R-05-01

Description of surface systems
Preliminary site description
Simpevarp sub area – Version 1.2

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March 2005

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Preface

SKB started site investigations for a deep repository for spent nuclear fuel in 2002 at two different sites in Sweden, Forsmark and Oskarshamn. The investigations should provide necessary information for a license application aimed at starting underground exploration. For this reason, ecosystem data need to be interpreted and assessed into site descriptive models, which in turn are used for safety assessment studies and for environmental impact assessment. Descriptions of the surface system are also needed for further planning of the site investigations.

This report describes the surface ecosystems of the Simpevarp site (e.g. hydrology, regolith, chemistry, vegetation, animals and the human population). This ecosystem description is an integrated description of the site and its regional setting, covering the current state of the biosphere as well as the ongoing natural processes affecting the long-term evolution. Development of descriptions is an important activity during both the initial and the complete site investigation phase. Before the start of the initial phase in Oskarshamn, version 0 of the site descriptive model was developed /SKB, 2002/. The results of the initial site investigation phase will be compiled into a preliminary site description of Simpevarp (version 1.2) in early 2005 /SKB, 2005/. This report should be seen as an input, or background paper to the biosphere description, in the 1.2 version of the Simpevarp site description.

The basis for this interim version is quality-assured field data from the Simpevarp sub area and regional area, available in the SKB SICADA, and GIS data bases as of April 2004 as well as version 1.1 of the Site Descriptive Model /SKB, 2004a/.

To achieve an ecosystem site description there is a need to develop discipline-specific models by interpreting and analysing primary data. The different discipline-specific models are then integrated into a system describing interactions and the flows and stocks of matter between and within functional units in the biosphere. Methodologies for developing descriptive- and ecosystem models are described briefly in this report, but for thorough methodology descriptions see references.

The work has been conducted by the project group SurfaceNet together with other discipline-specific collaborators, engaged by members of the project group. The members of the project group represent the disciplines ecology, hydrology, quaternary geology, soil science, limnology, oceanography, hydrogeology, hydrogeochemistry, environmental science, physical geography and human geography. In addition, some group members have specific qualifications of importance, e.g. experts in GIS modelling and in statistical data analysis.

The following persons contributed to the project and/or to the report:

- Tobias Lindborg (SKB) – project leader and editor,
- Björn Söderbäck, Sara Karlsson (SKB) – limnic description, limnic ecosystem, surface water chemistry,
- Linda Kumblad (Dept. of System Ecology, Stockholm University), Erik Wijnbladh (SKB) – marine description, marine ecosystem,
- Anders Löfgren (Dept. of botany, Stockholm univ.), Lasse Kyläkorpi, Sofia Miliander (Swedpower AB) – terrestrial description, terrestrial ecosystem, human description,
- Per Erik Jansson, David Gustafsson (Royal Institute of Technology, KTH) – terrestrial ecosystem modelling (Coup model),
- Kjell Wallin (Svensk Naturförvaltning AB) – terrestrial mammal descriptions,
- Sten Berglund, Emma Bosson, (SKB) Per Olov Johansson (Artesia Grundvattenkonsult AB), Kent Werner (Golder Associates AB) – hydrology description, hydrology models, transport properties, climate description, wells,
- Gustav Sohlenius, Anna Hedenström, (Geological Survey of Sweden, SGU) – regolith, overburden, soil, quaternary deposits, descriptions and models,

- Lars Brydsten, (Dept. of ecology and environmental science, Umeå univ.) – landscape geometry, topography, bathymetry, DEM-model,
- Anders Engqvist, (Dept. of system ecology, Stockholm univ.) – oceanographic descriptions and modelling,
- Ulf Jansson, (Dept. of human geography, Stockholm univ.) – historical description, land use and human population,
- Ulrik Kautsky, Jacob Jones (SKB) – safety assessment and dose modelling,
- Johan Carlsson (SKB) – project administration,
- Helena Nyman (SWECO Position) – Geographical Information System (GIS-modelling).

Stockholm, Mars 2005

Tobias Lindborg

Site Investigations – Analysis

Summary

Swedish Nuclear Fuel and Waste Management Co is currently conducting site characterisation in the Simpevarp area. The area is divided into two subareas, the Simpevarp and the Laxemar subarea. The two subareas are surrounded by a common regional model area, the Simpevarp area. This report describes both the regional area and the subareas. This report is an interim version (model version 1.2) of the description of the surface systems at the Simpevarp area, and should be seen as a background report to the site description of the Simpevarp area, version 1.2 /SKB, 2005/. The basis for this description is quality-assured field data available in the SKB SICADA and GIS databases, together with generic data from the literature.

The Surface system, here defined as everything above the bedrock, comprises a number of separate disciplines (e.g. hydrology, geology, topography, oceanography and ecology). Each discipline has developed descriptions and models for a number of properties that together represent the site description. The current methodology for developing the surface system description and the integration to ecosystem models is documented in a methodology strategy report /Löfgren and Lindborg, 2003/. The procedures and guidelines given in that report were followed in this report.

Compared with version 1.1 of the surface system description /SKB, 2004a/, this report presents considerable additional features, especially in the ecosystem description (Chapter 4) and in the description of the surface hydrology (Section 3.4). A first attempt has also been made to connect the flow of matter (carbon) between the different ecosystems into an overall ecosystem model at a landscape level. A summarised version of this report is also presented in /SKB, 2005/, together with geological-, hydrogeological-, transport properties-, thermal properties-, rock mechanics- and hydrogeochemical descriptions.

Sammanfattning

Svensk Kärnbränslehantering AB (SKB) håller för närvarande på att ta fram en platsbeskrivning för Simpevarpsområdet i Oskarshamns kommun. Platsen är uppdelad i två mindre områden, Simpevarp- och Laxemarområdet. De två mindre områdena är omgivna av ett allmänt regionalt modellområde, Simpevarpsområdet. Den här rapporten beskriver både de lokala områdena samt det regionala området. Rapporten presenterar den preliminära versionen (modellversion 1.2) av beskrivningen av ytsystemen i Simpevarpsområdet, och är en bakgrundsrapport till platsbeskrivningen av Simpevarpsområdet version 1.2 /SKB, 2005/. Som grund för denna beskrivning ligger kvalitetssäkrad fältdata tillgänglig i SKB:s databaser (SICADA och GIS), så väl som generisk data från litteratur.

Ytsystemet, som är definierat som allt ovanför berggrunden, innefattar ett antal separata vetenskapliga discipliner (t.ex. hydrologi, geologi, topografi, oceanografi och ekologi). Varje disciplin har utvecklat beskrivningar och modeller för ett antal egenskaper som tillsammans representerar platsbeskrivningen. Den aktuella metodiken för utvecklandet av ytsystemsbeskrivningen och integreringen till ekosystemsmodeller är dokumenterade i en metodikstrategirapport /Löfgren och Lindborg, 2003/. I det nuvarande arbetet, har procedurerna och riktlinjerna angivna i den rapporten följts.

Jämfört med version 1.1 av ytsystembeskrivningen /SKB, 2004a/, har det gjorts betydande tillägg i den här rapporten, speciellt i ekosystemsbeskrivningen (Kapitel 4) och i beskrivningen av ythydrologin (Avsnitt 3.4). Det har också gjorts ett första försök att koppla flödet av ämnen (kol) mellan olika ekosystem i en samlad ekosystemsmodell på landskapsnivå. En summerad version av den är rapporten är även presenterad i /SKB, 2005/, tillsammans med geologiska-, hydrogeologiska-, transportegenskaps -, termiska egenskaps -, bergsmekanik- och hydrogeokemiska beskrivningar.

Contents

1 Introduction

1.1 Background

The Swedish Nuclear Fuel and Waste Management Company (SKB) is undertaking site characterisation at two different locations, the Forsmark and Simpevarp areas, with the objective of siting a geological repository for spent nuclear fuel. The characterisation work is divided into an initial site investigation phase and a complete site investigation phase /SKB, 2001/. The results of the initial investigation phase will be used as a basis for deciding on a subsequent complete investigation phase. On the basis of the complete site investigation, a decision will be made whether detailed characterisation will be performed (including sinking of a shaft).

