenrör, samt manuella grundvattennivåmätningar. Dessutom har andra undersökningar bidragit till modelleringen, främst genom att tillhandahålla data avseende geometri (bl a topografi), data från geologiska ytundersökningar och borrningar i kvartära avlagringar, samt data som beskriver bergets hydrogeologiska egenskaper.

Den beskrivande och konceptuella modelleringen innefattar en identifiering och grundläggande beskrivning i termer av typområden, domäner och gränser mellan domäner inom modellområdet. Det ytliga och ytnära flödessystemet beskrivs och hydrogeologiska egenskaper tilldelas till HSDs (Hydraulic Soil Domains; hydraualiska jorddomäner) baserat på en kombination av platsundersökningsdata och generiska/regionala data. Användningen av data och modeller från andra discipliner som stöd för beskrivningen diskuteras och exemplifieras också.

Den kvantitativa flödesmodelleringen har genomförts med två modelleringsverktyg, en GIS-baserad hydrologisk modell och en processbaserad MIKE SHE-modell. GIS-modellen simulerar stationära flödesförhållanden och baseras på indata i form av en uppskattad specifik avrinning samt en topografisk modell (höjdmodell). MIKE SHE-modellen simulerar hela den transienta hydrologiska cykeln inom det valda modellområdet, inkluderande både grundvattenströmning och omättad strömning ovanför grundvattenytan, samt ytvattenflöden i vattendrag.

Den GIS-baserade fllödesmodelleringen har utförts för hela det regionala modellområdet. Modellresultaten används för att illustrera det ytliga och ytnära flödesmönstret samt den topografiskt styrda fördelningen av in- och utströmningsområden. Modellen används också för att jämföra modellberäknade och verkliga lägen för vattendrag, liksom modellberäknade och fältkontrollerade avrinningsområdesgränser.

MIKE SHE-modelleringen har fokuserats på avrinningsområdet ”Simpevarp 7”, där bl a Frisksjön är belägen. Detta är också modellområdet för den ekologiska systemmodelleringen. Modellen används för att kvantifiera vattenbalansen för avrinningsområdet och för att illustrera det tredimensionella grundvattenflödes-systemet från djupet 150 m under havsnivån upp till markytan. Indata avseende bergets hydrauliska egenskaper och trycket vid den nedre modellranden har importerats från den hydrogeologiska modelleringen i Simpevarp 1.1. Modellresultaten illustrerar även förändringarna i fördelningen av in- och utströmningsområden under året, baserat på högupplösta meteorologiska data för ett utvalt ”representativt” år.

Osäkerheterna i den aktuella modellversionen identifieras och diskuteras baserat på resultaten av den konceptuella, beskrivande och kvantitativa flödesmodelleringen. De viktigaste osäkerheterna i denna modellversion kan relateras till den geometriska beskrivningen av systemet (höjdmodellen, den geologiska beskrivningen och beskrivningen av vattendragen), den begränsade informationen om jordlagrens hydrauliska egenskaper, samt det begränsade underlag som finns tillgängligt för värdering av tidsmässiga variationer i de hydrologiska och hydrogeologiska processerna. Nästa ”datafrys”, Laxemar 1.2, kommer att innehålla resultat från geologiska och hydrogeologiska undersökningar inom delområde Laxemar och längre tidsserier från lokala meteorologiska och hydrologiska mätningar, vilka förväntas medföra att de huvudsakliga osäkerheterna kan reduceras.

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 models of the Forsmark /SKB, 2004c/ and Simpevarp /SKB, 2004a/ areas. The present report is produced as a part of the version 1.2 modelling of the Simpevarp area. The 1.2 models 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 model Simpevarp 1.2 will be followed by Laxemar 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 will be located outside the subarea prioritised for geological investigations for the repository.

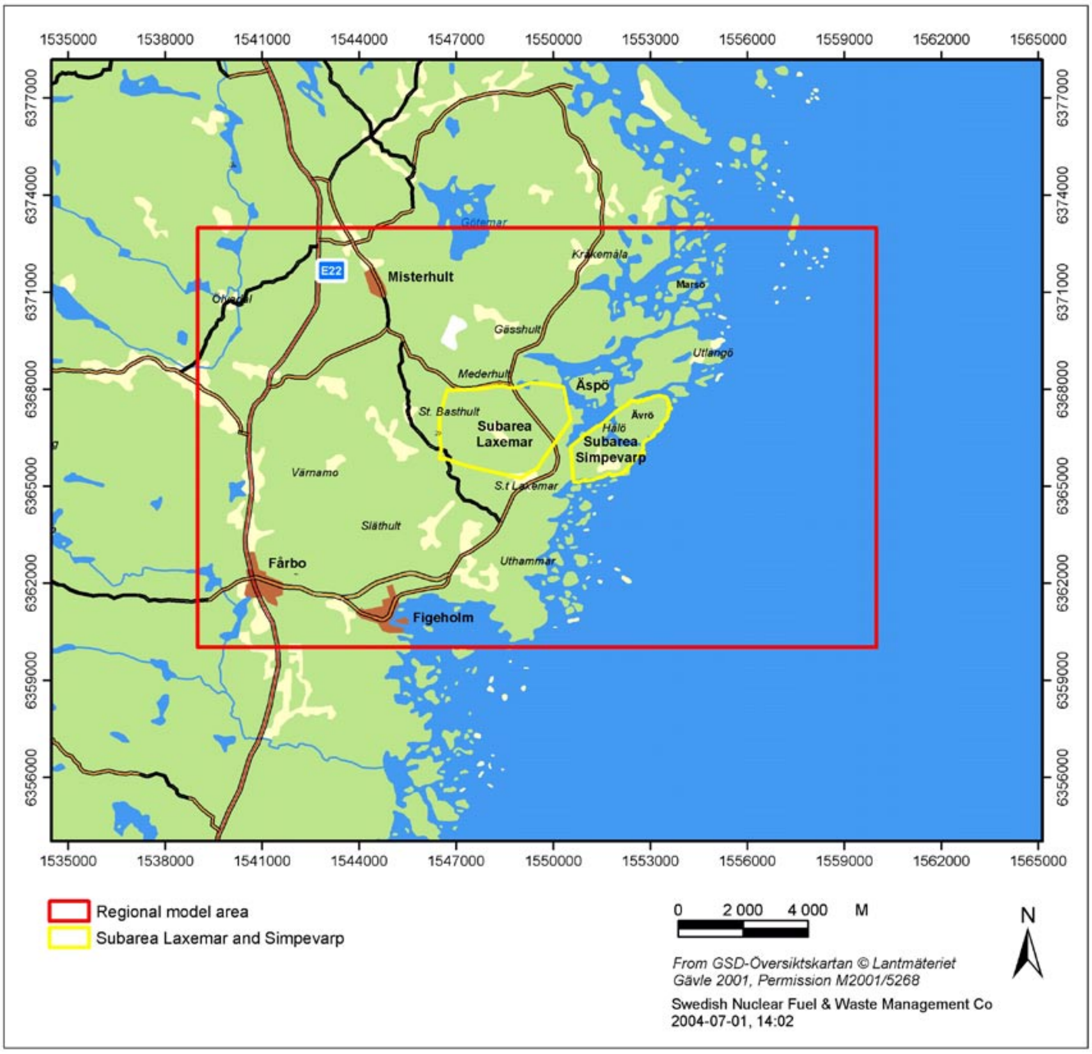


Figure 1-1. *Overview of the Simpevarp area and identification of the Simpevarp and Laxemar subareas.*

1.2 Objectives and scope

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

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

- analyse and present the data available in the Simpevarp 1.2 dataset,
- update the descriptive model presented in the previous model version /SKB, 2004a/,
- present the results of the initial flow modelling undertaken in order to obtain an overview of the site and to support the ecological system modelling,
- summarise and present the results in the form of an updated site description.

As further described below, only a relatively small amount of site data were available at the time for the "data freeze" Simpevarp 1.2 (April 1, 2004). This implies that the data evaluation and, in particular, the work conducted in the area of quantitative flow modelling have been limited, as compared to the modelling effort that will be made when results of local discharge and meteorological measurements and a more detailed geological and hydrogeological characterisation are available. It should also be noted that the "data freeze" has not been applied strictly as a last date for input data to the present work. In particular, the time series of meteorological parameters and "simple discharge measurements" have been extended to September 2004.

Thus, it should be emphasised that although significant steps have been taken in the descriptive modelling, there are still substantial uncertainties in the model description. The main reasons for this are the limited amount of primary data and that time has been insufficient to carry out supporting exploratory analyses and modelling exercises.

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), cf Figure 1-1. The Simpevarp area (including the Simpevarp and Laxemar subareas) is located close to the shoreline of the Baltic Sea. The regional model area indicated in the figure 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 power plants and the interim storage facility for spent fuel, 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 areal size of the Simpevarp subarea is approximately 6.6 km^2, whereas the Laxemar subarea covers some 12.5 km^2.

The site investigations that provide the basis for the present model version have been focused on the Simpevarp subarea. This implies that the data available from drillings and installations of measurement devices, measurements, and detailed mapping for the most part have been carried out there. However, some surface data of importance for the hydrological modelling, such as vegetation and soil types maps, are presented on the regional scale only; these maps are in most cases already available.

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 (HSDs). The HSDs are to be specified in terms of geometry and hydrogeological parameters, as described in the strategy report.

The description based on HSDs 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 runoff 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.

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 can be studied (which is the case for Forsmark 1.2, but not for Simpevarp).

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. Furthermore, coupled hydrogeological and hydrogeochemical modelling is performed within the framework of the hydrogeochemical modelling (the HAG group). 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.

It should be noted that whereas the interactions indicated in Figure 1-2 indeed have taken place in the form of inputs to the numerical flow modelling presented herein, feed-backs 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. Data and models that could be used to support the modelling of surface hydrology and near-surface hydro-geology are further discussed in Chapter 4.

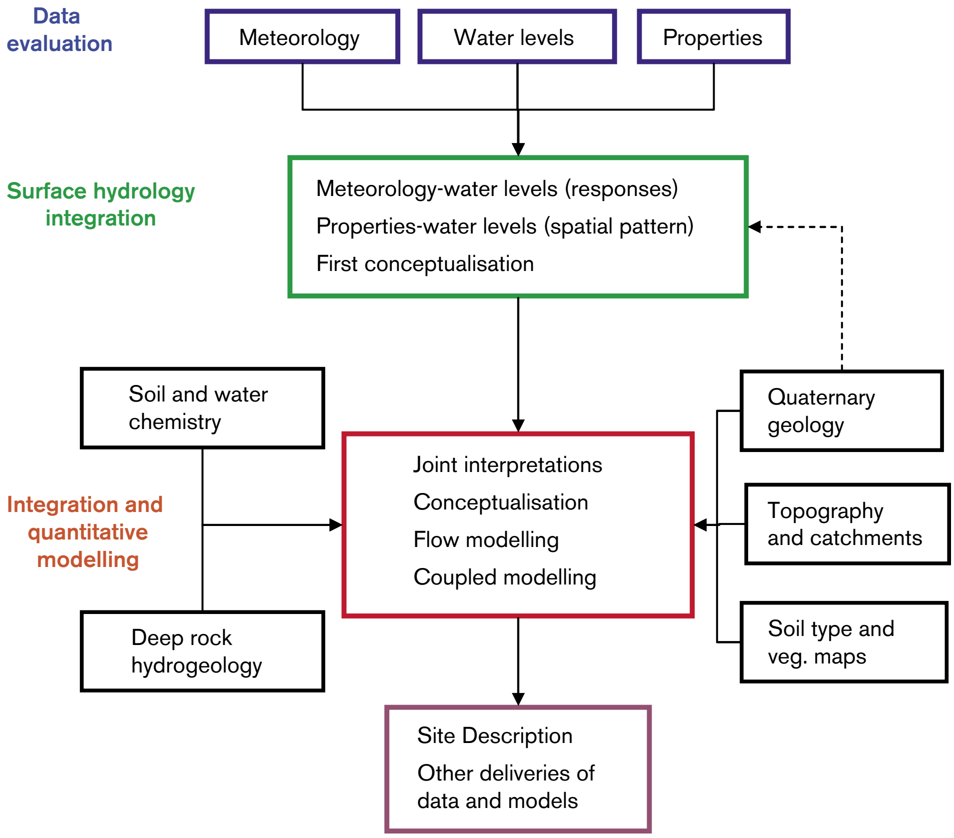


Figure 1-2. *Overview of the modelling process.*

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 parameters, 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 water courses and lakes, and surface water divides and the associated catchments and sub-catchments.
- *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 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 for appropriate parametrisation and identification of boundary conditions.

1.4.3 Organisation of work

The 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 HAG teams. As indicated above, the actual results of these contacts in 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 pave the way for future co-operation.

The SurfaceNet modelling for Simpevarp 1.2 is reported in /Lindborg (ed), 2005/, which provides input to the Simpevarp 1.2 SDM report /SKB, 2005/. 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 available primary 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 descriptive model is described in Chapter 4, and the quantitative flow modelling in Chapter 5. Finally, the resulting description is presented in Chapter 6.

2 Investigations and available data

2.1 Previous investigations

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

S0 /SKB, 2002/ was developed before the beginning of the site investigations in the Simpevarp area. It was based on information from the feasibility study /SKB, 2000/, selected sources of "old" 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 it was identified that local data were missing in the official databases. Hence, the lack of official data was not considered to have influenced the S0 modelling work to any significant degree. 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 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, four 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.

2.2 Meteorological, hydrological and hydrogeological investigations

Between the S1.1 (July 1, 2003) and S1.2 (April 1, 2004) data freezes, the meteorological, surface hydrological and near-surface hydrogeological investigations have comprised the following main components:

- Establishment of a local meteorological station on Äspö.
- Delineation and description of catchment areas, water courses and lakes.
- Establishment of local surface-hydrological stations for discharge measurements.
- "Simple discharge measurements" in water courses.
- Drilling and slug tests of groundwater monitoring wells.
- Manual groundwater level measurements.

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

2.3 Other investigations contributing to the modelling

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

- Topographical and other geometrical data.
- Data from surface-based geological investigations.
- Data from investigations in boreholes in Quaternary deposits.
- Data on the hydrogeological properties of the bedrock.

2.4 Summary of available data

Table 2-1 gives references to site investigations and other reports that contain meteorological, hydrological and hydrogeological data used in the S1.2 modelling. Table 2-2 provides the corresponding information with respect to other disciplines or types of investigations. Table 2-3 specifies the SKB-reports referred to in Table 2-1 and 2-2.

Table 2-1. Available meteorological, hydrological and hydrogeological data and their handling in S1.2.

Available site data Data specification	Ref.	Usage in S1.2 Analysis/Modelling	Cf. section	Not utilised in S1.2 Arguments/ Comments
Meteorological data				
Regional Version 0 data				
Summary of precipitation, temperature, wind, humidity and global radiation up to 2,000.	TR-02-03 R-99-70 SICADA	Basis for general description and quantitative modelling of surface water and near-surface groundwater flow.	3.1.1 5.1–5.2	
Site Investigation data				
Precipitation, temperature, wind, humidity, global radiation and potential evaporation September 2003–September 2004 from meteorological station on Äspö.	SICADA	Comparison with regional meteorological data.	3.1.2	
Hydrological data				
Regional Version 0 data				
Regional discharge data.	TR-02-03 R-99-70	Characteristics of catchment areas. Specific discharge in GIS-based flow models.	3.2.6 5.1–5.2	
Site Investigation data				
Investigation of potential locations for discharge stations.	P-03-04		3.2.6	Not used explicitly; used as general information and for planning purposes only
Geometric data on catchment areas, lakes and water courses.	P-04-242	Delineation and characteristics of catchment areas and lakes.	3.2.1 5.1–5.2	
Simple discharge measurements in water courses, lakes and the sea.	P-04-13 P-04-75 SICADA	General description of temporal variability in ground-water and surface water flow.	3.2.6 4.3.2	

Available site data Data specification	Ref.	Usage in S1.2 Analysis/Modelling	Cf. section	Not utilised in S1.2 Arguments/ Comments
Hydrogeological data				
Inventory of private wells.	P-03-05	Description of available hydrogeological information.	3.3.3	No attempt is made to infer hydraulic parameters from drilling data
Manually measured groundwater levels.	SICADA	Basis for identifying depth of unsaturated zone.	3.3.2 4.3.2	
Data on installed groundwater monitoring wells.	P-03-80 P-04-46 P-04-121	General description and evaluation of hydraulic properties.	3.3.1 4.3.1	
Hydraulic conductivity of Quaternary deposits.	P-04-122 SICADA	Basis for assigning hydraulic conductivity of Quaternary deposits in descriptive and numerical models.	3.3.1 4.3.1	

Table 2-2. Input data from other disciplines and their handling in S1.2.

Available site data Data specification	Ref.	Usage in S1.2 Analysis/Modelling	Cf. section	Not utilised in S1.2 Arguments/ Comments
Topographical data				
Digital Elevation Model (DEM).	P-04-03 SICADA	Flow modelling (ArcGIS and MIKE SHE).	4.3.1 5.1–5.2	
Surface-based geological data				
Soil type investigation.	P-04-243	Flow modelling (MIKE SHE).	5.2	
Geological mapping of Quaternary deposits.	P-04-22	Basis for defining HSD (Hydraulic Soil Domains) in the Simpevarp subarea Flow modelling (MIKE SHE).	4.3.1 5.2	
Airborne geophysical data.	P-03-17 P-03-100 SICADA	Basis for defining HSD (Hydraulic Soil Domains) in the Laxemar subarea.	4.3.1 5.2	
Geological data from boreholes				
Drilling and sampling in Quaternary deposits.	P-03-80 P-04-46 P-04-121	Stratigraphical information in the Simpevarp subarea – used as input to descriptive and quantitative modelling.	4.3.1 5.2	
Hydrogeological properties of the rock				
Modelled hydraulic conductivity and pressure distributions in the upper part of the rock – results from DarcyTools S1.1.	R-04-65	Flow modelling (MIKE SHE) – parametrisation and identification of boundary conditions.	5.2	
Vegetation				
Vegetation map.	P-03-83 SICADA	Flow modelling (MIKE SHE) – parametrisation for evapo-transpiration and unsaturated flow calculations.	5.2	

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

P-03-04	**Lärke A, Hillgren R.** Rekognocering av mätplatser för ythydrologiska mätningar i Simpevarpsområdet.
P-03-05	**Morosini M, 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 of 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-04-22	**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	J**ohansson 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.
R-99-70	**Lindell S, Ambjörn C, Juhlin B, Larsson-McCann S, Lindquist K.** Available climatological and oceanographical data for site investigation program.
R-04-65	**Follin S, Stigsson M, Svensson U, Berglund S.** Variable-density groundwater flow simulations and particle tracking in support of the Preliminary Site Description for the Simpevarp area (version 1.1).
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 primary data

3.1 Meteorological data

The regional meteorological conditions in the Simpevarp area are described by /Larsson-McCann et al. 2002/. They list meteorological stations of interest for the Simpevarp regional area, and present long-term average data for selected meteorological stations that are considered representative for different meteorological parameters. This list and presentation of data (reproduced in Section 3.1.1) was utilised to characterise the regional Simpevarp area in terms of climate in SDM S1.1.

For S0 and S1.1, meteorological data were available only from relatively distant meteorological stations, operated by SMHI (the Swedish Meteorological and Hydrological Institute), Vägverket (the Swedish National Road Administration), and (for some meteorological parameters) OKG AB, owner and operator of the nuclear power plant in Simpevarp. 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 modelling, local meteorological data are therefore also available for a one-year period (September 2003 to September 2004) from the Äspö station. The collected data include wind speed and wind direction at 10 m a g l (metres above ground level), and air temperature, humidity, precipitation, global radiation and air pressure at 2 m a g l. The data are collected every second, and saved as average values every 30 minutes.

It can be noted that one more meteorological station will be installed during 2004 in the western part of the Simpevarp area, c 10 km west of the station on the Äspö island /SKB, 2004a/. Furthermore, snow depth and ground frost depth are being measured at one location (on Äspö) and at 1–2 locations in the Laxemar subarea, west of the Simpevarp peninsula.

Section 3.1.2 presents the currently available data from the Äspö station. 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, long-term average meteorological conditions. On the other hand, the station on Äspö can for obvious reasons be regarded as more relevant for the local meteorological conditions in the Simpevarp area, and hence as a basis for the site descriptive modelling. However, this station has so far only been in operation for a single year. Section 3.1.2 therefore also includes a comparison between the one-year data from Äspö and the corresponding data (for some selected meteorological parameters) from three of the regional SMHI meteorological stations.

3.1.1 Long-term regional data

Figure 3-1 shows the locations of the regional meteorological stations of interest for the Simpevarp area /Larsson-McCann et al. 2002/. The figure also includes the relevant hydrological and oceanographical stations. The meteorological stations are listed in Table 3-1.

The following sections give a brief description of the meteorological conditions in the Simpevarp regional area for each relevant meteorological parameter. "Reference station" denotes a meteorological station considered to be most suitable in /Larsson-McCann et al. 2002/ for describing the meteorological conditions in the Simpevarp area for the parameter in question. More details can be found in /Larsson-McCann et al. 2002/.

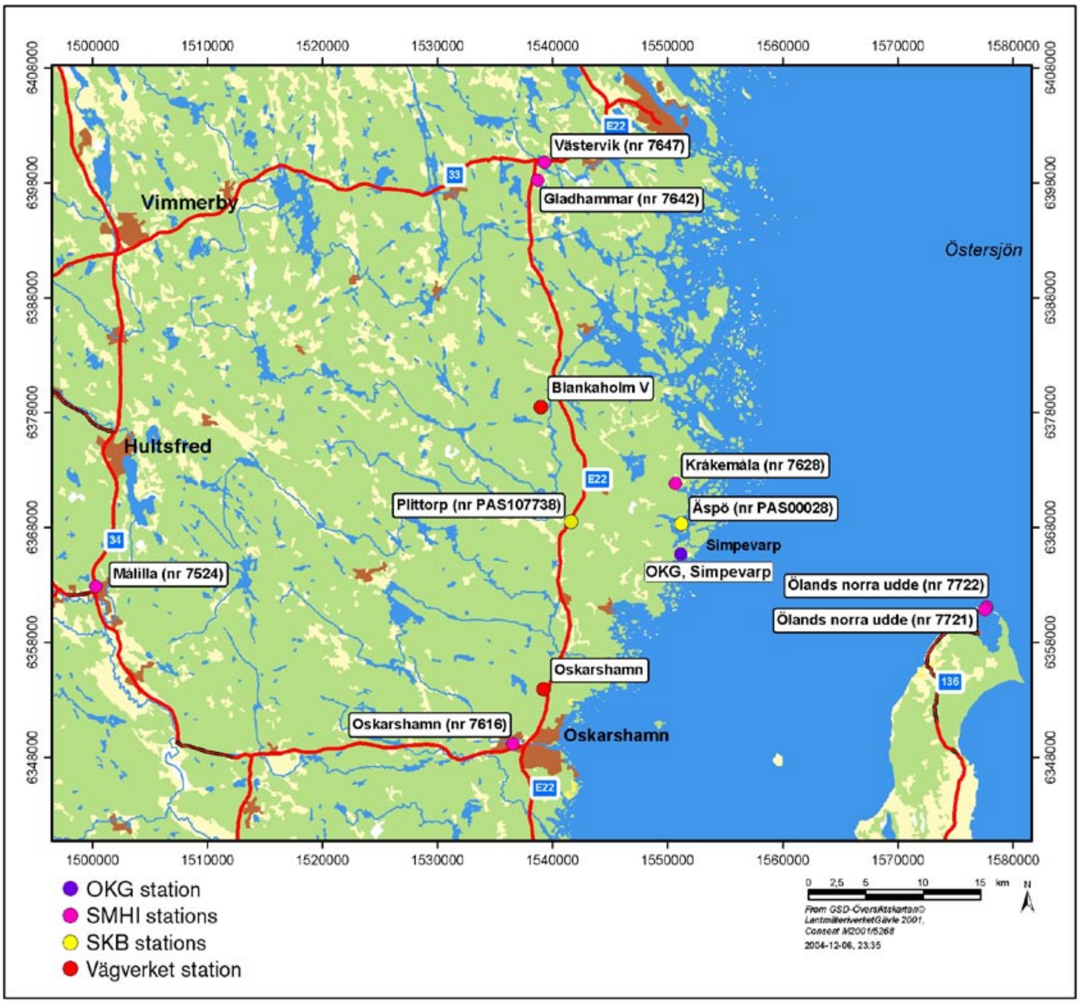


Figure 3-1. Meteorological stations of interest for the Simpevarp area /SKB-GIS, 2004/.

Table 3-1. Meteorological stations and data of interest for the Simpevarp area /Larsson-McCann et al. 2002/; data fom the Äspö station area available in SICADA.

Station no	Station name	Period	Information
7722	Ölands norra udde	1880–1995	
7721	Ölands norra udde A	1996–	Reference station for relative humidity, air pressure, global radiation and wind.
7616	Oskarshamn	1918–	Reference station for temperature and precipitation; measures only these two parameters.
7628	Kråkemåla	1990–	Measures only precipitation.
7524	Målilla	1931–	
7647	Västervik	1951–1995	
7642	Gladhammar A	1995–	
823	Blankaholm V [2]	1990–	
822	Oskarshamn [3]	1990–	
	OKG, Simpevarp [4]	1971–	
PAS00028	Äspö [5]	September 2003–September 2004	Local meteorological station, established in 2003.
PAS107738	Plittorp		Local meteorological station, to be established in 2004.

[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.
[4] Wind speed and direction at 25 and 100 m above ground, temperature at 2 m, temperature difference at 2–70 m and 2–100 m. Data available for 1996–2000.
[5] Air pressure, precipitation, relative humidity, air temperature and wind (direction and speed).

Wind

The reference station for wind is the meteorological station at Ölands norra udde (northern cape of the island of Öland). A wind rose is shown in Figure 3-2. 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. This means that the differences between coastal sites and their inland neighbourhood generally are less pronounced. However, locations near the coast are still far more exposed to strong winds than inland sites.

Since the Simpevarp area to a large extent is forested, the heavy wind exposure close to the sea has diminished considerably only a few kilometres inland. Within the site investigation programme, local meteorological data will be obtained from one coastal and one inland station (cf Chapter 2).

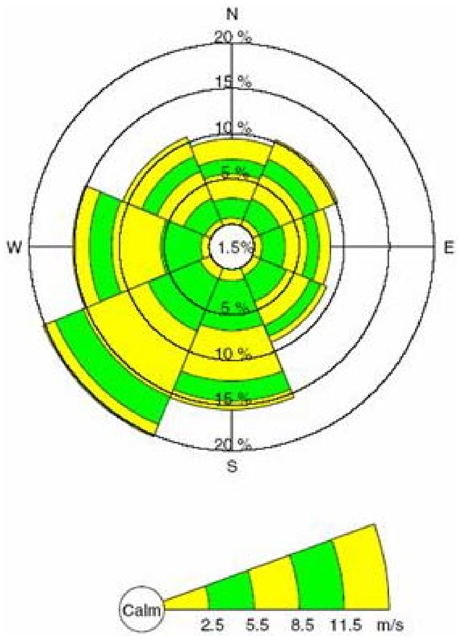


Figure 3-2. *Wind rose based on data collected 1968–1995 from the SMHI meteorological station at Ölands norra udde /Larsson-McCann et al. 2002/.*

Precipitation

The reference station for precipitation is SMHI's meteorological station at Oskarshamn. The annual precipitation (measured) amounts to 500–600 mm in the region with a slight tendency to increase inland. The measured precipitation is always smaller than the actual because of losses due to evaporation, adhesion and wind effects. The correction factor for the measured precipitation is c 1.15–1.2. The mean annual (corrected) precipitation at the Oskarshamn station is 681 mm for the period 1991–2000. The average monthly and yearly precipitation values at Oskarshamn are shown in Figure 3-3 and Figure 3-4. About 20% of the precipitation falls in the form of snow.

Potential evapotranspiration

Potential evapotranspiration for the stations Västervik/Gladhammar, Ölands norra udde and Målilla 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. The Penman formula provides a realistic estimate of potential evapotranspiration from grass surfaces and short crops where there is no shortage of water /Larsson-McCann et al. 2002/. The monthly potential evapotranspiration for Västervik/Gladhammar is shown in Figure 3-5.

Air temperature

The reference station for air temperature is SMHI's meteorological station in Oskarshamn. The average monthly mean temperature varies between –2°C in January–February and 16–17°C in July (Figure 3-6). The winters are slightly milder at the coast than inland, and the average annual temperature at Ölands norra udde is about 2°C higher than at the more inland stations at Oskarshamn and Målilla. The vegetative period (daily average temperature exceeding 5°C) is about 200 days.

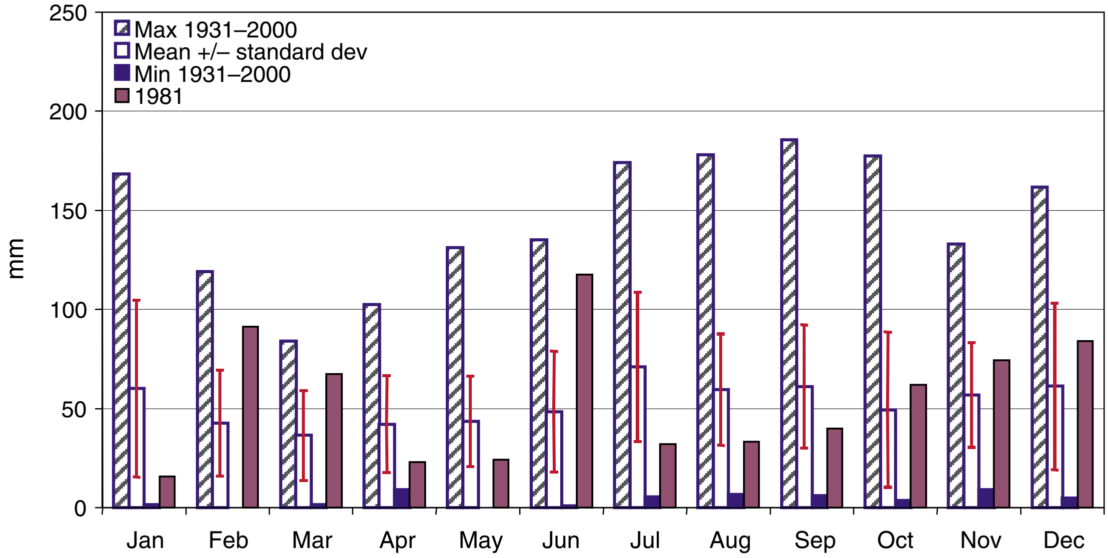


Figure 3-3. *Monthly mean, maximum and minimum precipitation for the standard normal period 1961–1990 (mean and standard deviation) and extreme values for the period 1931–2000, station Oskarshamn. Vertical lines: ± 1 standard deviation from the mean. Red bar: Monthly sums for the selected (representative) year 1981 /Larsson-McCann et al. 2002/.*

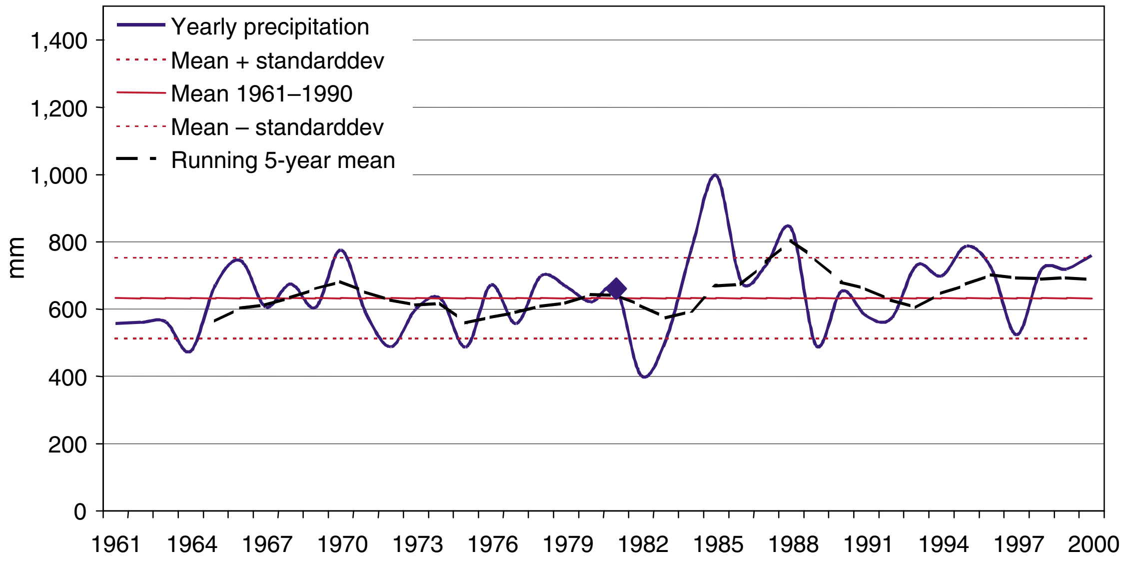


Figure 3-4. *Annual precipitation, 5-year running average precipitation and mean of the total annual precipitation for the standard normal period 1961–1990, station Oskarshamn. Dashed lines: ± 1 standard deviation from the mean /Larsson-McCann et al. 2002/.*

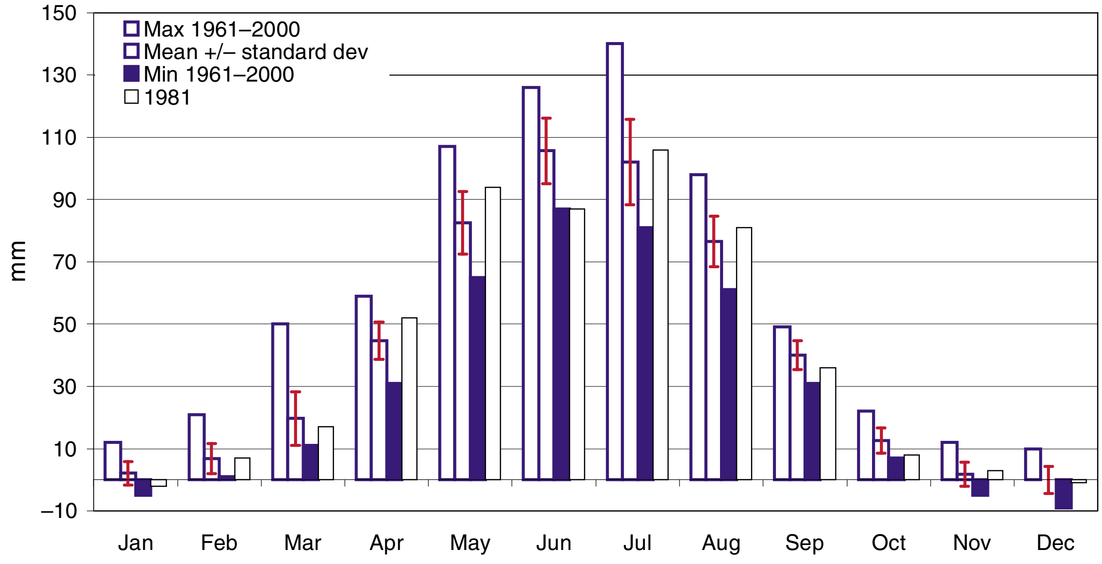


Figure 3-5. *Station Västervik/Gladhammar: Monthly mean, maximum and minimum of the sum of potential evapotranspiration per month for the standard normal period 1961–1990, station Oskarshamn. Vertical lines: ± 1 standard deviation from the mean. Unfilled bar: Monthly sums for the selected (representative) year 1981 /Larsson-McCann et al. 2002/.*

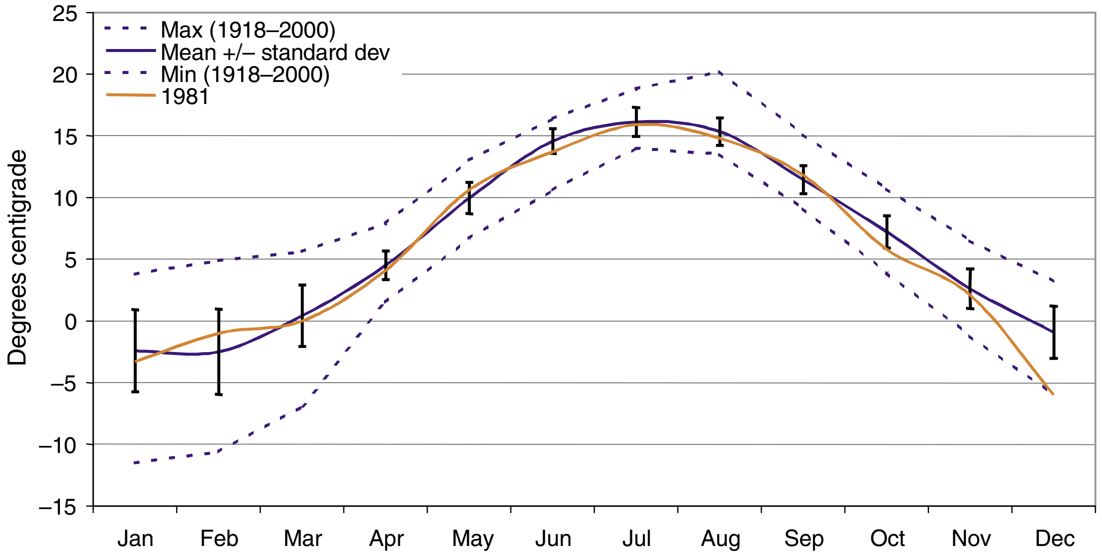


Figure 3-6. *Monthly mean temperature for the standard normal period 1961–1990, station Oskarshamn. Vertical lines: One standard deviation. Dashed lines: Maximum and minimum of monthly mean temperature. Red line: Monthly mean for the selected (representative) year 1981 /Larsson-McCann et al. 2002/.*

Hours of sunshine, cloudiness and global radiation

The reference station for hours of sunshine, cloudiness and global radiation is Ölands norra udde. The annual hours of sunshine are 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 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 glocal radiation varies from 8.5 kWh×m^{-2} in December to 179.5 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 Ölands norra udde. The relative humidity is 80–100% in the winter and 70–90% in the summer. In each case 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 One-year local data

This section presents local meteorological data, collected during the period September 2003–September 2004 at SKB's meteorological station on the northern part of the island of Äspö. For the reasons discussed in the beginning of this chapter, a comparison is also made between the Äspö data and the corresponding data (for some selected meteorological parameters) from three regional SMHI meteorological stations. As meteorological data with a high temporal resolution were not available from the SMHI stations at the time of writing, monthly SMHI data were taken from the SHMI publication "Väder och vatten" ("Weather and water"). This official publication includes meteorological data (quality controlled by SMHI) for the stations Ölands norra udde, Gladhammar and Målilla /SMHI, 2003; 2004/.

For Äspö, high-resolution (daily) data are presented in graphs for the parameters precipitation (uncorrected) and global radiation. As more detailed data are considered unnecessary for the present purposes, only calculated monthly average values are presented for air temperature, air pressure and relative humidity.

During the period September 2003–September 2004, the precipitation (Figure 3-7) was fairly evenly distributed, except for some periods during the summer 2004 with heavy rainfall. For the whole period, the measured (uncorrected) precipitation (Figure 3-8) on Äspö (671 mm) was most similar to the SMHI station Gladhammar (677 mm) among the SHMI stations included in the comparison.

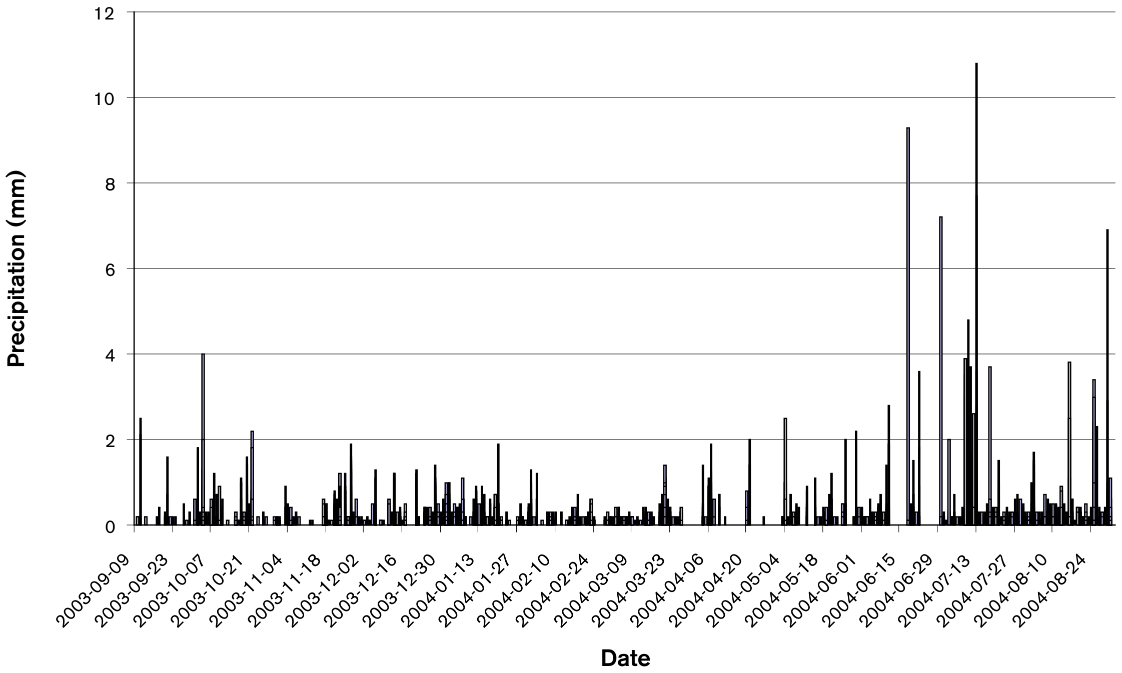


Figure 3-7. *Precipitation (uncorrected) on Äspö during the period September 2003–August 2004. The total uncorrected precipitation during the whole period was 671 mm.*

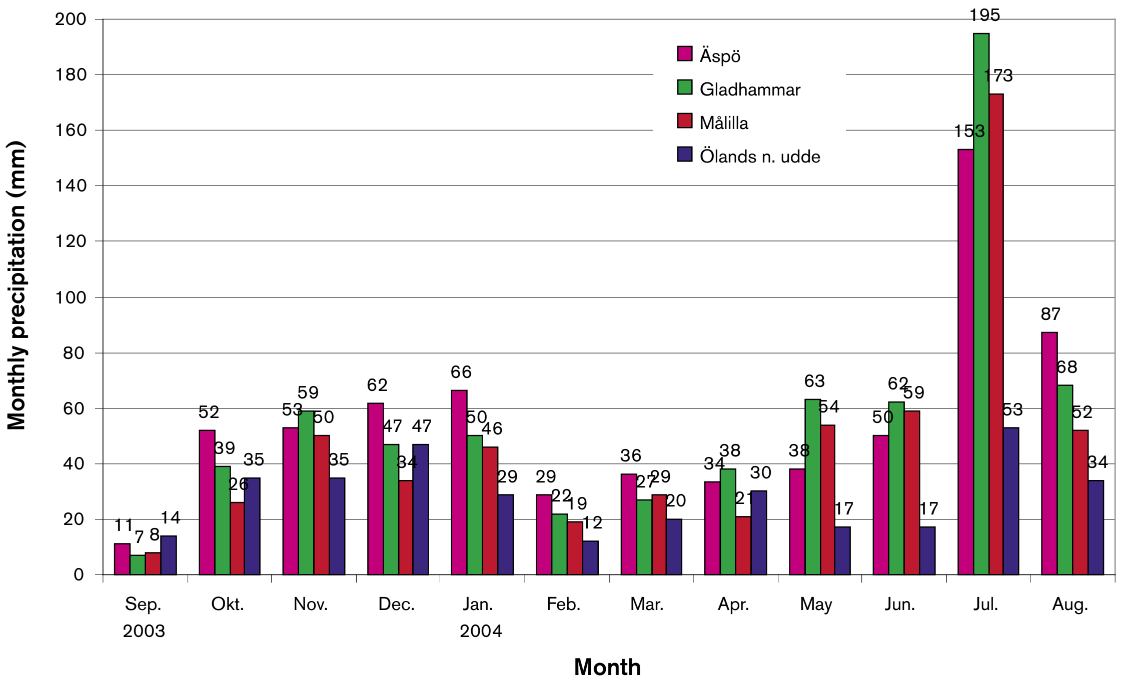


Figure 3-8. *Monthly (uncorrected) precipitation on Äspö during the period September 2003–August 2004, and corresponding values for the SMHI meteorological stations Gladhammar, Målilla and Ölands norra udde /SMHI, 2003; 2004/.*

The average air temperature measured on Äspö (Figure 3-9) was 7.4°C, which also in this case was closest to the station in Gladhammar (7.2°C) when comparing to SMHI stations in the region. However, it should be noted that there are only data available for one single year from the Äspö station; other stations may very well be found more relevant as reference stations when longer time series from the site are at hand.

The global radiation shows the expected annual variation (Figures 3-10 and 3-11), with low radiation during winter and high during summer. On Äspö, the monthly average air pressure was approximately 1,000 hPa during the period (Figure 3-12), whereas the monthly average of the relative humidity was in the interval 80–90% during the winter 2003/2004, and 70–80% during the summer 2004 (Figure 3-13).

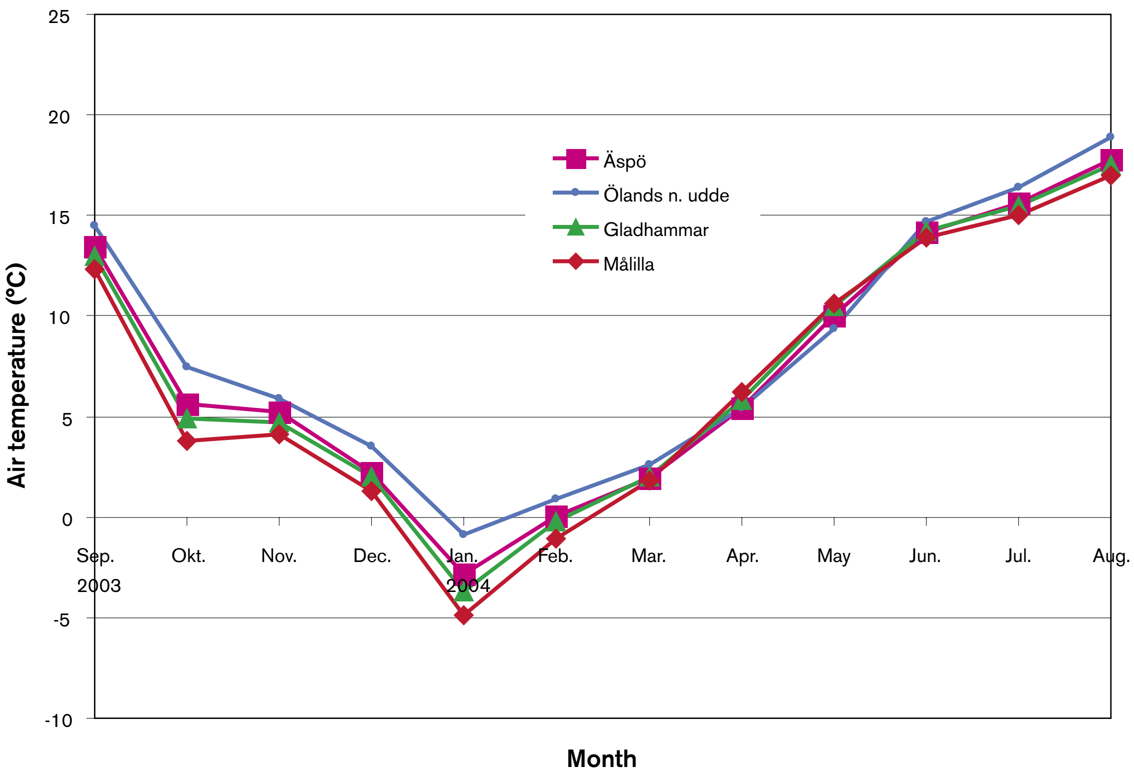


Figure 3-9. *Monthly average air temperature (°C) on Äspö during the period September 2003–August 2004, and corresponding values for the SMHI meteorological stations Ölands norra udde, Gladhammar, and Målilla /SMHI, 2003; 2004/.*

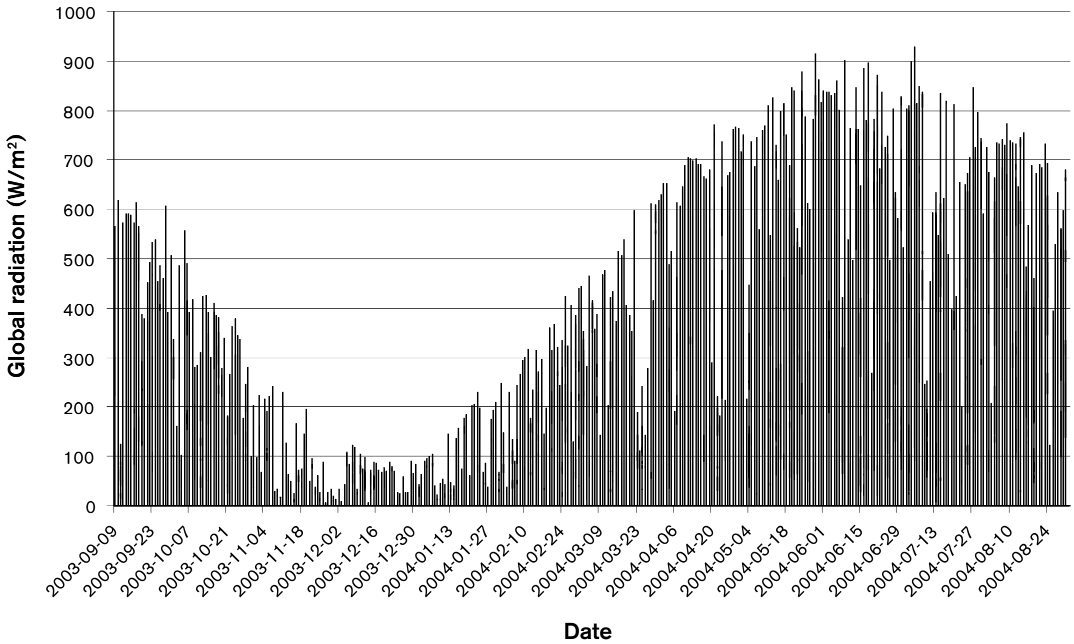


Figure 3-10. *Global radiation (W×m^{-2}) on Äspö during the period September 2003–September 2004.*

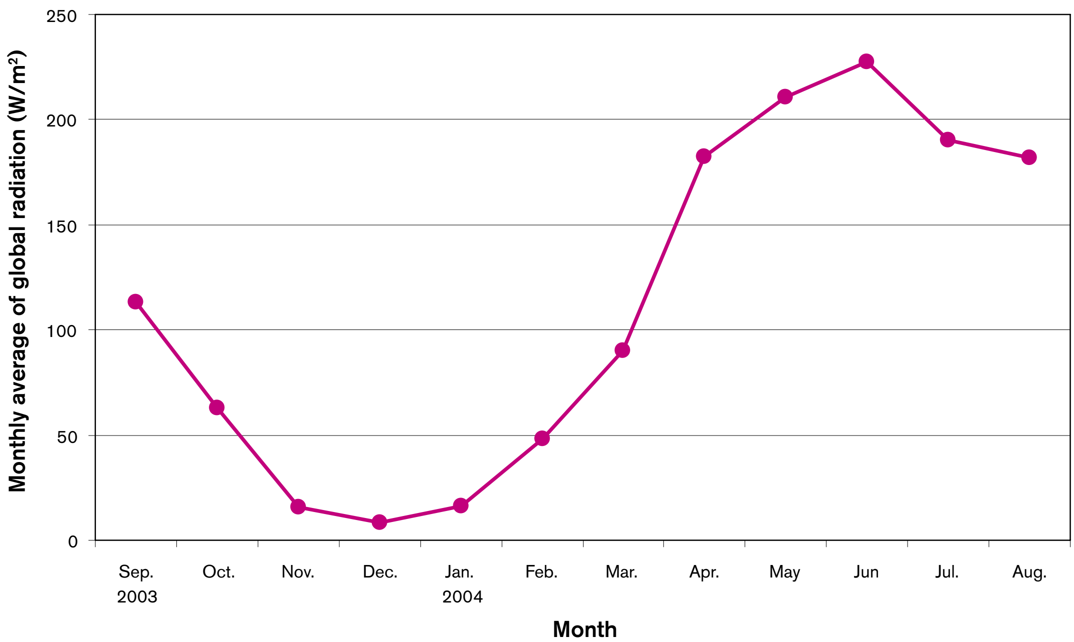


Figure 3-11. *Monthly average of global radiation (W×m^{-2}) on Äspö, September 2003–August 2004.*

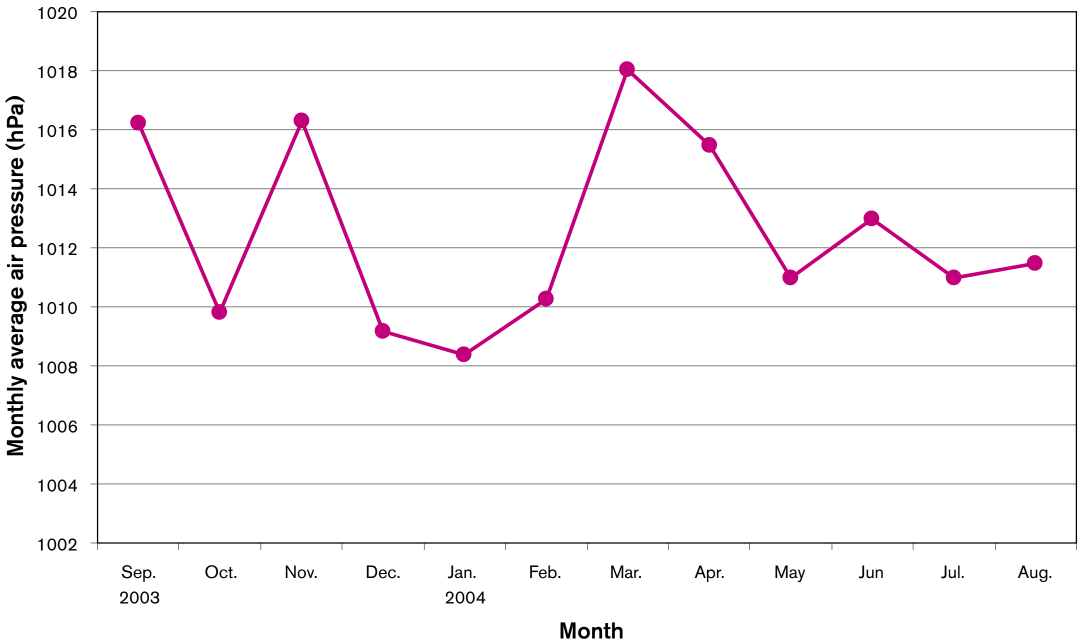


Figure 3-12. *Monthly average of air pressure (hPa) on Äspö, September 2003–August 2004.*

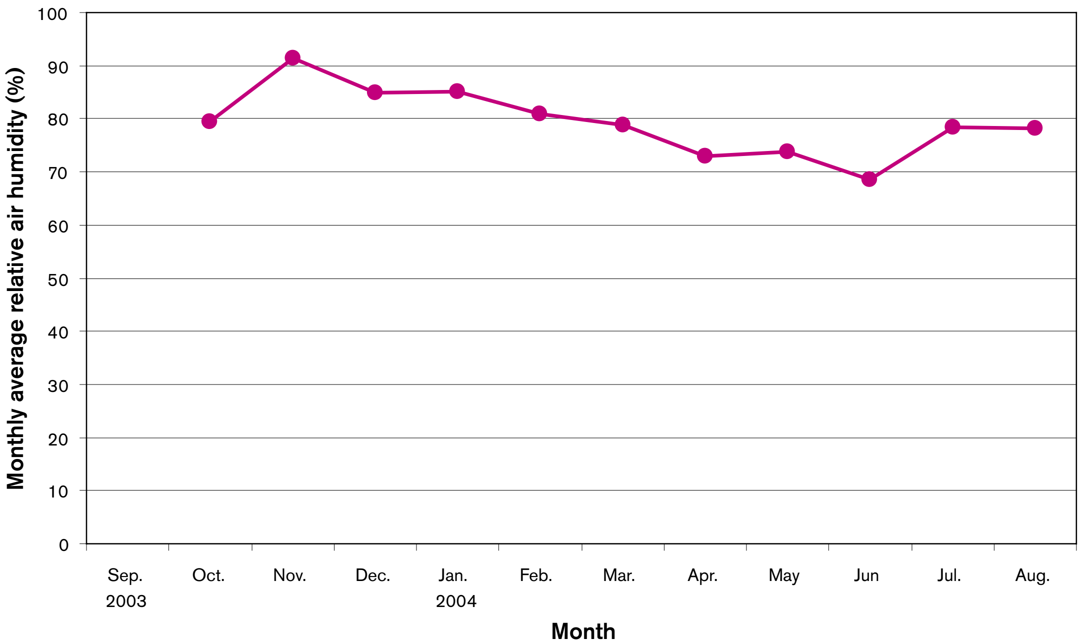


Figure 3-13. *Monthly average of relative humidity (%) on Äspö, October 2003–August 2004.*

3.2 Hydrological data

The delineation, size and land-use description of catchment areas presented in SDM S1.1 were only preliminary. Furthermore, no site-specific data were available on lakes, water courses and wetland areas. In addition, discharge data were only available from hydrological stations installed elsewhere within the region prior to the site investigations.

For S1.2, a detailed delineation and land-use description of catchment areas is available for the regional model area. The relative areas of different types of wetlands have also been calculated for each of the identified catchments areas in the Simpevarp regional area. Main water courses and lakes within the catchment areas have also been identified, although no complete set of morphologic data (cross-sections, bottom and surface water levels) is yet available. In addition, a set of data from simple (manual) discharge measurements in some of the water courses has been reported to SICADA.

3.2.1 Catchment areas

The data on catchment areas were updated during 2004 based on an updated topographical map, air photographs and field checks, conducted in the spring and summer of 2004 /Brunberg et al. 2004/. This work resulted in a detailed delineation of 26 catchment areas in the Simpevarp area, as shown in Figure 3-14 below. These 26 catchment areas are further divided into totally 96 sub-catchments /Brunberg et al. 2004/. All 26 catchment areas are located within the SMHI catchment area no 72/73. Basic data (water courses/lakes, area and land use) for each catchment area are provided in Table 3-2. The notations for the land-use types (MA) are explained in Table 3-3.

Figure 3-14. *Delineation and numbering of the 26 catchment areas in the Simpevarp regional area. The map also shows the locations of the 6 identified lakes in the area (see Section 3.2.2).*

Table 3-2. 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 3-14. Names of water courses within quotation marks (“ ”) are working names for the site investigations.

CA no	Water course/lake	CA area (km^2)	MA1 (%)	MA2 (%)	MA3 (%)	MA4 (%)	MA5 (%)	MA6 (%)	MA7 (%)	MA8 (%)	MA9 (%)	MA10 (%)	MA11 (%)	MA19 (%)
1	“Långbonäsbäcken”	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
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 water course/ 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	”Flakvarpebäcken”	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	”Stekflagebäcken”	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	”Lindströmmebäcken”	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

Table 3-3. Explanations of the land-use types in Table 3-2 /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

There are totally 6 lakes in the regional Simpevarp area /Brunberg et al. 2004/:

- 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 the list, 7:2 denotes sub-catchment area no 2 in the "main" catchment area no 7. Morphometry parameters for 5 of the above lakes are presented in Table 3-4. The table also includes the SKB hydrological stations currently in operation (as of November 2004). No data are yet available for the lake Grangöl, as it was not included in the field investigation programme /Brunberg et al. 2004/.

Moreover, there are four additional lakes situated within the upper parts of Laxemarån, within catchment area no 10, which were not included in the field investigations, partly because they were judged completely dry from IR photos. Thus, the main reason for not including these lakes was their unclear hydrological conditions; however, the final judgement is that they are also part of the catchment area no 10 /Brunberg et al. 2004/. The locations of the lakes are shown in Figure 3-14.

Table 3-4. Morphometry parameters 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
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 ($m^3 \times s^{-1}$)	0.0098	0.0016	0.0036	0.0369	0.0028
Retention time (days)	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	PSM000348		PSM000344	PSM000342	PSM000359

The terms used in Table 3-4 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.

It should be noted that the lake Söråmagasinet originally was a natural bay, which is now bounded by a dam wall and thereby has been turned into a lake. Lake Söråmagasinet is used as a reserve water supply for OKG AB /Kenneth Gustafsson, OKG AB, pers comm/. Sometimes, water is pumped from Ström at the water course Laxemarån to Söråmagasinet in order to maintain the water storage in the lake (see also Section 3.4).

3.2.3 Wetlands

S0 stated that "there are no wetlands within the Simpevarp regional model area and its surroundings that can affect the hydrological conditions". S1.1 gave only a general description of different types of wetlands, but included no site-specific data.

For S1.2, the relative areas of different types of wetlands have been calculated for each of the identified 26 catchments areas in the Simpevarp regional area /Brunberg et al. 2004/. This is done by adding the land-use types MA3 and MA7–11 in Table 3-3. The coverage (in %) of wetland areas thus represents varying parts of the other calculated land-use types. 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 repeated below the table.

As can be seen in Table 3-5, there are wetland areas in almost all catchments, except for catchments 6, 9, 20, and 24–26. There are currently no stratigraphical data or other information on peat or fine-grained sediments in lakes, shallow bays or wetlands. Such data will be available after the data freeze for Laxemar 1.2. The results from the investigations of Quaternary deposits show that many of the wetlands in the Simpevarp regional model area contain peat.

At two of the drilled sites in the Simpevarp subarea (SSM000020 and SSM000022), sand and gravel is covered by peat. The peat is often thinner than one metre /Rudmark, 2004/. The thickest observed peat layer is 1.5 m (SSM000022). The wetlands that contain peat have been ditched. 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 is therefore the dominating soil type in the wetlands. This soil type is probably common also in ditched wetlands.

Table 3-5. Basic data for wetlands in the Simpevarp area /Brunberg et al. 2004/.

Catchment	Relative wetland area (%)	Total wetland area (km²)	% 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 3-6. Explanations of the land use types in Table 3-5 /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

3.2.4 Water courses

A description of the main water courses was presented by /Brunberg et al. 2004/. The names and locations of the main water courses are presented in Table 3-7 and Figure 3-15. The mean discharge for each main water course was calculated as the estimated regional specific discharge (5.7 $l \times s^{-1} \times km^{-2}$) times the area of each catchment /Brunberg et al. 2004/. For S1.2, only X- and Y-coordinates for the water courses are stored in SKB-GIS. Data on surface-water levels or bottom levels along water courses are not yet available. Table 3-7 also gives the names of the associated SKB hydrological stations where discharge measurements are carried out.

Table 3-7. Main water courses in the Simpevarp area and estimated mean discharge /Brunberg et al. 2004/.

CA (cf Figure 3-14)	Water course	Mean discharge ($m^3 \times s^{-1}$)	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	PSM000364[1]
11	No water course	–	
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	PSM000370
22	"Stekflagebäcken"	0.0019	
23	"Vadvikebäcken"	0.0016	PSM000341
24	"Lindströmmebäcken"	0.0010	
25	"Gloebäcken"	0.0007	PSM000343
26	"Skölkebäcken"	0.0009	PSM000345

[1] Not yet in operation (as of November 2004).

Figure 3-15. *Names and locations of the main water courses in the Simpevarp regional model area /Brunberg et al. 2004/.*

3.2.5 Surface-water levels

For S0 and S1.1, no site-specific surface-water level data were available. For S1.2, surface water levels are available for five of the lakes in the regional area, see Table 3-8.

Table 3-8. Surface water levels for 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

3.2.6 Discharge data

Hydrological stations for discharge measurements were established during winter 2003/2004 in the Simpevarp area (three stations on Ävrö). However, new data from these stations were not available at the time of the Simpevarp 1.1 data freeze. Therefore, only results from pre-existing discharge stations in the region could be used for Simpevarp model version 1.1. For S1.2, data from simple discharge measurements, performed in connection to surface water sampling, in some water courses are stored in SICADA. Automatically logged data from local discharge stations are at the time of writing only stored in HMS (Hydro Monitoring System); as these data are not yet quality controlled by SKB, they are not included in the present report.

Regional discharge data

The hydrological station Forshultesjön nedre was used by /Larsson-McCann et al. 2002/ to provide an estimate of the regional discharge in the Simpevarp regional area. The regional mean specific discharge was estimated to 5.7 $l \times s^{-1} \times km^{-2}$, which corresponds to a runoff of approximately 180 $mm \times year^{-1}$. They also simulated the daily mean discharge for two other hydrological stations, Gerseboån (station GE1) and Laxemarån (station LA1). The calculated mean specific discharges for these stations are 4.7 and 5.4 $l \times s^{-1} \times km^{-2}$, respectively, corresponding to a runoff (discharge) of c 150 and 170 $mm \times year^{-1}$. The characteristic discharge of the three discharge stations Forshultesjön nedre, GE1 and LA1 are reproduced in Table 3-9.

Table 3-9. Characteristic discharge ($l \times s^{-1} \times km^{-2}$) for hydrological stations near Oskarshamn /SKB, 2004a/.

Station	Name	Characteristic discharge						Period
		Obs min	MLQ	MQ	MHQ	HHQ50	HHQ100	
1619	Forshultesjön	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

The terms in the Table 3-9 are explained as follows:

MLQ: Long-term average of annual minimum discharge.

MQ: Long-term average of annual discharge.

MHQ: Long-term average of annual maximum discharge.

HHQ50: Highest maximum flow, 50 years.

HHQ100: Highest maximum flow, 100 years

The characteristic discharges are based on daily mean values. The HHQ50 and HHQ100 values are based on calculations /Larsson-McCann et al. 2002/. The results for GE1 and LA1 are based on calculations, and those for lake Forshultesjön on measurements. Monthly discharge values for the station Forshultesjön nedre are shown in Figure 3-16. Also the daily mean discharges in the water courses Gerseboån (GE1) and Laxemarån (LA1) were simulated by SMHI /Larsson-McCann et al. 2002/. The results are summarised in Figures 3-17 and 3-18, which show calculated daily values each month.

It can be seen in Figures 3-16 to 3-18 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 model area, the discharges calculated for September and October are much larger than those during 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).

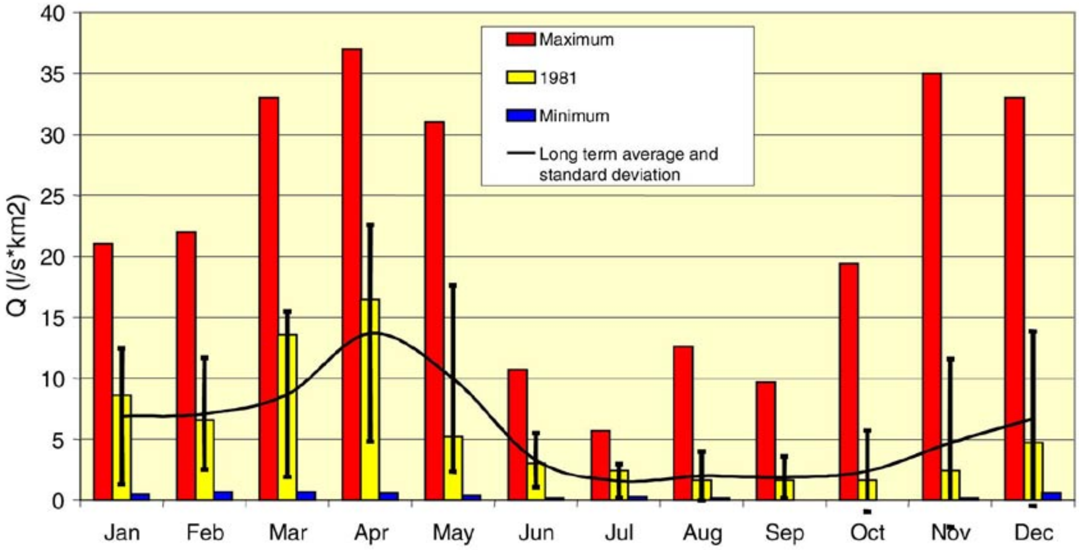


Figure 3-16. *Monthly discharge at hydrological station Forshultesjön nedre, 1955–2000; maximum and minimum daily mean, long term average and standard deviation ($l \times s^{-1} \times km^{-2}$). The year 1981 is selected as a representative year /Larsson-McCann et al. 2002/.*

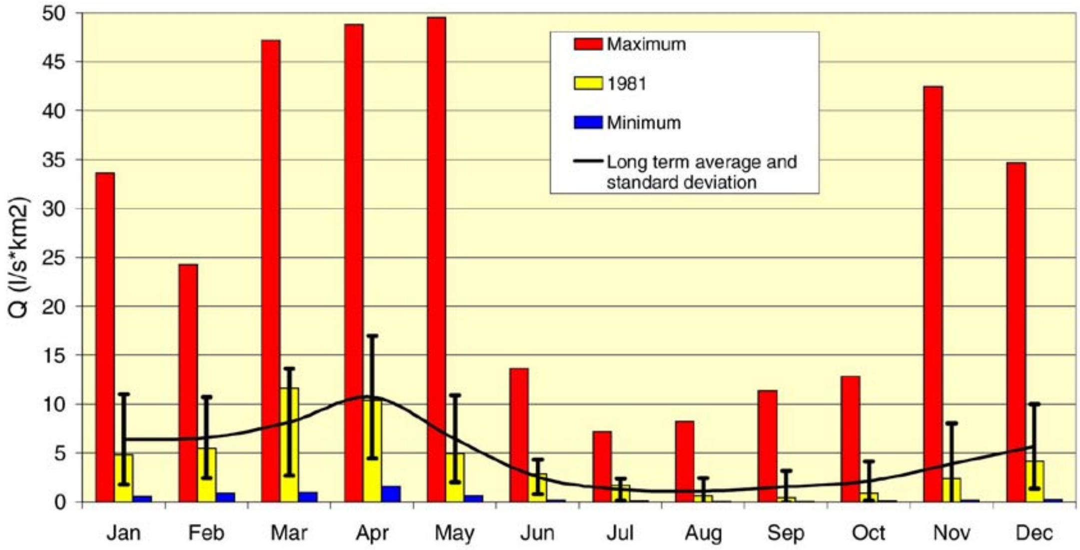


Figure 3-17. *Monthly simulated discharge at GE1 Gerseboån, 1962–2001; maximum and minimum daily mean, long term average and standard deviation ($l \times s^{-1} \times km^{-2}$). The year 1981 is selected as a representative year /Larsson-McCann et al. 2002/.*

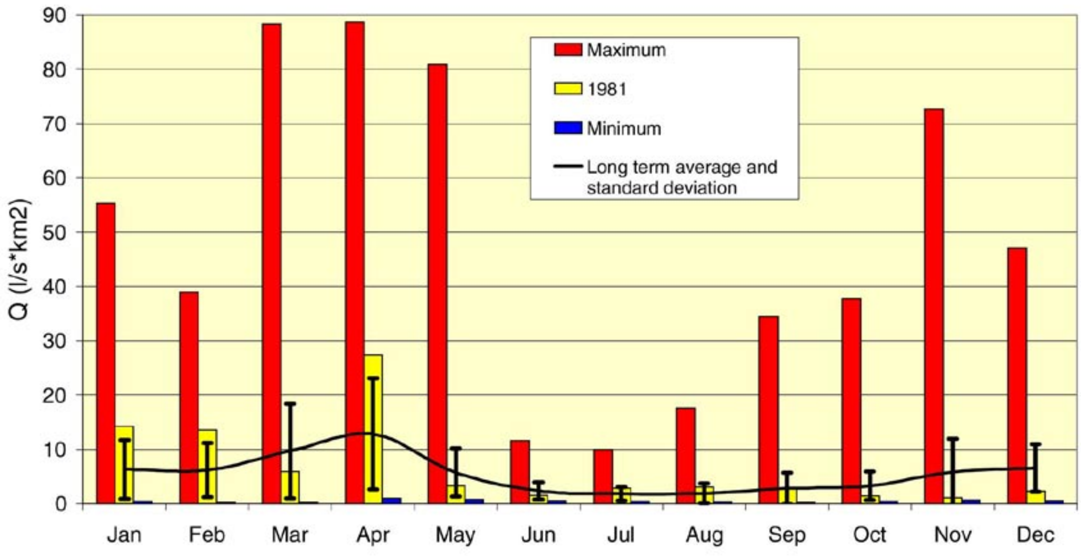


Figure 3-18. *Monthly simulated discharge at LA1 Laxemarån, 1961–2001; maximum and minimum daily mean, long term average and standard deviation ($l \times s^{-1} \times km^{-2}$). The year 1981 is selected as a representative year /Larsson-McCann et al. 2002/.*

Local discharge data

The planning for the hydrological measurement stations in the Simpevarp area is presented in /Lärke and Hillgren, 2003/. The table below summarises the status of local hydrological stations as of S1.2 (HMS = Hydro Monitoring System). Note that the table also includes measurement stations in lakes and in the sea. It is evident that a significant amount of hydrological information will be available when these stations have been in operation for some time. The locations of the stations are shown in Figure 3-19.

Table 3-10. Status of hydrological stations in the Simpevarp area.

Station	Type of measurements	Location, water course/lake, catchment area no	Data status for S1.2
PSM000341	Water level/discharge in water course, el cond, water temp	Ävrö, "Vadvikebäcken", catchment area 23	Data stored in HMS, not QC by SKB
PSM000342	Lake water level	Laxemar, lake Jämsen, catchment area 10	No data available
PSM000343	Water level/discharge in water course, el cond, water temp	Ävrö, "Gloebäcken", catchment area 25	Data stored in HMS, not QC by SKB
PSM000344	Lake water level	Laxemar, lake Plittorpsgöl, catchment area 10	No data available
PSM000345	Water level/discharge in water course, el cond, water temp	Ävrö, "Skölkebäcken", catchment area 26	Data stored in HMS, not QC by SKB
PSM000347	Lake water level	Laxemar, lake Frisksjön (in), catchment area 7	Not yet in operation
PSM000348	Lake water level	Laxemar, lake Frisksjön (out), catchment area 7	No data available
PSM000353	Water level/discharge in water course	Laxemar, Laxemarån (upper), catchment area 10	No data available; not yet surveyed
PSM000359	Lake water level	Simpevarp peninsula, lake Söråmagasinet, catchment area 11	Data stored in HMS, not QC by SKB

Station	Type of measurements	Location, water course/lake, catchment area no	Data status for S1.2
PSM000364	Water level/discharge in water course	Laxemar, Laxemarån (lower), catchment area 10	Not yet in operation
PSM000365	Water level/discharge in water course	Laxemar, “Ekerumsån”, catchment area 9	Simple discharge measurements available in SICADA
PSM000368	Water level/discharge in water course	Laxemar, Kärrviksån, catchment area 5	No data available
PSM000369	Sea water level	Äspö	Data stored in HMS, not QC by SKB
PSM000370	Sea water level	Äspö	Data stored in HMS, not QC by SKB
PSM000371	Sea water level	Simpevarp peninsula	Data stored in HMS, not QC by SKB

Figure 3-19. *Map showing the locations of the stations for discharge and water level measurements for which coordinates currently are available. The borders of the catchment areas are also shown.*

In connection to surface water sampling, “simple discharge measurements” have been performed at a number of locations in the water courses. The measurements have been carried out since the summer of 2003. The results are presented in /Ericsson and Engdahl, 2004a,b/; they were not included in S1.1. The sampling points PSM000362 and PSM000365 are located at two SKB hydrological stations. As the catchment areas for these stations have been estimated /Lärke and Hillgren, 2003/, rough estimates of the specific discharge ($l \times s^{-1} \times km^{-2}$) for these stations are included in the table. It can be seen that these estimates indicate considerably larger discharges than the regional one given above ($5.7\ l \times s^{-1} \times km^{-2}$). This is probably due to incomplete and inaccurate measurements, rather than a reflection of the actual site conditions. The locations of the stations are shown in Figure 3-20.

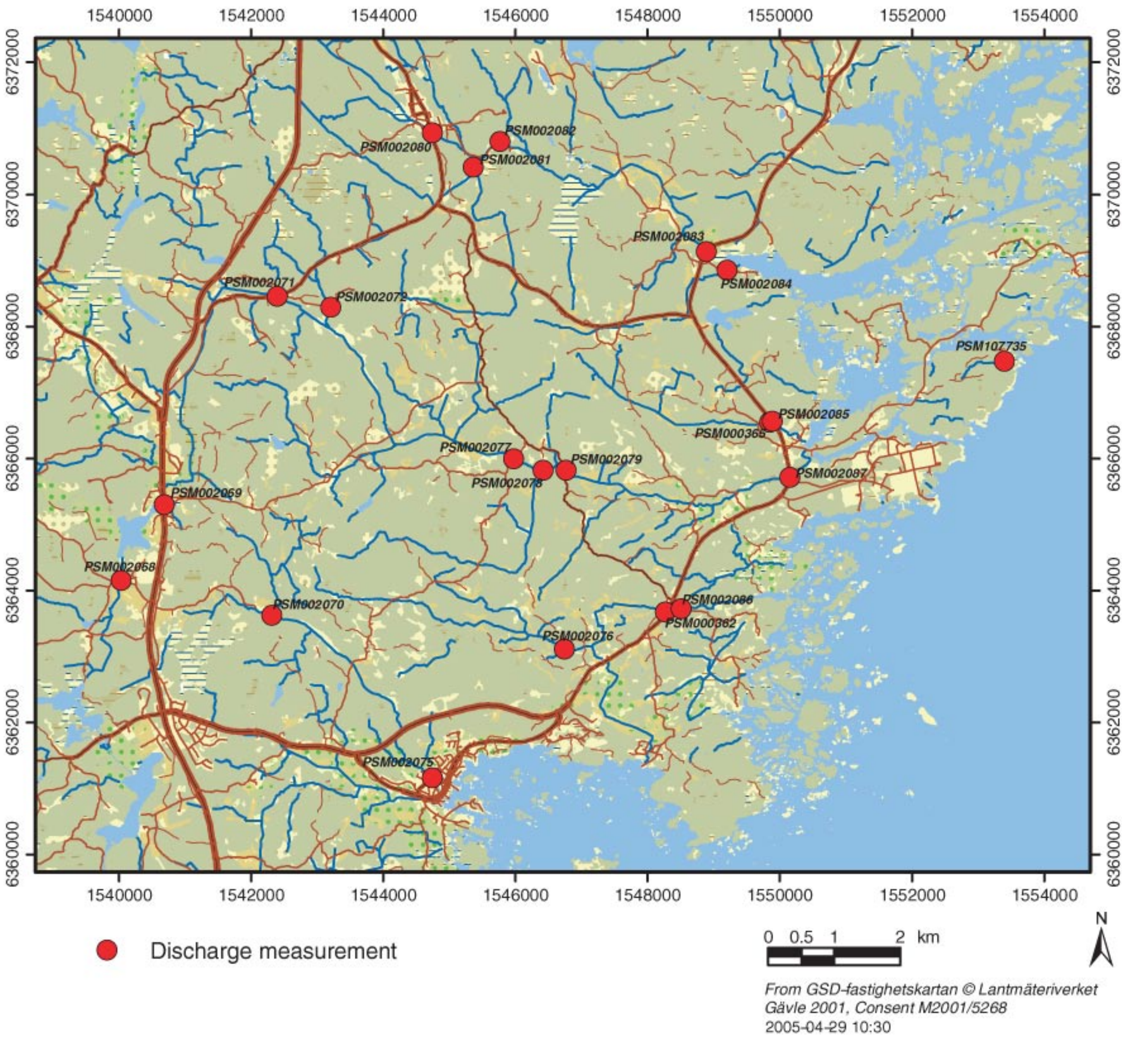


Figure 3-20. *Map showing the locations of simple discharge measurements in water courses.*

Table 3-11. Average runoff from simple discharge measurements in water courses /Ericsson and Engdahl, 2004a,b/.

Station	Location	Average discharge ($m^3 \times s^{-1}$)	Period with available discharge data (YYYY-MM-DD)	Number of measurements
PSM000362	SKB hydrological station. "Stålglobäcken", catchment area 13	2.98×10^{-2}	2004-03-17 to 2004-05-18	5
	Catchment area for station = 1.0 km^2 – specific discharge c 29.8 $l \times s^{-1} \times km^{-2}$			
PSM000365	SKB hydrological station, "Ekerumsån", catchment subarea 9:1	2.43×10^{-2}	2003-11-13 to 2004-06-14	13
	Catchment area for station = 2.4 km^2 – specific discharge 10.1 $l \times s^{-1} \times km^{-2}$			
PSM002068	Köksmåla, tributary to Laxemarån, catchment subarea 10:30	4.57×10^{-2}	2002-11-20 to 2004-09-27	52
PSM002069	int in water course (in Jämserum, lake Jämsen, at border between catchment subareas 10:25 and 10:30)	6.55×10^{-2}	2002-11-20 to 2004-08-24	55
PSM002070	Flohult, tributary to Släthultebäcken, border between catchments subareas 18:1 and 18:6	5.96×10^{-2}	2002-12-02 to 2003-12-15	23
PSM002071	Plittorp, tributary to Laxemarån, catchment subarea 10:25	1.18×10^{-1}	2002-12-02 to 2004-09-26	71
PSM002072	Lillekvarn, tributary to Laxemarån, catchment subarea 10:20	2.67×10^{-2}	2002-12-02 to 2003-12-19	26
PSM002075	Figeholm, Släthulte-bäcken/Norrån, border between catchment subareas 18:1 and 18:2	6.98×10^{-2}	2002-11-18 to 2003-12-02	29
PSM002076	Övrahammar, "Uthammarsån", catchment subarea 17:1	4.34×10^{-2}	2002-12-02 to 2004-08-25	26
PSM002077	Brolund, Laxemarån, catchment subarea 10:1	1.67×10^{-1}	2002-11-18 to 2003-12-17	31
PSM002078	Sillebäcken, tributary to Laxemarån, border between catchment subareas 10:1 and 10:8	3.68×10^{-2}	2002-11-18 to 2004-08-11	45
PSM002079	Kvarnstugan, tributary to Laxemarån, border between catchment subareas 10:1 and 10:7	1.45×10^{-1}	2002-11-18 to 2004-09-27	54
PSM002080	Misterhult, "Kärrviksån", catchment subarea 5:1	3.82×10^{-2}	2002-12-02 to 2003-12-19	17
PSM002081	Perstorpet, tributary to "Kärrviksån", catchment subarea 5:8	6.25×10^{-2}	2002-11-19 to 2004-05-11	23
PSM002082	Misterhultsbäcken, in "Kärrviksån", catchment subarea 5:1	1.91×10^{-1}	2002-11-19 to 2004-05-26	35
PSM002083	Smedtorpet, "Mederhultsån", catchment area 6	1.95×10^{-1}	2002-10-29 to 2004-09-27	70
PSM002084	Kärrsvik, "Kärrviksån", catchment subarea 5:1	4.54×10^{-2}	2002-10-29 to 2004-09-27	57
PSM002085	Ekerum, "Ekerumsån", catchment subarea 9:1	2.66×10^{-2}	2002-10-29 to 2004-08-25	50
PSM002086	Basteböla, "Stålglobäcken, catchment area 13	6.77×10^{-2}	2002-10-29 to 2004-07-13	27
PSM002087	Ekhyddan, Laxemarån, catchment subarea 10:1	2.25×10^{-1}	2002-10-29 to 2004-09-27	63
PSM107735	Ävrö, "Vadvikebäcken", catchment area 23	2.24×10^{-2}	2003-12-10 to 2004-08-10	11

The results of the simple discharge measurements, stored in SICADA, are shown in graphs in Appendix B. The figures show that surface water discharge in the water courses is a highly transient process during the year. There are several measurements with zero discharge, but also occasions with large discharges. These observations indicate that the discharge in the water courses mainly occurs in the form of "peaks" in connection to precipitation events and/or snow melt periods, and that the hydrologic system is relatively stagnant in between these events/periods.