An integrated component in the characterisation work is the development of a site descriptive model that constitutes an integrated description of the site and its regional setting, covering the current state of the geosphere and the biosphere, as well as those ongoing natural processes that affect their long-term evolution. The site description includes two main components:

- A written synthesis of the site summarising the current state of knowledge as well as describing ongoing natural processes which affect their long-term evolution, and;
- One or several site descriptive models, in which the collected information is interpreted and presented in a form which can be used in numerical models for rock engineering, environmental impact and long-term safety assessments.

More information about the general principles for site descriptive modelling and its role in the site investigation programme can be found in the general execution programme for the site investigations /SKB, 2001/.

1.2 Objectives

This report was developed within the frame of the SurfaceNet project, with the main objective to produce a detailed description of the surface systems, based on available data from the Simpevarp area, and it will constitute a supporting report to the site description project. The specific objectives of the work were to:

- describe the functional units (abiotic and biotic) in the ecosystem,
- develop descriptive models of these units,
- construct ecosystem models of land, lakes and sea,
- give examples of how Safety Analyses can use the site description in dose modelling and in descriptions of the site development in the near and far future,
- show how the site models can be used to support simplifications and assumptions in the overall safety assessment.

1.3 The site location

The Simpevarp area is located in the province of Småland (County of Kalmar), within the municipality of Oskarshamn, see Figure 1-1 and Appendix 3. The site is characterised by a relatively low topography in a fissure valley landscape on the coastline of the Baltic Sea. The major settlement in the region is Oskarshamn, 23 km south-west of the site.

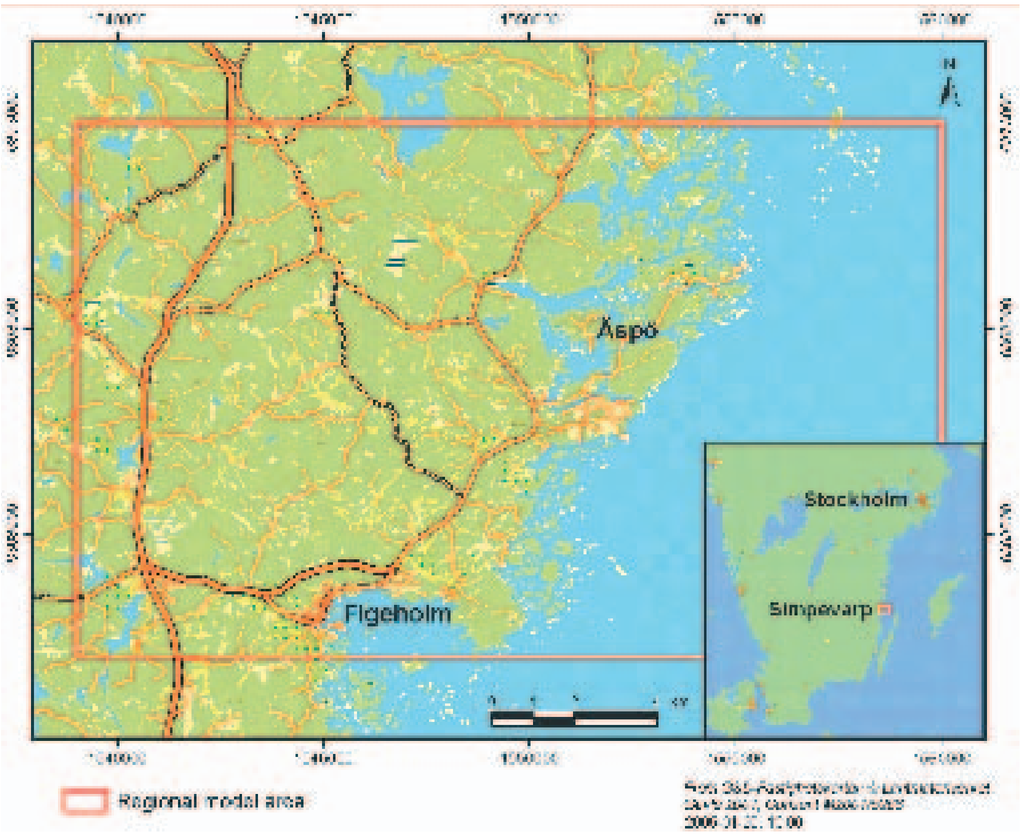

Figure 1-1. *Overview of the Simpevarp area and identification of regional model area.*

1.4 This report

This report consists of a number of descriptions representing different disciplines that together constitute the surface system. These descriptions cover the most important discipline specific patterns and processes at various spatial and temporal scales, e.g. temperature is affecting both temporal patterns such as production, and spatial patterns such as frost in the ground. Each description should be considered independent, aiming at a deepened understanding of the pattern and processes at the site. The different disciplines do also contribute with necessary information to the overall descriptive ecosystem models (Chapter 4), which together will be used to estimate and predict flow and accumulation of matter at a landscape scale in the safety assessment.

Below is a brief overview of the major headings and their content. If a specific reference has served as a major foundation for the chapter it is noted. The overview will serve as guidance for the reader as well as a short presentation of the different disciplines that together constitute the surface system.

The report starts with an introductory chapter, covering the background, objectives, how the work behind this report was organised, and the strategy of developing ecosystem descriptions /Löfgren and Lindborg, 2003/.

Chapter 2 describes the site investigation and the types of data that are used.

Chapter 3 contains the disciplinary descriptions and is divided into sections in accordance with the disciplines. Below follows a short description of the sections and their major content:

Historical description consists of three parts: (i) shoreline displacement describing the formation of virgin land /Brydsten, 1999/, (ii) post glacial succession of ecosystems that handles the temporal changes in ecosystems during historical time, and (iii) humans and land use describing the historical land-use, the changes in settlement and how people have been working and using the landscape over the last centuries /Jansson et al. 2004/. These descriptions will serve as a base for the predictions of future scenarios in the safety assessment.

Geometry presents a descriptive model for altitude and depth data covering the site, which is important input data for e.g. surface hydrological calculations and lake and sea descriptions.

Regolith describes the geomorphological conditions at the site that is highly important for the estimation of transport of mater and carbon in the soil. It is also an important predictor of the vegetation types at the site.

Climate describes a number of climate properties at the site, such as temperature and precipitation /Werner et al. 2005/. Climatic data sets the frame work for many processes and serves as important input for the surface hydrological modelling.

Hydrology describes the surface hydrology using measured properties as well as properties quantified using modelling tools /Werner et al. 2005/. Water is the main transport medium in the system models and hydrological properties are therefore a very important input to e.g. the terrestrial ecosystem model.

Oceanography describes a numerical model that quantifies water retention time in the marine basins outside the site, which is input data to the marine ecosystem model.

Chemical properties compile chemical data describing for example precipitation, surface water and soil. This section supports the limnic and marine ecosystem models with data describing the water chemistry.

Terrestrial biota is a compilation of data describing the primary producers and the consumers in terrestrial environments. It includes both a general description of the biota and information of biomass, production, and turnover of tissue, carbon content, used in the terrestrial ecosystem model.

Marine biota is a compilation of data describing the primary producers and the consumers in marine environments. It includes both a general description of the biota and information of biomass, production, and turnover of tissue, carbon content, used in the marine ecosystem model.

Limnic biota is a compilation of data describing the primary producers and the consumers in aquatic environments, such as lakes and streams. It includes both a general description of the biota and information of biomass, production, and turnover of tissue, carbon content, used in the limnic ecosystem model.

Human description is a compilation of data related to the human population at the site, their activities and current land use /Miliander et al. 2004/. This data is of major importance for identifying links between humans and different properties of the site, which supports the safety assessment to identify potential sources of exposure to radionuclides for humans.

Chapter 4 describes the construction of descriptive ecosystem models using data from Chapter 3. The overall aims are to describe the carbon cycle, both as a conceptual model and also by using quantitative data presenting a carbon budget for a catchment area, a lake and three marine basins. The chapter is subdivided in the following sections:

- *The terrestrial ecosystem* presents the descriptive model for the terrestrial area in a catchment area;
- *The limnic ecosystem* presents the descriptive model for the lake;
- *The marine ecosystem* presetns the descriptive model for the marine basins;
- *An integrated ecosystem description* connecting the terrestrial and aquatic ecosystems and the pools and fluxes between them. Data from the ecosystem models are here put together into an integrated ecosystem model, aiming at describing the major stocks and flows of matter within a landscape consisting of land, lakes and sea.

Appendix 1 is defining the model concepts used in this report.

Appendix 2 describes the strategy of the safety assessment of the potential deep repository and how this can be applied using hypothetical data from Chapter 3 and 4. The strategy covers spatial perspectives from a single catchment area up to a landscape level, but also a temporal perspectives ranging from 1,000 years to glacial cycles. Methods and tools of potential interest for dose modelling and exposure to biota and humans are briefly presented here.

Appendix 3 is a map over the Simpevarp site.

1.5 Development of ecosystem models

The building of a descriptive surface system model can be described in the following three steps Figure 1-2:

- Building a general conceptual model that describes stocks and flows of matter, using functional organism groups were it is possible. This demands a categorisation of the ecosystem into suitable units of resolution.
- Collecting site specific data to adapt the conceptual model to the specific site, resulting in a descriptive model describing stocks and flows of matter at the site for the suitable units of resolution. The data is presented in GIS.
- Describing processes affecting the transfer and accumulation of matter within and between units in a landscape.

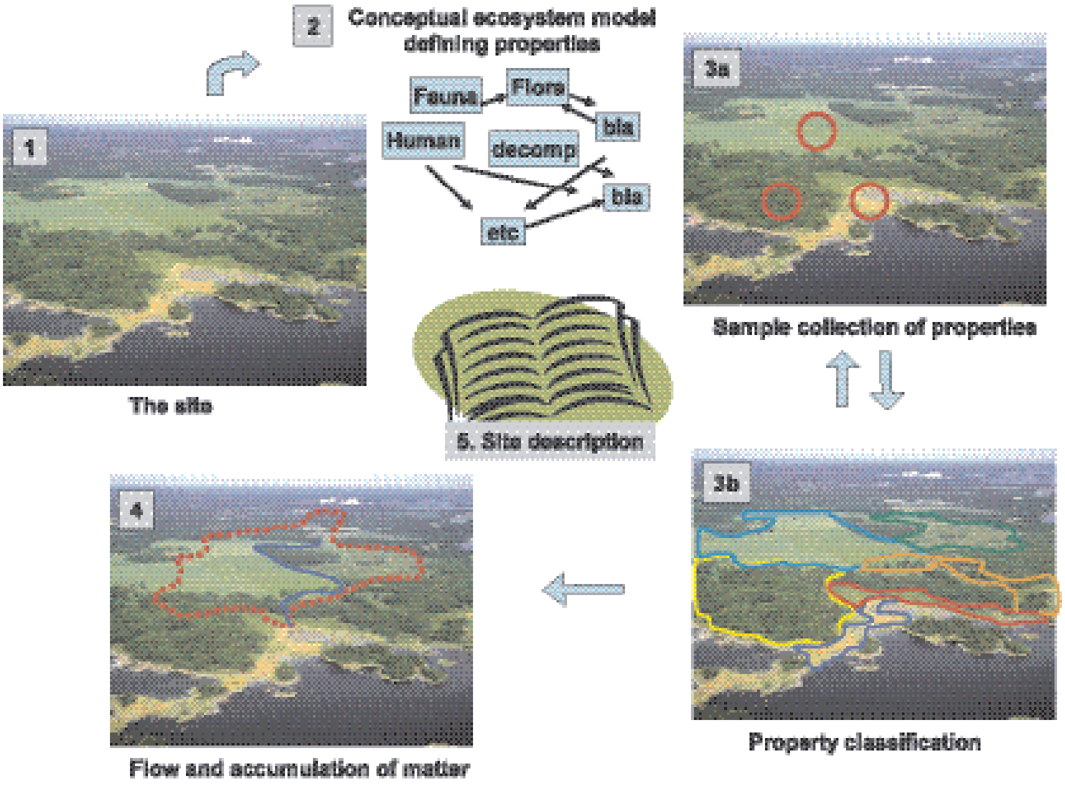

Figure 1-2. *The process of building a site descriptive ecosystem model. The site (1) is defined. A conceptual model (2) is produced describing functional units, properties and the fluxes between them. Samples are collected at the site (3a) using quantitative statistics to describe the biotic and abiotic properties in the conceptual model. The landscape is divided into a number of distributed models using site data and GIS (3b). Flows and accumulation of matter are described using hydrological tools, drainage areas and site data (4). All information is compiled into the site descriptive ecosystem model.*

1.5.1 A conceptual model

A conceptual model is necessary as a starting point when identifying the different properties affecting the stocks and flows of matter in the ecosystem at the site. The model does not have to be site specific and can be built upon literature and expertise from different fields of science /Löfgren and Lindborg, 2003/. This step will serve as the starting point for the planning of field surveys necessary for collecting the site-specific data in the next step (see conceptual models in Chapter 4).

The general conceptual model could later, when site data are collected, be adjusted to a site specific conceptual model. Thus, new information could be added or existing be taken away, i.e. the finding of a functional group needs to be considered or the biomass of another is too small to be relevant. One of the more difficult tasks is to find a suitable categorisation and classification of the landscape into more easily handled units. In this work, a first large-scale separation of the landscape into terrestrial, limnic and marine ecosystems was done. Further classification was done using units which could potentially constitute a base for budget calculation of organic matter. The units were then further described using functional groups within the food web. The spatial resolution of the gathered data is of course context dependent. However, the resolution of the terrestrial landscape has in our case been a function of the resolution of satellite classification techniques and the diversity of major vegetation types. Similarly, the spatial resolution of lakes has been set by the possibilities to monitor each lake separately and the categorization of lake habitats is done using a recently developed classification system of habitats /Brydsten et al. 2004/. The budgets of organic matter in terrestrial systems are described by means of biomass, primary production, secondary production, decomposition, mineralization and soil chemistry. The budgets of organic matter in lake and sea ecosystems are described by means of biomass, primary production, secondary production, decomposition and water chemistry /Kumblad et al. 2003/. The conceptual model should also identify and include those abiotic factors that are of importance for vertical or horisontal transport of matter, such as precipitation and ground water movement.

1.5.2 Site specific data

The two Swedish sites considered as potential sites for a future repository of spent nuclear fuel are both situated at the coast and do both include a large number of different ecosystems such as forests, agriculture land, wetlands, lakes and the sea. In this step we take the starting point from the conceptual model and uses site specific data to establish local budgets of standing stocks and flow of matter for the different units of resolution. The site-specific data is presented in GIS covering the specific area in a large database. This makes it possible to use over-layering techniques when merging data, e.g. making spatial explicit estimates of standing organic matter from different functional groups such as tree layer, shrub layer, field layer and ground layer.

1.5.3 Transfer and accumulation processes in the landscape

Carbon, energy, and biomass have been used interchangeable as currencies of the carbon and energy dynamics of ecosystems, because of the relative constancy of carbon and energy contents of organic matter /Chapin et al. 2002/. The proportions between carbon, nitrogen and phosphorous are often very constant within system, but differ between systems, e.g. terrestrial and limnic systems /Elser et al. 2000/. Matter is recycled between organisms in the food web and the physical environment within the ecosystem. Matter may also be accumulated within the terrestrial system, e.g. as peat. Accumulation often means that the matter leaves the short term recycling and that some kind of disturbance in the long term cycle has to occur to release it to circulation again, e.g. human starts to plough old lake beds or harvest peat. In the long term cycling, matter is leaching from the terrestrial ecosystem into streams, following watercourses into lakes and in the end discharging into the sea. Some matter is accumulated along this way, e.g. in lake beds. The intention of this work is to construct a spatially explicit ecosystem model that will be able to describe these processes in the landscape.