3.3 Hydrogeological data

3.3.1 Hydrogeological properties

In S0 and S1.1, no site-specific hydrogeological data (hydraulic conductivity, storativity) were available for the Quaternary deposits or the interface between the Quaternary deposits and the bedrock. These previous model versions therefore included literature data and expected ranges for the hydraulic properties for different types of Quaternary deposits typical for Swedish geological conditions.

In the S1.2 data freeze, results from so-called slug tests 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 these tests is to provide estimates of the hydraulic conductivity (*K*) of the Quaternary deposits and/or the soil/rock interface /Johansson and Adestam, 2004b/. The tested monitoring wells have an inner diameter of 50 mm, and the lengths of the screens are 1 or 2 m. The results of the slug tests are presented in Table 3-12. The slug-tested wells are shown with green dots in Figure 3-21 ("probing borehole, group 2"). Green and red ("probing borehole, group 3") are wells for which manual groundwater level data are reported to SICADA (see Section 3.3.2). Yellow dots ("probing borehole, group 1") are wells installed in Quaternary deposits, but in which no slug tests have been performed (and no groundwater level data are stored in SICADA).

Note that in the parameter evaluation, the transmissivity T obtained from a slug test is defined as $T = K \times B$, where B is the smallest of the screen length and the aquifer depth /Johansson and Adestam, 2004b/. In cases where more than one slug test was performed, the *K*-value corresponding to the *T*-value reported to SICADA is marked with a *-symbol in Table 3-12.

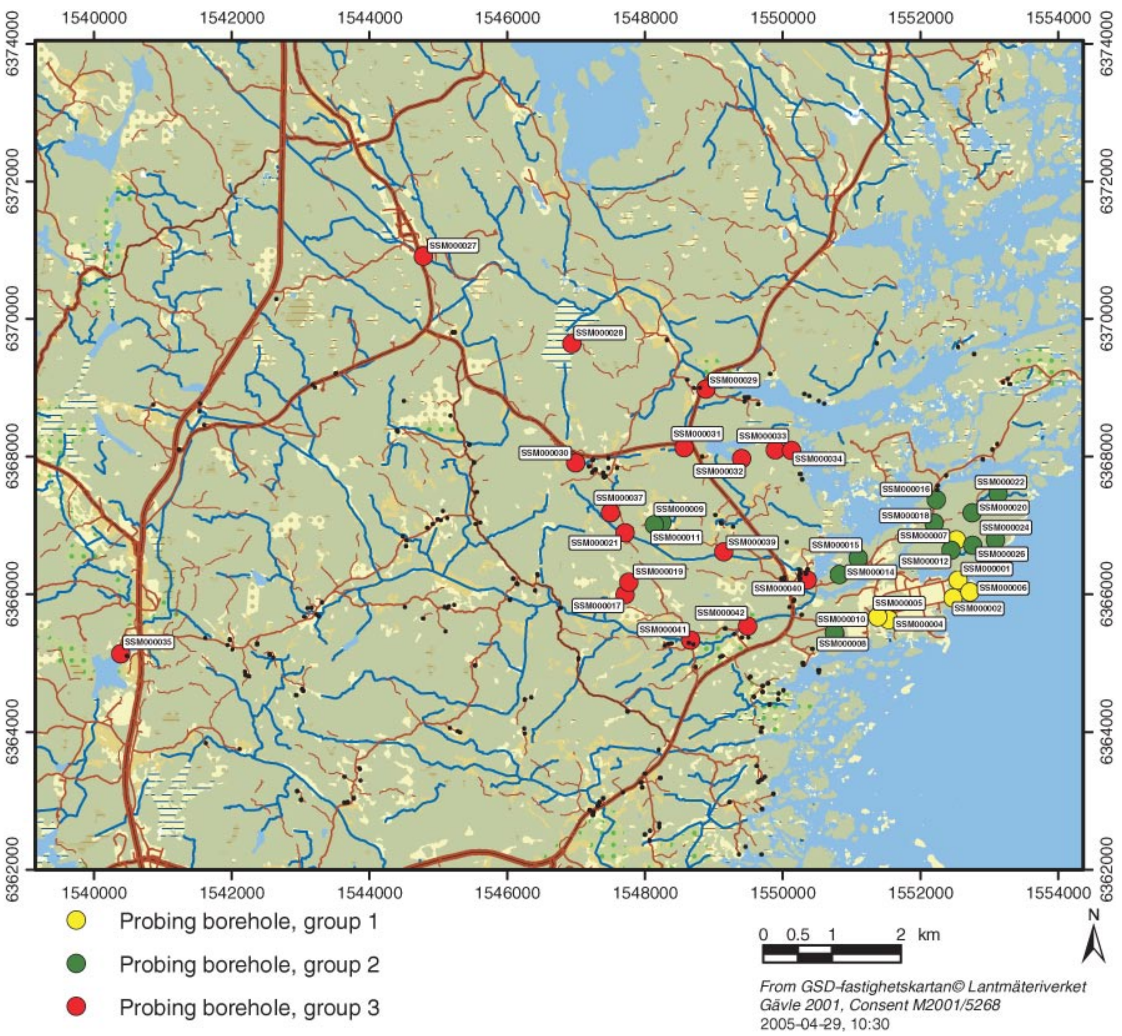


***Figure 3-21.** Map showing the locations of groundwater monitoring wells in the Simpevarp area. Green dots ("probing borehole, group 2") are wells where slug tests have been performed. Green and red dots ("probing borehole, group 3") are wells for which manual groundwater level data are reported to SICADA. Yellow dots ("probing borehole, group 1") are wells installed in Quaternary deposits, but in which no slug tests have been performed (and no groundwater level data are stored in SICADA).*

Table 3-12. Results of slug tests in 13 monitoring wells /Johansson and Adestam, 2004b/.

Well ID (location)	Evaluated hydraulic conductivity *K* ($m \times s^{-1}$)	Transmissivity *T* ($m^2 \times s^{-1}$), stored in SICADA	Screen length *B* (m)	Screen depth (m b g l[1])	Soil type at screen depth	Evaluation method
SSM000008 (Simpevarp peninsula)	4.03×10^{-5}	8.10×10^{-5}	2.00	2.6–4.6	Till (1.8–4.6), bedrock surface at 4.6	Hvorslev
SSM000009 (Laxemar)	5.67×10^{-6}	5.70×10^{-6}	1.00	2.6–3.6	Silty-sandy clay (2.5–3.0; no soil classification below 3.0), bedrock surface at 4.2	Bouwer and Rice

Well ID (location)	**Evaluated hydraulic conductivity *K* (m×s⁻¹)**	**Transmissivity *T* (m²×s⁻¹), stored in SICADA**	**Screen length *B* (m)**	**Screen depth (m b g l[1])**	**Soil type at screen depth**	**Evaluation method**
SSM000010 (Simpevarp peninsula)	2.52×10^{-5}	2.50×10^{-5}	1.00	1.4–2.4	Till (1.4–2.0; no soil classification below 2.0), bedrock surface at 2.0	Hvorslev
SSM000011 (Laxemar)	3.32×10^{-6}	5.50×10^{-6}	2.00 (B = aq thickness 1.66 m)	0.8–2.8	Bouldery-gravelly sand (0.5–2.0), silty-sandy till (2.0–2.8), bedrock surface at 2.8	Bouwer and Rice
SSM000012 (Ävrö)	2.16×10^{-6}	2.20×10^{-6}	1.00	4.7–5.7	Silty-sandy till (3.0–5.7), bedrock surface at 6.1	Hvorslev
SSM000014 (Hålö)	3.31×10^{-5}	3.30×10^{-5}	1.00	1.2–2.2	Clayey-gravelly sand (1.0–2.4), bedrock surface at 2.4	Bouwer and Rice
SSM000015 (Hålö)	1.19×10^{-4}	1.20×10^{-4}	1.00	3.8–4.8	No soil classification at screen depth, bedrock surface at 4.8	Hvorslev
SSM000016 (Ävrö)	1.48×10^{-4}	1.50×10^{-4}	1.00	1.5–2.5	Stony-gravelly sand (0.25–1.8; no soil classification below 1.8), bedrock surface at 2.6	Bouwer and Rice
SSM000018 (Ävrö)	*1.83×10^{-4} 6.10×10^{-4} ($T = 6.10\times10^{-4}$, $S = 5\times10^{-7}$)	1.80×10^{-4}	1.00	1.8–2.8	Clayey till (1.8–3.0), bedrock surface at 3.2	Hvorslev Cooper-Bredehoeft-Papadopulos
SSM000020 (Ävrö)	*6.61×10^{-5} 2.76×10^{-4} ($T = 1.10\times10^{-5}$, $S = 1\times10^{-5}$)	2.60×10^{-5}	1.00 (B = aq thickness 0.4 m)	1.5–2.5	Clay (0.6–2.0), gravelly-sandy till (2.0–2.3; no soil classification below 2.3), bedrock surface at 2.4	Hvorslev Cooper-Bredehoeft-Papadopulos
SSM000022 (Ävrö)	*1.85×10^{-5} 4.48×10^{-4} ($T = 4.48\times10^{-4}$, $S = 5\times10^{-7}$)	3.70×10^{-5}	2.00	4.6–6.6	Silty clay (4.6–4.8), silty sandy till (4.8–7.0), bedrock surface at 8.6	Hvorslev Cooper-Bredehoeft-Papadopulos
SSM000024 (Ävrö)	1.95×10^{-6}	2.00×10^{-6}	1.00	2.25–3.25	Sandy till (1.6–4.2), bedrock surface at 4.2	Bouwer and Rice
SSM000026 (Ävrö)	*1.52×10^{-5} 1.86×10^{-4} ($T = 1.86\times10^{-4}$, $S = 5\times10^{-7}$)	3.00×10^{-5}	2.00	1.8–3.8	Sandy till (1.7–4.0), bedrock surface at 4.2	Hvorslev Cooper-Bredehoeft-Papadopulos

[1] Metres below ground level.

The *K*-values obtained from the evaluation vary between 1.95×10^{-6} and 1.83×10^{-4} m×s^{-1}. Considering all wells, the geometric mean of *K* is 2.11×10^{-5} m×s^{-1}, whereas the arithmetic mean and the median of *K* are 5.09×10^{-5} and 2.52×10^{-5} m×s^{-1}, respectively. The standard deviation of log-*K* is 0.6815. Assuming a log-normally distributed *K*, the 95% confidence interval for the arithmetic mean hydraulic conductivity is $8.97\times10^{-6} < 2.11\times10^{-5} < 4.94\times10^{-5}$ m×s^{-1}. The 95% confidence interval for a new measurement is broader, $9.72\times10^{-7} < 2.11\times10^{-5} < 4.56\times10^{-4}$ m×s^{-1}.

It can be noted that an evaluation of slug tests by means of the Cooper-Bredehoeft-Papadopulos method provides values of both *K* and storativity (*S*) of the tested section, whereas the Hvorslev and Bouwer and Rice methods provide values of *K* only. The evaluated values of *S* are, however, not stored in SICADA; they are only available in the corresponding P-report /Johansson and Adestam, 2004b/.

Data from slug tests in an additional 17 groundwater monitoring wells planned or already installed in the Laxemar subarea (SSM000027–43) will be available in the L1.2 data freeze. It can also be noted that a rough estimation of the hydraulic conductivity of soil can be estimated using data from grain-size analyses as a complement to slug tests. Such data will also be included in the L1.2 data freeze.

3.3.2 Groundwater levels

No site-specific data on groundwater levels in Quaternary deposits were available for S0 or S1.1. The data freeze for S1.2 includes manually measured groundwater levels in 29 groundwater monitoring wells, installed in soil in both the Simpevarp and Laxemar subareas. The locations of these wells are shown as green ("borehole probe, group 2") and red dots ("borehole probe, group 3") in Figure 3-21. In addition, loggers for automatic measurements of the groundwater pressure have been installed in the following groundwater monitoring wells: SSM000001–2, SSM000004–5 and SSM000008 (Simpevarp peninsula), SSM000009 and SSM000011 (Laxemar), SSM000012 (Ävrö), SSM000014 (Hålö), and SSM000018 and SSM000022 (Ävrö). However, these automatically logged data are at time of writing only stored in HMS (Hydro Monitoring System); as these data are not yet quality controlled by SKB, they are not included in the present report.

Results of the manual groundwater level measurements stored in the SICADA database are presented in Table 3-13. It can be noted that groundwater levels were measured in connection to installation of each of the wells SSM000001–2 and SSM000004–5 /Ask, 2004a/, SSM000006–7 /Ask, 2004b/, SSM000008–12, SSM000014–16, SSM000018, SSM000020, SSM000022, SSM000024 and SSM000026 /Johansson och Adestam, 2004a/. However, data from these measurements are not stored in the SICADA database; generally, measurements performed just after well installations must be regarded as highly uncertain.

Monitoring wells SSM000001–26 (except SSM000009 and -11) are located in the Simpevarp subarea, whereas wells SSM000009–11 and SSM000027–42 are located in the Laxemar subarea. In the Laxemar 1.2 data freeze, manual groundwater level data and automatically logged groundwater pressure data will be available for longer time series.

Table 3-13. Manually measured groundwater levels. Numbers are rounded off to two decimals.

Well ID	Date (YYYY-MM-DD hh:mm)	Groundwater level (m b ToSP [1])	Ground level (m a s l)	ToSP [1] (m a s l)	Groundwater level (m a s l)
SSM000008	2004-03-22 09:33	0.45	4.24	4.64	4.19
	2004-03-23 07:25	0.40			4.24
	2004-06-15 09:53	0.71			3.93
SSM000009	2004-04-02 11:40	1.60	14.92	15.32	13.72
	2004-04-05 07:30	1.62			13.70
SSM000010	2004-03-22 09:00	0.83	4.49	5.09	4.26
	2004-03-23 07:40	0.80			4.29
	2004-06-16 07:40	1.11			3.98
SSM000011	2004-04-02 11:25	1.05	16.30	16.50	15.45
	2004-04-05 07:45	1.05			15.45
SSM000012	2004-03-24 08:43	0.80	1.47	1.77	0.97
	2004-03-25 09:23	0.83			0.94
SSM000014	2004-03-22 10:00	1.40	0.84	1.64	0.24
	2004-03-23 08:05	1.37			0.27
	2004-06-16 08:05	1.63			0.01
SSM000016	2004-03-22 10:40	1.35	1.87	2.37	1.02
	2004-03-23 09:45	1.10			1.27
SSM000017	2004-05-05 11:50	0.84	10.34	10.99	10.15
	2004-05-06 08:10	0.84			10.15
SSM000018	2004-03-22 10:20	0.37	0.58	0.78	0.41
	2004-03-23 09:30	0.37			0.41
	2004-06-16 09:30	2.43			–1.65
SSM000019	2004-05-05 11:20	2.55	12.72	13.21	10.96
	2004-05-06 07:55	2.27			10.94
SSM000020	2004-03-22 11:05	0.95	5.62	6.12	5.17
	2004-03-23 09:17	0.92			5.20
	2004-06-16 09:17	2.00			4.12
SSM000021	2004-05-05 10:45	1.57	12.18	12.63	11.06
	2004-05-06 08:25	1.59			11.04
SSM000022	2004-03-22 11:25	0.58	4.63	5.03	4.45
	2004-03-23 09:00	0.58			4.45
SSM000024	2004-03-25 08:55	0.66	2.36	2.90	2.24
SSM000026	2004-03-24 09:10	0.50	2.47	2.67	2.17
	2004-03-25 08:40	0.48			2.19
SSM000027	2004-09-25 08:40	1.64	9.01	9.21	7.57
	2004-09-27 08:50	1.62			7.59
SSM000028	2004-09-15 09:00	0.63	3.54	4.09	3.46
	2004-09-16 08:44	2.00			2.09
SSM000029	2004-09-15 08:30	0.79	0.76	1.26	0.47
	2004-09-16 08:25	0.91			0.35
SSM000030	2004-09-26 08:56	1.63	Not reported in SICADA	Not reported in SICADA	
	2004-09-27 08:34	1.60			
SSM000031	2004-09-08 09:50	1.10	5.72	6.32	5.22
	2004-09-09 08:15	1.11			5.21
SSM000032	2004-09-13 09:47	1.29	1.62	2.81	1.52
	2004-09-14 09:30	2.41			0.40
SSM000033	2004-09-13 09:47	0.94	5.12	5.82	4.88
	2004-09-14 09:30				
SSM000034	2004-09-13 08:56	0.62	–0.02	0.48	–0.14
	2004-09-14 08:55	0.72			–0.24
SSM000035	2004-09-22 08:25	1.59	26.61	27.11	25.52
	2004-09-23 08:40	2.78			24.33

Well ID	Date (YYYY-MM-DD hh:mm)	Groundwater level (m b ToSP [1])	Ground level (m a s l)	ToSP [1] (m a s l)	Groundwater level (m a s l)
SSM000037	2004-09-15 09:40	1.48	12.35	12.70	11.22
	2004-09-16 09:10	1.50			11.20
SSM000039	2004-09-08 09:25	3.38	11.10	11.70	8.32
	2004-09-09 07:55	3.37			8.33
SSM000040	2004-09-08 08:55	0.97	0.26	1.16	0.19
	2004-09-09 07:35	1.14			0.02
SSM000041	2004-09-22 09:15	1.97	3.36	4.15	2.18
	2004-09-23 09:11	1.96			2.19
SSM000042	2004-09-22 09:38	2.37	2.55	3.35	0.98
	2004-09-23 09:45	2.38			0.97

[1] ToSP denotes top of the stand pipe.

3.3.3 Private wells

Private wells in the regional area were investigated and summarised by /Morosini and Hultgren, 2003/. Appendix A provides a table with basic data on these wells, and Figure 3-22 shows their locations. 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 $m^3 \times h^{-1}$ (2.10×10^3 and 4.38×10^4 $m^3 \times y^{-1}$), with a mean value of 1.568×10^4 $m^3 \times y^{-1}$; the standard deviation is large, 1.614×10^4 $m^3 \times y^{-1}$.

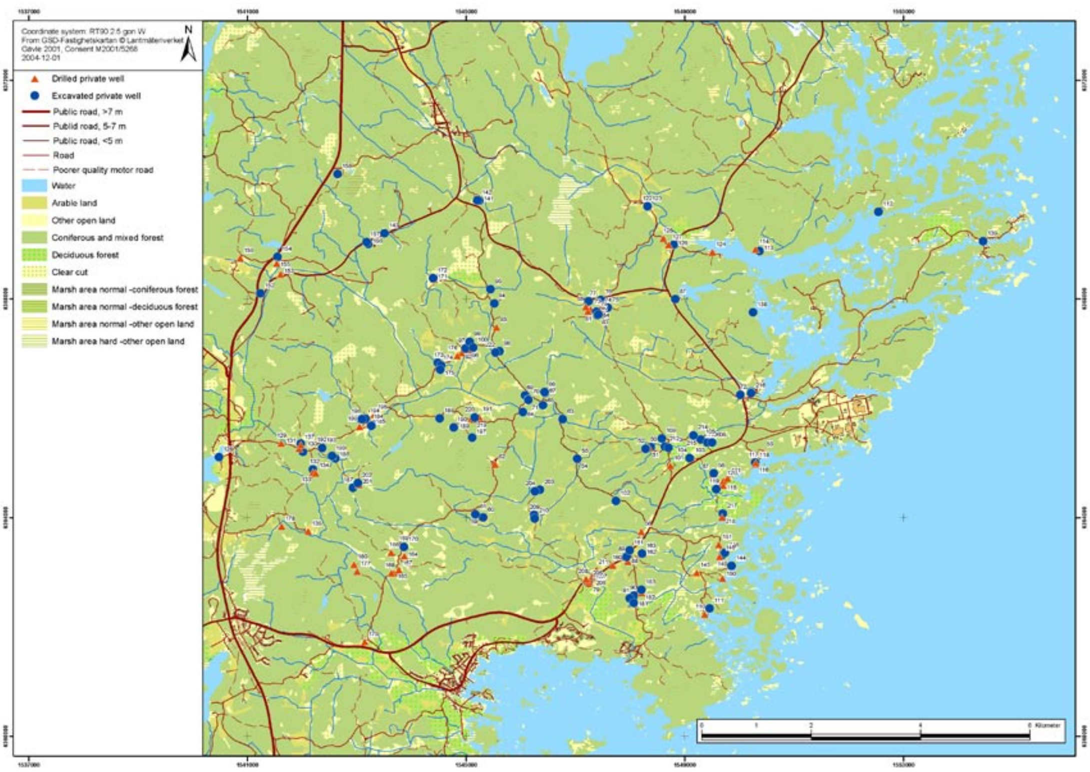


Figure 3-22. Map showing the locations of private wells in the Simpevarp regional model area.

3.4 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 AB, which owns and operates the nuclear power plant on the Simpevarp peninsula, in responsible for the major part of the artificial water handling activities in the regional model 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 primary data, and that more detailed material will be presented in connection with future model versions. Since 1972, data on surface water levels and pumping rates are available in a paper log-book at OKG AB. These data are not reported to the SICADA database and are therefore not used in the S1.2 analysis/modelling.

3.4.1 Water supply

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 AB):

- Up to the end of the 1980's, water was pumped from the lake Trästen (situated west of the Laxemar subarea, upstream of the lake Fårbosjön) into the lake Jämsen, which has its natural outlet in the water course Laxemarån. Drinking- and process water for OKG was during this period pumped from Ström in Laxemarån. The purpose of the pumping from the lake Trästen to the lake Jämsen was to compensate for the pumping from Laxemarån.
- Since 1983, drinking- and process water for OKG is pumped from the lake Götemaren (situated north of the Laxemar subarea) in a pipeline to OKG's own water plant. At present, approximately 150,000–200,000 m^3 of water is pumped each year (information from www.okg.se).
- At present, the lake Söråmagasinet is used as a 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 in Laxemarån into the lake Söråmagasinet in order to maintain the available water storage in the lake.
- Cooling water for the power plant is pumped from the sea.

3.4.2 Storm and waste water handling

The sea is the recipient for storm water from the OKG industrial area (pers. comm. with Pär Grahm, OKG AB). The main part of the storm water is discharged into Hamnefjärden, where it is mixed with the cooling water from the power plant. Storm water from the areas south and east of the O2 reactor building (including the central workshop and some oil tanks) are handled 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. The pond is connected to the sea via a creek. It 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 AB).

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.

4 Conceptual and descriptive modelling

4.1 General

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 (hydrogeological) descriptive model defines, based on a specified conceptual model, geometries of domains and parameters assigned to these domains. This chapter presents a discussion on the conceptualisation of the hydrological and hydrogeological processes within the regional model area, and an attempt to further develop the descriptive model of the site.

Thus, the aim of the present chapter is to provide a description of near-surface hydrogeological and surface-hydrological processes, and to identify data and specific parameters that can be used for quantitative modelling of site-specific groundwater and surface water flows (see Chapter 5). Specifically, the objectives of the descriptive modelling in S1.2, for both the Simpevarp and Laxemar subareas, are to:

- Provide an overview of the climatological, surface-hydrological and near surface-hydrogeological conditions.
- Describe areas, domains and interfaces between domains relevant for surface- and near-surface water systems.
- Describe the conditions for surface water and near-surface groundwater flow in the area.
- Exemplify how supporting evidence from other disciplines and models can be used.

The confidence and uncertainties related to the S1.2 descriptive model are discussed in Chapter 6.

Compared to S1.1, which treated hydrology and hydrogeology separately, the S1.2 descriptive modelling integrates the aspects of climate, hydrology and hydrogeology. In addition, S1.1 was regional in character. S1.2, as far as possible based on the currently limited amount of site-specific primary data (see Chapter 3), aims at local-scale modelling. Due to the small amount of site-specific data, the conceptual and descriptive modelling is also here based on the current general knowledge of the surface hydrology and near-surface hydrogeology in the regional model area.

Figure 4-1 illustrates SKB's systems approach to hydrogeological descriptive modelling of groundwater flow. The division into three types of hydraulic domains (overburden (soil), rock mass and conductors in rock) 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 (overburden) and the upper part of the bedrock, provide input to

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

In the present context, where the HSDs are investigated in detail, a further division is made of the near-surface hydrogeology (type areas, domains and interfaces) than shown in Figure 4-1.

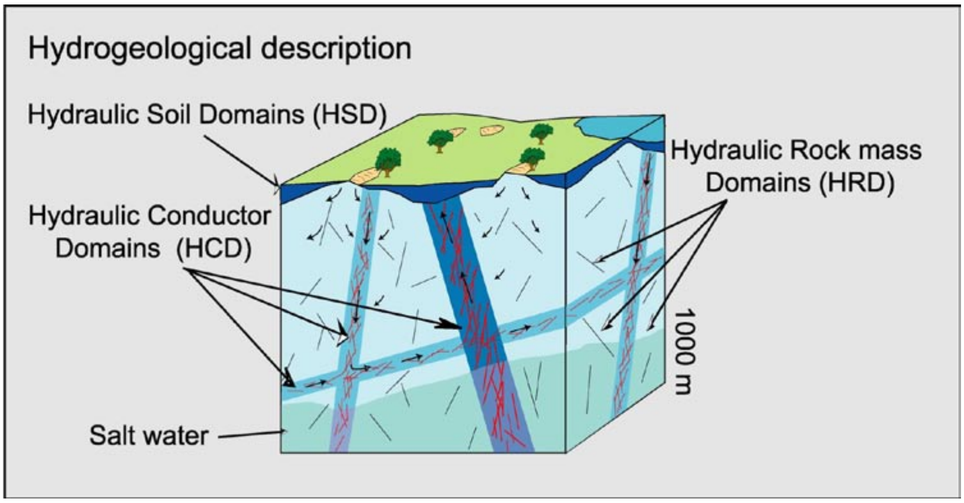


Figure 4-1. *Division of the Quaternary deposits (overburden) and the bedrock into hydraulic domains representing the overburden (HSD) and the rock domains (HRD) between fracture zones modelled as conductor domains (HCD). Within each domain the hydraulic properties are represented by mean values, or by statistical distributions /Rhén et al. 2003/.*

A complete descriptive model of the surface hydrology and the hydrogeology at a site involves a description of the integrated (continuous) hydrogeological-hydrological system, i.e. groundwater in bedrock, groundwater in Quaternary deposits and surface waters. The focus of the modelling presented here is on the surface- and near-surface conditions. The hydrogeological properties of the bedrock and the lower boundary condition used in the quantitative modelling are therefore not described in the descriptive model. The bedrock properties and the interaction between Quaternary deposits and bedrock are described in Chapter 5 (Quantitative flow modelling).

4.2 Overview of site conditions

The meteorological conditions in the Simpevarp area are characterised by a mean temperature that varies between –2°C (January–February) and 16–17°C (July). The measured (uncorrected) annual precipitation is 500–600 mm×y^{-1}, with a slight tendency to increase inland. During the period September 2003–September 2004, the average air temperature measured at the meteorological station on Äspö was 7.4°C. Among the nearby SMHI stations used for comparison, Gladhammar (7.2°C) showed the smallest temperature difference to Äspö. During the same period, the measured (uncorrected) precipitation on Äspö (671 mm) was also most similar to the station at Gladhammar (677 mm).

The model area is characterized by a relatively small-scale topographical undulation (see Figure 4-2) and by relatively shallow Quaternary deposits. Almost the entire area is below 50 m above sea level, and the whole Simpevarp regional area is located below the highest coastline. Hydrologically, the area can be described as consisting of a large number of relatively small catchments, and it also contains a relatively large number of water courses (most of them are small). A crude water balance for the regional model area, based on approximate ranges of actual precipitation and evapotranspiration, yields a runoff in the range 150–180 mm×year^{-1} /SKB, 2004a/. The specific discharge in the regional model area has been estimated to 5.7 l×s^{-1}×km^{-2} /Larsson-McCann et al. 2002/.

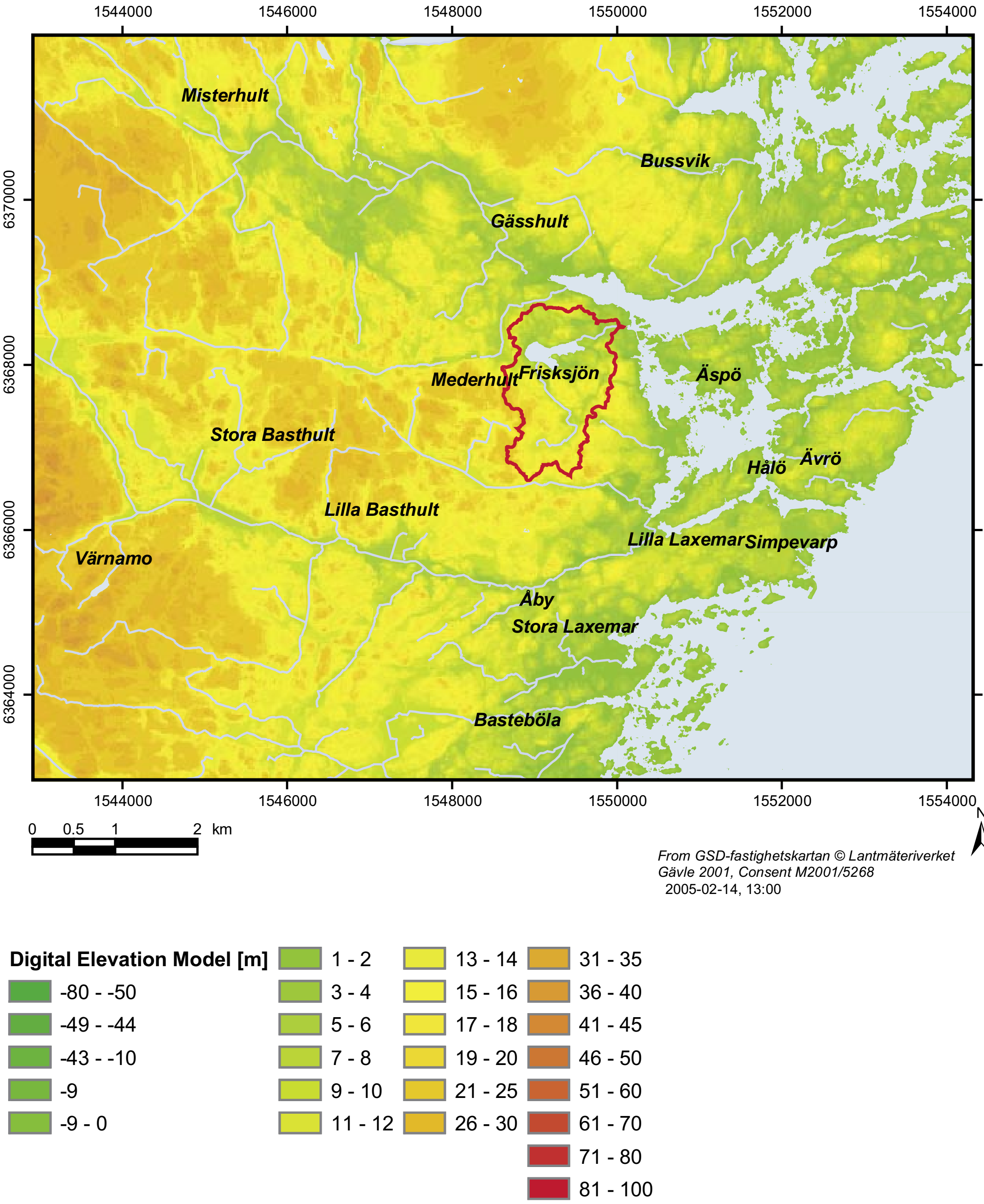


Figure 4-2. *Digital elevation model (DEM) of the regional model area.*

The Quaternary deposits are mainly located in the valleys, whereas the high-altitude areas are dominated by exposed bedrock, or thin layers of till and peat. Near-surface groundwater flow mainly takes place in the valleys, and is of a local character within each catchment area. The groundwater level in the Quaternary deposits is generally shallow. The hydrological, geological and hydrogeological conditions in the Laxemar subarea are currently less known. However, data on the surface distribution and stratigraphy of Quaternary deposits in the Laxemar subarea and the regional area will be provided in the L1.2 data freeze.

According to the presently available large-scale maps covering the Laxemar subarea, there is a lower degree of exposed bedrock and more abundant Quaternary deposits in Laxemar than in the Simpevarp subarea (see Figure 4-3). Furthermore, a preliminary conclusion is that the degree of exposed bedrock may be overestimated on the available geological maps. There are also three areas with glaciofluvial deposits (eskers) located in the Laxemar subarea.

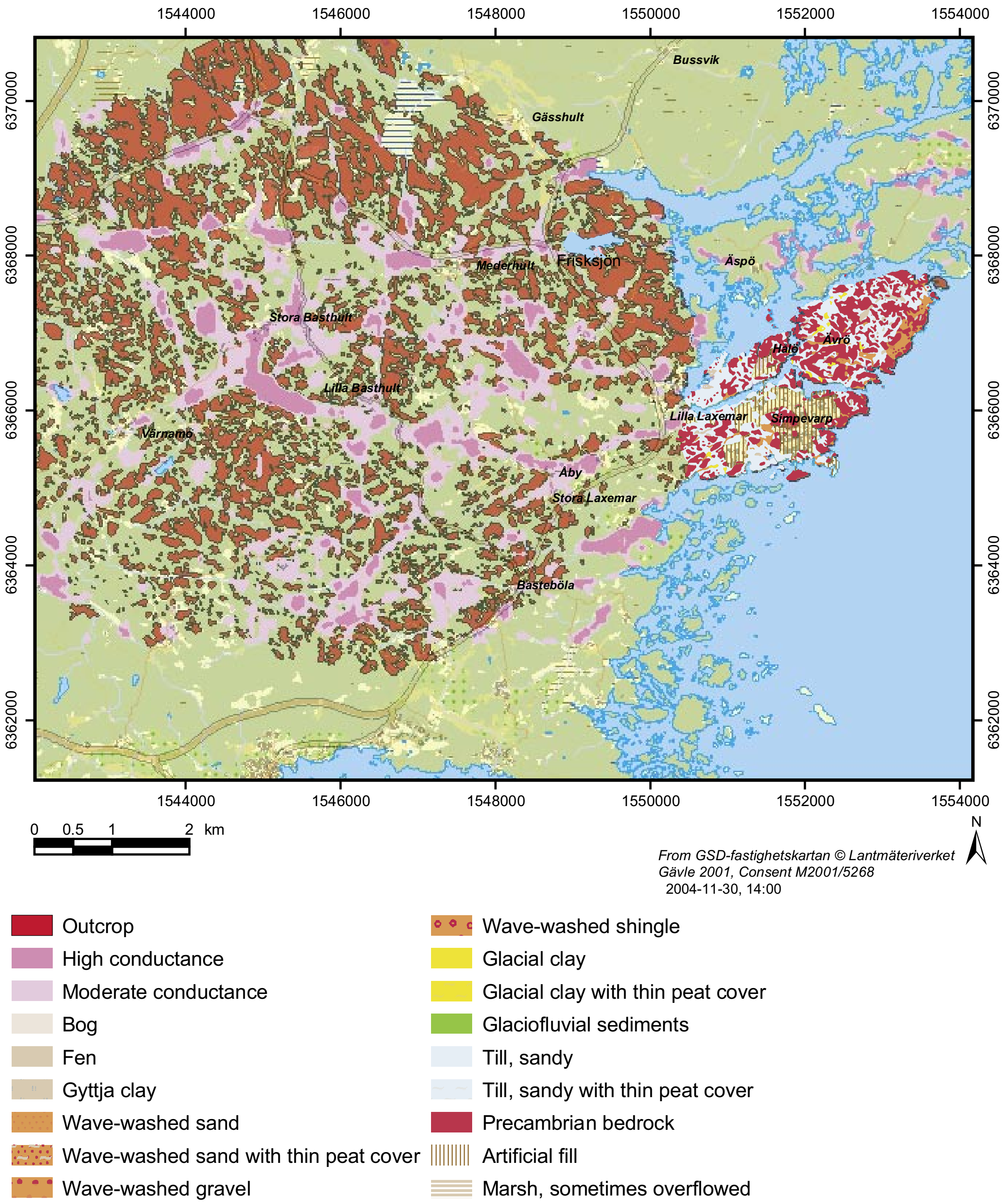


Figure 4-3. *Map showing map of Quaternary deposits (Simpevarp subarea) combined with results of air-borne geophysical measurements (Laxemar subarea).*

4.3 Descriptive model of surface hydrology and near-surface hydrogeology

4.3.1 Description of elements

The descriptive model of the regional area is based on three different types of hydrological/hydrogeological elements:

- **Type areas.** These are areas that are considered to be more or less similar from a geological-hydrological perspective.
- **Domains.** The overall SKB approach (Figure 4-1) is to divide the system into bedrock (HRDs and HCDs) and overlying deposits (HSDs). The focus in the present context is on HSDs, where several HSDs (types of Quaternary deposits) are identified and described, based on current data.
- **Interfaces between domains.** The interfaces between different parts of the hydrological-hydrogeological system are of interest, as these to a large extent control the flow of water between different subsystems.

The elements identified in the S1.2 modelling are described below.

Type areas

At present, most data on the Quaternary deposits (surface distribution and stratigraphy) are available from the Simpevarp subarea /Rudmark, 2004/. According to /Rudmark, 2004/, 47% of the Simpevarp subarea consists of exposed bedrock. In the regional model area, the present estimate is that the proportional surface distribution of Quaternary deposits and exposed bedrock is approximately 65% and 35%, respectively.

The Quaternary deposits mainly consist of till. The till can be characterized as sandy (at some locations sandy-gravelly), with a high frequency of stones and boulders. The thickest layers of Quaternary deposits are found in the low areas (valleys), where the till often is covered with postglacial deposits (clay and/or gyttja clay). A silt layer can be found between the till and the clay/gyttja clay. At many locations, a thin layer of sand is deposited above the clay/gyttja clay layer. A layer of fen peat/bog peat is formed above the other postglacial deposits at many locations. Coniferous forests and deciduous forests are covering most of the area and wetlands are found in places.

Three glaciofluvial deposits are located in the regional model area. The largest glaciofluvial deposit is Tunaåsen (the Tuna esker), located in the western part of the regional model area. The two smaller glaciofluvial deposits are located in the northern part of the regional model area. Artificial fill is located in the areas surrounding the power plant on the Simpevarp peninsula. There are also gravelly areas with a wave-washed surface layer, and some small fen areas on Ävrö and Hålö.

Based on presently available data on topography and Quaternary deposits, three basic hydrogeological type areas are identified in the present descriptive model (Figure 4-4 illustrates the first two of these type areas):

1. **Higher-altitude areas with exposed bedrock.** In these areas, till and/or peat occur in smaller depressions. It should be noted that also in some areas marked as exposed bedrock on the detailed map of Quaternary deposits /Rudmark, 2004/, there may be a thin (< 0.5 m) layer of soil and/or organic material, as the mapping depth (i.e. the depth at which the spatial distribution of deposits is mapped) is approximately 0.5 m.

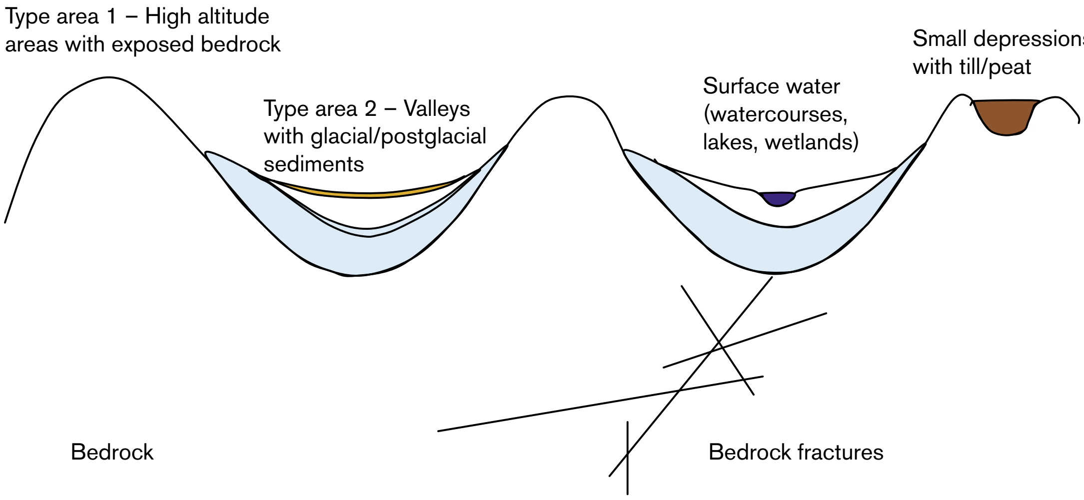


Figure 4-4. *Schematic cross-section illustrating the descriptive model of HSDs.*

2. **Valleys with glacial/postglacial sediments.** Large parts of the valleys are covered with till overlain by clay/gyttja clay, sand and peat at some locations.
3. **Glaciofluvial deposits.** Three areas with glaciofluvial deposits have been identified in the regional model area, cf above.