The first step is to connect the different units by quantifying flows of matter between units within the ecosystem. Surface hydrology is considered to be the most important component determining transport of matter /e.g. Blomqvist et al. 2000/, and it will be subjected to quantitative modelling and simulation using site specific data in order to understand vertical and horisontal movement of surface water. The functional units of the landscape are defined by catchment areas that are constructed from water divides in the landscape Figure 1-3. This gives us a tool to separate or link different subareas and ecosystem within the landscape. Moreover, together with hydrology models it gives us the ability to calculate turnover time for any chosen part of the site.

The aquatic systems are important for transport of matter, but also for accumulation in the lake or sea bed. Budget calculations describing the flows of matter at the level of catchment area are done, based on hydrology and water chemistry, and will provide information concerning transport of matter into running water and lakes. By quantifying recharge and discharge it will be possible to quantify input and loss of matter in the lake. Calculations of matter transport in streams gives an estimation of the actual leakage from the terrestrial systems. This makes it possible to compare estimated leakage and actual leakage from terrestrial systems.

The final recipient of the transported water and matter is the sea where the water discharges, e.g. into a bay. Here we have an accumulation of transported solid matter and shallow bays may typically show large primary production due to high nutrient availability. The bay also serves as the interface to the open sea, through which important exchange of matter may occur depending on water currents and hypsography.

In the end, this model will be turned into a numerical model to predict how and where matter is accumulated. During this step will the uncertainty of the model be evaluated.

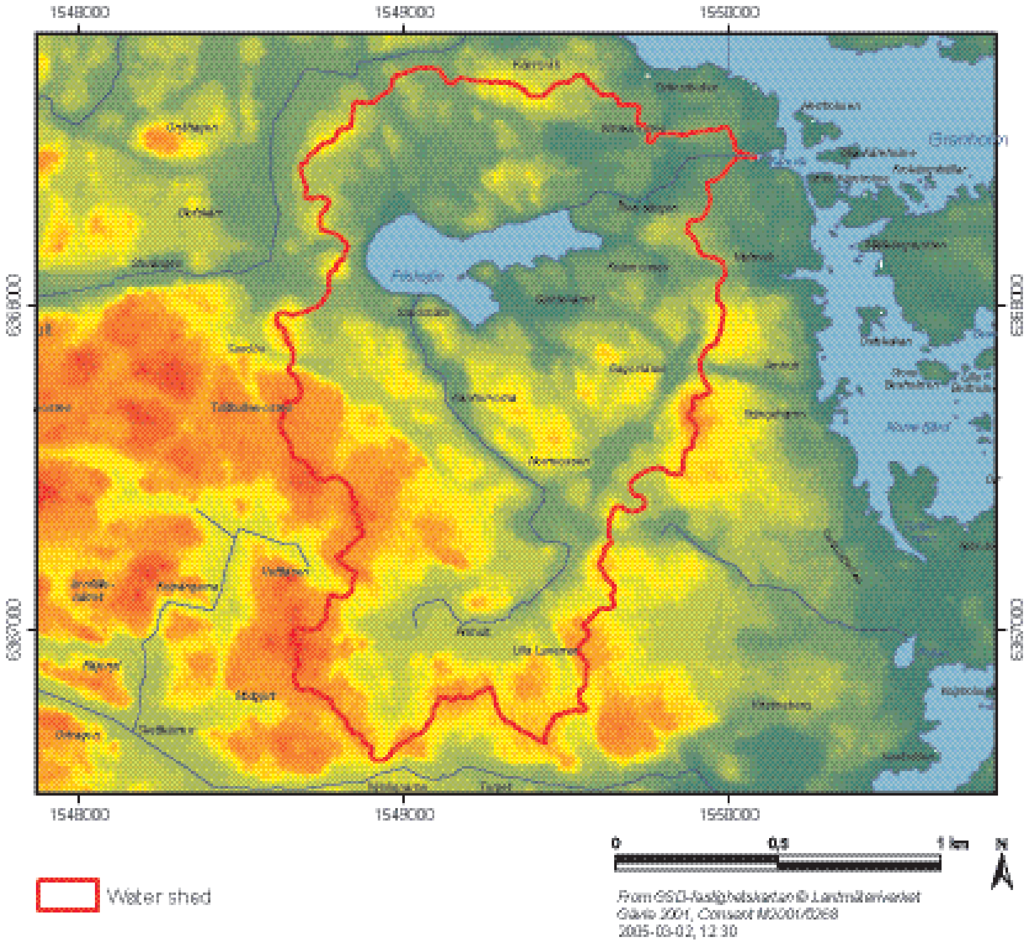

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***Figure 1-3.** Example of a model area in Simpevarp. The drainage area Lake Frisksjön with the water shed (red line) as the model boundary. Elevation is shown from orange (high altitude) to green (low altitude).*

In risk assessment of radionuclides, the focus has, until recently, been the protection of humans and thus the pathways leading to human consumption /e.g. Strand and Larsson, 2001; Copplestone et al. 2004/. Consequently, ecological components have been omitted or incompletely described /e.g. IAEA, 1999; Vieno and Nordman, 1999/. This approach has been increasingly questioned and new regulations require that effects on ecosystem should be considered /e.g. IAEA, 1999; SSI, 1998/. The suggested method is based on an ecosystem approach where ecosystems are delimited and described and later put together into a spatially explicit ecosystem model covering a landscape. This is an inter-disciplinary work incorporating several scientific disciplines.

One of the great challenges will be to integrate all possible data. During this integration, a number of simplifying assumptions have to be made. However, it will always be possible to back-track the information in larger details if necessary due to the extensive site-specific database. This approach ensures that many of the simplifying assumptions made going from step 2 to 3 Figure 1-2 may be modelled and tested. A mass-balanced ecosystem model with food webs provide a way of analysing how matter are linked to different ecosystem components through fluxes of e.g. carbon.

The balance of nutrients required to support maximal growth for terrestrial plants is general, and the nutrient that most strongly limits growth determines cycling rates of all nutrients. This stoichiometry defines patterns of cycling of most nutrients in ecosystems /Elser and Urabe, 1999/. It is thereby possible to establish quotients between important elements in e.g. the vegetation to facilitate mass-calculations of other nutrients or radionuclides from established carbon masses. Moreover, by estimating inflow and outflow of matter in the ecosystem units, it is possible to reduce the potential variation by setting the physical and biological limits for estimations of e.g. carbon accumulation in a lake bed. We therefore strongly believe that the ecosystem modelling approach, combined with the use of site-specific data, will result in more accurate and precise estimations of flow and accumulation of matter because of the site specific limitations that are introduced.

When we can describe standing stocks and flow of matter accurately, we will have a baseline for making predictions of dispersal and accumulation of chemical elements or substances, such as radionuclides, released in the area. Thereby, we provide the safety assessment with a tool to predict how and were radionuclides are transported and accumulated in the landscape, making it possible to calculate potential dose to humans at the specific site, see Figure 1-4, /Kumblad et al. 2003/. By adding the historical perspective on the landscape, we will also be able to predict transport and accumulation of matter during succession and different management regimes.

Figure 1-4. *Picture of Frisksjön, Simpevarp area, heading west.*

2 Site investigations and overview of available data

2.1 Overview of site investigations

The surface investigations that began in March 2002 have comprised the following major components:

- Airborne photography (performed in 2001),
- Airborne and surface geophysical investigations,
- Lithological mapping of the rock surface,
- Mapping of catchments areas and lake morphometry,
- Mapping of Quaternary deposits and soils,
- Marine geological investigations,
- Hydrogeochemical sampling and analysis of surface waters,
- Vegetation investigations at land, lakes and sea,
- Mammal inventories at land, lakes and sea,
- Monitoring boreholes that were established in the regolith/overburden.

All data are stored in the SKB databases SICADA and SKB GIS. The basic primary data are also described in the SKB P-series of reports.

2.2 Site-specific data

This section summarises the data that were available at the time of the site description and distinguishes data used and data not used in the modelling. The bases for the presentation are two tables (Table 2-1 and 2-2) developed for abiotic and biotic input data respectively. In each table, the first two columns set out the data available, columns 3 and 4 identify the data that were actually used, whereas column 5 identifies data not used, and presents arguments in support of their not being used.