For L1.2, a much larger amount of site specific data on the surface distribution and stratigraphy within the Laxemar subarea will be available. Consequently, the division into type areas will most likely be more detailed in the L1.2 model.

Domains

The HSDs (cf Figure 4-1) as defined in S1.2 are listed in Table 4-1. The definitions of the HSDs are expected to be developed further after L1.2. For instance, the hydraulic properties and the thickness of glaciofluvial deposits (eskers) as well as other types of deposits (sand/gravel, clay, gyttja clay, gyttja, and peat) will be detailed when their occurrence and spatial distribution is better known. Table 4-1 shows the hydraulic properties of the Quaternary deposits (HSDs) that are used in the S1.2 modelling. The values within parentheses in the table are assumed in the MIKE-SHE modelling of the "Simpevarp 7" catchment area (see Chapter 5).

For the bedrock (HCDs and HRDs), the DarcyTools modelling team has provided input in terms of the spatial distribution of hydraulic conductivity (see Chapter 5). The hydraulic conductivity used for till is the average value from the slug tests performed in observation wells with the screen in till /Johansson and Adestam, 2004b/.

For peat, a range of K-values obtained from field tests in auger holes reported in the literature was presented by /Kellner, 2004/. The field data reported by /Kellner, 2004/ also indicate that K_H decreases with depth, whereas the ratio between the horizontal (K_H) and the vertical hydraulic conductivity (K_V) increases with depth. The specific yield S_Y for the different types of Quaternary deposits is taken from the literature, whereas the same value of the storage coefficient is used for all Quaternary deposits (see Chapter 5).

In the S1.2 descriptive model, it is assumed that isotropic conditions prevail within the individual soil layers (till, clay), i.e. that the horizontal and vertical hydraulic conductivities are equal ($K_H = K_V$). The occurrence of and reasons for anisotropic conditions in till have

Table 4-1. Assignment of hydraulic properties to HSDs in S1.2.

HSD	Type of Quaternary deposit	Thickness (m)	Hydraulic conductivity, K_H (ms^{-1})	K_H/K_V	Specific yield, S_Y (–) [4]	Storage coefficient, S_S (m^{-1}) [5]
1	Till (sandy) [1]	0.5–3 (1)	1.5×10^{-5}	1	0.16	0.001
2	Fine-grained glacial and postglacial sediments: clay and gyttja clay [2]	~ 1 (larger in some valleys) > 1.5 on Ävrö (4)	1×10^{-10}–1×10^{-8} (1×10^{-8})	1	0.03	0.001
3	Sand/gravel [2]	0.2 ~ 3 on Ävrö	10^{-4}–10^{0}	1	0.30–0.40	0.001
4	Peat [3]	0.5–1	10^{-7}–10^{-4}	0.1–3	0.24	0.001
5	Glaciofluvial deposits: coarse sand, gravel [2]	< 30 (large esker in W part of reg model area)	10^{-4}–10^{0}	1	0.30–0.40	0.001

[1] Site-specific data from slug tests /Johansson and Adestam, 2004b/.
[2] Generic data from the literature /Knutsson and Morfeldt, 1993/.
[3] Generic data from the literature /Kellner, 2004/.
[4] Generic data from the literature /Domenico and Schwartz, 1998/.
[5] Data from /DHI Sverige, 1998/.

been investigated by e.g. /Lind and Nyborg, 1988/. In the S1.2 model, the thin till layer (~ 1 m) combined with the fact that there is no field evidence of different till layers and/or other (low-permeable) layers within the till, motivate the present assumption of isotropic conditions. This assumption will be further tested in future model development in L1.2. The same hydraulic properties for each type of Quaternary deposit are also assigned to the whole regional area. However, the majority of the data are from the Simpevarp subarea, which implies that e.g. different types of till may be identified during further site investigations.

The conceptual model for S1.2 implies that near-surface groundwater flow mainly takes place in the valleys between the higher-altitude areas with exposed bedrock (or with a thin layer, on the order of a few decimetres) of till/peat. Hence, the valleys act as large-scale "flow channels" for the near-surface groundwater. There is a large degree of surface runoff taking place in areas with exposed bedrock, which is diverted into the valleys. Thin Quaternary deposits imply that the deposits only can carry small volumes of groundwater flow. Although the near-surface groundwater flow pattern has not yet been analysed in detail due to the scarcity of site-specific data, it can be assumed that this flow is characteristic within each catchment, directed towards surface waters, lakes, wetlands, and other near-surface drainage systems.

Interfaces between domains

Important factors in the characterisation of ground- and surface water flow are the interfaces (contacts) between different domains, as these to a large degree control the flow of water between the domains. For S1.2, three important interfaces have been identified (see also Chapter 5):

- The interface between "near-surface" bedrock and "deep" bedrock. In the S1.2 flow modelling (Chapter 5), this interface is defined at the level –150 m a s l.
- The interface between Quaternary deposits and bedrock. In the S1.2 modelling, the main flow of water across this interface is assumed to take place at locations where bedrock fractures are in contact with Quaternary deposits.
- The interfaces between groundwater and surface water (lakes, water courses and wetlands). In S1.2, these interfaces are modelled with a low-permeable layer of clay, thus limiting the water flow between groundwater and surface water.

4.3.2 Description of the surface and near-surface flow system

As described in Section 4.1, the present description is focussed on the surface and near-surface part of the integrated hydrological-hydrogeological system. The whole system is transient due to the fact that precipitation and temperature vary with time. Concerning seasonal variability, Sweden can be divided into 4 regions based on the "typical" variations of the groundwater level during a year /SGU, 1985/.

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 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 (water courses, lakes or wetlands).

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 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.

These concepts are illustrated in Figure 4-5. In a generalized form, the figure illustrates the descriptive model for the surface-hydrological and near-surface hydrogeological conditions across a hypothetical valley in the regional model area. The figure also illustrates the interfaces identified in the S1.2 modelling (Section 4.3.1).

Not all discharge areas are saturated up to the ground surface; the near-surface groundwater flows in the uppermost most permeable part of the soil profile, or along the interface with the bedrock. 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 at high (recharge) areas, and lower in low (discharge) areas. However, the depth to the groundwater level below the ground surface is assumed to be smaller in low areas compared to high areas.

Water courses are considered to be discharge areas. The simple discharge measurements in water courses (reported to SICADA) and preliminary water-level data from automatic loggers (stored in HMS, not yet quality controlled nor reported to SICADA) indicate that there is no water flow in many of the water courses 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 water courses 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 runoff in water courses imply that simple averaging of a few individual measurements may lead to erroneous estimates of the total annual runoff.

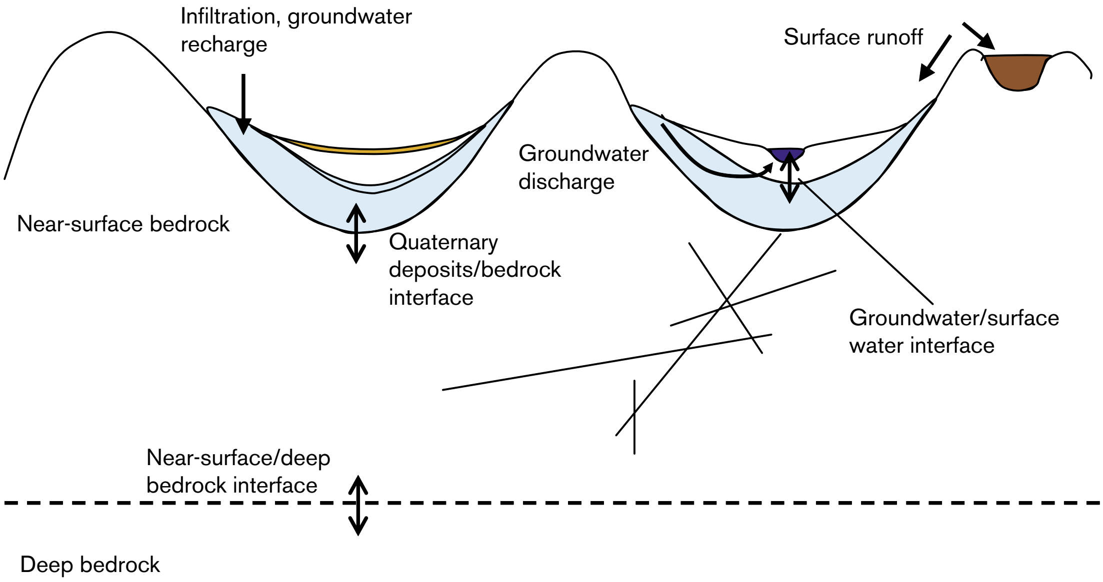


Figure 4-5. *Schematic cross-section, illustrating the descriptive model of the surface-hydrological and near-surface hydrogeological conditions in the regional model area. The figure also shows the interfaces that are discussed in the S1.2 modelling.*

As mentioned above, lakes can function both as 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. 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 4.3.1). In the Simpevarp area, drilling and soil sampling have not yet been performed in the lake sediments to investigate the type of sediments. In the S1.2 modelling, the lake bottoms are assumed to consist of fine sediments with low hydraulic conductivity.

Wetlands (bogs and mires) can either be in direct contact with the groundwater and constitute typical discharge areas, or be separate systems with low-permeable bottom and little or no hydraulic contact with the groundwater zone (see discussion on interfaces in Section 4.3.1). Information needs to be collected to clarify the hydraulic contact between groundwater and the major wetlands. Probably the bottoms are covered with fine sediments with low permeability.

Interaction between near-surface groundwater flow in Quaternary deposits and near-surface flow in bedrock takes place where bedrock is in contact with Quaternary deposits (see discussion on interfaces in Section 4.3.1). Discharge from the bedrock into the Quaternary deposits will probably mostly take place in the topographically defined major discharge areas.

Based on the regional water balance, a regional runoff of 150–180 mm×year^{-1} is assumed for the Simpevarp area /SKB, 2004a/. However, the sizes of recharge and discharge areas, and the groundwater recharge and discharge in these areas, need to be quantified by means of model simulations (see Chapter 5). The manual groundwater level measurements (Section 3.3.2) show that there is a small depth to the groundwater table (usually less than 1 m). A shallow groundwater table indicates that the identified boundaries of the catchment areas /Figure 3-14; Brunberg et al. 2004/ can be used as no-flow boundaries also for quantitative modelling of groundwater flow.

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 1 m in discharge areas /Knutsson and Morfeldt, 1993/. The annual groundwater level fluctuation is usually a few metres in recharge areas and about 1 m in discharge areas /Knutsson and Morfeldt, 1993/. 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.

The groundwater flow in the three identified glaciofluvial deposits, and their interface with their surroundings, are not shown in the descriptive model (cross-section) in Figure 4-5. However, in its most simple form, the groundwater flow in the three identified 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.

4.4 Supporting evidence from other disciplines and models

4.4.1 Different types of supporting analyses

The descriptive model of surface hydrology and near-surface hydrogeology can be supported by a number of different types of data and models, both hydrological/hydrogeological and from other modelling disciplines. Important aspects that can be evaluated using data and models from other disciplines include the overall flow pattern, especially the spatial distribution of recharge and discharge areas. The methods for support and evaluation of the descriptive model can be summarised as follows:

Hydrological and hydrogeological data: Mapping/comparison of "independent" data, i.e. data not used in the model development (e.g. measured groundwater levels or flow rates).

GIS-based hydrological models: Flow modelling based on topography and possibly also other meteorological, geological and/or land-use parameters (see Chapter 5).

Hydrological and hydrogeological process modelling: Flow modelling based on analytical or numerical solutions of flow equations, integrating various hydrological/hydrogeological data with other inputs.

Mapping of Quaternary deposits and soil types: Comparison of flow pattern with spatial distributions of quaternary deposits or soil types; the evaluation is based on assumed or observed correlations between geology/soil type and hydrological/hydrogeological characteristics.

Mapping of vegetation: Comparison of flow pattern with spatial distribution of vegetation; the evaluation is based on assumed or observed correlations between vegetation and hydrological/hydrogeological characteristics.

Evaluation of remote sensing data: Evaluation and application of parameters related to soil wetness; the evaluation is based on correlations/constitutive equations.

Topographical data and tools and classification systems based on topographical data: Direct comparisons with the Digital Elevation Model (DEM) or classifications based on quantities derived from the DEM (slope or higher-order derivatives); the TOPMODEL system has been applied within the site investigations /Lundin et al. 2004/.

Hydrochemical data: Direct comparisons with spatial distributions of hydrochemical parameters; main elements (e.g. chloride) and specific components such as isotopes (e.g. oxygen-18 and tritium) can be used to distinguish "water types" and to infer information on the flow pattern ("water age").

Coupled hydrogeological and hydrogeochemical modelling: Use of coupled quantitative modelling of flow and hydrogeochemical processes for joint evaluation of hydrogeochemical and hydrological/hydrogeological data.

Whereas most of the data and models listed above are or will be available within the site investigations (presently, all except remote sensing data), it should be noted that the existing basis for these supporting activities is weak. However, first attempts on GIS-based and process-based hydrological modelling are presented in this report. Furthermore, evaluations of the limited amount of hydrochemical data available are presented in the main SurfaceNet report /Lindborg (ed), 2005/ and in the background reports from the hydrogeochemical modelling /SKB, 2004b,d/.

In L1.2, a more extensive dataset on the hydrogeochemical parameters will be provided and evaluated as support for the further development of the site-descriptive model. For instance, by the use of oxygen-18 as a tracer, information can be obtained of the runoff generation process as well of groundwater reservoir volumes /Lindström and Rodhe, 1986; Johansson, 1987; Rodhe, 1987/.

A first attempt on coupled hydrogeological and hydrogeochemical modelling, including an evaluation of surface water and near-surface groundwater data, has made as a part of the hydrogeochemical modelling. The quantitative modelling considers the whole "freshwater system", which implies that the groundwater flow model has a depth of 1,000 m within the Laxemar subarea. Therefore, the modelling results are primarily useful for developing and analysing hypotheses regarding a relatively large-scale flow pattern. Results relevant for further development of the description of surface and near-surface processes in this report are not obtained. However, the modelling illustrates a useful methodology that can be applied also when more data is at hand. In addition, some results of the data evaluation, such as the observed differences in water composition between different lakes, should be further investigated in future model versions.

4.4.2 Interpolation of known water levels

Topographical data and quantities derived from those are used in the modelling of surface hydrology and near-surface hydrogeology, both as a basic input (the DEM) and for supporting analyses. Furthermore, the topography is used as a basis for setting top boundary conditions in groundwater flow models for the deep rock (when a pressure condition is used). However, the topographical variations are larger than the corresponding spatial variations in the groundwater level. It is therefore of some interest to provide alternative estimates of the near-surface groundwater levels. Such estimates are also useful as a starting point and support for detailed simulations of the near-surface system.

Figure 4-6 shows the result of an interpolation of known water levels in the Simpevarp area. The interpolation is based on surface water levels in lakes, water courses and wetlands identified on the Fastighetskartan map (the Real Estate map), with the levels obtained from the DEM; the locations of the points used in the interpolation are shown in the figure. Thus, the map shows the "actual" water levels in the main discharge areas for groundwater (subject to errors in the DEM), and levels that are lower than the actual groundwater levels between these areas. The interpolated surface can be used as a basis for "constructing" the groundwater level also between the main discharge areas. However, in the present context the map also gives a useful impression of the large-scale flow pattern in the surface system, i.e. a flow pattern without the locally higher groundwater levels that are associated with the recharge areas.

Figure 4-7 shows a map where the interpolated "groundwater surface" in Figure 4-6 has been subtracted from the topography. Thus, the figure displays an estimate of the depth to the "groundwater surface". Since the local maximum groundwater levels between the surface waters are not included, the groundwater depth is overestimated in these areas. Nevertheless, the overall impression is that the groundwater level is close to the ground surface in most of the area. In Figure 4-7, also the points used in the interpolation are indicated.

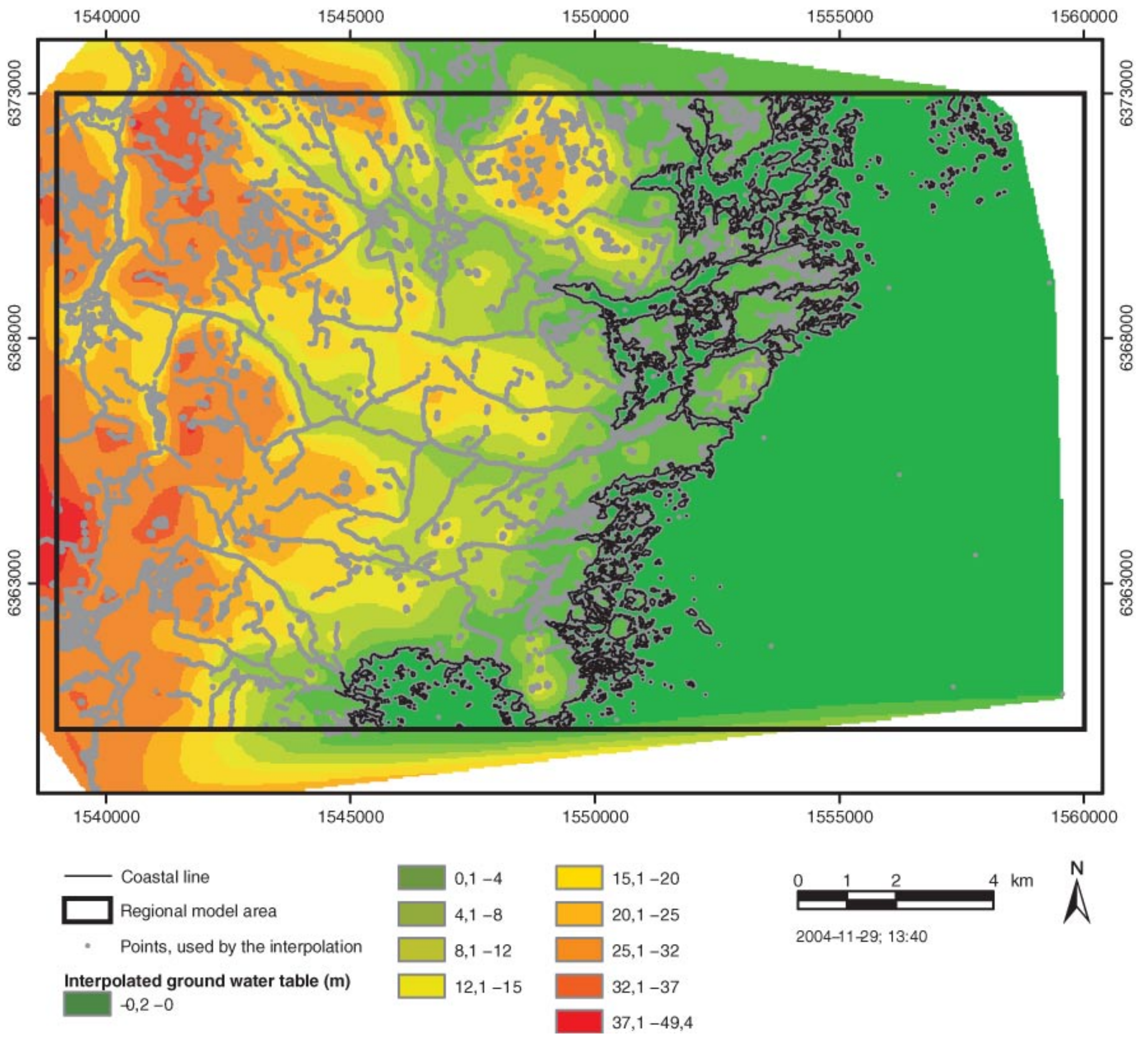


Figure 4-6. *Interpolation of known water levels in the regional model area. The points used in the interpolation are indicated by grey dots.*

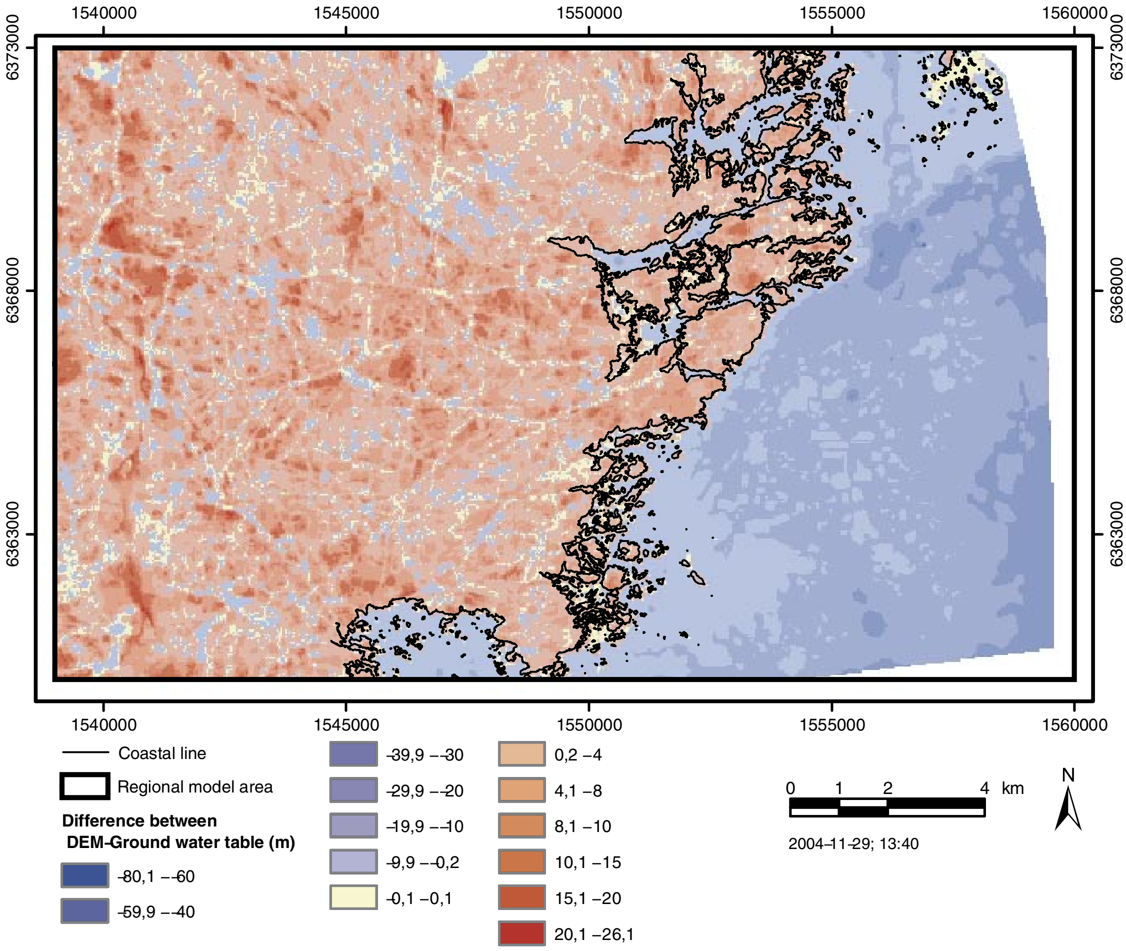


Figure 4-7. *"Groundwater depth" based on DEM and interpolated groundwater level in Figure 4-6.*

4.4.3 Comparison of DEM and geological map

As another example on how evidence from other disciplines and models can be used as support of the conceptual and descriptive models, the Digital Elevation Model (DEM) is compared to a map integrating the currently available data on Quarternary deposits and bedrock outcrops in the "Simpevarp 7" catchment area. The reason is that the definition of type areas (Section 4.3.1) is highly dependent on the coupling between topography (high and low areas) on the one hand, and the locations of areas with Quaternary deposits and surface waters on the other hand. A quantitative model of the ground- and surface water flow in this catchment area is described in Chapter 5.

Figure 4-8 shows that the higher-altitude areas define the water divide (red line). Surface waters (lakes and water courses) are located in low areas. In Figure 4-9, areas with bedrock outcrops are red, whereas Quaternary deposits (till) are assumed to be located in the green areas. Areas with "high" or "moderate conductance" are assumed to be covered with water-laid sediments (clay and/or peat), and these areas are also assumed to be associated with thicker layers of Quaternary deposits.

A comparison of Figures 4-8 and 4-9 shows that areas described as bedrock outcrops (Figure 4-9) are modelled as high-altitude areas in the DEM (Figure 4-8). On the other hand, low areas are mapped as areas with till (green colour in Figure 4-9) and/or areas with water-laid sediments ("high" or "moderate conductance"). Hence, this simple comparison provides at least qualitative evidence in support of the definition of type areas associated with the descriptive model.

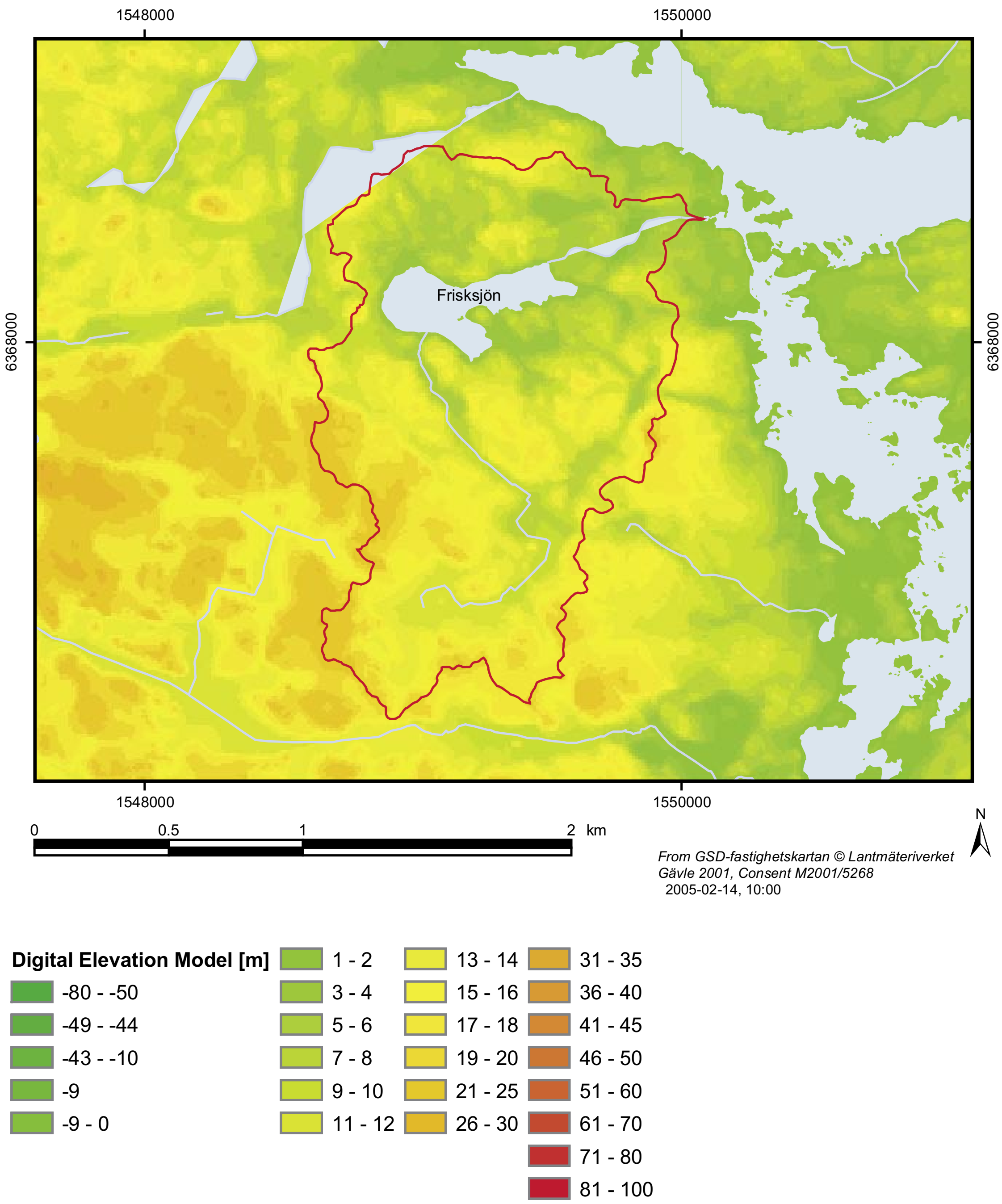


Figure 4-8. *Digital Elevation Model (DEM) of the "Simpevarp 7" catchment area.*

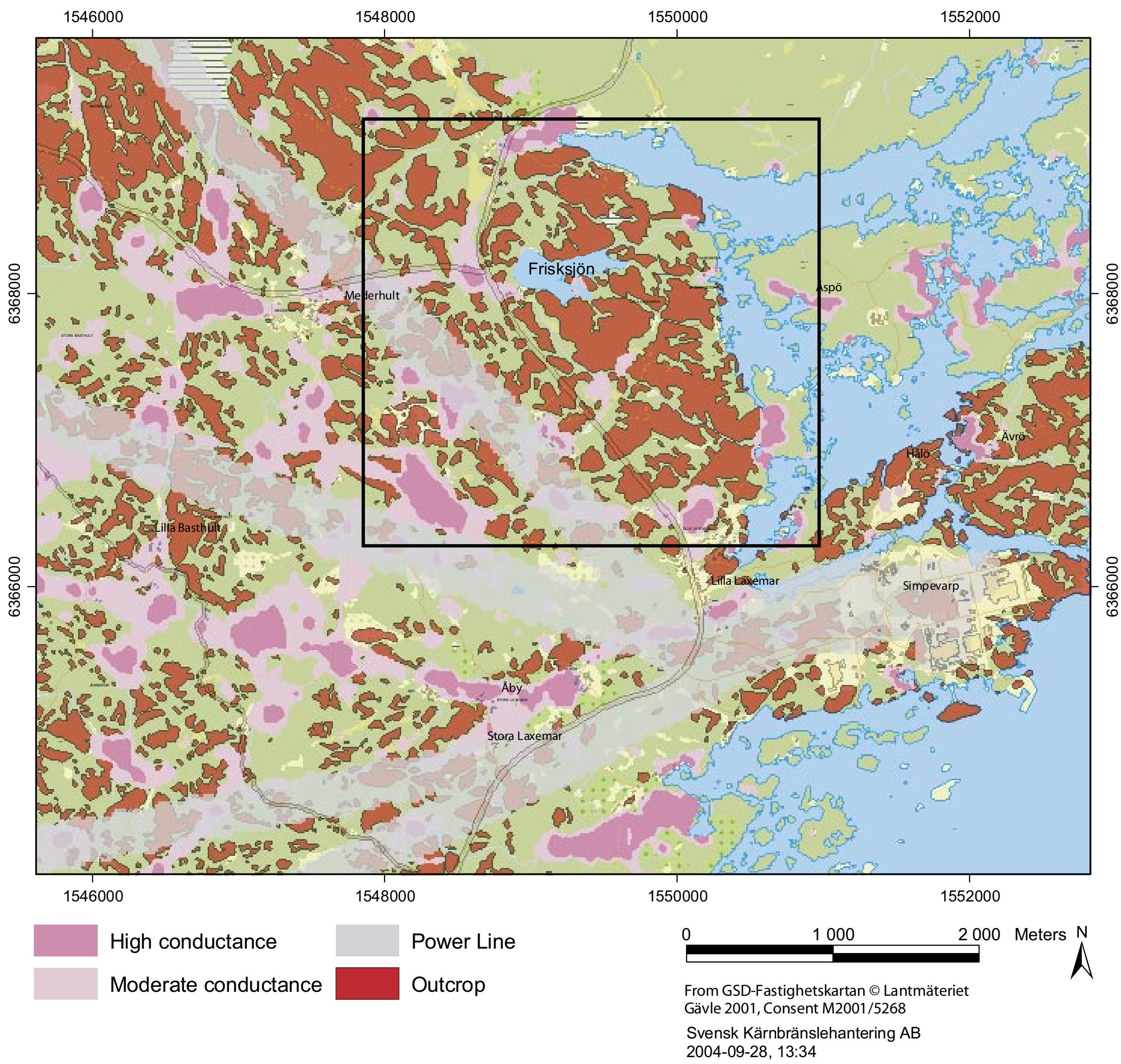


Figure 4-9. *Detail of the map in Figure 4-3, showing Quaternary deposits (Simpevarp subarea) and results of air-borne geophysical measurements (Laxemar subarea). The rectangle indicates the approximate coverage of the map in Figure 4-8.*

5 Quantitative flow modelling

5.1 Introduction and general objectives

As described by /Rhén et al. 2003/, quantitative flow modelling is performed as an integrated part of the site descriptive modelling. Specifically, the flow modelling serves three main purposes /see also SKB, 2004a/:

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 performed in order to explore the impact of different assumptions of hydraulic properties, boundary conditions and initial conditions.

Description of flow paths and flow conditions: Model calculations useful for the general understanding of the groundwater flow system at the site.

For reasons described in Chapter 1 and 4, i.e. primarily the limited data available and the "immature" state of the surface and near-surface flow modelling in general, only a limited modelling effort has been made in S1.2. The overall objectives are to

- start developing the site understanding by testing a few specific aspects of the descriptive model,
- deliver specific output data to the ecological system modelling within SurfaceNet,
- test selected modelling tools within the SKB environment.

Although the flow modelling is presented separately and without detailed references to the conceptual and descriptive modelling discussed in the preceding chapter, it should be noted that the modelling activities have been integrated. However, the first-attempt and code-testing purposes of the flow modelling, in combination with the limited time available, has implied less interactions (and iterations) between the descriptive and quantitative modelling than in a "complete process". The code-testing aspects of the work are also the reason for the relatively detailed description of the modelling tools.

5.2 GIS-based hydrological modelling

5.2.1 Model components

The Hydrological Modelling extension in ArcGIS 8.3 is a modelling tool in which relatively simple, topography-driven hydrological models can be developed. The tool requires a Digital Elevation Model, DEM, as input. The DEM is the basis for the flow direction and flow accumulation calculations. In the model, the water is flowing downgradient towards areas of lower elevation. No other driving forces or processes than the differences in elevation are considered. There are three main functions in the ArcGIS Hydrological Modelling extension:

Fill sinks: The DEM has to be corrected so that it does not contain any local sinks, e.g. cells that will accumulate water. A local sink is defined as a cell situated lower than all surrounding cells /Brunberg et al. 2004/. Local sinks are filled up to the level of the lowest neighbouring cell.

Flow direction: The flow direction for each cell is calculated. Using the DEM as input, the slope gradient direction is calculated. Information about the elevation in the actual cell and the eight adjacent cells are used to define the direction of the flow. The water can flow in eight different directions. In the following text, the resulting grid is referred to as the "direction grid".

Flow accumulation: Using the "direction grid" as input, the number of cells generating water to a specific cell is calculated. Thus, the new grid gives the accumulated flow in each cell. The cells with the highest accumulation values are considered to be stream locations. In the following text this grid is referred to as the "accumulation grid".

Since a low value in the accumulation grid indicates that there are no upstream cells, the grid can be used to identify recharge areas. A high value in the accumulation grid specifies a stream or a discharge area. By using the accumulation grid and a specified values of the specific discharge in the area as input (must be estimated separately), it is possible to calculate the discharge in each cell.

By converting the two grid files (direction grid and accumulation grid) to shape files, and then combine the information in the two files, it is possible to calculate flow paths for water in the whole area. The information in the direction shape file is converted from a value in the interval 1–128 degrees and combined with the accumulation shape file. By using the option "graduated value", it is possible to obtain flow-weighted arrows as a legend on the map. The direction of an arrow is given by the information in the "direction file", and the length of the arrow is weighted according to the information in the "accumulation file". The result is a map with arrows showing the flow paths; the longer the arrow, the more water is discharged through that particular cell.

Other GIS-based hydrological modelling tools provide extended capabilities, as compared to the purely topographical quantification of the total runoff described above. For example, the PCRaster-POLFLOW approach involves empirical equations for quantification of the total runoff and its distribution on surface and subsurface flows, using spatially variable meteorological, geological and/or land use parameters. Thus, the components of the water balance are calculated based on empirical relations and input data related to the processes, not "imported" in the form of a specific discharge. PCRaster-POLFLOW has been applied to pre site-investigation data from the Forsmark area /Jarsjö et al. 2004/, and is currently used within the site-descriptive modelling. However, results are not available for the present model version.

5.2.2 Objectives

The main objective of the S1.2 modelling with ArcGIS is to calculate the spatial distribution of total runoff, which is used in the ecological system modelling. Furthermore, the GIS-based modelling is used to illustrate the overall flow pattern within the Simpevarp regional model, to estimate discharges in water courses, and to evaluate uncertainties related to the DEM.

5.2.3 Assumptions and input data

The only input data used in the hydrological GIS-model is the Digital Elevation Model (DEM) for the Simpevarp area /Brydsten, 2004/ and the specific discharge. The specific discharge in the Oskarshamn area has been estimated to 5.7 $l \times s^{-1} \times km^{-2}$ /Larsson-McCann et al. 2002/.

As described above, the model is driven by topographical gradients only. It is a steady-state model and the input value on the specific discharge is an annual mean value. The model considers the total runoff only, which means that no distinction is made between surface water and groundwater flows. Thus, the calculated discharges can be assumed to represent surface water flows in the downstream part of a catchment, and the sum of surface water and groundwater flows in the upstream part. This also implies that surface water divides are assumed to coincide with groundwater divides.

In addition, it should be noted that the modelling is subject to uncertainties related to the DEM. Specifically, ditches and other "constructions" resulting from water-related activities that alter the "natural" flow field may be lost in the interpolations underlying the DEM. This may cause result in local differences between actual flow directions and those modelled by use of the DEM.

5.2.4 Results

Runoff and water courses

A high value in the "accumulation grid" indicates a water course. Figure 5-1 shows modelled water courses and the water courses obtained from the Fastighetskartan map (the Real Estate map). The red lines show grid cells that have a mean annual discharge above 0.5 $l \times s^{-1}$, which means that even very small streams are included in the figure. The majority of these small streams are likely dry during most of the year.

Since the model is driven by topography only (as given by the DEM), there are some areas where the modelled water courses do not match the actual ones on the Fastighetskartan map. This can be seen in the outlet of Lake Frisksjön and in the northern part of Ävrö. In these areas, the model indicates that the surface waters are influenced by human impact such as ditching. A new outlet from Lake Frisksjön has been constructed, but is not accounted for in the DEM. Other reasons for deviations from the mapped water courses can be associated with the resolution of the DEM. Since the DEM grid cells are 10 m, small ditches or sinks may not be included in the model.

The calculated discharges in the outlets to the sea (cf Figure 5-1) are listed in Table 5-1. The discharge points are marked in Figure 5-1 with the character Q and an index with the first letter in the name of the water course. It can be seen that Laxemarån by far is the largest water course in the area. The estimated discharge in Laxemarån, 264 $l \times s^{-1}$ (c 23,000 $m^3 day^{-1}$), is more than 15 times larger than that of the second largest water course (Ekerumsån). Most of the other water courses are very small, with estimated discharges in the range 0.7–3 $l \times s^{-1}$.

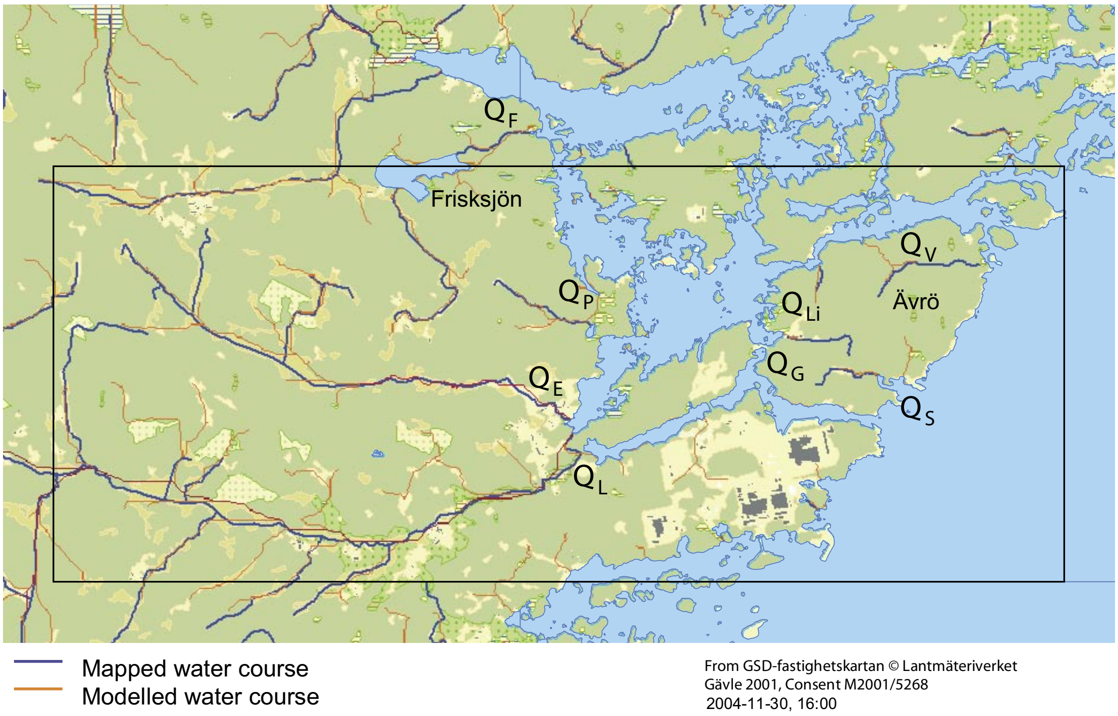


Figure 5-1. *Modelled water courses and water courses from the Fastighetskartan map (the Real Estate map).*

Table 5-1. Calculated discharge in the Simpevarp area.

Catchment area number	Water course	Symbol in Figure 5-1	Discharge (l×s^{-1})
7	Kåreviksån	Q_K	11
8	Pistlanbäcken	Q_P	3
9	Ekerumsån	Q_E	17
10	Laxemarån	Q_L	264
23	Vadevikebäcken	Q_V	2
24	Lindströmmebäcken	Q_{Li}	1
25	Gloebäcken	Q_G	0.7
26	Skölkebäcken	Q_S	1

Recharge and discharge areas

Recharge and discharge areas have been identified with the GIS-based model. A zero value in the accumulation grid indicates a recharge area. Areas with an accumulation value equal to zero are marked with red colour in Figure 5-2. Areas with a value higher than 500 are marked with a blue colour. Since each grid cell is 10 m, this implies that areas receiving water from an area larger than 0.05 km^2 are defined as discharge areas.

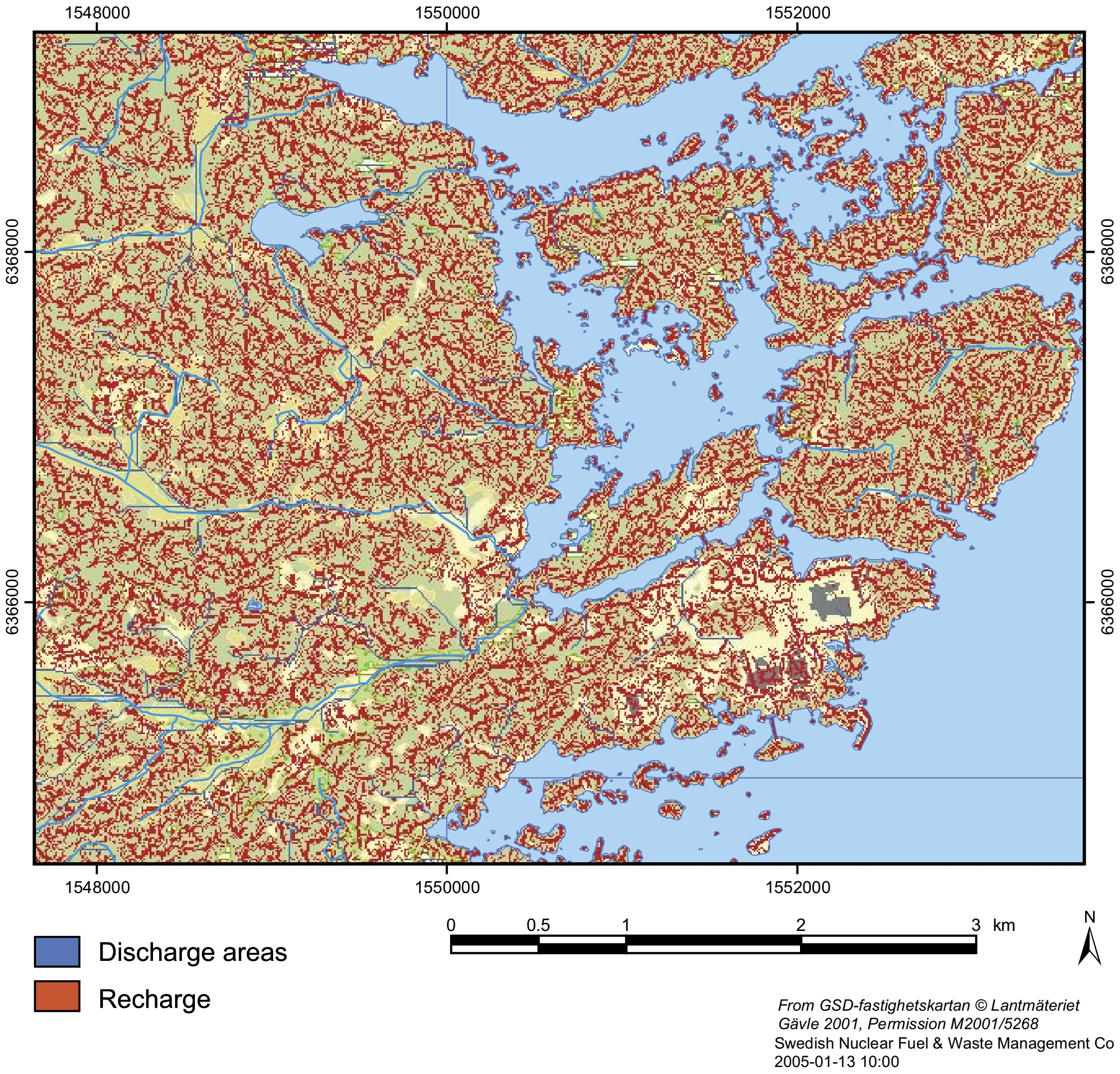


Figure 5-2. *Recharge and discharge areas.*

Figure 5-2 illustrates the local flow systems described in the conceptual and descriptive modelling in Chapter 4. Although recharge areas are restricted to cells of zero accumulation only, it can be seen that they occupy a relatively large part of the total area. Obviously, the relation between "intermediate areas" and discharge areas is determined by the arbitrarily chosen definition of the latter. It can be noted that the locations of recharge and discharge areas are strongly influenced by the local topography.

Flow pattern

The GIS-modelled flow pattern gives a visualisation of the surface water system in the area. The flow pattern in the catchment area "Simpevarp 7", which includes Lake Frisksjön, is illustrated in Figure 5-3 and the flow pattern on the Ävrö island is illustrated in Figure 5-4. The arrows are flow weighted; a long arrow indicates a higher value in the "accumulation grid". By following the field-controlled water divide (red line) one can investigate the accuracy of the model. In some areas the arrows are crossing the field controlled water divide. These errors can be related to errors in the DEM. The flow pattern also shows how the water in the outlet of Lake Frisksjön and the Vadvikebäcken water course on Ävrö are redirected by man made outlets. The blue line shows the present outlet, and the arrows show where the outlet would have been located without human influence.

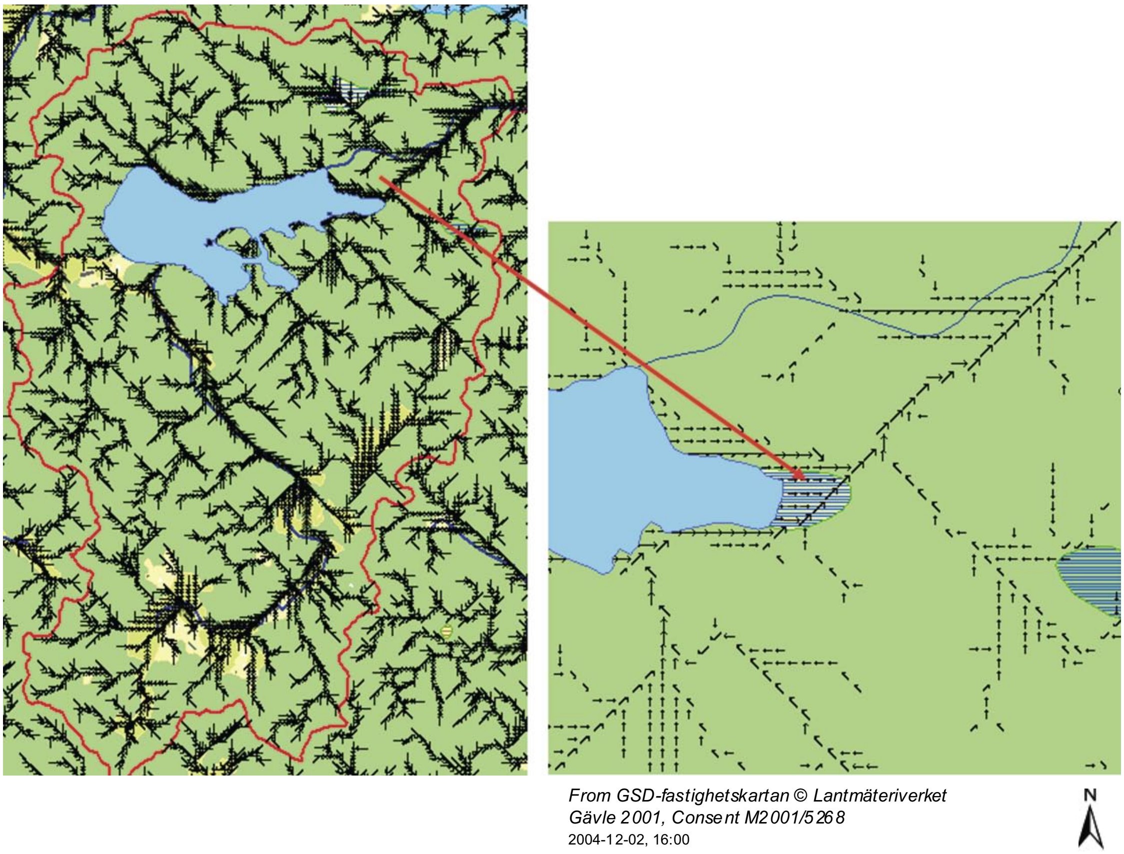


Figure 5-3. *Flow pattern in the catchment area "Simpevarp 7".*

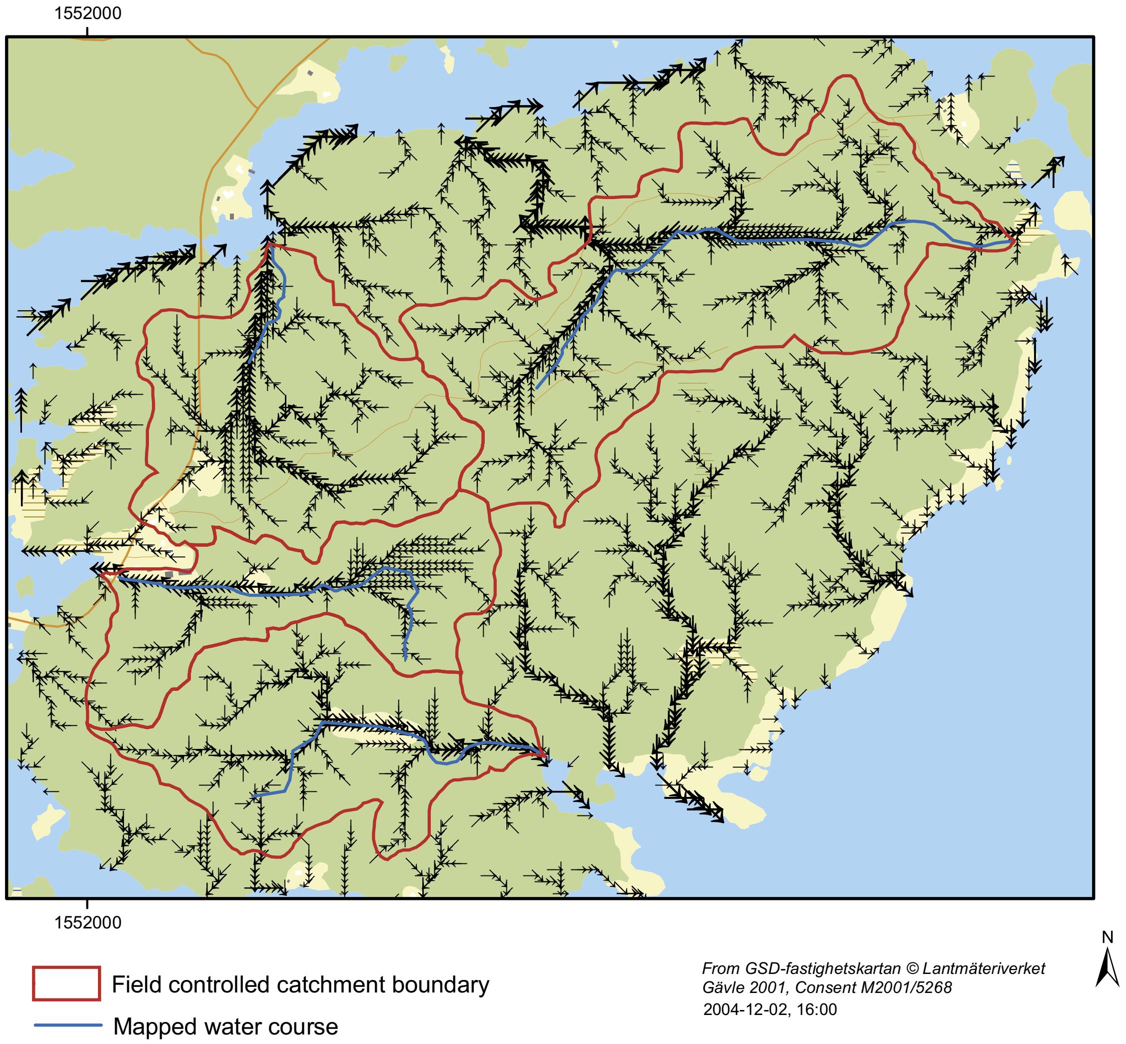


***Figure 5-4.** Flow pattern on the island of Ävrö.*

Identification of catchments

In the Simpevarp regional model area, 26 catchment areas have been identified /Brunberg et al. 2004/. All the catchment area boundaries in the local model area are field controlled. However, the GIS-based model can be used to identify sub-catchments, e.g. the drainage area to a specific wetland area. In the main part of the model area, the modelled catchments coincide with the field controlled catchment boundaries, cf Figure 5-5. The field controlled boundaries are marked with dashed lines and the number of each catchment is marked in the figure. The modelled catchments are marked with different colours.

With the GIS-model it is possible to locate all the 26 catchment areas, except from no 15. In the GIS-model, catchment area no 15 is a part of catchment area no 14. Catchment area no 16 consists in the GIS-model of two sub-catchments. The total area of these two catchments is, however, almost the same as the area of the field-controlled catchment area no 16. The DEM, which constitutes the basis for the GIS model, is valid within the whole model area. However, the resolution is lower in some areas west and north of the regional model area; see /Lindborg (ed), 2005/ for a detailed description of the DEM area. This has probably affected the modelling results, especially in the westernmost part of the model area (cf below).

The areas of each field-controlled catchment and the corresponding GIS-modelled catchment are listed in Table 5-2. The results shown in Figure 5-5 and Table 5-2 can be used to investigate the quality of the DEM within the model area. For example, there is a distinct difference between the field-controlled boundaries of catchments no 13 and 18 and the corresponding modelled catchment boundaries. Furthermore, Figure 5-5 shows that there is a relatively large area that is part of catchment no 5 in the field delineation of catchments, but belongs to catchment no 10 in the GIS model.

The comparison illustrated in Figure 5-5 and quantified in terms of absolute and relative differences in Table 5-2 (a negative difference means that the area estimated by the GIS model is smaller than the field-controlled area) shows that the differences between modelled and field-controlled areas range from very small (1–2%) to the order of the size of the catchment area (catchment no 2). However, the absolute differences related to the individual catchments are in most cases small when compared to the total area of all catchments (sum of field-controlled areas = 101.5 km^2).

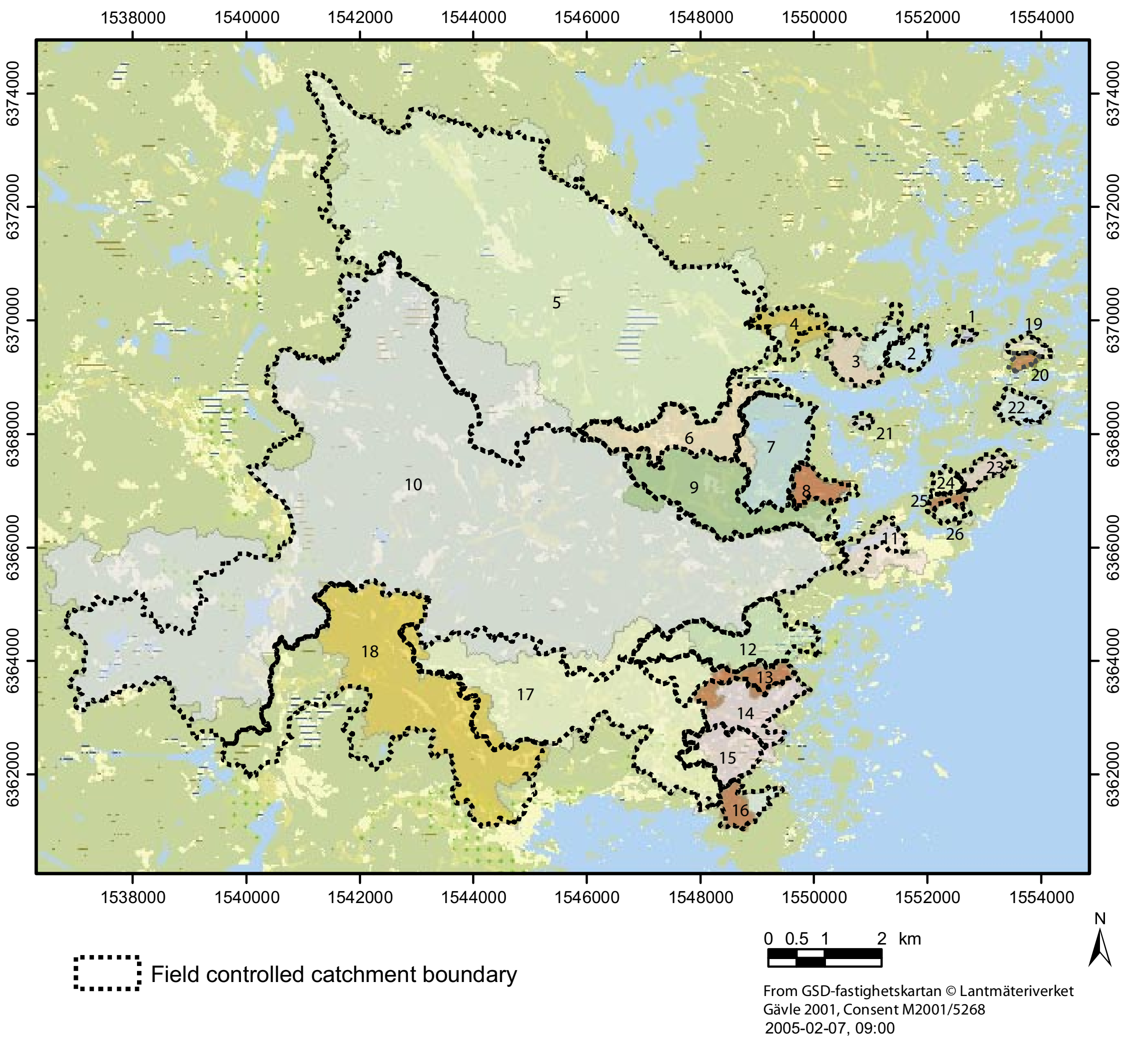


Figure 5-5. *Modelled and field-controlled catchment area boundaries (FC). DEM = coloured areas, FC = dotted lines.*

Table 5-2. Comparison of field-controlled and modelled catchment areas.

Catchment area no	Field-controlled area (km^2)	Modelled area (km^2)	Difference (km^2)	Relative difference (%)
1	0.070	0.066	–0.004	–5.7
2	0.380	0.760	+0.380	+100.0
3	1.000	0.600	–0.400	–40.0
4	0.632	0.580	–0.052	–8.2
5	27.154	24.600	–2.554	–9.4
6	2.003	2.049	+0.046	+2.3
7	2.062	1.936	–0.126	–6.1
8	0.499	0.460	–0.039	–7.8
9	2.834	3.016	+0.182	+6.4
10	40.976	46.315	+5.339	–13.0
11	0.523	0.868	+0.345	+66.0
12	2.054	1.689	–0.365	–17.8
13	1.033	0.622	–0.411	–39.8
14 [1]	1.338	2.118	–0.187	–8.1
15 [1]	0.967			
16 [2]	0.504	0.528	+0.024	+4.8
17	7.019	7.937	+0.918	+13.1
18	8.958	6.665	–2.293	–25.6
19	0.184	0.220	+0.036	+19.6
20	0.111	0.114	+0.003	+2.7
21	0.063	0.062	–0.001	–1.6
22	0.359	0.430	+0.071	+19.8
23	0.307	0.294	–0.013	–4.2
24	0.192	0.183	–0.009	–4.7
25	0.131	0.124	–0.007	–5.3
26	0.165	0.189	+0.024	+14.6

[1] Areas 14 and 15 are one single area in the GIS model; comparison made with sum of 14 and 15.
[2] Modelled catchment area no 16 consists of 2 sub-catchments; sum of these used in comparison.

It should be noted that the errors in the modelling of the two largest catchments (no 5 and no 10) are on the order of 10% in relative terms, but larger than the total areas of many other catchments in absolute terms. In particular, the deviations in the westernmost part of catchment no 10 and in the central part of the model area (along the boundary between areas no 5 and 10) will have some effect on the overall flow pattern and on predictions of discharges in coastal outlets.

The quality of the DEM is generally relatively low close to the coastline. This is illustrated in Figure 5-6, which shows a close-up of the difference between modelled and field-controlled boundaries of catchment no 8. However, the GIS model could possibly be improved by adjusting the parameters governing the functions listed in Section 5.2.1; the potential for such improvements has not been fully explored as yet.

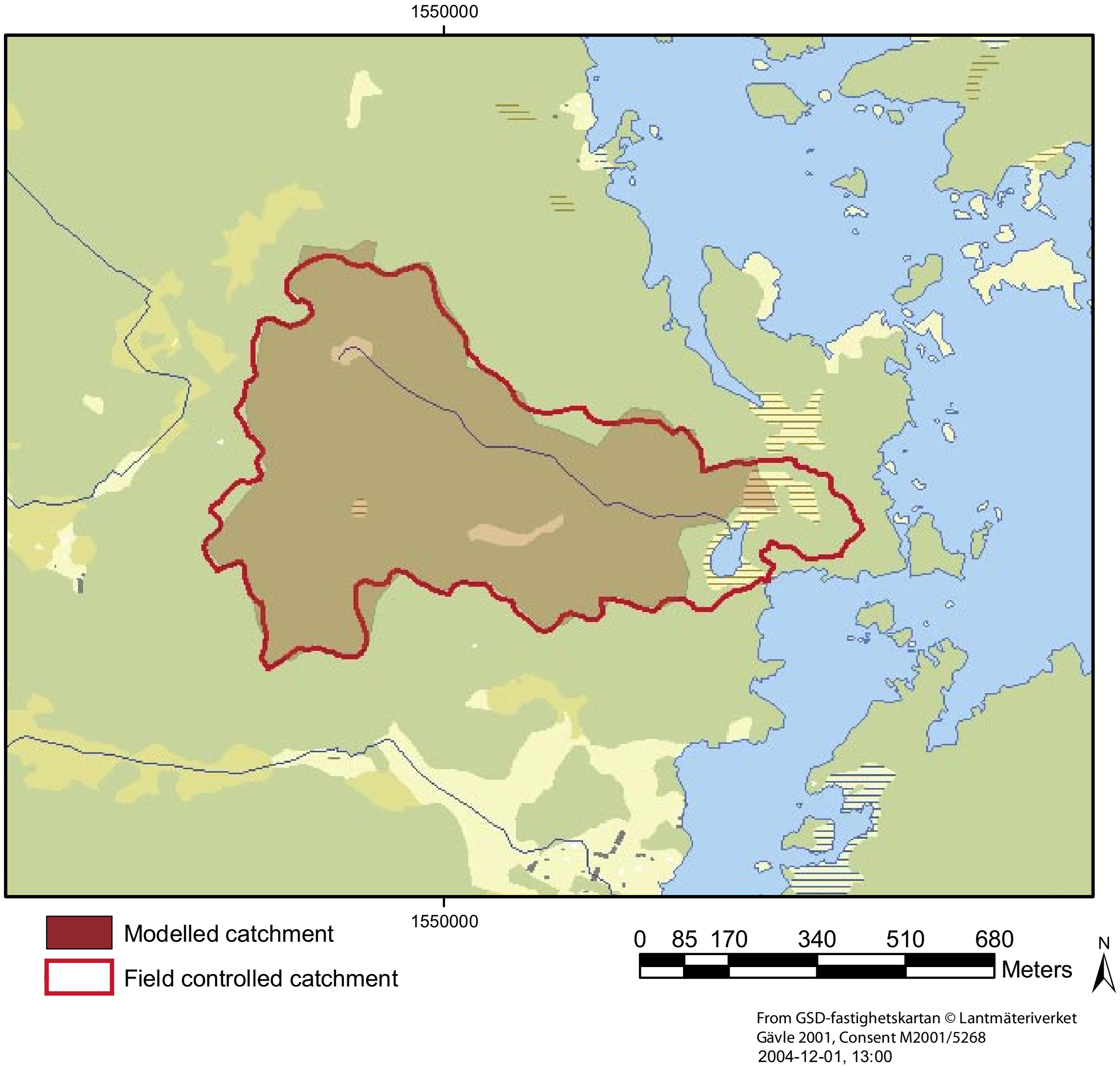


Figure 5-6. *Modelled catchment area no 8 and the corresponding field-controlled catchment area.*

5.2.5 Evaluation of uncertainties

Five main groups of uncertainties associated with the GIS-based flow modelling have been identified. These include uncertainties related to

- the Digital Elevation Model (DEM),
- the GIS modelling functions,
- the basic assumptions and restrictions in the GIS model,
- the conceptual model of the site,
- the other input data used in the modelling.

The main uncertainties with a GIS-based model are those associated with the DEM and the fact that the model is driven by the modelled topography. Since the horizontal resolution of the DEM is 10 m, all details in the topography are not included in the modelling. Large divergences from the real topography occur in some parts of the DEM, not only in areas with small ditches or local sinks and heights. The calculated catchments do not always coincide with the field controlled water divides. In areas with a flat terrain, small errors in the DEM may cause large differences in flow patterns.

The fact that the DEM does not take the details of human impacts, such as ditching, into account is an important source to uncertainty in the runoff estimates for the individual catchments. This uncertainty will to large extent be resolved when more field data on the water courses becomes available. For areas where information about ditching is already available, the model can be used to investigate the effects of human impact on the flow pattern. This type of information is valuable, since the DEM is used as input data in all hydrological and hydrogeological modelling. This modelling includes the modelling of surface hydrology and near-surface hydrogeology discussed in the present report, but also the modelling of deep rock hydrogeology.

The uncertainty related to the "fill sink function" is judged to be the most important one associated with the GIS modelling functions. As described above, this function fills up a local sink to the lowest level of the adjacent cells. This means that no surrounding cell has a lower elevation than the actual cell. This may cause "artificial" flow patterns. The sensitivity to the parameters governing this function has not been evaluated in the present work.

In the conceptual model presented in Chapter 4, it is assumed that the groundwater divides coincide with the surface water divides. If the actual water divides for surface water and groundwater differ significantly, the GIS model would strictly be valid for the surface water system only. It should be noted that the present GIS model provides quantitative information on the total runoff only, whereas the distribution on groundwater and surface water flows is not quantified. Furthermore, the GIS model is restricted to steady-state conditions, which implies that the potential significance of transients for the discharge estimates cannot be tested.

The specific discharge is the only additional input parameter that could cause uncertainty in the flow model. In the present model, the value for the specific discharge is based on long-term discharge measurements made outside the model area and hydrological modelling based on regional meteorological data /Larsson-McCann et al. 2002/. The value can be considered a rough estimate of the real discharge in the area. No spatial or temporal variations are considered. Whereas, in principle, each cell in the model could be assigned an individual value of the specific discharge, the capabilities for testing the effects of temporal variations are limited (cf above).

5.3 Hydrological modelling with MIKE SHE

5.3.1 Overview of tools and capabilities

MIKE SHE (Système Hydrologique Europeen) is a physically based, distributed model that simulates water flows from rainfall to river flow. It is a commercial code, developed by the Danish Hydraulic Institute (DHI). This sub-section presents the basic processes and the governing equations in MIKE SHE. For a more detailed description, see the user's guide and technical reference /DHI Software, 2003/.

MIKE SHE describes all the different processes in the land phase of the hydrological cycle. The precipitation can either be intercepted by leaves or fall to the ground. The water on the ground surface can infiltrate, evaporate or form overland flow. Once the water has infiltrated the soil, it enters the unsaturated zone. In the unsaturated zone, it can either be extracted by roots, and leave the system as transpiration, or it can percolate down to the saturated zone, see Figure 5-7. MIKE SHE is fully integrated with a channel-flow program, MIKE 11. The exchange of water between the two modelling tools takes place during the whole simulation, i.e. the two programs run simultaneously.

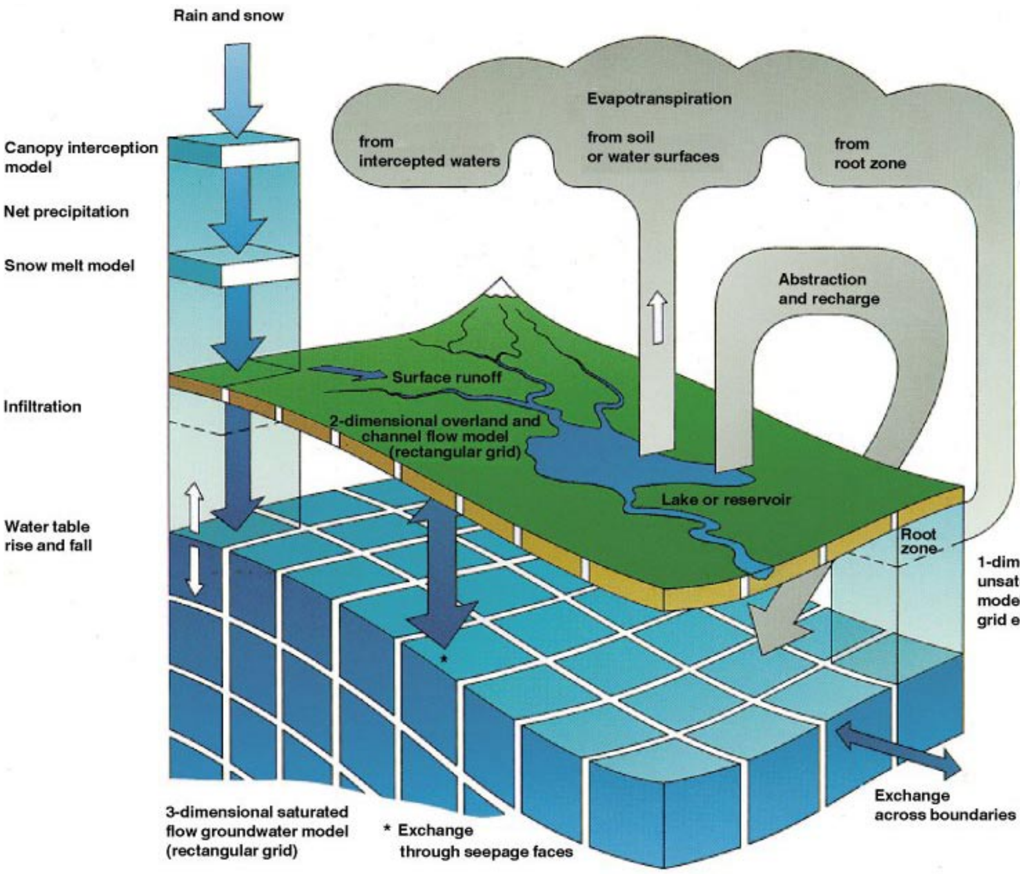


Figure 5-7. *The MIKE SHE model /DHI Sverige, 1998/.*

MIKE SHE is primarily developed to model groundwater transport in porous media. However, in the present modelling the bedrock is also included. The bedrock is parameterised by use of data from the Simpevarp 1.1 groundwater flow model developed using the code DarcyTools /Follin et al. 2004/. In DarcyTools, a discrete fracture network (DFN) is used as a basis for generating hydrogeological properties for a continuum model /Svensson et al. 2004/. Thus, hydrogeological parameters can be imported directly to the corresponding elements in the MIKE SHE model, provided the spatial resolution is the same.

There are five different compartments in the MIKE SHE model. The water flow is calculated in different ways in each single compartment. In addition to the different compartments there is a frame component that runs simultaneously with the other components of the model. The frame component takes care of the coupling and water exchange between the different compartments.

Overland flow

The overland flow is calculated in two dimensions with the diffusive wave approximation of the Saint Venant's equation. The equation is solved numerically with a finite difference method. Overland water is water that is ponding on the ground surface when the net rainfall rate exceeds the infiltration capacity of the soil. This water can flow down-gradient until it reaches an area where it can infiltrate, or until it reaches a lake or a water course. The quantity of water that is routed down-gradient is determined by the topography, the surface resistance and losses due to evaporation and infiltration.

The contact between overland water and groundwater can be described as either "reduced" or "full contact". Full contact means that the water exchange depends on the groundwater level fluctuations, since there is no hydraulic gradient over the ground surface. Reduced contact implies that the water exchange is dependent on the hydraulic conductivity of the uppermost layer and a leakage coefficient [s^{-1}]. The leakage coefficient represents a low permeable layer on the ground surface.

Evapotranspiration

The total evapotranspiration is modelled as a sum of interception, evaporation from the soil surface, transpiration from plants and evaporation from ponded water. The evapotranspiration calculations are based on land use data, vegetation parameters and potential evapotranspiration. Each vegetation group is described according to LAI (Leaf Area Index), root depth and K_c-value (actual transpiration/potential evaporation). The evapotranspiration model is based on the work of /Kristensen and Jensen, 1975/.

Unsaturated zone

The unsaturated zone (UZ) plays a central role in the groundwater modelling with MIKE SHE. The unsaturated zone is the link between the surface water flow and the groundwater flow. All other components are dependent of the boundary conditions related to the unsaturated zone. Since the unsaturated zone is dominated by vertical flow the unsaturated flow is calculated in one dimension using Richard's Equation (1D transient flow in variably saturated porous media). The full Richard's equation is used in the uppermost calculation layer only. In deeper layers, the unsaturated flow is calculated without the tension term in Richard's equation. Therefore, the root depth should not exceed the depth of the uppermost calculation layer.

The computational time for UZ calculations can be very long. In order to accommodate this, MIKE SHE enables the modeller to compute the UZ flow in a reduced subset of grid cells. The grid cells are chosen automatically by the pre-processor and a classification is made according to soil types, vegetation types, climatic zones, and depths to the groundwater table. The number of calculation points is dependent on the vertical discretisation of the unsaturated zone. The user can also define the calculation grid cells manually. This is done after the pre-processor has defined the different UZ-classes. For small scale studies it is possible to compute the UZ flow in all grid cells.

Since the model is developed to simulate groundwater flow in porous media, there is no obvious way to describe bedrock outcrops. In this work, the bedrock is described in the soil database as a soil with very low saturated water content and low hydraulic conductivity. If the porosity is very low the infiltration capacity is easily exceeded and the water will run off as overland flow.

Saturated zone

The saturated zone component calculates the saturated subsurface flow in three dimensions. The variation in space and time of the dependent variable, the hydraulic head, is mathematically described by the non-linear Boussinesq's equation. The equation is solved numerically by an iterative finite difference technique. The water exchange with other compartments is represented as source/sink terms in the equation.

The saturated zone is described with geological layers and geological lenses in three dimensions. The lenses are local areas with a geology that differs from the general geology in the area, e.g. lake sediments or peat formations in wetland areas. Each layer and lens is described in terms of hydraulic conductivity, storage coefficient and specific yield. The properties for each layer can vary in the horizontal plane. Geological layers and computational layers are separated in MIKE SHE. The computational layers are defined by the user after the geological model is defined.

The boundary conditions for the saturated zone can be of three types:

1. Dirichlet's conditions: The hydraulic head is prescribed on the boundary.
2. Neumann's conditions: The gradient of the hydraulic head across the boundary is prescribed.
3. Fourier's condition: The head-dependent flux is prescribed on the boundary.

The boundary conditions can vary in different parts of the model. It is also possible to specify internal boundary conditions.

Channel flow

The flows in water courses and lakes are simulated in the separate (but fully integrated) channel flow code MIKE 11. The water flow and water levels in MIKE 11 are described in one dimension and calculated with the fully dynamic Saint Venant's equation. The water exchange between the aquifer and the water course depends on the head difference between the surface water and the surrounding saturated zone. If the riverbed is low-permeable, the contact between the aquifer and the water course can be reduced by defining a leakage coefficient.

Input data

The input data to the MIKE SHE model includes data on topography, land use, geology, hydrogeology and meteorology. In addition, MIKE 11 requires information on the river network within the model area. Table 5-3 lists the different input data needed for each compartment of the model. There is a direct coupling between the GIS program ArcMap and MIKE SHE. This is a large advantage since most of the input data to the present modelling can be obtained in GIS format. It is possible to use both shape files and ESRI grid files as input. The resolution of the input data must not be of the same resolution as the grid size of the MIKE SHE model.

As mentioned above, the geological layers and the computational layers are separated in MIKE SHE. The user starts by defining the geological model and all the different geological layers. The thickness of a geological layer can be zero, which implies that it is possible to describe a geological layer that exists in parts of the model area only. The next step is to define the computational layers and the boundary conditions for each layer. The thickness of both the computational layers and the geological layers can vary within the model area.

Summary of model simplifications

The main simplifications in the MIKE SHE model are made in the modelling of unsaturated flow and the processes connected to ground frost. Specifically, unsaturated flow is calculated in one dimension only, i.e. in the vertical direction. Processes connected to ground frost are not included in MIKE SHE. The snow routine takes snow accumulation and snow melt into consideration (based on air temperature), but the freezing processes within the porous medium, and the associated effects on hydrogeological properties and processes, are not modelled.

Table 5-3. Input data required for the MIKE SHE modelling.

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
	K_c-value
Overland flow/channel flow	River network
	Cross-sections
	Permeability of the river bed
	Manning's number
Unsaturated flow	Map of Quaternary deposits
	Hydraulic parameters for unsaturated flow
Saturated flow	Geological model
	Horizontal saturated hydraulic conductivity
	Vertical saturated hydraulic conductivity
	Storage coefficient
	Specific yield

5.3.2 Objectives

The general objectives of the quantitative modelling in S1.2 are described in Section 5.1. The specific objectives of the MIKE SHE modelling are to

- perform initial modelling studies of site-specific conditions with regard to (1) the hydraulic contact between groundwater in Quaternary deposits and in fractured rock, (2) the water exchange between groundwater and surface waters, (3) the spatial distribution of recharge and discharge areas, and (4) the temporal variations in the various components of the water balance,
- deliver output data on the components of the water balance (evapotranspiration, surface water and groundwater flows) to the ecological system modelling,
- test the MIKE SHE tool, including its coupling to GeoEditor and MIKE 11, within the SKB environment.

The assumptions and conclusions made in the conceptual and descriptive modelling, presented in Chapter 4, are demonstrated and tested in the numerical modelling. The overall conceptual model and the parameters in the descriptive model provide the basis for the quantitative numerical modelling. However, it is recognised that the interactions between descriptive modelling and flow modelling have not been fully developed, as proposed in the modelling strategy, in the present model version. Time constraints and the limited access to site data are the main reasons for this. When time series from the sites are available, the MIKE SHE model could be calibrated and validated. Thus, the next step in the modelling work is to investigate whether calculated groundwater levels and stream discharges agree with those measured at the site.

The aim is to simulate the water movement in the Quaternary deposits and the interaction between surface water and groundwater. Furthermore, the purpose is to model the coupling of surface waters and the deep groundwater. Normally, it is assumed that the bottom boundary condition in a MIKE SHE model is a no-flow boundary. In this application, the boundary at the bottom of the model is a "head-controlled flux boundary" which provides an opportunity to simulate the flow of water between "deep" and near-surface groundwater.

Since the flows of matter in different ecosystems are strongly connected to the hydrology, the model results are important for the ecosystem modelling. Information about the water balance, especially the evapotranspiration from different part of the model area, are results that have been used in the ecosystem modelling. As compared to the GIS-based hydrological modelling, transient process-based modelling provides opportunities to explore a multitude of additional aspects and properties of the system, such as time-dependent processes and interactions between different sub-systems.

5.3.3 Model area

The ecosystem modelling in S1.2 is focused on the catchment area referred to as "Simpevarp 7" in /Brunberg et al. 2004/, see Figure 5-8. Therefore, this area is chosen for the MIKE SHE flow modelling. The "Simpevarp 7" catchment has a total area of 2.062 km^2, and consists of two sub-areas: the Lake Frisksjön sub-catchment (no 7:2; 1.848 km^2) and a smaller sub-catchment (no 7:1; 0.213 km^2) between the lake and the outlet of the "Kåreviksån" water course in the Baltic (Granholmsfjärden).

Figure 5-8. The model area, the "Simpevarp 7" catchment.

The catchment consists of a number of different ecosystems, and is considered to be representative for the regional Simpevarp area with respect to geology and vegetation. It contains both a water course and a lake, which implies that all the MIKE SHE compartments are included in the simulations. The properties and parameters characterising the catchment are described in detail in /Brunberg et al. 2004/.

5.3.4 Input data

As shown in Table 5-3, many different types of input data are required to develop a MIKE SHE model. At present, site-specific data are not available on all the input parameters in the model. However, the site investigations are not completed, and the input data will be updated in future versions of the MIKE SHE model for the Simpevarp area. Table 5-4 gives information about whether the various types of data used in the S1.2 model application are site-specific or not. References to the relevant data reports are also included in the table, whereas some additional references to generic data are given in the text.