Table 2-1. Available abiotic data from the surface system and their handling in this report.

Available site data data specification	Reference, for compleate list see Chapter 5	Usage in this work, analysis/modelling	Section in report	Not utilised in this work, arguments/comments
Geometrical and topographcal data				
Digital Elevation Model (DEM)	P-04-03 SICADA	Basic input to flow and mass transport models.	3.2	
Geological data				
Map of Quaternary deposits	P-04-22 R-98-55	Description of surface distribution of Quaternary deposits in the Simpevarp subarea.	3.3	
Helicopter borne survey data	P-03-100	Description of surface distribution of Quaternary deposits in the Simpevarp subarea.	3.3	
Electric soundings	P-03-17	Description of depth of overburden in the Simpevarp regional model area.	3.3	
Stratigraphy of Quaternary deposits	P-04-22	Description of stratigraphical distribution and total depth of deposits in the Simpevarp subarea.	3.3	

Available site data data specification	**Reference, for compleate list see Chapter 5**	**Usage in this work, analysis/modelling**	**Section in report**	**Not utilised in this work, arguments/comments**
Drilling and sampling in Quaternary deposits	P-04-121 P-04-46 P-03-80	Description of stratigraphical distribution and total depth of deposits in the Simpevarp subarea.	3.3	
Map of Quaternary deposits at the sea bottom	SKB-GIS	Description of surface distribution of Quaternary deposits at the sea bottom.	3.3	
Stratigraphy of Quaternary deposits from the sea bottom	SKB-GIS	Description of stratigraphical distribution and total depth of Quaternary deposits in the sea.	3.3	
Stratigraphy of water laid Quaternary deposits from the sea bottom	R-02-47			
Old maps of Quaternary deposits	SGU Ac 5 (1904)		3.3	Old map with low geographic accuracy.
Map of soils	P-04-243 SICADA	Distribution of soil types in the Simpevarp regional model area.	3.3	
Meteorological data				
Regional data (version 0)	TR-02-03 R-99-70	General description. Flow modelling.	3.4	
Data from meteorological station on Äspö (Oct. 2003–Sept. 2004)	SICADA	Comparison with regional meteorological data.	3.4	
Hydrological data				
Regional discharge data (version 0)	TR-02-03 R-99-70	General description. Water balance.	3.4	
Investigation of potential locations for discharge stations	P-03-04		3.4	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 characterics of catchment areas and lakes.	3.4	
Simple discharge measurements in water courses, lakes and the sea	P-04-13 P-04-75	Description of temporal variability in runoff.	3.4	
Hydrogeological data				
Inventory of private wells	P-03-05	Description of available hydrogeological information.	3.4	No attempt made to infer hydraulic parameters from capacity data.
Manually measured groundwater levels	SICADA	Basis for estimating depth of unsaturated zone	3.4	
Data on installed groundwater monitoring wells	P-04-121 P-04-46 P-03-80	Description of measurements and evaluation of hydraulic properties.	3.4	
Hydraulic conductivity of Quaternary deposits	P-04-122 SICADA	Basis for assigning hydraulic conductivity of Quaternary deposits in conceptual and mathematical models.	3.4	
Modelled hydraulic conductivity and pressure distributions in the upper part of the rock	R-04-65	Parametrisation and identification of boundary conditions in flow model.	3.4	
Oceanographic data				
Regional oceanographic data	TR-02-03 R-99-70	Quantitative modelling.	3.5	
Chemistry data				
Surface water sampling	P-04-13 P-04-75	Description.	3.6	

Table 2-2. Available biotic data from the surface system and their handling in this report.

Available site data Data specification	Ref.	Usage in this work, Analysis/Modelling	Section	Not utilised in this work, Arguments/Comments
Terrestrial biota				
Compilation of existing information 2002	R-02-10	Description.	3.7	
Bird population survey	P-04-21	Description.	3.7	
Mammal population survey	P-04-04	Description, modelling.	3.7	
Amphibians and reptiles	P-04-36	Description, modelling.	3.7	
Soil fauna	/Lohm and Persson, 1979/	Generic description.	3.7	
Vegetation inventory	P-04-20	Description.	3.7	
Vegetation mapping	P-03-83	Description, modelling.	3.7	
Biomass and NPP of the vegetation	NFI	Modelling, tree layer.	3.7	
Biomass and NPP of the vegetation	/Gower et al. 2001/	Modelling, shrub layer.	3.7	
Biomass and NPP of the vegetation	P-03-90, /Bisbee et al. 2001/	Modelling, field layer and ground layer.	3.7	
Biomass and NPP of the vegetation	/Vogt et al. 1982/	Modelling, fungi.	3.7	
Biomass of the vegetation	P-04-20, /Berggren et al. 2004/, P-03-90	Modelling, dead organic material.	3.7	
Data from soil mapping	P-04-243	Description, modelling.	3.7	
Limnic biota				
Limnic producers	P-04-242 P-04-253	Description, modelling.	3.8	
Limnic consumers	P-04-253 P-04-251	Description, modelling.	3.8	
Marine biota				
Compilation of existing information 2002	R-02-10	Description.	3.9	
Habitat borders	P-04-242	Description.	3.9	
Barythymetical measurements	P-04-254	Description, modelling.	3.9	
Light penetration depth	P-04-13 and field measurements (SICADA)	Description.	3.9	
Zooplankton, phytoplankton	P-04-253	Description, modelling.	3.9	
Identification of dominating species	P-03-68	Description.	3.9	
Macrophyte communities	P-03-69	Description, modelling.	3.9	
Soft bottom infauna	P-04-17	Description, modelling.	3.9	
Bentic fauna	P-04-251	Description, modelling.	3.9	
Reed	P-04-316	Description, modelling.	3.9	
Fish surveys	P-04-19	Description, modelling.	3.9	
Bird population survey	P-04-21	Description.	3.7, 3.9	
Humans and land use				
Humans and land use	R-04-11	Description, modelling.	3.10	

3 Descriptive models

3.1 Historical description

3.1.1 Geological development during the Quaternary period

Quaternary development of Sweden

The Quaternary is the present geological period and is characterised by alternating cold glacial and warm interglacial stages. The glacial stages are further subdivided into cold phases, stadials and relatively warm phases, interstadials (Figure 3-1). A combination of climatic oscillations with high amplitude, together with the intensity of the colder periods is characteristic of the Quaternary period. At the Geological Congress in London, 1948 the age of the Tertiary/Quaternary transition, as used here, was determined to be 1.65 million years. More recent research, however, suggests that the Quaternary period started c. 2.4 million years ago /e.g. Ŝibrava, 1992; Shackleton, 1997/. The Quaternary period is subdivided into two epochs: the Pleistocene and the Holocene. The latter represents the present interglacial, starting c. 11,500 years ago (Figure 3-1).

Results from studies of deep-sea sediment cores suggest as many as fifty glacial/interglacial cycles during the Quaternary /Shackleton et al. 1990/. The climate during the past c. 900,000 years has been characterised by 100,000 years long glacial periods interrupted by interglacials lasting for approximately 10,000–15,000 years. The coldest climate, and largest ice sheets, occurred toward the end of each glacial period. Most research indicates that the long-term climate changes (> 10,000 years) are trigged by variations in the earth's orbital parameters. However, there is not a universal agreement on this point. The warm interglacials are relatively short compared to the glacial periods. It is therefore likely that the present interglacial Holocene will be followed by a long period of colder climate and Scandinavia will probably be covered by ice once more. Quaternary climatic conditions, with focus on Sweden, have been reviewed by /e.g. Morén and Påsse, 2001/.

The most complete stratigraphies used in Quaternary studies are from the well-dated sediment cores retrieved from the deep sea, which have been used for studies of e.g. oxygen isotopes /e.g. Shackleton et al. 1990/. The marine record has been subdivided into different Marine Isotope Stages (MIS), which are defined based on changes in the global climatic record. Quaternary stratigraphies covering the time before the Last Glacial Maximum (LGM) are sparse in areas that have been repeatedly glaciated, such as Sweden. Furthermore these stratigraphies are often disturbed by erosion and are difficult to date absolutely. Our knowledge of pre-LGM Quaternary history of Sweden is, therefore to a large extent based on indirect evidence from non-glaciated areas.