Table 5-4. Input data used in the MIKE SHE model of the "Simpevarp 7" catchment area.

Compartment	Input data	Site specific	Data report
Frame	Topography	X	P-04-03
	Model boundary (water divide)	X	P-04-242
Evapotranspiration/snow routine	Potential evapotranspiration	X	TR-02-03
	Precipitation	X	TR-02-03
	Snow melt constants		
	Temperature	X	TR-02-03
	Vegetation	X	P-03-83
	Leaf Area Index (LAI)		
	Root depth		
	Root distribution		
	K_c-value		
Overland/Channel flow	River network		
	Cross sections		
	Permeability of the river bed		
	Manning's number		
Unsaturated zone	Map of Quaternary deposits	X	
	Hydraulic parameters for unsaturated flow		
Saturated flow	Geological model	X	
	Horizontal hydraulic conductivity	X	P-04-122
	Vertical hydraulic conductivity	X	P-04-122
	Storage coefficient		
	Specific yield		

Meteorological input data

The meteorological input data is taken from the SMHI station no 7722, located at Ölands norra udde (Chapter 3; Figure 5-9). Data is taken from 1981, which has been selected as a statistically representative year during the period 1961–2000 /Larsson-McCann et al. 2002/. Precipitation has been measured every twelfth hour, temperature every third hour, and monthly mean values are used for the potential evapotranspiration.

The annual uncorrected precipitation at Ölands norra udde is 470 mm and the potential evapotranspiration is 556 mm. The measured precipitation is always less than the real, because of losses due to wind, evaporation and adhesion. Therefore, time series for precipitation must be corrected. The correction factors for yearly and monthly mean values given in /Larsson McCann et al. 2002/ are used to correct the precipitation data from 1981. The yearly corrected precipitation is 576 mm. For a more detailed description of the meteorological conditions, see Chapter 3.

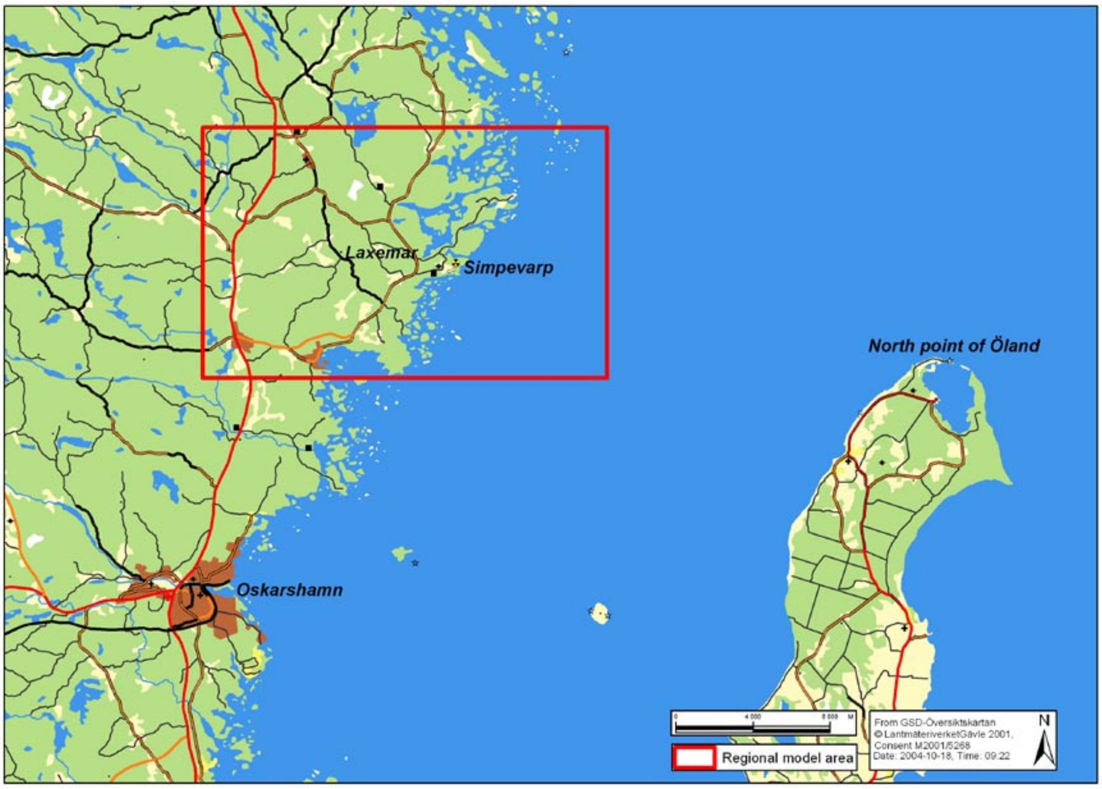


Figure 5-9. *The meteorological station no 7722 at Ölands norra udde and the regional model area.*

Geological model and hydraulic properties

Bedrock

The part of the geological model containing the bedrock is described by data taken from the hydrogeological S1.1 modelling with DarcyTools /Follin et al. 2004/. Data is taken from three different levels of the DarcyTools model: –150 m a s l, 60 m below the ground surface and 20 m below the ground surface. The bedrock is described in terms of vertical and horizontal hydraulic conductivity. The values for the horizontal hydraulic conductivity for the bedrock, the HRD described in Chapter 4, is in the range 1×10^{-11}–1×10^{-10} $m\times s^{-1}$. The hydraulic conductivity for the fracture zones, the HCD described in Chapter 4, is in the range 1×10^{-8}–1×10^{-7} $m\times s^{-1}$.

The horizontal hydraulic conductivity at –150 m a s l is illustrated in Figure 5-10. The contrast between bedrock and fracture zones is clearly seen in the figure. Furthermore, it can be seen that the main E-W fracture zone goes through the area where the lake is located. Generic data are used for the specific yield and the storage coefficient. The values are based on data from previous MIKE SHE applications /DHI Sverige, 1998/. The specific yield for the bedrock is set to 0.01 (–) and the storage coefficient for the bedrock is set to 1×10^{-5} m^{-1}.

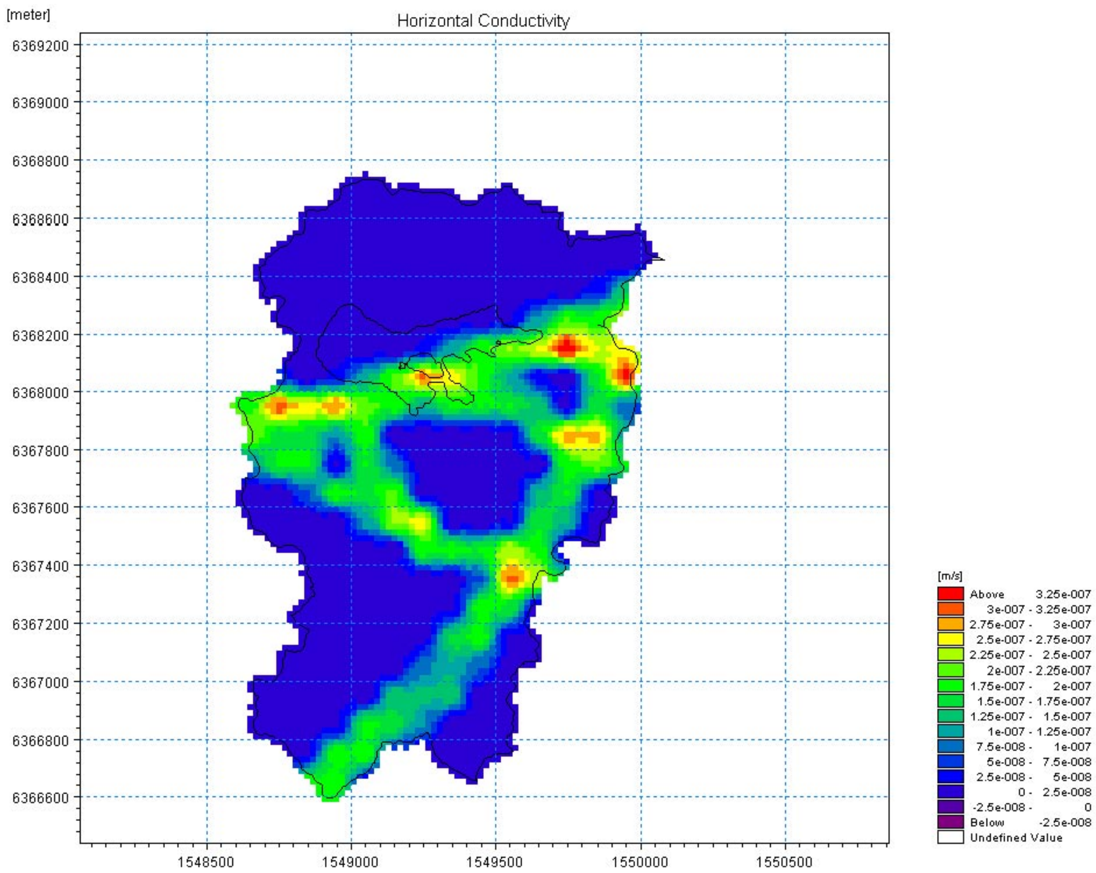


Figure 5-10. *Horizontal hydraulic conductivity [ms^{-1}] at –150 m a s l.*

Quaternary deposits

A geological model, based on the information in Figure 5-11, has been made for the model area. The information is based on data from airborne geophysical investigations; for a detailed description, see /Lindborg (ed), 2005/ and Chapter 4. In areas with bedrock outcrops, the depth of the Quaternary deposits is set to zero. In high conductance areas, except from areas where the high conductance is caused by power lines, the soil profile is assumed to contain clay. The thickness of the clay is set to four metres. The clay is underlain by one metre of sandy till. In the remaining areas, the depth of Quaternary deposits is set to one metre consisting of sandy till (Figure 5-12).

There is presently no information available about the lake sediments. Hence, it is assumed that Lake Frisksjön is located on clay. It can be noted that two of the three type areas described in Chapter 4 are included in the Simpevarp 7 MIKE SHE model. There are no areas with glaciofluvial deposits in the modelled catchment area.

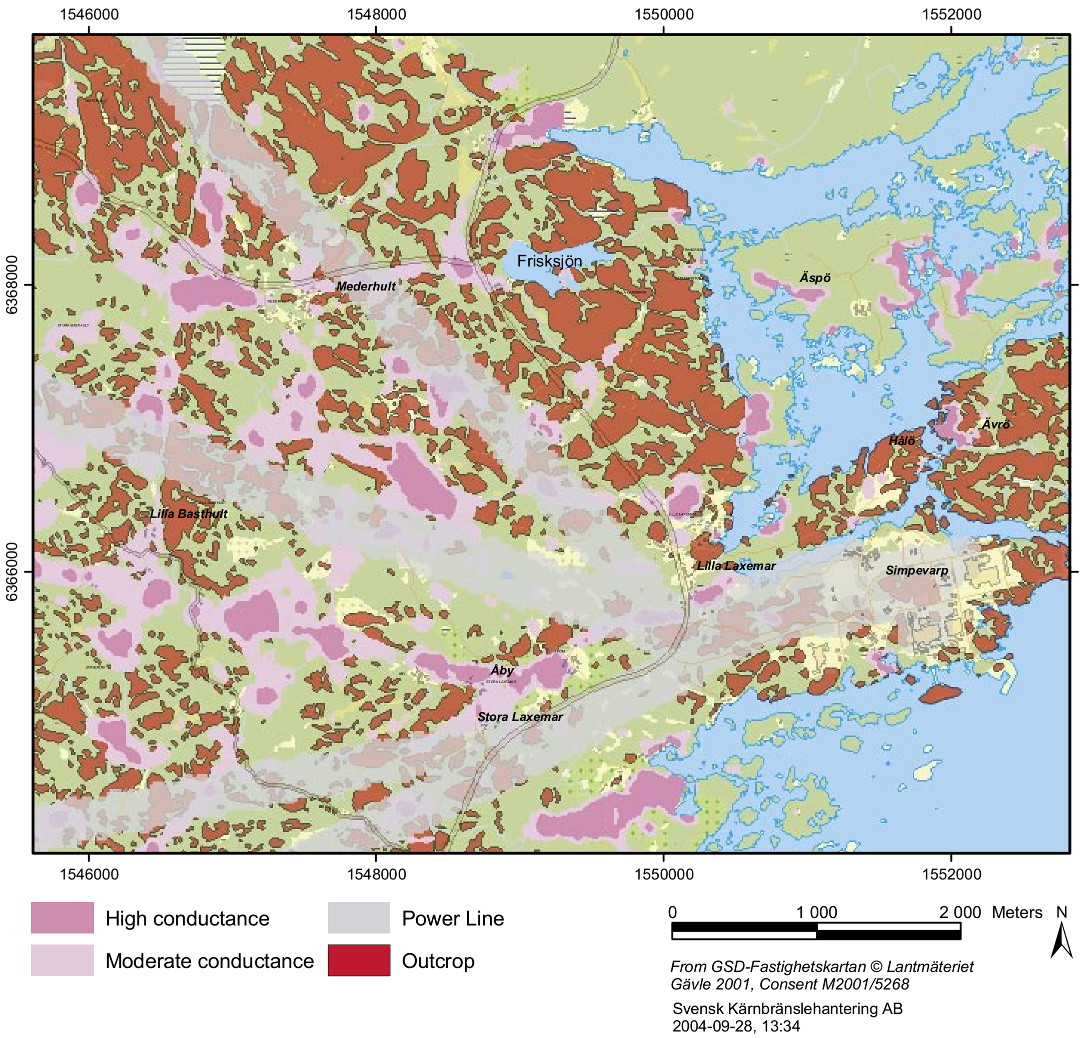


Figure 5-11. *Quaternary deposits in the Simpevarp 7 catchment area.*

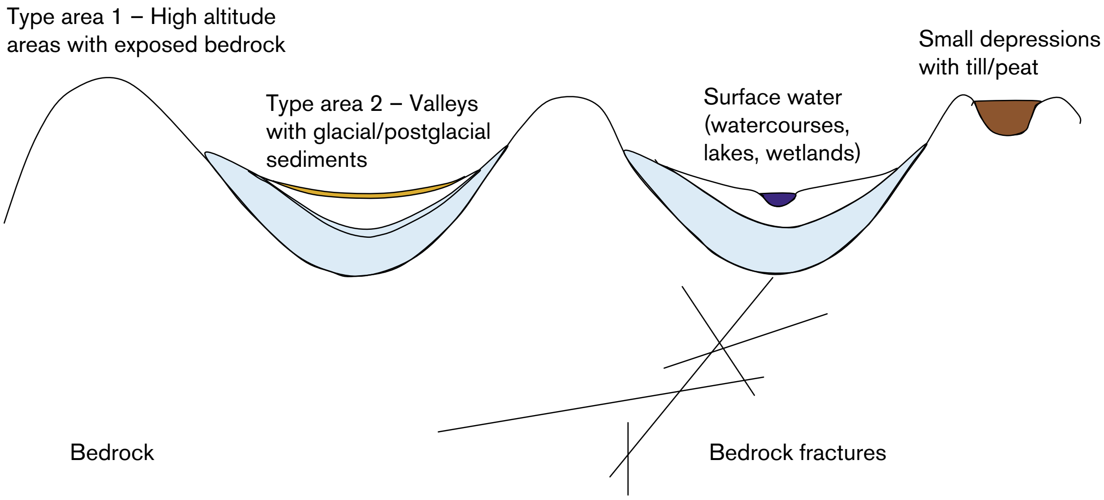


Figure 5-12. *Conceptual geological model for the "Simpevarp 7" catchment area.*

The hydraulic conductivity of the till is taken from slug tests made in the area (cf Chapters 3 and 4). The value for both the horizontal and the vertical hydraulic conductivity is set to 1.5×10^{-5} m×s^{-1}. No slug tests have been performed in clayey soil. Thus, the *K*-value for the clay is generic; it is set to 1×10^{-8} m×s^{-1}. Generic data are used also for the specific yield /Domenico and Schwartz, 1998/, see Table 5-5. The values for "Till, sand" and "Clay" are used in the model. The storage coefficient for the Quaternary deposits is set to 0.001 m^{-1} in the entire model area /DHI Sverige, 1998/.

The parameters for the unsaturated flow are taken from the soil database in the MIKE SHE program (Figure 5-13). The database has been developed by DHI Sverige. The hydraulic conductivity function is described by the Averjanov function (Equation 1).

$$K(\theta) = K_s \left(\frac{\theta - \theta_r}{\theta_s - \theta_r} \right)^n \qquad (1)$$

K_s saturated hydraulic conductivity (m×s^{-1})

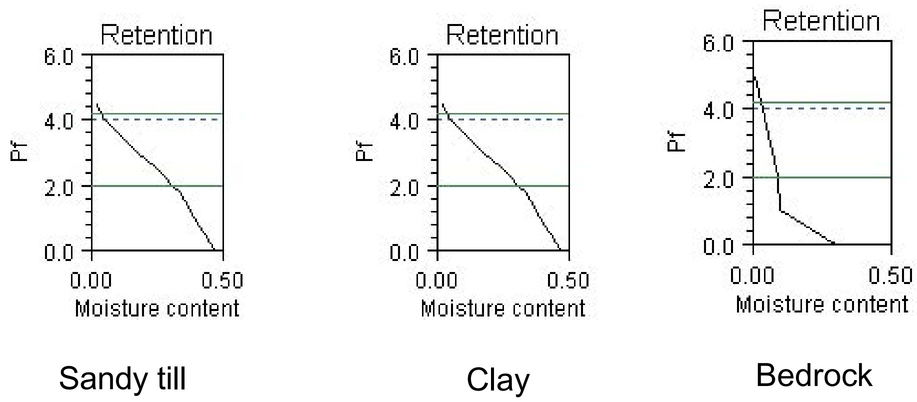
θ_s water content at saturation (–)

θ_r residual water content (–)

n empirical parameter (–)

Table 5-5. Specific yield for different soil types /Domenico and Schwartz, 1998/.

Material	Specific yield (%)
Gravel, coarse	23
Gravel, medium	24
Gravel, fine	25
Sand, coarse	27
Sand, medium	28
Sand, fine	23
Silt	8
Clay	3
Peat	44
Till, silt	6
Till, sand	16
Till, gravel	16



	Clay	Sandy Till	Bedrock
Ks [ms^{-1}]	1.00E-08	1.50E-05	1.00E-10
θ_s	0.615	0.47	0.03
θ_r	0.23	0.018	0.01
n	15	8	2

Figure 5-13. *Retention curves and parameters for unsaturated flow. The notation is explained in connection with Equation 1 below.*

Vegetation-related parameters

Based on the tree layer from the inventory of the vegetation /Boresjö Bronge and Wester, 2003/, a classification of the vegetation was made. The model area was divided into five vegetation groups: coniferous forest, deciduous forest, mixed forest, grass and water, cf Figure 5-14.

Each vegetation group is assigned properties expressed in terms of Leaf Area Index (LAI), root depth, K_c-value, and the empirical parameters used in the Kristensen and Jensen model /Kristensen and Jensen, 1975/. The values vary in time. The values for the different properties are taken from the database developed by DHI. Root depth and LAI for the water are zero, which implies that the transpiration component of the actual evapotranspiration is zero in these areas.

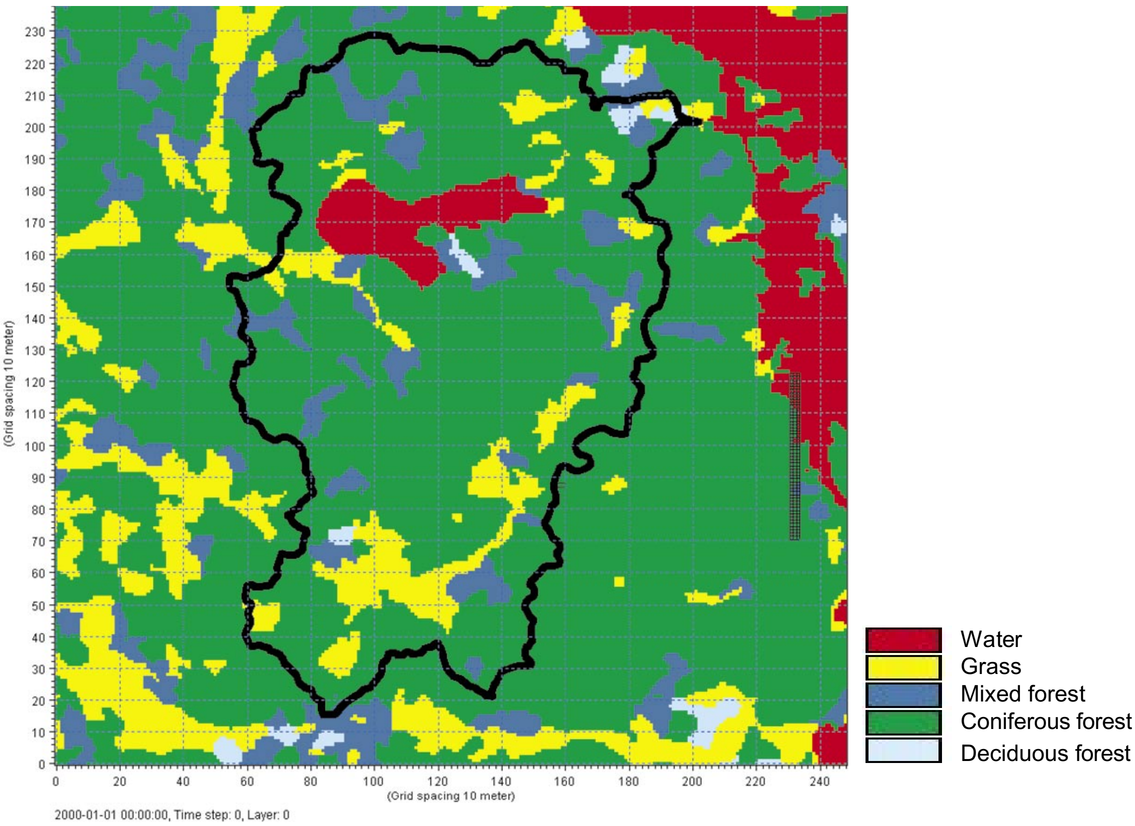


Figure 5-14. *Vegetation classes in the model area.*

5.3.5 Initial and boundary conditions

A so-called "hot start" is used to generate the initial conditions of the model. The model is run until semi steady-state conditions are reached. This means that the model is run, with the time-dependent boundary conditions given by the meteorological data for the reference year, until the variations during the year have stabilised (e.g. the pressure at a certain point shows more or less the same variation from one year to the next). The results from the simulation are used as initial conditions for simulations with a higher temporal resolution. The model has been run for three years, based on data from 1981, to get proper initial conditions.

The surface water divide is assumed to coincide with the groundwater divide. Thus, the boundary condition for lateral flow is a no-flow boundary, see Chapter 4. The top boundary condition is given by the precipitation and the evapotranspiration. The precipitation is assumed to be uniformly distributed over the model area and is introduced into the model as a time series. The boundary condition for the saturated zone is described by the processes in the unsaturated zone. Water is taken out from the model by the MIKE 11 river network. The water course from the outlet of Lake Frisksjön ("Kåreviksån") crosses the model boundary, and water is there transported out from the model area. The amount of water flowing to MIKE 11 is dependent on the conditions in other compartments of the model. Water is transported to MIKE 11 via overland flow, and from the saturated zone.

The bottom boundary condition is a fixed head boundary condition. Model result from the S1.1 DarcyTools groundwater flow modelling /Follin et al. 2004/ is used as input data for the bottom boundary condition. The calculated hydraulic head from –150 m a s l is imported to the MIKE SHE model (Figure 5-15). The bottom boundary condition is constant with time.

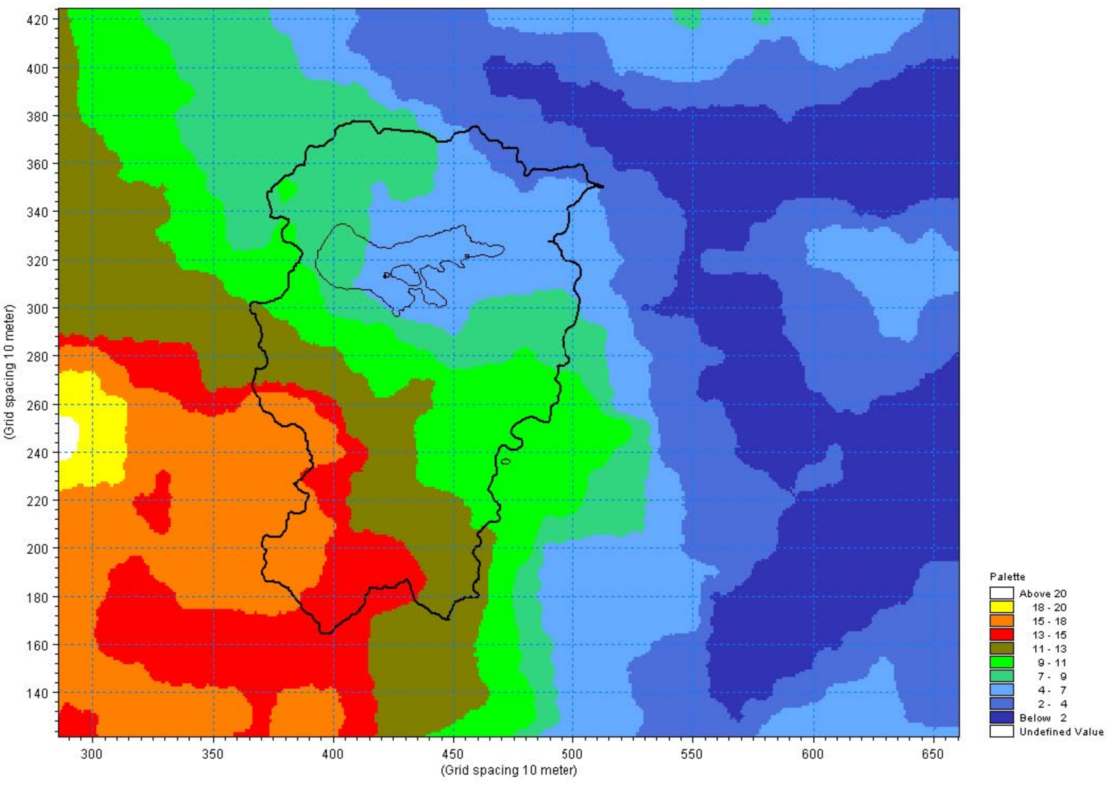


***Figure 5-15.** The hydraulic head at –150 m a s l, as calculated with DarcyTools in the S1.1 modelling /Follin et al. 2004/.*

5.3.6 Results

As described above, the model was run until semi steady-state conditions were reached, in order to get proper initial conditions for the detailed simulations. A time period of one year was considered in the detailed simulations. Since the flow model has not yet been tested against field data, only a small subset of the available results are presented in this report, focusing on the water balance and the groundwater flow in the model area. The modelling work will also be analysed with respect to the capabilities of MIKE SHE as a modelling tool in the site investigation work.

Water balance

The regional specific discharge for the area is estimated to 5.7 $l \times s^{-1} \cdot km^{-2}$ /Larsson-McCann et al. 2002/, which corresponds to 180 mm/year. The modelled average specific discharge within the "Simpevarp 7" catchment area is 4.9 $l \times s^{-1} \cdot km^{-2}$, corresponding to 154 $mm \times year^{-1}$. The total actual evapotranspiration was calculated to 426 $mm \times year^{-1}$. There is a small water balance error in the results, which occurs in the unsaturated zone component of the model. However, the calculated water balance agrees with the general conceptual model for the water flow system that was presented in Chapter 4.

Figure 5-16 illustrates the overall water balance and the exchanges of water between different compartments in the model. The water balance error mentioned above causes a difference between the precipitation and the sum of transpiration and runoff. The water balance is calculated in all the compartments of the model. Thus, arrows labelled "evaporation" are indicated both in the overland compartment and in the unsaturated zone compartment. The total actual evapotranspiration is a sum of evaporation from snow, intercepted water, soil surface and ponded water, and transpiration. The runoff is the net flow of water transported to the MIKE 11 model. MIKE 11 calculates the discharge and water levels in the water course.

The discharge in the water course, "Kåreviksån", varies during the year and is highly dependent of the precipitation (Figure 5-17). Upstream from the lake, the discharge is close to zero from the middle of April to the middle of June. The water course is dry in the end of July. There is a large fluctuation in the discharge to the lake. As shown in Figure 5-17, the lake has a smoothening effect on the hydrograph. The maximum discharge from "Kåreviksån" to Lake Frisksjön is approximately 40 $l \times s^{-1}$, whereas the maximum discharge to the sea is approximately 27 $l \times s^{-1}$. The two maxima do not appear simultaneously; there is a delay of the maximum discharge to the sea, which is caused by the lake.

The maximum discharge occurs during the spring. Even though the rain intensity is higher in the summer, the discharge in the water course does not reach the same level as in the spring. The intervals between the rains in the summer are longer than those between the precipitation/recharge events during the spring. The level of saturation is lower in the summer, which means that more water can be stored in the soil before it enters the water course. This leads to lower peaks in the hydrograph.

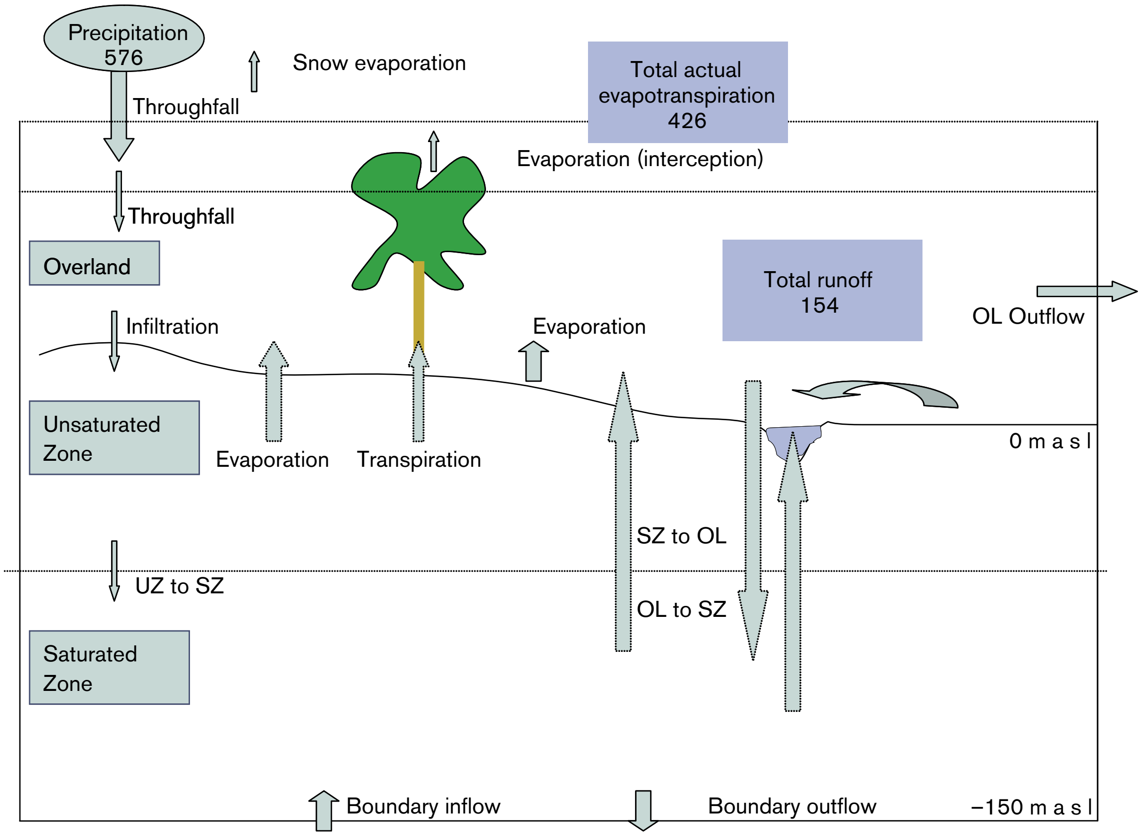


__Figure 5-16.__ Water balance for the Simpevarp 7 catchment area (mm/year), and modelled water exchanges between the different compartments in the MIKE SHE flow model.

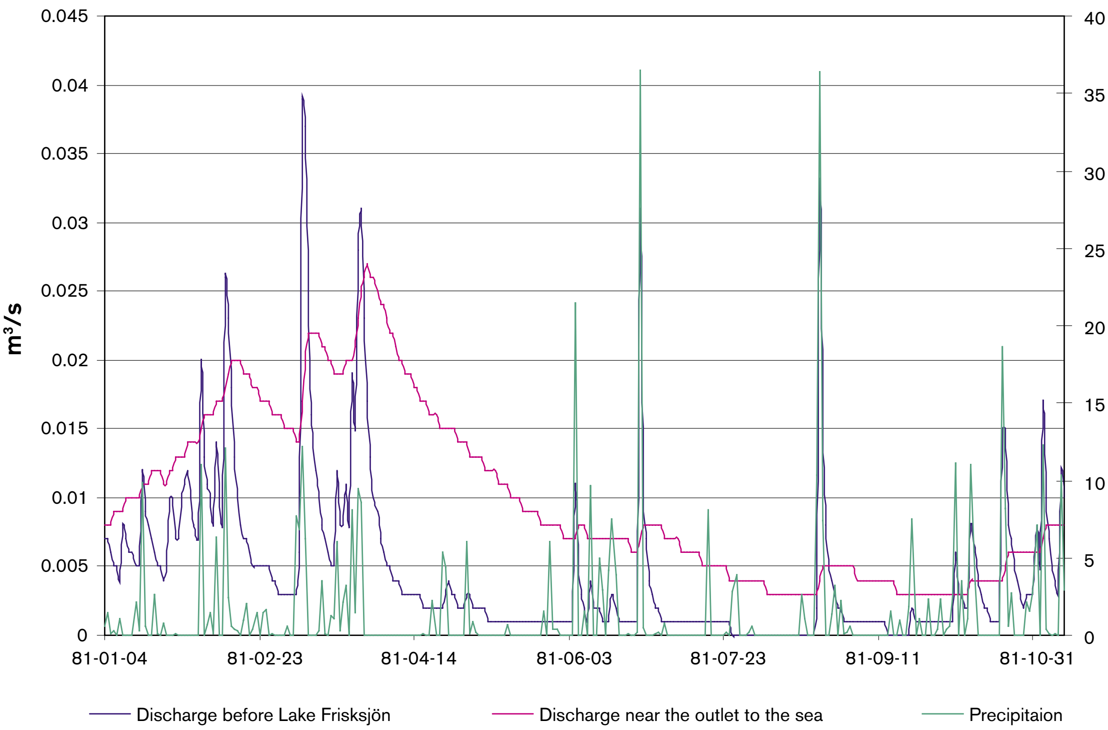


__Figure 5-17.__ Calculated discharge in Kåreviksån.

Groundwater levels

Generally, the groundwater level within the modelled area is close to the ground surface. For example, the mean groundwater level in April (averaged over the whole catchment) is 1.3 m below the ground surface. However, there is a certain variation during the year. As shown in Figure 5-18, the depth to the groundwater table is varying in the model area. The figure shows the depth to the groundwater table in the end of May. The maximum depth is around 12 m below the ground surface, and is found at the topographic heights near the catchment area boundary in the eastern part of the catchment area.

A yellow or red colour in the figure indicates there is ponded water (overland water) on the ground surface. The depth of ponded water is illustrated in Figure 5-18. In these areas, the soil profile is fully saturated, i.e. the groundwater reaches the ground surface. In the lake, the modelled "ground surface" is equivalent to the lake bathymetry. The blue and green areas give a visualisation of the depth to the groundwater table in the catchment area. All the values in Figure 5-18 are given relative to the ground surface. Except from Lake Frisksjön, there are two areas, in the eastern part of the catchment area, where the water is ponding. Specifically, the model produces two small lakes that do not exist in reality. This result can be related to errors in the DEM and man-made structures that not are included in the present model. The area marked with a black dashed line in Figure 5-18 is a wetland area. The groundwater level is here very close to the ground surface, and during most of the year there is ponded water on the ground surface.

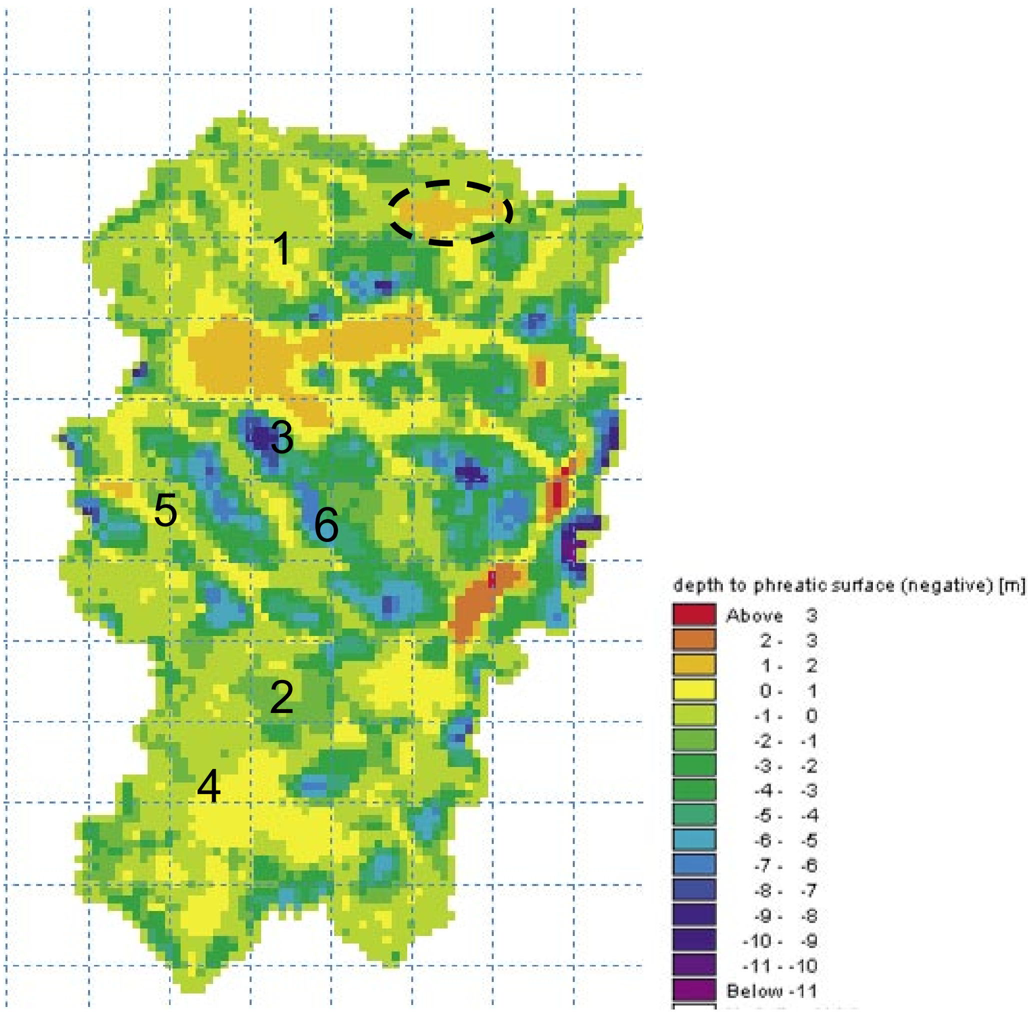


Figure 5-18. *Depth to ground water table (metres below the ground surface).*

Time series showing the fluctuations of the groundwater level (expressed relative to the ground level) in the numbered points in Figure 5-18 are shown in Figures 5-19 and 5-20. Points no 1, 2, 4 and 5 are locations where the groundwater table is shallow (close to the ground surface), whereas points no 3 and 6 are located at topographic heights where the depth to the groundwater table is larger. Note that the figures display two different depth intervals, but that the vertical resolution is the same.

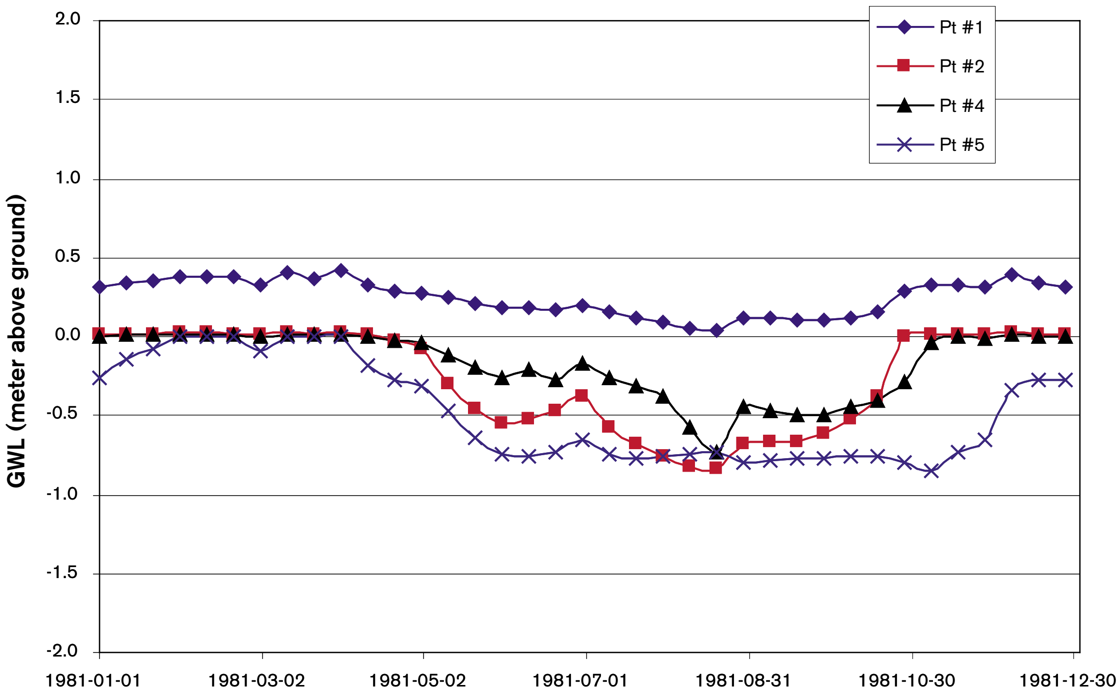


Figure 5-19. *Time series of groundwater levels in points no 1, 2, 4 and 5 (cf Figure 5-18).*

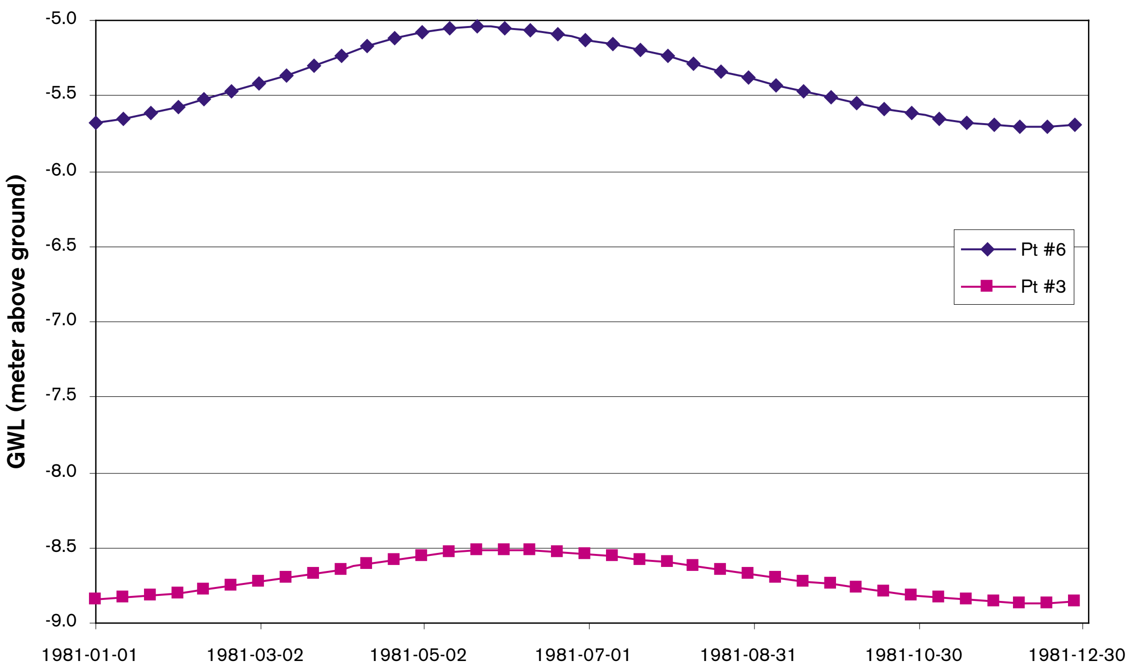


Figure 5-20. *Time series of groundwater levels in points 3 and 6 (cf Figure 5-18).*

Comparing the results in Figures 5-19 and 5-20, it can be noted that the two groups of observation points show somewhat different patterns of temporal variability. In the points of shallow groundwater levels, the calculated groundwater levels are sensitive to variations in the meteorological conditions. Specifically, Figure 5-19 shows that the groundwater level is above or very close to the ground surface during spring and autumn, and lower during the summer. Furthermore, these points show short-term variations that are not observed where the groundwater depth is larger (Figure 5-20).

As shown in Figure 5-20, the curves for the groundwater levels below the topographic heights are smoother. The groundwater levels increase during spring and decrease during summer and autumn. It can also be noted that the differences between annual maximum and minimum levels are similar in the shallow and deep observation points. The smallest variations are obtained for the shallowest and deepest groundwater levels.

The calculated hydraulic head in the uppermost calculation layer in the saturated zone is illustrated in Figure 5-21. The red and yellow areas are typical recharge areas. The light green areas are recharge areas during most of the year. The locations of discharge and recharge areas are affected by the meteorological conditions. The blue areas are typical discharge areas. The lake and the water course are discharge areas throughout the year.

Figure 5-22 shows a cross-section with the calculated hydraulic heads in each of the twelve calculation layers; the green line in Figure 5-21 shows where the cross-section is taken. The positions of the calculation layers in the vertical profile are indicated by the colours of the lines; the lighter green the head elevation curve, the more shallow the calculation layer. The location of Lake Frisksjön is marked in the figure.

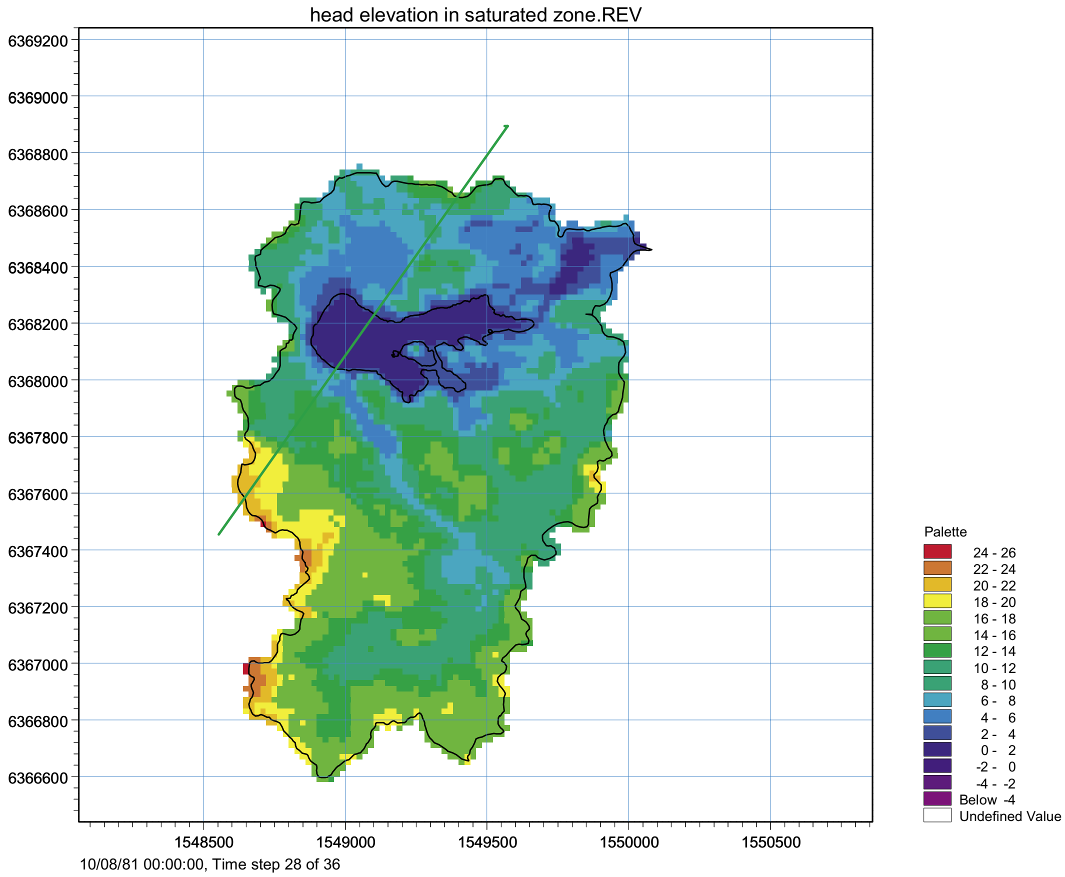


***Figure 5-21.** Head elevation in uppermost calculation layer in the saturated zone.*

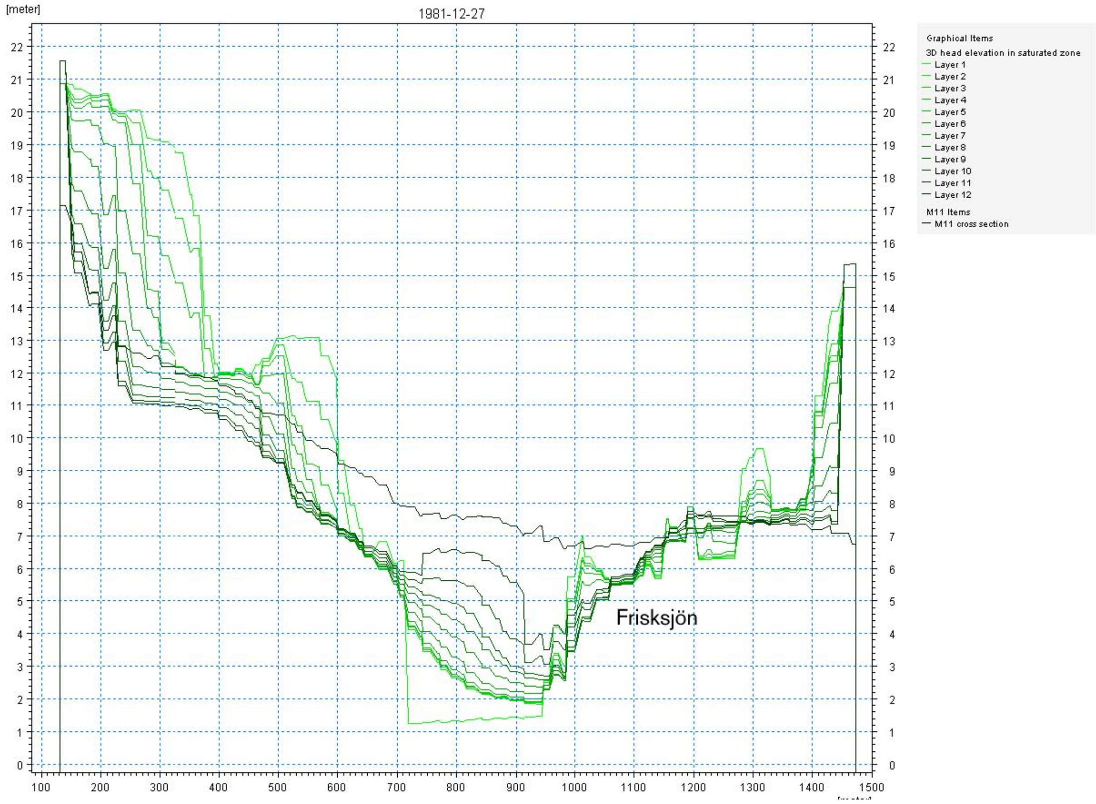


Figure 5-22. *The head elevations in the calculation layers in the saturated zone along the section indicated in Figure 5-21; the lighter green the head elevation curve, the more shallow the calculation layer.*

It can be seen in Figure 5-22 that the hydraulic head generally is higher at the topographic heights. The topographic heights are typical recharge areas and the lowest points, around the lake and the water course, are discharge areas. This is shown by the order in which the curves for the different layers appear in the figure. In the higher-altitude areas, the more shallow (lighter green) layers show the highest hydraulic heads, indicating a downward flow through the soil profile (recharge). Conversely, the shallow layers display the lowest hydraulic heads in the lower-altitude areas, which indicates upward flow (discharge). Thus, the shift in the relative positions of the different calculation layers along the cross-section illustrates the shift from recharge to discharge conditions.

Recharge, discharge and exchange with deep rock

Figure 5-23 shows the calculated vertical groundwater flow in the uppermost calculation layer in the saturated zone. The left figure shows results from just after a heavy rain, whereas the picture to the right is from a very dry period. It can be seen that the vertical flow varies in space and time. The local topography has a strong influence on the location of discharge and recharge areas. The areas marked with yellow to beige and red colours in Figure 5-23 have upward flow in the uppermost saturated layer, and can therefore be considered as discharge areas. The two pictures show that the lake and the water course constitute distinct discharge areas.

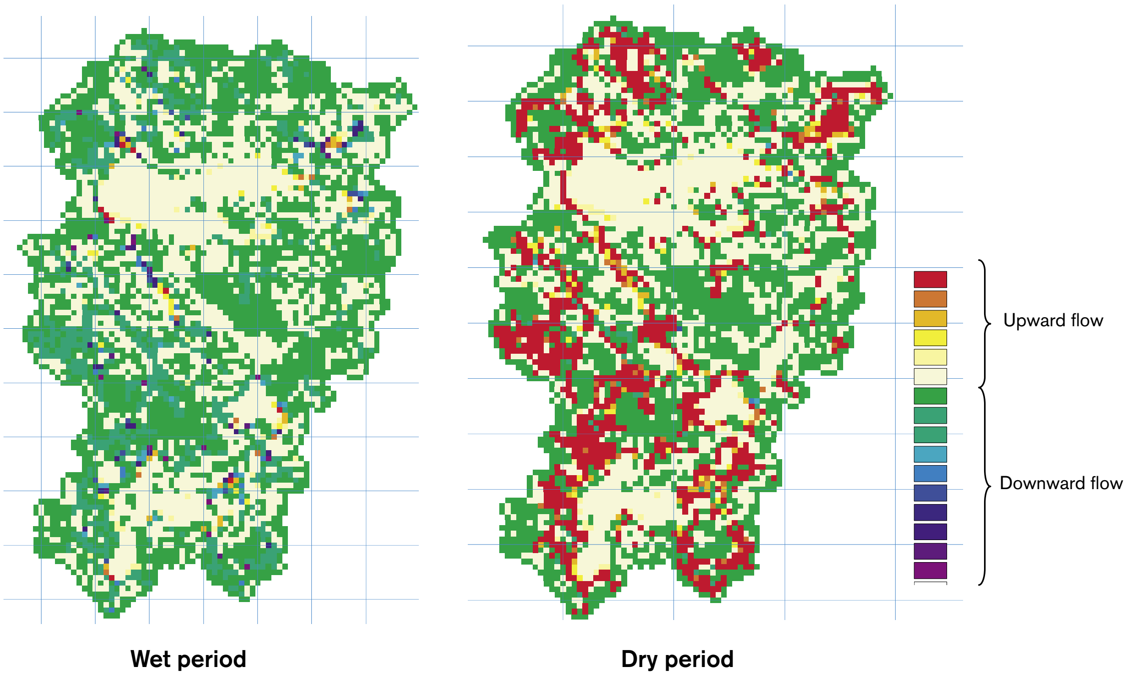


Figure 5-23. *Vertical groundwater flow in the uppermost calculation layer in the saturated zone.*

The vertical groundwater flow in the areas between the topographic heights and the low-altitude areas is highly dependent on the meteorological conditions. This implies that areas that are recharge areas under wet conditions become discharge areas during dry periods. However, the lake and the area close to the water course are discharge areas throughout the year. Thus, the modelling results agree with the description in Chapter 4, which states that lakes and rivers are permanent discharge areas whereas bedrock outcrops in high-altitude areas are recharge areas. In the flat areas in between, the spatial distribution of recharge and discharge areas varies during the year.

The simulation results show that most of the water turnover takes place in the Quaternary deposits. In comparison, the water exchange between Quaternary deposits and bedrock can be regarded as small. The groundwater flow in the bedrock is dominated by the flow in the fracture zones, implying that most of the flow between Quaternary deposits and rock occurs at interfaces between fracture zones and the overlying deposits. There is a net inflow of water over the bottom boundary. The groundwater flow in the fracture zones has an upward direction and was calculated to 3 mm per year. The net groundwater flow in the bedrock was calculated to less than 0.5 mm per year and is directed downwards.

The calculated groundwater flow over the bottom boundary has been compared to the calculated groundwater flow in the Darcy Tools model. In Darcy Tools, the mean groundwater flow between –150 m a s l and –60 m a s l is 2.4 mm per year and has an upward direction. The net inflow over the bottom boundary in the MIKE SHE model is 1.8 mm/year. Thus, the net calculated groundwater flows in the two models are in the same range and have the same direction.

Figure 5-24 shows the calculated vertical groundwater flow in all calculation layers along the cross-section indicated in the smaller figure to the right. The figure to the right also shows the horizontal hydraulic conductivity in the bedrock (cf Figure 5-10), thereby indicating where the section goes through fracture zones. The figure illustrates the vertical groundwater flows in the model area. It should be noted that in some locations the direction of the flow vector changes during the year, in connection with, e.g. heavy rains and dry periods.

It is clearly seen in Figure 5-24 that the flow rates generally are much higher in the uppermost layers in the Quaternary deposits than in the bedrock, and that the fracture zones dominate the flow in the rock (no flow vectors are visible in the rock between the zones). The water movement under Lake Frisksjön has an upward direction. The groundwater flow in other parts of the fracture zone is influenced by the local topography, and can be directed both upwards and downwards.

Concerning the interactions between the near-surface and deep rock groundwater flow models, it should be noted that the model presented here is based on the S1.1 modelling of the deep rock, which means that the description of the fractured rock is not fully consistent with that presented as a part of the S1.2 hydrogeological modelling. Hence, no iterations or comparisons have been made that could lead to modifications of the boundary conditions and to potential improvements of both the near-surface and the deep rock flow models. The potential for such interactions and improvements will be explored in future model versions.

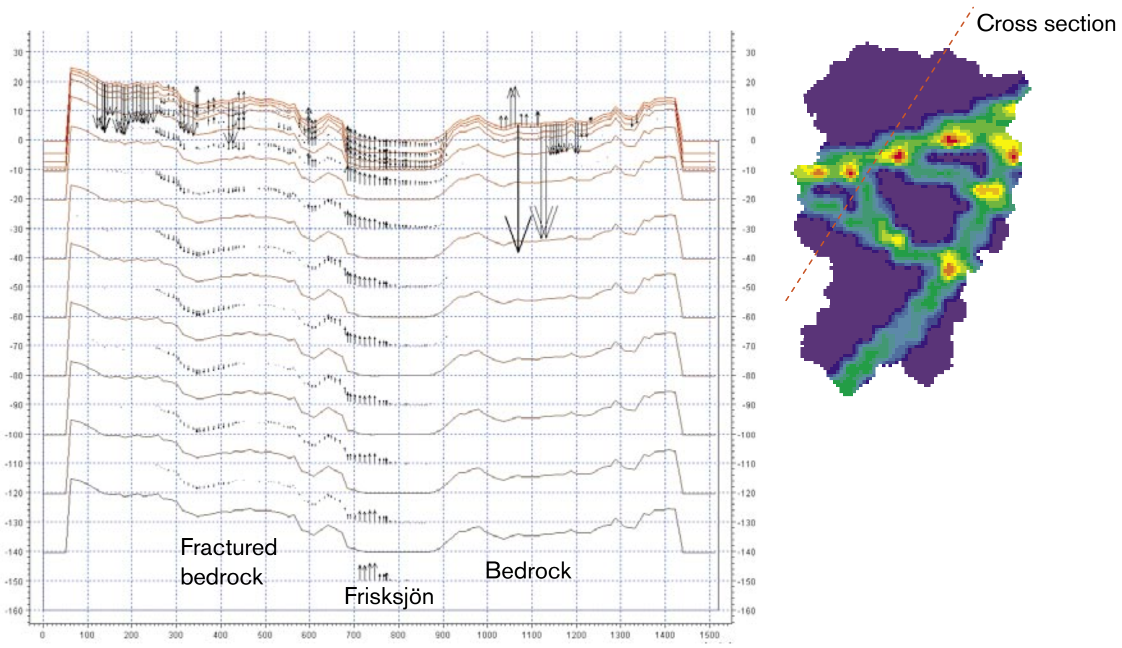


Figure 5-24. *Vertical flow in all calculation layers (left). The position of the cross-section is indicated in the figure to the right, which also shows the spatial distribution of the horizontal hydraulic conductivity in the bedrock.*

5.3.7 Evaluation of uncertainties

As described above, the present MIKE SHE simulations of the "Simpevarp 7" catchment area are based on regional (non site-specific data, considered "representative") and spatially uniform meteorological data and very limited site data on the geological and hydrogeological properties of the modelled system. It follows that there are a number of uncertainties associated with the application of the simulation results for describing the present situation within the Simpevarp area. The main uncertainties can be summarised as follows:

- Uncertainties in input data and models from other disciplines:
  - The topographical description (the DEM).
  - The geological descriptions of bedrock and Quaternary deposits (spatial distribution and stratigraphy).
  - The vegetation map.
- Uncertainties in the classification and parametrisation of different types of vegetation for use in the modelling of evapotranspiration and unsaturated flow.
- Uncertainties in the hydraulic parameters for saturated flow in Quaternary deposits and fractured rock, and in the parameters for unsaturated flow.
- Uncertainties in the delineation of catchment boundaries (the boundaries of the model) and in the description of the water courses (positions and cross-sections).
- Uncertainties related to simplifications in process models in MIKE SHE, primarily the modelling of unsaturated flow, and soil freezing and thawing.
- Uncertainties in other input data, primarily the meteorological parameters and their spatial and temporal variability within the model area.

Generally, the uncertainties associated with the limited access to site data are judged most important at the present stage of model development. The present lack of data on the modelled area concerns both basic properties of the system (e.g. geological and hydrogeological parameters) and data needed to evaluate the model (e.g. measured flow rates and water levels). Thus, the uncertainty evaluation provided here is primarily of qualitative character, focusing on identification and qualitative description rather than quantification.

The geological information on the Quaternary deposits within the "Simpevarp 7" catchment area is quite limited. Therefore, the geological model used in the development of the flow model is schematic; the uniform till layer of one metre will likely be changed in future versions of the flow model. Furthermore, site data on the variations in hydraulic properties within the model area will improve the model. Some preliminary sensitivity studies have been undertaken in order to investigate the effects of anisotropy in the hydraulic properties of the Quaternary deposits and the representation of exposed bedrock in the model. Although these studies have indicated only small effects on the overall flow pattern and flow rates, extended sensitivity studies will be valuable for assessing geological and hydrogeological uncertainties. Site data are needed to constrain these sensitivity studies.

The geological/hydrogeological model of the bedrock is taken from the S1.1 modelling /SKB, 2004a/. Since there is a large contrast in hydraulic conductivity between fracture zones and rock mass, with most of the hydrogeological interactions between rock and Quaternary deposits taking place in connection with the fracture zones, uncertainties in the geological model for the rock and the associated hydrogeological parameters could be important for the surface system model. As indicated by the water balance calculations, it can be expected that the surface/near-surface hydrology/hydrogeology is more important for the deep rock hydrogeology than vice versa. However, it should be noted that the details of these interactions are crucial for the modelling of radionuclide transport to and within the surface system.

The vegetation classification is based on field inventory of the tree layer. The classification and the parameters describing the properties of each vegetation class are associated with uncertainties; these parameters affect the water balance through the modelling of the evapotranspiration. Since the potential evapotranspiration is the maximum evapotranspiration, the different parameters have a moderate effect on the actual evapotranspiration. The K_c-value (defined as actual transpiration/potential evaporation) is the only parameter that can make the actual transpiration larger than the potential evapotranspiration.

Since the potential evapotranspiration is calculated for a grass field, it could be motivated to use a K_c-value different from one. A few sensitivity simulations have been performed to investigate how the K_c-value affects the actual evapotranspiration. Since the model area is dominated by coniferous trees, only the K_c-value for this vegetation group has been changed in the simulations. Similar to the results in Figure 5-16, the evapotranspiration is expressed as an average over the whole model area (in $mm \times year^{-1} = l \times m^{-2} \times year^{-1}$).

Simulations with constant K_c-values of 1 and 1.3 resulted in total average evapotranspiration values of 426 $mm \times year^{-1}$ and 476 $mm \times year^{-1}$, respectively. In addition, a simulation was performed with time-varying K_c-values taken from the "CoupModel" simulations performed as a part of the SurfaceNet ecosystem modelling /Lindborg (ed), 2005/. These K_c-values, corresponding to an annual mean of 1.39, are listed in Table 5-6. The resulting total evapotranspiration is 354 $mm \times year^{-1}$. It can be concluded that the K_c-value has a considerable effect on the total evapotranspiration, and hence on the total runoff. Among the parametrisations tested here, a constant value of 1 appears to give the best fit with the regional water balance (Chapter 4).

The description of the surface water system is important for the modelling of surface hydrology and near-surface hydrogeology. In particular, the various threshold levels and flow resistances in the water courses determine, together with the hydrogeological properties, the distribution of the total runoff on the surface and subsurface systems. So far, no field inventories have been performed of the cross-sections of the water courses or of the

Table 5-6. Temporally variable K_c-values obtained from "CoupModel" and used in sensitivity simulation with MIKE SHE.

	K_c-value
January	2.00
February	2.00
March	1.25
April	0.95
May–July	0.75
August	0.95
September	1.25
October	2.00
November	2.00
December	2.00

bottom profiles along them. In the present model, the cross-sections in the MIKE 11 river network are assumed to have triangular shapes, and the depth from the bank level to the bottom is set to one metre. Future field inventories will also be directed towards the results of drainage operations and other human impacts on the surface hydrology (e.g. ditching and redirection of water), currently not included in the model.

In MIKE SHE, the snow cover is simulated with the degree-day-method. The degree-day factor is the amount of snow that melts each day when the temperature is above the threshold temperature (the temperature at which the snow starts to melt). Furthermore, the soil freezing processes are not included in MIKE SHE. However, these processes are modelled in the one-dimensional "CoupModel", which is used within the SurfaceNet modelling /Lindborg (ed), 2005/. Thus, comparisons between MIKE SHE and "CoupModel" can be conducted in order to address the process model simplifications in the former model.

5.4 Concluding remarks

The S1.2 quantitative flow modelling has included GIS-based modelling of steady-state flow (total runoff), using the DEM and a spatially uniform specific discharge estimated from regional meteorological data as inputs, and process-based modelling with MIKE SHE, using temporally variable meteorological data for a "representative" regional site during a "representative" year. In addition, the MIKE SHE model is based on geological, hydrogeological and vegetation data from the Simpevarp area, but no detailed information from soil drillings within the modelled area (the Simpevarp 7 catchment) has been available. The observations and conclusions of the flow modelling are summarised in Section 6.2.2.

It is emphasised that the quantitative flow modelling of the Simpevarp area has only just started. So far, the modelling has to a large extent been focused on the production of outputs required for the ecosystem modelling, and on model tests. In particular, the present version of the MIKE SHE model of the "Simpevarp 7" catchment area contains very little site-specific geological and hydrogeological data, and is primarily developed for investigating capabilities and limitations of the code in the present context. The Laxemar 1.2 modelling will to a much larger extent address issues related to site understanding, including interactions with other modelling disciplines.

The various aspects of the descriptive model (Chapter 4) that have been tested have also been confirmed by the flow modelling, at least to the degree of detail considered in the present evaluations. The local topography has a strong influence on the flow pattern in the area. Within the "Simpevarp 7" catchment area, the lake is an obvious discharge area, and the topographic heights are recharge areas. The discharge in the water course is highly dependent on the precipitation, i.e. responds quickly to rainfall events. This is probably an effect of the large proportion of bedrock outcrops in the catchment area, implying that the rain intensity easily exceeds the infiltration capacity such that surface runoff occurs.

The implications of the simplifications in the modelling of unsaturated flow and freezing should be further analysed. As discussed above, comparisons between MIKE SHE-results and results from "CoupModel" simulations could be used for this purpose. Preliminary sensitivity studies have shown that variations in the input parameters to the evapotranspiration calculations have considerable effects on the overall water balance. However, these and other simulation results are difficult to associate to the actual site conditions before site-specific time series of groundwater levels, discharges in water courses and meteorological parameters become available.

Most of the water turnover in the integrated hydrological-hydrogeological system at the site takes place in the Quaternary deposits. Therefore, it is important to develop a proper stratigraphical model of the Quaternary deposits, and to obtain adequate hydraulic parameters for the various geological materials. The fracture zones in the rock dominate the hydrogeological interactions between the rock and Quaternary deposits. This implies that the details of the hydraulic properties at interfaces between zones and overlying deposits must be adequately described. The properties of this interface are of particular importance for radionuclide transport simulations, and for assessing the effects of groundwater level drawdown during the construction and operation phases of a nuclear waste deposit.

6 Resulting description of the Simpevarp site

6.1 Developments since previous model version

Local meteorological and surface-hydrological data were not available for the version 1.1 modelling, whereas there is a limited access to such data in version 1.2. Long time series on meteorological and hydrological parameters are available from regional SMHI stations; these data were also used in the previous model versions (including version 0). In version 1.2, local meteorological data (from a new station at Äspö) are available for a period of one year. Since the previous model version, catchment areas have been delineated (field controlled) and described. A number of stations for hydrological (discharge, surface-water levels) and hydrogeological (groundwater levels) measurements are now established, but no quality-controlled data from these stations have been accessible for the present modelling work.

Quality-controlled data include simple discharge measurements in water courses, and manual groundwater level measurements in monitoring wells. The hydraulic conductivity in sandy till, which is the dominant type of Quaternary deposit in the model area, is obtained from slug tests in groundwater monitoring wells. Generic (literature) data are used for other types of deposits in the area. The majority of the slug tests have been performed within the Simpevarp subarea, which implies that the current quantitative information on hydrogeological properties mainly concerns this area. This is also the case with the detailed geological information, which includes data obtained from drillings and the detailed geological map that was available already in version 1.1.

The conceptual and descriptive models have been improved. The S1.1 descriptive modelling involved a single HSD (Hydraulic Soil Domain), having a constant depth over the whole model area. In the S1.2 modelling, it has been possible to identify and describe the main type areas, domains and interfaces between domains, relevant for the surface water and near-surface groundwater systems. However, it should be noted that the quantitative information on, for example, soil depth and hydraulic properties is still limited, especially outside the Simpevarp subarea.

Quantitative flow modelling has been performed as a part of the version 1.2 site descriptive modelling. The modelling activities have included GIS-based hydrological modelling of the regional model area and more detailed process modelling of the surface hydrology and near-surface hydrogeology within the "Simpevarp 7" catchment area. Modelling results have been delivered to the ecological systems modelling, and the modelling has also contributed to and confirmed the site understanding expressed in the descriptive model.

6.2 Summary of present knowledge

6.2.1 Conceptual and descriptive model

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

- The meteorological conditions in the Simpevarp regional model area are characterised by an annual (uncorrected) precipitation of 500–600 mm; for the identified representative year (1981), the corrected precipitation was 576 mm at the selected reference meteorological station (the SMHI station "Ölands norra udde"). During the period September 2003–September 2004, the measured (uncorrected) precipitation on Äspö was as high as 671 mm (the uncorrected precipitation is always smaller than the corrected), and the average air temperature was 7.4°C.
- The topography of the model area is characterized by a relatively small-scale undulation. The area consists of a large number of catchment areas, and it contains many small water courses. The surface hydrology is affected by human activities, primarily in the form of ditching, which implies that actual flow directions in some areas deviate from those obtained from the interpolated Digital Elevation Model (DEM). A detailed description of the water courses in the area is not yet available.
- There is a large fraction of areas with exposed bedrock in the higher-altitude areas, and the thickness of Quaternary deposits is generally small. The thickest Quaternary deposits are located in the valleys. Till is the dominating type of Quaternary deposit. The groundwater level is generally close to the ground surface. The boundaries of the 26 catchment areas, defined as areas contributing to the discharge into surface waters such as lakes, surface waters and wetlands, are in the present modelling assumed to coincide with the corresponding near-surface groundwater divides.
- Results from "simple" discharge measurements in water courses indicate that the discharge is highly transient during the year. During some periods there is no measurable discharge, whereas the discharge is large during other periods. The water flow system is therefore conceptualised such that discharge from Quaternary deposits, as well as surface runoff (assumed to be significant due to large areas with exposed bedrock), into surface waters in the valleys mainly take place in connection to precipitation events and/or snow melt periods. The relatively thin Quaternary deposits imply that the available storage capacity of these deposits is small, such that there is a quick response in the form of groundwater recharge. Near-surface groundwater and surface water flows are of a local character within each catchment area.

The S1.1 descriptive modelling involved a single HSD (Hydraulic Soil Domain), having a constant depth over the whole model area. In the S1.2 modelling, it has been possible to identify the following types of "elements": 3 type areas (high-altitude areas with exposed bedrock, valleys with Quaternary deposits, and areas with glaciofluvial deposits), 5 domains (till, fine-grained glacial and postglacial sediments (clay/gyttja clay), sand/gravel, peat, and glaciofluvial deposits), and 3 important interfaces between domains ("near-surface"/"deep" bedrock, Quaternary deposits/bedrock, and groundwater/surface water). In the S1.2 modelling, the HSDs are assigned properties as shown in the table below.

The type areas refer to a horisontal division of the regional model area, whereas domains refer to different types of Quaternary deposits (HSDs) within the type areas. In the S1.2 descriptive model, generic data are used for the hydrogeological properties (hydraulic conductivity, specific yield and storage coefficient) of all HSDs, except from till. Based on hydraulic (slug) tests, the till HSD, which is of a sandy and at some locations sandy-gravelly type, is assigned a hydraulic conductivity of 1.5×10^{-5} m×s^{-1}.

Table 6-1. Assignment of hydraulic properties for HSDs in S1.2 (cf Table 4-1).

HSD	Type of Quaternary deposit	Thickness (m)	Hydraulic conductivity, K_H (ms^{-1})	K_H/K_V	Specific yield, S_Y (–) [4]	Storage coefficient, S_S (m^{-1}) [5]
1	Till (sandy) [1]	0.5–3 (1)	1.5×10^{-5}	1	0.16	0.001
2	Fine-grained glacial and postglacial sediments: clay and gyttja clay [2]	~ 1 (larger in some valleys) > 1.5 on Ävrö (4)	1×10^{-10}–1×10^{-8} (1×10^{-8})	1	0.03	0.001
3	Sand/gravel[2]	0.2 ~ 3 on Ävrö	10^{-4}–10^{0}	1	0.30–0.40	0.001
4	Peat [3]	0.5–1	10^{-7}–10^{-4}	0.1–3	0.24	0.001
5	Glaciofluvial deposits: coarse sand, gravel [2]	< 30 (large esker in W part of reg model area)	10^{-4}–10^{0}	1	0.30–0.40	0.001

[1] Site-specific data from slug tests /Johansson and Adestam, 2004b/.
[2] Generic data from the literature /Knutsson and Morfeldt, 1993/.
[3] Generic data from the literature /Kellner, 2004/.
[4] Generic data from the literature /Domenico and Schwartz, 1998/.
[5] Data from /DHI Sverige, 1998/.

Identification and characterisation of interfaces are important, as they may have a large influence on the flow of water between different parts of a catchment area. For instance, the actual discharge of groundwater into lakes, water courses and wetlands is highly dependent on the hydraulic contact between groundwater and surface water. At present, the actual geometries and properties of these entities (type areas, domains and interfaces) are not well known. However, the definition and characterisation of them will be developed when more site-specific data are available.

6.2.2 Quantitative flow modelling

The observations and conclusions from the quantitative flow modelling with the ArcGIS and MIKE SHE modelling tools can be summarised as follows:

- The results from the GIS modelling are in accordance with the assumptions made in the descriptive model. The model is highly sensitive to the topography, as this is the only parameter determining the flow pattern. Consequently, the simulated locations of recharge and discharge areas are strongly influenced by the local topography. Ditches, diverted water courses and other human impacts on the system are important in some parts of the model area. These and other types of "man-made structures" are not fully considered in the topographical model (the DEM), and therefore need to be investigated further in order to get a proper description of the surface water and near-surface groundwater systems.
- The water balance for the "Simpevarp 7" catchment area, calculated with the MIKE SHE modelling tool, agrees with the presented conceptual and descriptive models for the flow system. The transient model simulations for the selected reference year result in an annual total runoff of 154 mm and a total actual evapotranspiration of 426 mm. These values are considered to be reasonable for the Simpevarp area, but cannot at present be tested against site-specific measurements. The MIKE SHE model produces a shallow groundwater table, which is in accordance with groundwater level measurements within other parts of the regional model area (no data are available for the modelled "Simpevarp 7" catchment), and with the overall conceptualisation of the system. Generally, a shallow groundwater table implies that the surface water and groundwater divides can be assumed to coincide.

- The modelling results show that most of the groundwater flow occurs in the Quaternary deposits, from topographic heights towards the valleys. The results also illustrate the importance of the fracture zones for the groundwater recharge to, or discharge from, the bedrock (the model includes the bedrock to a depth of –150 m a s l). Considering a vertical cross-section through the model domain, groundwater flow can be observed throughout the whole cross-section in areas with fractured bedrock. Thus, there is a hydraulic contact in the fracture zones, although the calculated flow rates are small relative to other components of the water balance. In comparison, the groundwater flow in the bedrock between fracture zones is negligible. There is a small exchange of groundwater across the bottom boundary of the model (i.e. the interface between "deep" and "near-surface" bedrock, here at 150 m depth below sea level). The head boundary condition at this interface provides a possibility to couple models for "deep" and "near-surface" groundwater flow; presently, this is the only type of boundary condition that can be used in MIKE SHE.
- The presence of shallow Quaternary deposits and large areas with exposed bedrock implies that the storage capacity for water is small. The modelled discharge in the water course within the "Simpevarp 7" catchment area (referred to as "Kåreviksån" by /Brunberg et al. 2004/) is highly transient; it is large in connection to precipitation events and/or snow-melt periods, and dry during some periods between these events. The results also show that Lake Frisksjön reduces the temporal discharge variations in the water course downstream from the lake.
- Similar to the GIS modelling, the process-based modelling with the MIKE SHE model shows that the locations of recharge and discharge areas are strongly influenced by the local topography. In addition, it can be noted that meteorological parameters (precipitation, snow melt and temperature) also affect the locations of recharge and discharge areas. For the studied area (the "Simpevarp 7" catchment area), the model simulates topographic heights as recharge areas and water courses in valleys as well as Lake Frisksjön as discharge areas throughout the year. However, the locations of local recharge and discharge areas in between these two "extremes" are influenced by the meteorological conditions, and may thus vary during the year.

6.3 Evaluation of uncertainties

New data on, for example, catchment and sub-catchment boundaries, local meteorological conditions, and hydrogeological properties have been obtained and analysed in the present model version. However, the limited amount of site data is still the main source to uncertainty in the present model of surface hydrology and near-surface hydrogeology. Specifically, the main uncertainties are related to the following types of data and other inputs:

- ***Uncertainties in the geometrical description of the system:*** The geometrical uncertainties include uncertainties in the DEM, the geological description (especially the surface distribution and stratigraphy of Quaternary deposits outside the Simpevarp subarea), and the description of water courses (locations, water levels and cross-sections). These uncertainties will be reduced in L1.2, when additional data are provided for the Laxemar subarea and the regional model area. Sensitivity analyses will be performed for investigating uncertainties in the DEM and the geological model.

- ***Uncertainties in the description of hydrogeological properties of site-specific materials:*** At present, no hydraulic parameters are available for some of the material in the descriptive model. For the materials represented in the database, the amount of data is judged too small to evaluate the spatial variability. Furthermore, the database is restricted to hydraulic conductivity data (with a few exceptions). Additional data from hydraulic testing in the Laxemar subarea will be provided in L1.2. Possibly, some data on unsaturated flow parameters will also be delivered. This will enable an improved description of the site-specific materials in L1.2, although the potential for quantification of the uncertainty related to spatial variability is still expected to be low.
- ***Uncertainties in the description of temporal variability:*** The present data indicate significant transients in surface water flows, but there is practically no quantitative information available on these transients, or on the temporal variations in the near-surface groundwater in general. Time series on meteorological parameters, surface water levels and discharges, and groundwater levels are crucial for the evaluation of the hydrological/hydrogeological temporal variability. Data on these parameters will be provided in L1.2, but the time series will be short in some cases (i.e. a few months). Nevertheless, this will enable a first attempt on an integrated evaluation in L1.2.

The present descriptive model of the surface-hydrological and near-surface hydrogeological system is considered to be acceptable in a qualitative sense, which means that the general description of the hydrological and hydrogeological driving forces and the overall flow pattern will be the same in future models. 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. The identified type areas, domains and interfaces need to be developed, detailed and parametrised with site-specific data. Some sensitivity studies have been reported in this model version, for instance, the comparison of field-controlled and DEM-based catchment areas. In addition, the statistics of measured hydraulic conductivities are presented, which gives an indication of the uncertainty associated with spatial variability. However, no systematic or complete quantification of uncertainties has been performed in the present model version.

6.4 Implications for future investigations

The database on the geological and hydrogeological properties of the near-surface system will be considerably improved by the data included in the L1.2 data freeze. Furthermore, time series (at least short ones) of locally measured meteorological and hydrological parameters will become available for the modelling. This implies that the site investigations will deliver the various types of data that are judged most crucial for reducing the uncertainties in the present model (cf above). Whether the additional data actually lead to significantly reduced uncertainties will be evaluated in the L1.2 modelling. A detailed evaluation of the existing database and the need for further investigations is performed after the completion of the L1.2 descriptive model.

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Appendix A

List of private wells in the Simpevarp regional area

Table A-1. Basic data of private wells in the Simpevarp regional model area /Morosini and Hultgren, 2003/. X- and Y-coordinates are given in the coordinate system RT90, Z-coordinates in the height system RHB70.