In most parts of Sweden, the relief of the bedrock is mainly of Pre-Quaternary age and has only been slightly modified by glacial erosion /Lidmar-Bergström et al. 1997/. The magnitude of the glacial erosion seems, however, to vary considerably geographically. Pre- Quaternary deep weathered bedrock occurs in areas such as the inland of eastern Småland, southern Östergötland and the inner parts of northernmost Sweden /Lundqvist, 1985; Lidmar-Bergström et al. 1997/. The occurrence of saprolites indicates that these areas have only been affected to a small extent by glacial erosion.

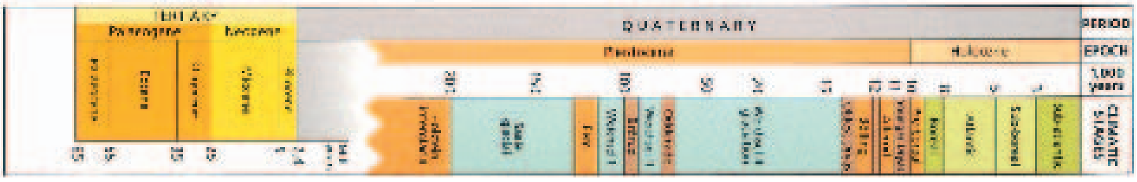


Figure 3-1. The geological timescale showing the subdivision of the late Quaternary period with climatic stages from /Fredén, 2002/.

In some areas, such as in large parts of inner northern Sweden, deposits from older glaciations have been preserved, which indicates that the subsequent glaciations have had a low erosional capacity /e.g. Hättestrand and Stroeven, 2002; Lagerbäck and Robertsson, 1988/. However, such deposits occur also in areas, e.g. Skåne, which have been glaciated during a relatively short period of time.

The Pleistocene

The global oxygen isotope record indicates numerous glaciations during the Quaternary Period. Several of these glaciations have probably affected Sweden. It is, however, at present impossible to state the total number of Quaternary glaciations in Sweden.

In Sweden the preserved geological information from the Pleistocene is, as mentioned above, fragmentary. Pleistocene deposits have mainly been found in areas, which have been subjected to glaciations during a short period of time, e.g. Skåne or where the glacial erosion has been low due to cold-based ice conditions. It has been suggested that these latter conditions occurred in the inner pats of northern Sweden during the middle and late parts of the latest glaciation, the Weichselian. Most Pleistocene deposits have been correlated with the stadials and interstadials, which took place during the latest glaciation. There are, however, a few sites with older Pleistocene deposits. Inorganic deposits such as glacial till have not been dated with absolute methods and such deposits from early stages of the Quaternary Period may therefore exist.

There are traces of three large glaciations, Elster (MIS 8), Saale (MIS 6) and Weichsel (MIS2-5d), that reached as far south as northern Poland and Germany. /e.g. Fredén, 2002/. Saale had the largest maximum extension of any known Quaternary ice sheet. There were two interstadials, Holstein and Eem, between theses three glacials.

The oldest interglacial deposits in Sweden, dated by fossil composition, was probably deposited during the Holstein interglacial (MIS 7, c. 230,000 years ago) /e.g. Ambrosiani, 1990/. The till underlying the Holsteinian deposits may have been deposited during Elster and is the oldest known Quaternary deposit in Sweden.

Deposits from the Eemian interglacial (MIS 5e, 130,000–115,000 years ago) are known from several widely spread sites in Sweden /e.g. Robertsson et al. 1997/. The climate was periodically milder than it has been during the present interglacial, the Holocene. The sea level was, at least periodically, higher then and present at large parts of the Swedish lowland were probably covered with brackish or marine water.

The latest glacial, the Weichselian started c. 115,000 years ago. The model presented by /e.g. Fredén, 2002/ and /Lundqvist, 1992/ is often used to illustrate the history of Weichsel. It is characterised by colder phases, stadials, interrupted by milder interstadials. Numerous sites with deposits from the early part of Weichsel are known from the inner parts of northern Sweden. Two interstadials took place during the early part of Weichsel, approximately 100,000–90,000 (MIS 5c) and 80,000–70,000 years ago (MIS 5a). Most of Sweden was free of ice during these interstadials, but the climate was considerably colder than today and tundra climate with shrub vegetation probably characterised northern Sweden. The south of Sweden was covered with coniferous forests during the first of these interstadials.

The second interstadial (correlated with MIS 5a) was colder and the vegetation in southern Sweden was probably characterised by a sparse birch forest. Most researchers agree that the ice did not reach further south than the Mälaren Valley during the Early Weichselian stadials. The ice advanced south and covered southern Sweden first during Mid Weichselian (c. 70,000 years ago). Most of Sweden was thereafter covered by ice until the deglaciation at around 12,000 years BP. Parts of Skåne were, however, free of ice until a few thousand years before LGM.

The model presented by /Fredén, 2002/ and /Lundqvist, 1992/ have been questioned. Most researchers agree that at least two interstadials, with ice-free conditions, did occur during the Weichselian glaciation. However, since the dating of such old deposits is problematic the timing