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000001	Gässhult 1:1 > 1	1.60		E	6369670.000	1551400.000		A: 0.69
PSM000002	Bussvik 2:10 > 1	58.00		D	6369202.873	1549813.810	4.347	A: 5.95
PSM000003	Bussvik 2:10 > 1	2.72		E	6368875.794	1550381.935	2.764	A: 1.20
PSM000004	Bussvik 2:10 > 1		36–38	D	6368906.822	1550308.214	4.099	A: 0,65
PSM000005	Gässhult 1:7 > 1	80.00		D	6368759.136	1549641.133	7.665	A: 7.13
PSM000006	Lilla Laxemar Båtsmanstorpet 1:3 > 1	3.00		E	6367753.421	1550254.634	1.066	A: 0.69
PSM000007	Lilla Laxemar 1:11 > 1	3.00		E	6367669.455	1550276.813	1.776	A: 1.40
PSM000008	Lilla Laxemar 1:10 > 1	40.00		D	6366361.044	1550239.966	2.467	A: 1.75
PSM000009	Lilla Laxemar 1:10 > 1	3.25		E	6366274.266	1550231.007	2.656	A: 1.96
PSM000010	Lilla Laxemar 1:5 > 6	3.00		E	6366300.125	1550335.792	2.369	A: 2.08
PSM000011	Lilla Laxemar 2:8 > 1	36.00		D	6365920.000	1550175.000		A: 4.99
PSM000012	Lilla Laxemar 2:5 > 1	82.00		D	6366122.410	1550121.437	9.858	A: 8.41
PSM000013	Lilla Laxemar 1:4 > 1	2.80		E	6366306.567	1550249.718	2.274	A: 1.65
PSM000014	Lilla Laxemar 1:9 > 1	31.00		D	6366233.633	1550247.864	6.893	A: 6.37
PSM000015	Lilla Laxemar 2:16 > 1	3.50		E	6366241.187	1550029.526	4.804	A: 2.11
PSM000016	Lilla Laxemar 2:10 > 1			D	6366228.363	1549979.392	10.340	A: 6.20
PSM000017	Lilla Laxemar 2:13 > 1			D	6366173.838	1550025.251	5.764	A: 2.40
PSM000018	Lilla Laxemar 2:9 > 1		32	D	6366203.000	1550240.000		A: 2.31
PSM000019	Stora Laxemar 1:17 > 1	25.00		D	6365136.000	1550434.000		A: 0.56
PSM000020	Långö 2:16 > 1			D	6367516.540	1552238.060	2.238	A: 2.62
PSM000021	Långö 2:12 > 1			D	6367574.758	1552250.998	1.570	A: 6.73
PSM000022	Långö 2:14>1	3.00		E	6367963.190	1552899.908	1.324	A: 1.27

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000023	Långö 2:18 > 1	24.00		D	6368183.096	1553112.159	9.642	A: 5.11
PSM000024	Ävrö 1:16 > 1	3.40		E	6367610.519	1553491.780	2.168	A: 0.41
PSM000025	Bussvik 2:16 > 1	2.93		E	6369592.278	1552544.345	1.450	A: 0.99
PSM000027	Gässhult 1:4 > 1	40.00		D	6368863.526	1549445.335	4.840	A: 3.75
PSM000028	Gässhult 1:5 > 1	43.00		D	6368860.413	1549466.761	5.487	A: 4.72
PSM000030	Sandböla 1:2 > 1	4.35		E	6367999.000	1548828.000		A: 4.12
PSM000031	Lilla Laxemar 1:6 > 1	2.82		E	6366979.587	1549278.093	11.678	A: 1.40
PSM000032	Lilla Laxemar 1:7 > 1	3.00		E	6367027.035	1549106.877	12.502	A: 2.13
PSM000033	Lilla Laxemar 1:8 > 1	103.00		D	6367154.224	1549023.497	14.606	A: 0.64
PSM000034	Lilla Laxemar 1:13 > 1	54.00		D	6366759.487	1550057.316	7.831	A: 5.80
PSM000035	Lilla Laxemar 2:14 > 1	46.00		D	6365817.833	1550101.400	8.521	A: 5.44
PSM000036	Stora Laxemar 1:18 > 1	36.00		D	6365706.825	1550272.263	6.588	A: 5.23
PSM000037	Långö 1:2 > 1	3.00		E	6369050.285	1553293.118	1.142	A: 2.29
PSM000038	Långö 1:4 > 1	37.00		D	6369075.171	1553198.509	2.886	A: 2.38
PSM000039	Lilla Laxemar 1:2 > 1	3.60		E	6366363.173	1550358.682	2.600	A: 2.62
PSM000040	Långö 2:13 > 1		> 40	D	6367726.647	1552372.176	2.040	A: 7.62
PSM000041	Glostad 1:7 > 1	3.50		E	6365043.100	1550343.700		A: 1.42
PSM000044	Långö 2:21 > 5			D	6368108.249	1553042.210	6.492	A: 5.93
PSM000045	Gässhult 1:3 > 1	3.00		E	6368799.886	1549449.589	4.928	A: 0.83
PSM000046	Gässhult 1:3 > 1	47.00		D	6368804.718	1549452.464	5.260	A: 4.56
PSM000047	Lilla Laxemar 1:7 > 1	46.00		D	6367046.290	1549101.673	12.634	A: 2.25
PSM000048	Långö 1:2 > 1	40.00		D	6369125.026	1553264.377	5.842	A: 5.35
PSM000049	Lilla Laxemar 2:8 > 1				6365911.215	1550158.963	5.844	A: 5.58
PSM000050	Åby 1:11 > 1	2.80		E	6365260.000	1548364.000		S: 1.16
PSM000051	Åby 1:11 > 1		61	D	6365280.000	1548346.000		No data

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000052	Åby 1:11 > 1	0.50		E	6365257.000	1548287.000		S: 1.36
PSM000053	Åby 1:17 > 1		75	D	6365207.000	1550431.000		No data
PSM000054	Åby 1:4 > 1		76	D	6365060.000	1547041.000		No data
PSM000055	Åby 1:4 > 1	2.40		E	6365077.000	1547036.000		S: 0.72
PSM000056	Bastböle 1:3 > 1		90	D	6363745.000	1548206.000		S: 2.55
PSM000057	Stora Laxemar 1:14 > 1		72	D	6364792.000	1549514.000		No data
PSM000058	Stora Laxemar 1:5 > 1	4.37		E	6364810.000	1549530.000		S: 2.45
PSM000059	Jämserum 1:11 > 1			D	6364010.000	1545283.000		No data
PSM000060	Jämserum 1:11 > 1	4.04		E	6363999.000	1545314.000		S: 2.55
PSM000061	Jämserum 1:11 > 1	3.00		E	6364057.000	1545174.000		S: 0.51
PSM000062	Jämserum 1:14 > 1			D	6364973.000	1545531.000		No data
PSM000063	Jämserum 1:38 > 1	2.00		E	6365798.000	1546771.000		S: 1.80
PSM000064	Jämserum 1:45 > 1	2.30		E	6365928.000	1546041.000		No data
PSM000065	Lilla Basthult 1:2 > 2	3.27		E	6366055.000	1546410.000		S: 0.87
PSM000066	Lilla Basthult 1:3 > 1		50–60	D	6366293.000	1546441.000		No data
PSM000067	Lilla Basthult 1:3 > 1	2.18		E	6366282.000	1546445.000		S: 1.70
PSM000068	Lilla Basthult 1:3 > 1	2.20		E	6366293.000	1546437.000		S: 1.05
PSM000069	Lilla Bsthult 1:5 > 3	2.40		E	6366235.000	1546082.000		S: 1.70
PSM000070	lilla Basthult 1:9 > 1	4.23		E	6366160.000	1546143.000		S: 0.65
PSM000071	Lilla Basthult 1:9 > 1	2.05		E	6366150.000	1546144.000		S: 0.50
PSM000072	Lilla Laxemar 2:16 > 1	5.55		E	6366244.000	1550019.000		S: 1.95
PSM000073	Mederhult 1:10 > 1		82	D	6367818.000	1547283.000		No data
PSM000074	Mederhult 1:11 > 1		100	D	6367841.000	1547473.000		No data
PSM000075	Mederhult 1:11 > 1	5.57		E	6367841.000	1547595.000		S: 0.90
PSM000076	Mederhult 1:12 > 1	3.05		E	6367983.000	1547469.000		S: 2.40

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000077	Mederhult 1:15 > 1	4.94		E	6367956.000	1547244.000		S: 2.11
PSM000078	Mederhult 1:16 > 1	4.38		E	6367768.000	1547390.000		S: 1.50
PSM000079	Mederhult 1:18 > 1	3.50		E	6362797.000	1547242.000		S: 2.30
PSM000080	Mederhult 1:19 > 1			D	6367703.000	1547409.000		S: 0.50
PSM000081	Mederhult 1:20 > 1		40	D	6367775.000	1547234.000		S. 0.20
PSM000082	Mederhult 1:5 > 1		78	D	6367711.000	1547400.000		No data
PSM000083	Mederhult 1:5 > 1	4.55		E	6367704.000	1547406.000		S: 2.48
PSM000084	Medehult 1:19 > 1	3.98		E	6367719.000	1547425.000		S: 1.82
PSM000085	Mederhult 1:14 > 1		97	D	6367862.000	1547190.000		No data
PSM000086	Övrehammar 1:2 > 1		85	D	6362799.000	1547245.000		No data
PSM000088	Skurö 1:11 > 1		30	D	6363198.000	1547961.000		No data
PSM000089	Skurö 1:11 > 1	4.40		E	6363275.000	1547941.000		S: 1.30
PSM000090	Skurö 1:11 > 1	3.25		E	6362570.000	1548076.000		S: 0.90
PSM000091	Skurö 1:11 > 1	6.15		E	6362520.000	1547994.000		S: 2.12
PSM000092	Stora Basthult 1:19 > 1		32	D	6367020.000	1544921.000		S: 4.60
PSM000093	Stora Basthult 1:14 > 1		52–65	D	6367486.000	1545557.000		No data
PSM000094	Stora Basthult 1:15 > 1			E	6367917.000	1545517.000		No data
PSM000095	Stora Basthult 1:16 > 1			E	6368180.000	1545450.000		No data
PSM000096	Stora Basthult 1:17 > 1		80	D	6367072.000	1545040.000		No data
PSM000097	Stora Basthult 1:17 > 1	2.80		E	6367093.000	1544994.000		S: 0.52
PSM000098	Stora Basthult 1:20 > 1	3.13		E	6367043.000	1545613.000		S: 0.45
PSM000099	Stora Basthult 1:9 > 1	3.14		E	6367212.000	1545067.000		S: 0.62
PSM000100	Stora Basthult 1:9 > 1	3.95		E	6367107.000	1545134.000		S: 2.20
PSM000101	Stora Laxemar 1:15 > 1			D	6364949.000	1548739.000		No data
PSM000102	Stora Laxemar 1:16 > 1	2.00		E	6364301.000	1547746.000		S: 0.55

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000103	Stora Laxemar 1:5 > 2			D	6365109.000	1549124.000		No data
PSM000104	Stora Laxemar 1:5 > 2	6.20		E	6365087.000	1549090.000		S: 4.74
PSM000105	Ström 1:20 > 1	3.00		E	6365425.000	1549296.000		S: 1.41
PSM000106	Ström 1:7 > 9		46	D	6365374.000	1549405.000		No data
PSM000107	Ström 1:7 > 9	4.30		E	6365372.000	1549415.000		S: 1.80
PSM000108	Ström 1:7 > 9	6.07		E	6365372.000	1549501.000		S: 2.68
PSM000109	Åby 1:11 > 1	2.00		E	6365447.000	1548581.000		S: 1.46
PSM000110	Södra Uvö 1:3 > 1		23	D	6362225.000	1549366.000		No data
PSM000111	Södra Uvö 1:3 > 21	2.15		E	6362333.000	1549459.000		S: 0.42
PSM000115	Glostad 1:2 > 1		30	D	6364586.000	1549705.000		No data
PSM000116	Glostad 1:5 > 1		60	D	6364981.000	1550292.000		A: 3.90
PSM000117	Glostad 1:6 > 1	3.38		E	6365007.000	1550289.000		A: 1.53
PSM000118	Glostad 1:6 > 1		72	D	6365007.000	1550299.000		S: 3.95
PSM000119	Glostad 2:3 > 1	3.02		E	6364516.000	1549578.000		S: 1.98
PSM000120	Glostad 1:3 > 1			D	6364674.000	1549709.000		No data
PSM000121	Glostad 1:9 > 1			D	6364716.000	1549784.000		No data
PSM000122	Gässhult 1:1 > 1	2.70		E	6369695.000	1548323.000		S: 1.67
PSM000123	Gässhult 1:1 > 1	2.90		E	6369695.000	1548323.000		S: 1.70
PSM000124	Gässhult 1:6 > 1		37	D	6368861.000	1549505.000		A: 4.41
PSM000125	Gässhult 1:8 > 1		35	D	6369114.000	1548609.000		S: 2.57
PSM000126	Gässhult 1:13 > 1	1.75		E	6368994.000	1548798.000		S: 0.73
PSM000127	Gässhult 1:14 > 1		42	D	6368998.000	1548710.000		S: 5.32
PSM000128	Jämserum 1:15 > 1	4.35		E	6365104.000	1540481.000		S: 2.70
PSM000129	Jämserum 1:26 > 1		20	D	6365363.000	1541618.000		S: 4.66
PSM000130	Jämserum 1:32 > 1	3.80		E	6365199.000	1542019.000		S: 1.28

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000131	Jämserum 1:51 > 1			D	6365266.000	1541947.000		No data
PSM000132	Jämserum 1:61 > 1	2.28		E	6364878.000	1542199.000		S: 0.91
PSM000133	Jämserum 1:62 > 1		70	D	6364828.000	1542201.000		No data
PSM000134	Jämserum 1:66 > 1		65–70	D	6364813.000	1542249.000		S: 2.90
PSM000135	Jämserum 1:72 > 3		110	D	6363751.000	1542115.000		S: 8.38
PSM000136	Jämserum 1:80 > 1	2.75		E	6365350.000	1541978.000		S: 0.87
PSM000137	Jämserum 1:80 > 1		100	D	6365333.000	1541978.000		No data
PSM000138	Lilla Laxemar Båtsmanstorpet 1:3 > 1	1.90		E	6367755.000	1550250.000		S: 0.48
PSM000139	Långö 1:16 > 1			E	6369059.000	1554459.000		S: 3.55
PSM000140	Långö 2:19 > 1			D	6368764.000	1544581.000		No data
PSM000141	Misterhult 4:8 > 1	3.65		E	6369802.000	1545244.000		S: 0.70
PSM000142	Misterhult 4:5 > 1	1.85		E	6369807.000	1545209.000		S: 0.18
PSM000143	Misterhult 4:16 > 1	2.00		E	6369204.000	1543511.000		Artesian groundwater
PSM000144	Näs 1:2 > 1	3.25		E	6363109.000	1549860.000		S: 2.50
PSM000145	Näs 1:3 > 1		36	D	6362992.000	1549222.000		S. 2.50
PSM000146	Näs 1:5 > 1		56	D	6363305.000	1549678.000		S: 5.53
PSM000147	Näs 1:5 > 1	2.78		E	6363311.000	1549700.000		S: 0.77
PSM000148	Näs 1:5 > 1	2.24		E	6363352.000	1549737.000		S: 1.57
PSM000149	Näs 1:5 > 1			D	6363281.000	1549639.000		S. 9.65
PSM000150	Näs 1:7 > 1		49	D	6362887.000	1549695.000		S: 3.90
PSM000151	Näs 1:8 > 1		91	D	6363505.000	1549622.000		S. 5.45
PSM000152	Plittorp 1:4 > 1	1.50		E	6368103.000	1541240.000		S: 0.60
PSM000153	Plittorp 1:10 > 1		90	D	6368456.000	1541608.000		S: 3.35
PSM000154	Plittorp 1:11 >	2.96		E	6368770.000	1541553.000		S: 0.65

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000155	Plittorp 1:12 > 1		72	D	6368657.000	1541539.000		No data
PSM000156	Plittorp 1:13 > 1	1.90		E	6369005.000	1543215.000		S: 0.46
PSM000157	Plittorp 1:13 > 1	2.75		E	6369042.000	1543183.000		S: 0.30
PSM000158	Plittorp 1:14 > 1	2.80		E	6370287.000	1542652.000		S: 0.92
PSM000159	Plittorp 1:13 > 1			D	6368751.000	1540870.000		S: 1.90
PSM000160	Skurö 1:6 > 1			D	6363128.000	1547685.000		S. 4.80
PSM000161	Skurö 1:7 > 1	2.60		E	6363400.000	1547994.000		S. 2.45
PSM000162	Skurö 1:8 > 1		51	D	6363338.000	1548237.000		No data
PSM000163	Skurö 1:8 > 1	4.78		E	6363339.000	1548221.000		S: 1.24
PSM000164	Släthult 1:26 > 1		80	D	6363296.000	1543871.000		No data
PSM000165	Släthult 1:32 > 1		85	D	6362988.000	1543681.000		No data
PSM000166	Släthult 1:40 > 1		70	D	6363355.000	1543633.000		No data
PSM000167	Släthult 1:41>1		16	D	6363045.000	1543773.000		S: 1.10
PSM000168	Släthult 1:42 > 1			D	6362984.000	1543635.000		No data
PSM000169	Släthult 1:43 > 1		79	D	6363476.000	1543858.000		S. 3.45
PSM000170	Släthult 1:43 > 1	3.30		E	6363460.000	1543868.000		S: 0.50
PSM000171	Stora Basthult 1:2 > 1		120	D	6368364.000	1544414.000		No data
PSM000172	Stora Basthult 1:2 > 1	3.08		E	6368382.000	1544399.000		S. 0.86
PSM000173	Stora Basthult 1:18 > 1	2.52		E	6366835.000	1544484.000		S. 0.75
PSM000174	Stora Basthult 1:18 > 1	2.43		E	6366785.000	1544546.000		S. 0.45
PSM000175	Stora Basthult 1:18 > 1	2.47		E	6366706.000	1544532.000		S. 0.38
PSM000176	Stora Basthult 1:21 > 1			D	6366962.000	1544842.000		No data
PSM000177	Stora Fighult 1:10 > 1		20	D	6363017.000	1543006.000		S: 2.22

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000178	Stora Fighult 1:22 > 1		112	D	6363839.000	1541627.000		S: 1.23
PSM000179	Stora Fighult 1:30 > 1		75	D	6361723.000	1543148.000		No data
PSM000180	Stora Fighult 1:32 > 1		40	D	6363144.000	1542953.000		S. 5.50
PSM000181	Uthammar 2:8 > 1	3.70		E	6362432.000	1548071.000		S: 0.70
PSM000182	Uthammar 2:20 > 1		> 80	D	6362624.000	1548210.000		No data
PSM000183	Uthammar 2:20 > 1	2.80		E	6362675.000	1548210.000		S. 1.05
PSM000184	Värnamo 1:2 > 1		33 m	D	6365708.000	1543237.000		S. 1.03
PSM000185	Värnamo 1:2 > 1	1.85		E	6365680.000	1543269.000		S: 0.60
PSM000186	Värnamo 1:2 > 1	1.35		E	6365081.000	1542609.000		S: 0.80
PSM000187	Värnamo 1:2 > 1	3.15		E	6364542.000	1542935.000		S: 0.83
PSM000188	Värnamo 1:7 > 1	2.55		E	6365812.000	1544520.000		S: 1.20
PSM000189	Värnamo 1:8 > 1		7	D	6365812.000	1545096.000		No data
PSM000190	Värnamo 1:9 > 1	1.87		E	6365648.000	1544777.000		S: 0.56
PSM000191	Värnamo 1:10 > 1		107	D	6365845.000	1545236.000		No data
PSM000192	Värnamo 1:11 > 1		35	D	6365284.000	1542368.000		S: 0.90
PSM000193	Värnamo 1:11 > 1	3.00		E	6365273.000	1542369.000		S: 0.63
PSM000194	Värnamo 1:13 > 1	3.80		E	6365806.000	1543162.000		S. 0.90
PSM000195	Värnamo 1:13 > 1		42	D	6365886.000	1543316.000		S. 1.10
PSM000196	Värnamo 1:14 > 1	3.38		E	6365796.000	1543098.000		S. 0.82
PSM000197	Värnamo 1:17 > 1	2.83		E	6365460.000	1545112.000		S: 0.23
PSM000198	Värnamo 1:19 > 1		30	D	6365670.000	1543053.000		S: 5.55
PSM000199	Värnamo 2:2 > 1		98	D	6365128.000	1542553.000		S: 2.21
PSM000200	Värnamo 2:2 > 1	4.32		E	6365123.000	1542560.000		No data

Well ID	Property	Measured depth (m below ToSP)	Estimated depth (m below ToSP)	Well type (D = drilled, E = excavated	Northing	Easting	Elevation of ToSP (m a s l)	Depth to groundwater level (m below ToSP), A = average value of several measurements, S = single measurement
PSM000201	Värnamo 3:1 > 1		97	D	6364600.000	1543042.000		No data
PSM000202	Värnamo 1:2 > 1	1.45		E	6364628.000	1543023.000		S: 1.07
PSM000203	Åby 1:12 > 1	3.00		E	6364507.000	1546354.000		S: 1.10
PSM000204	Åby 1:12 > 1	2.50		E	6364475.000	1546261.000		S. 0.55
PSM000205	Övrehammar 1:4 > 1		40–50	D	6362851.000	1547255.000		S: 1.50
PSM000206	Övrehammar 1:4 > 1		120	D	6362934.000	1547312.000		No data
PSM000207	Övrehammar 1:4 > 4			D	6362986.000	1547339.000		No data
PSM000208	Övrehammar 1:5 > 1		100	D	6362874.000	1547197.000		S: 8.90
PSM000209	Övrehammar 1:6 > 1	2.40		E	6364035.000	1546253.000		S: 1.20
PSM000210	Övrehammar 1:6 > 1	3.15		E	6363979.000	1546257.000		S: 1.05
PSM000211	Övrehammar 1:8 > 1		40	D	6363045.000	1547390.000		S: 3.10
PSM000212	Åby 1:5 > 1	3.52		E	6365278.000	1548660.000		S: 3.17
PSM000213	Åby 1:5 > 1	2.97		E	6365274.000	1548702.000		S: 1.67
PSM000214	Ström 1:15 > 1	1.35		E	6365506.000	1549161.000		S: 0.70
PSM000215	Ström 1:15 > 1	0.94		E	6365501.000	1549160.000		S: 0.74
PSM000217	Glostad 1:8 > 1	3.31		E	6364070.000	1549698.000		S: 1.13
PSM000218	Glostad 1:8 > 1		34–36	D	6364003.000	1549685.000		S: 1.20
PSM000219	Värnamo 1:15 > 1		100	D	6365799.000	1545134.000		No data
PSM000220	Köksmåla 10:1 > 1	6.80		E	6363375.000	1540508.000		S: 4.65
PSM000221	Misterhult 4:15 > 1		110	D	6368594.000	1545182.000		S. 5.58
PSM000222	Stora Basthult 1:8 > 1	3.25		E	6366997.000	1545546.000		S: 0.83

Appendix B

Results of simple discharge measurements

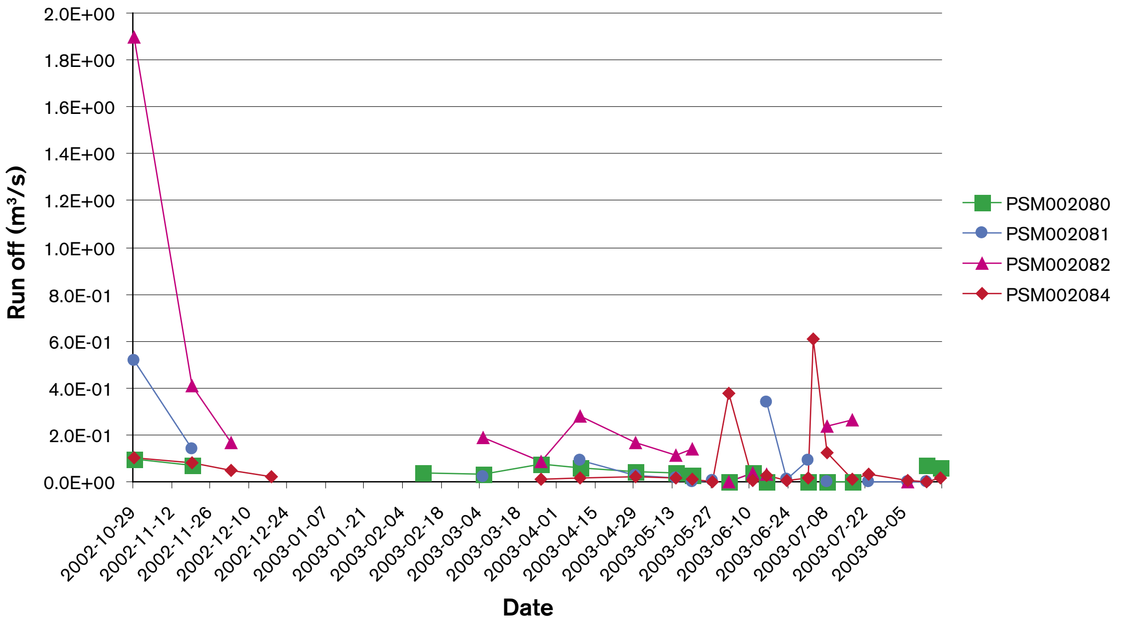

Figure B-1. *Results from simple discharge measurements in water courses at the sampling points PSM002080–82 and 002084 in catchment area 5.*

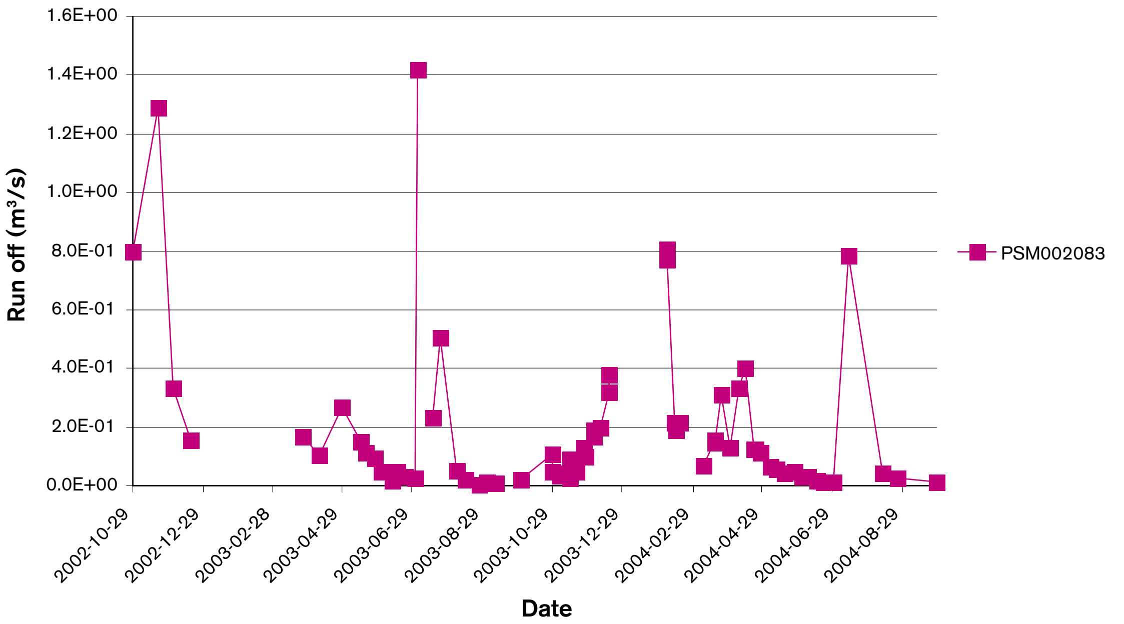

Figure B-2. *Results from simple discharge measurements in a water course at the sampling point PSM002083 in catchment area 6.*

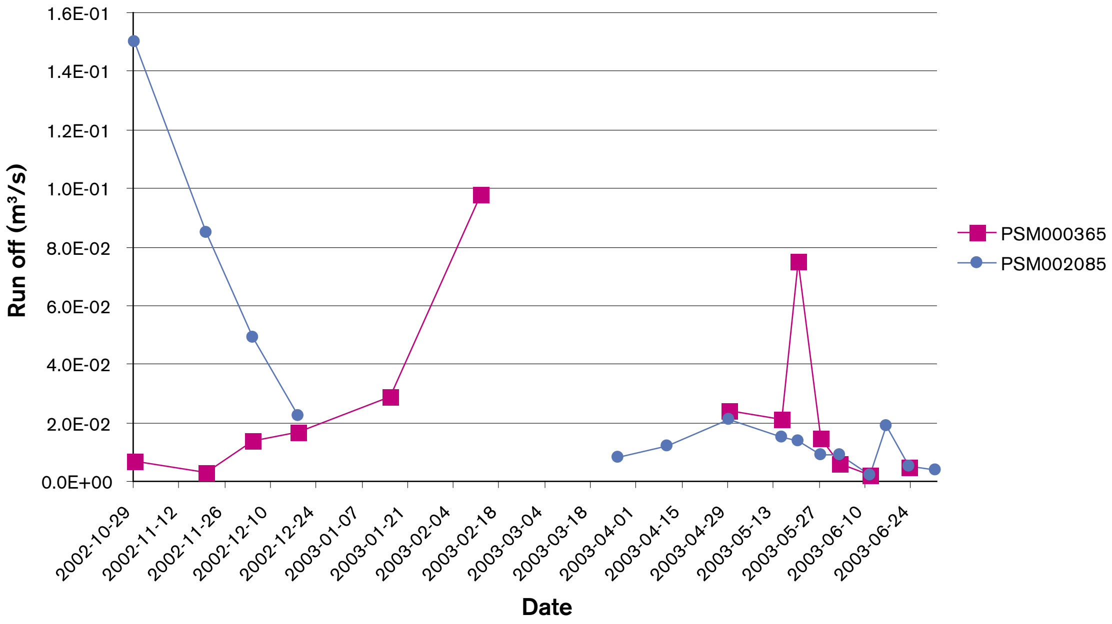

Figure B-3. *Results from simple discharge measurements in water courses at the sampling points PSM000365 and 002085 in catchment area 9.*

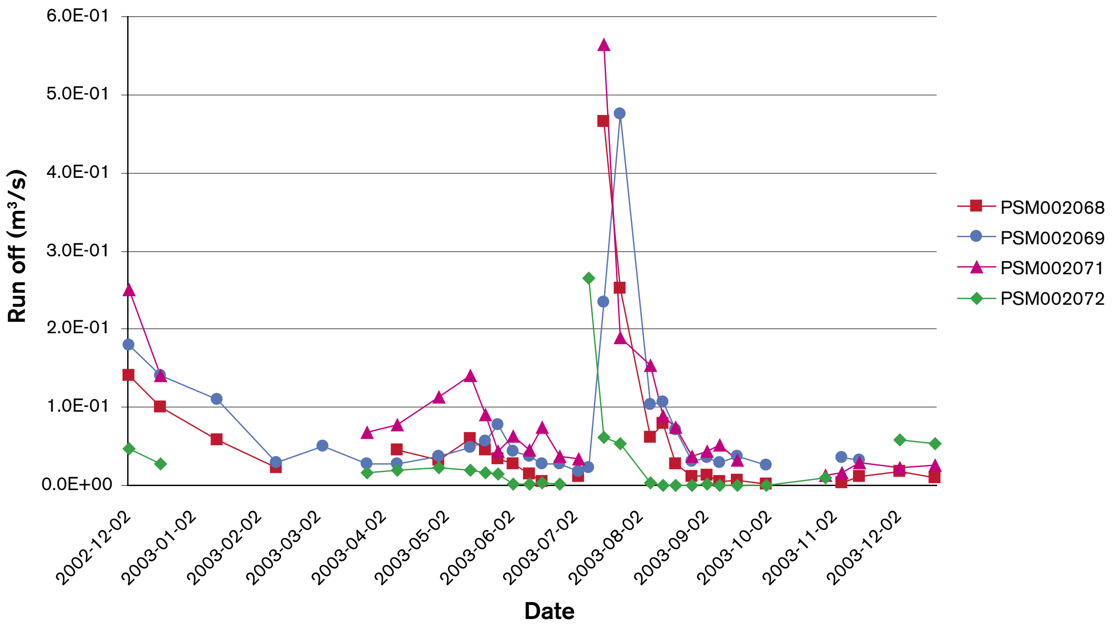

Figure B-4. *Results from simple discharge measurements in water courses at the sampling points PSM002068–69 and,002071–72 in catchment subareas 10:20, 10:25, and 10:30.*

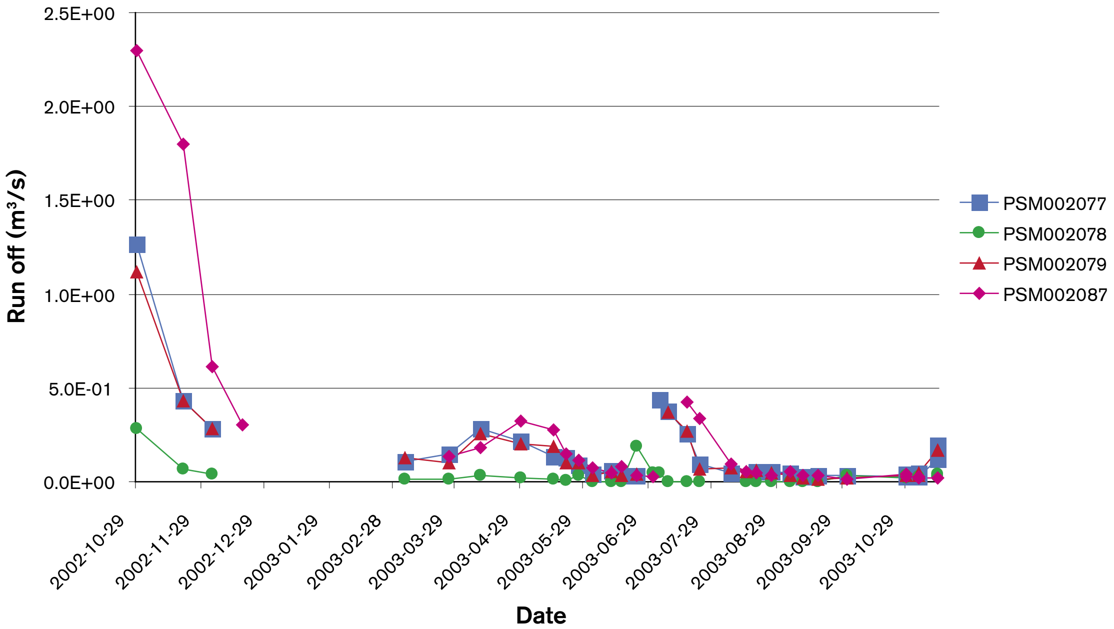

Figure B-5. *Results from simple discharge measurements in water courses at the sampling points PSM002077–79 and 002087 in catchment subareas 10:7 and 10:8.*

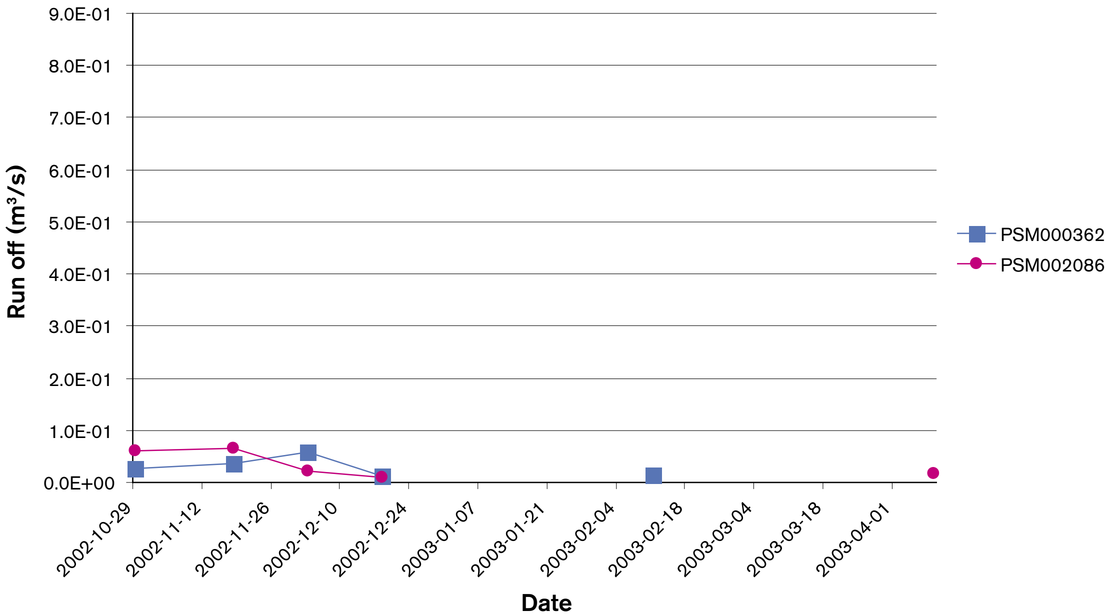

Figure B-6. *Results from simple discharge measurements in water courses at the sampling points PSM000362 and 002086 in catchment area 13.*

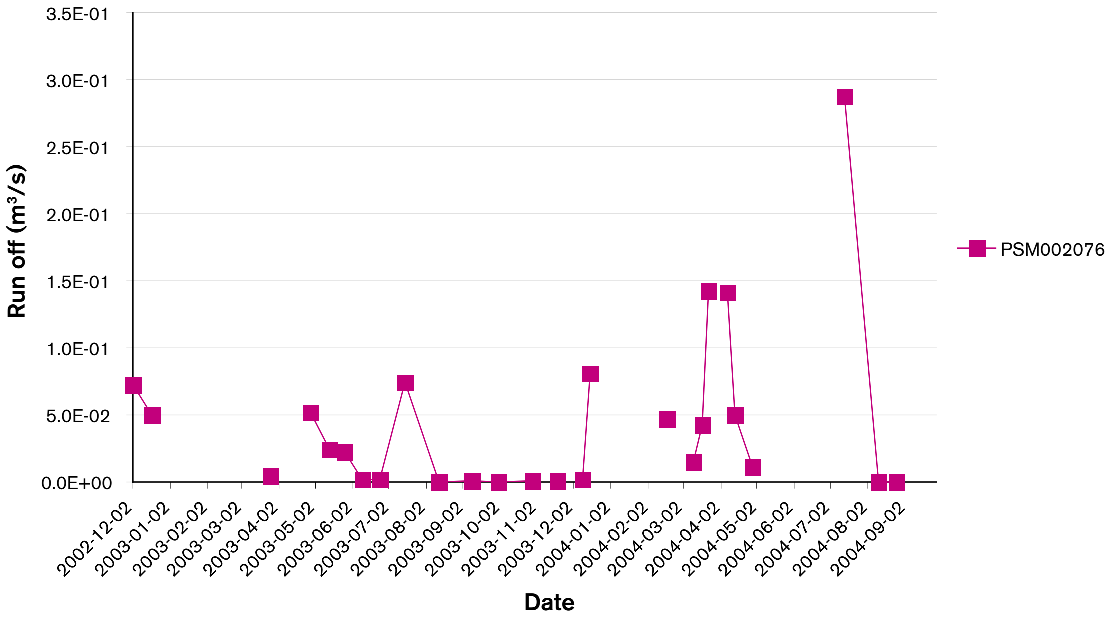

Figure B-7. *Results from simple discharge measurements in a water course at the sampling point PSM002076 in catchment area 17.*

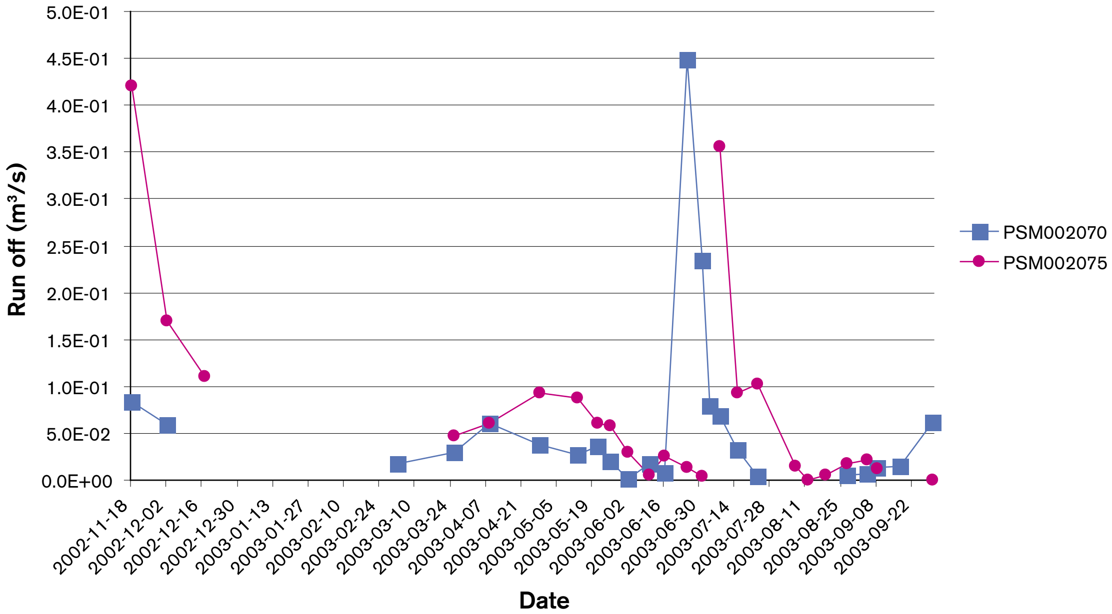

Figure B-8. *Results from simple discharge measurements in water courses at the sampling points PSM002070 and 002075 in catchment area 18.*