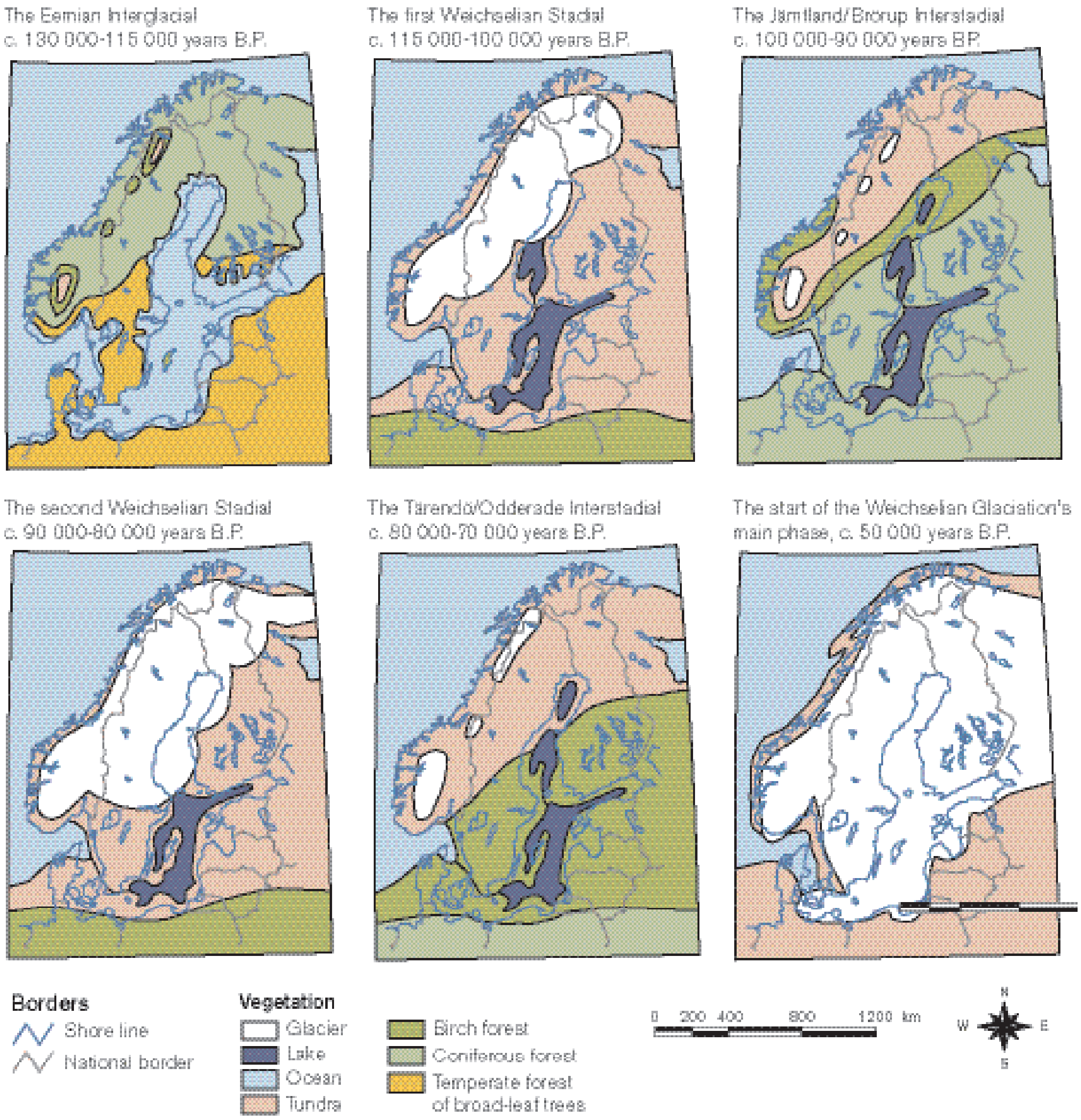


Figure 3-2. *The development of vegetation and ice cover in northern Europe during the latest interglacial (Eem) and first half of the last ice age (Weichsel). The different periods have been correlated with the Major Isotope stages (MIS). The maps should be regarded as hypothetical due to the lack of well dated deposits from the different stages.*

of these interstadials is uncertain. Investigations from both Finland and Norway suggest that most of the Nordic countries were free of ice during parts of Mid Weichselian (MIS 3-4) /e.g. Olsen et al. 1996; Ukkonen et al. 1999/. That may imply that one of the interstadials attributed to Early Weichselian by /Fredén, 2002/ may have occurred during Mid Weichsel. In large parts of Sweden the total time of ice cover during Weichsel may therefore have been considerably shorter than previously has been suggested by e.g. /Fredén, 2002/.

During the last glacial maximum (LGM), c. 20,000 years ago (MIS 2), the continental ice reached its southernmost extent (Figure 3-3). The Weichselian ice sheet reached as far south as the present Berlin, but had a smaller maximal extent than the two preceding glacials (Saale and Elster).

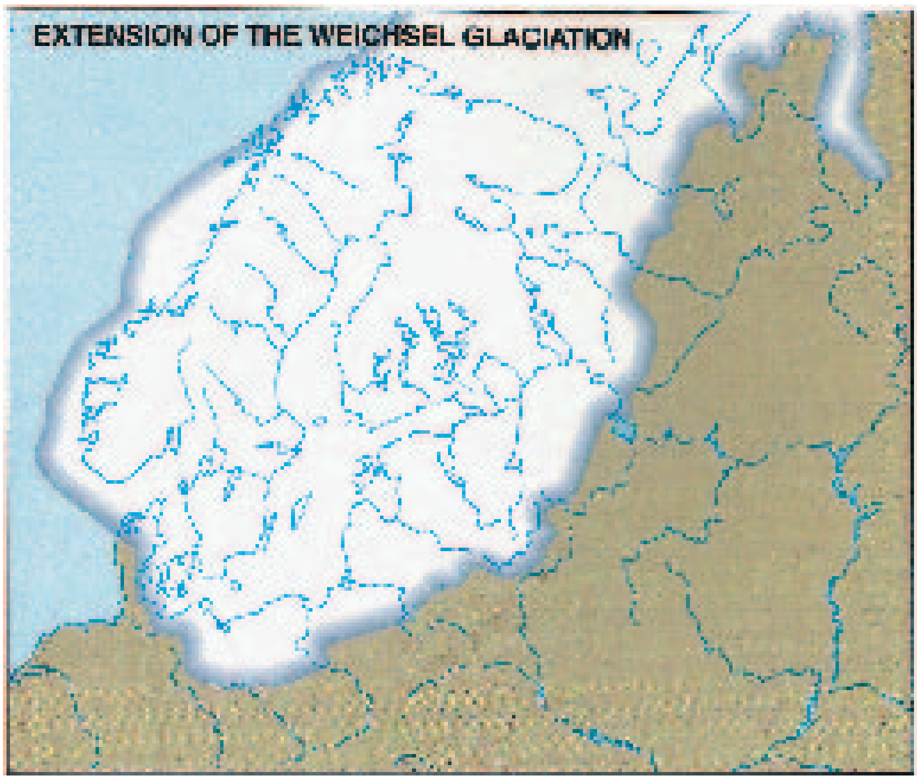


***Figure 3-3.** The last glacial of the Weichselian ice sheet during MIS 2 approximately 20,000 years ago.*

The latest deglaciation

A marked improvement in climate took place about 18,000 years ago, shortly after LGM and the ice started to withdraw, a process that was completed after some 10,000 years.

The timing of the deglaciation of Sweden has been determined with ^{14}C dates and clay-varve chronology. The deglaciation of eastern Sweden, including the Simpevarp and Forsmark areas, has mainly been studied by using clay-varve chronologies /Kristiansson, 1986; Strömberg, 1989; Brunnberg, 1995; Ringberg et al. 2002/, whereas the timing of the deglaciation in other parts of Sweden has been determined with ^{14}C dates. These two chronologies have recently been calibrated to calendar years /e.g. Fredén, 2002; Lundqvist and Wohlfarth, 2001/.

There were several standstills and even readvances of the ice front during the deglaciation of southern Sweden. In western Sweden zones with end moraines reflect these occasions. The correlations of ice marginal zones at regional scale across Sweden are, however, problematic. In southeastern Sweden few end moraines developed because a lot of stagnant ice remained in front of the retreating ice sheet.

There was a major standstill and in some area readvances of the ice front during a cold period called Younger Dryas (c. 13,000–11,500 years ago). The ice front then had an east west extension across Västergötland and Östergötland (Figure 3-4). The end of Younger Dryas marks the onset of the present interglacial the Holocene. The ice retreated more or less continuous during the early part of the Holocen.

Climate and vegetation after the latest deglaciation

Pollen investigations from southern Sweden have shown that a sparse *Betula* (birch) forest covered the area soon after the deglaciation /e.g. Björck, 1999/. There was a decrease in temperature during a cold period called the Younger Dryas (c. 13,000–11,500 years ago) and the deglaciated parts of Sweden were consequently covered by a herb tundra. At the beginning of the Holocene

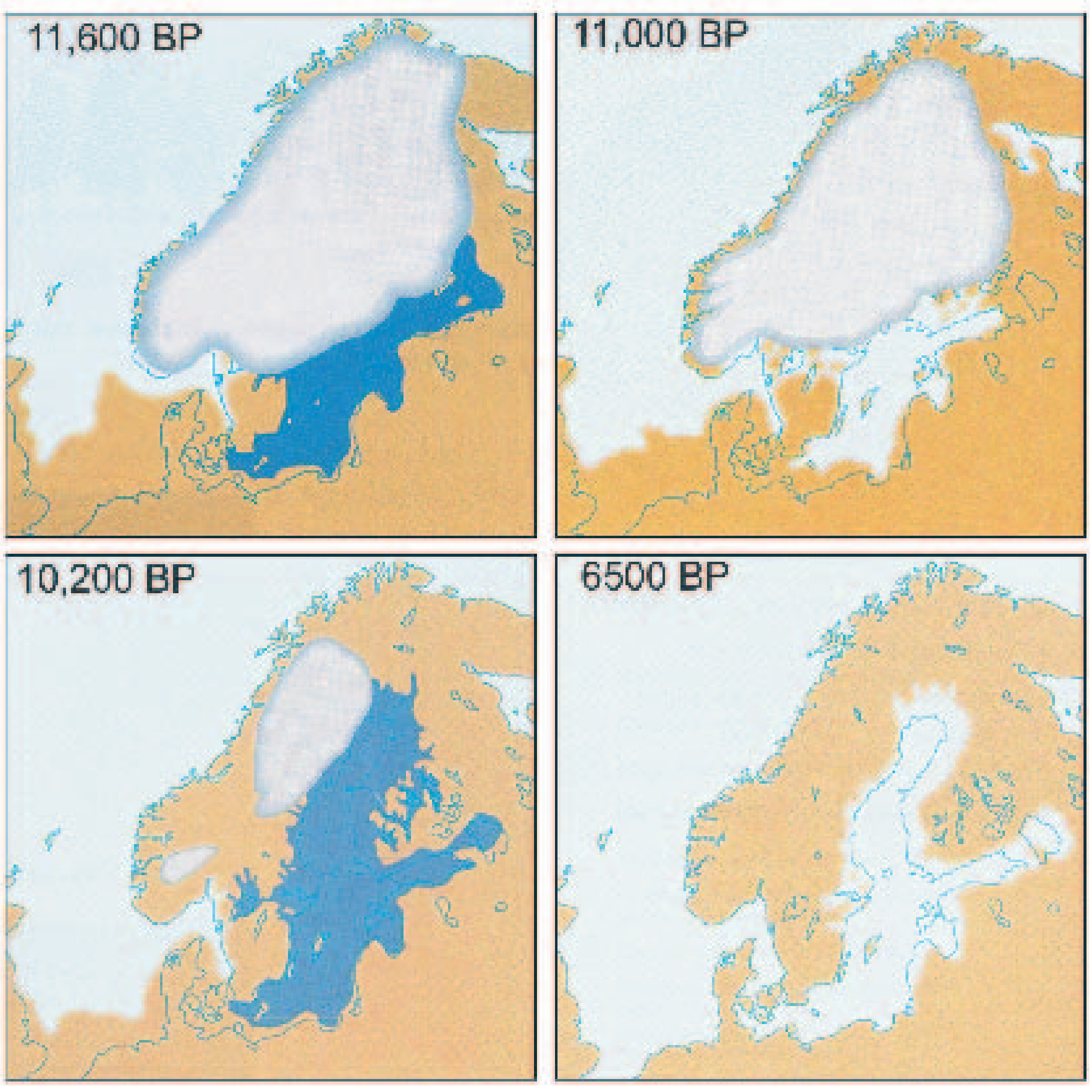


Figure 3-4. *Four main stages are characterising the development of the Baltic Sea since the latest deglaciation: A) the Baltic Ice Lake (15,000–11,550), B) the Yoldia Sea (11,500–10,800), C) the Ancylus Lake (10,800–9,500) and D) the Litorina Sea (9,500–present). Fresh water is symbolised with dark blue and marine/brackish water with light blue.*

c. 11,500 years ago the temperature increased and southern Sweden was first covered by forests dominated *Betula* and later by forests dominated by *Pinus* (pine) and *Corylus* (hazel). The timing and climatic development of the transition between the Pleistocene and the Holocene has been discussed by /e.g. Björck et al. 1996/ and /Andrén et al. 1999/. Northern Sweden was deglaciated during the early part of Holocene when the climate was relatively warm. These areas were therefore covered by forest, mainly birch and pine, shortly after deglaciation.

Between 9,000 and 6,000 years ago the summer temperature was approximately 2° warmer than at present and forests with *Tilia* (lime), *Querus* (oak) and *Ulmus* (elm) covered large parts of southern Sweden. These trees then had a much more northerly distribution than the present. The temperature has subsequently decreased, after this warm period, and the forests became successively more dominated by coniferous trees. During the Holocene *Picea* (spruce) has naturally spread successively from northernmost Sweden towards south. This tree has not yet spread to Skåne and the Swedish west coast. The composition of vegetation has changed during the last few thousand years due to human activities, which have decreased the areas covered by forest. The ecological history of Sweden during the last 15,000 years has been reviewed by /e.g. Berglund et al. 1996/.

Development of the Baltic Sea after the latest deglaciation

A major phenomenon that has affected and continues to affect northern Europe, following melting of the latest continental ice, is the interplay between isostatic recovery on the one hand and eustatic sea level variations on the other. During the latest glaciation, the global sea level was in the order of 120 m lower than the present, due to the large amounts of water stored in ice /Fairbanks, 1989/.

In northern Sweden the heavy continental ice depressed the Earth's crust by as much as 800 m below its present altitude. As soon as the pressure started to decrease, due to thinner ice coverage, the crust started to rise (isostatic land uplift). This uplift started before the final deglaciation and is still an active process in most parts of Sweden. In Sweden the highest identified level of the Baltic Sea or the West Sea is called the highest shoreline. This shoreline is situated at different altitudes throughout Sweden depending on how much the crust has been uplifted. The highest levels, nearly 300 m, are found along the coast of northern Sweden and lowest below 20 m.a.s.l. in southernmost Sweden.

The development of the Baltic Sea since the last deglaciation is characterised by changes in salinity, which have been caused by variations in the sea level. This history has therefore been divided in four main stages /Björck, 1995; Fredén, 2002/, which are summarised in Table 3-1 and Figure 3-4. The most saline period occurred 6500 years ago when the surface water salinity in the Baltic proper (south of Åland) was 10–15‰ compared to approximately 7‰ today /Westman et al. 1999/.

The shoreline displacement in northern Sweden has been mostly regressive due to a large isostatic component. Along the southern part of the Swedish east and west coasts, the isostatic component was less and declined earlier during the Holocene, resulting in a complex shoreline displacement with alternating transgressive and regressive phases. The shoreline displacement in Sweden has been summarised by e.g. /Risberg et al. 1991; Påsse, 2001/.

Quaternary history of the Simpevarp area

No studies dealing with the Quaternary history have been carried out within the regional model area and our understanding of that history is therefore dependent on information from other areas.

All known overburden in the Simpevarp regional model area has been deposited during or after the Weichselian glaciation. Older glacial till and fluvial sediment of unknown age were, however, found during the SGU's mapping of QD in Västervik, c. 40 km north of Simpevarp /Svantesson, 1999/. It can therefore not be excluded that QD, older than the last glaciation, exist also in the Simpevarp area. Furthermore several sites with saprolites (remaining rock after weathering) of Pre-Quaternary age are known in the inland of Småland, the closest c. 50 km west of the Simpevarp regional model area /Lidmar-Bergström et al. 1997/. These deposits indicate that the intensity of glacial erosion has been low in the areas west of Simpevarp. The occurrence of such "old" saprolite deposits in the regional model area can therefore not be excluded.

The marine isotope record suggests numerous glaciations during the Quaternary Period. The number of glaciations covering the Simpevarp area is, however, unknown. End moraines from three glaciations are known from northern Poland and Germany. It can therefore be concluded that the Simpevarp area has been glaciated at least three times, but probably more, during the Quaternary Period.

Table 3-1. The four main stages of the Baltic Sea. The Litorina Sea here includes the entire period from the first influences of brackish water 9,500 years ago to the present Baltic Sea.

Baltic stage	Calender year BP	Salinity
Baltic Ice Lake	15,000–11,550	Glacio-lacustrine
Yoldia Sea	11,500–10,800	Lacustrine/Brackish /Lacustrine
Ancylus Lake	10,800–9,500	Lacustrine
Litorina Sea sensu lato	9,500–present	Brackish

The Baltic Sea level was higher than at present during the Eemian interglacial and it is therefore likely that the local model areas were covered with brackish water during the main part of that interglacial. The area was probably free of ice during the early Weichselian stadials and interstadials. It has been assumed that tundra conditions prevailed during the stadials (Fredén, 2002). The vegetation during the first Weichselian interstadial was probably dominated by coniferous forest whereas the second interstadial was colder, the forest sparse and dominated by *Betula* (Birch). The ice advanced south and covered the Simpevarp area first during Mid Weichselian (c. 70,000 years ago). The exact timing of the Mid Weichselian glaciation is, however, unknown and there are indications of ice free condition in large parts of Fennoscandia during parts of Mid Weichsel /Ukkonen et al. 1999/. The total time of ice coverage in the Simpevarp area may therefore have been considerably shorter than in the model presented by /Fredén, 2002/.

According to mathematical and glaciological models, the maximum thickness of the ice cover in the Oskarshamn region was more than 1.5 km at 18,000 years BP /Näslund et al. 2003/. Glacial striae on bedrock outcrops indicate a youngest ice movement from N30°W–N45°W and N40°W–N60°W the Västervik and Oskarshamn areas respectively /Svantesson 1999; Rudmark, 2000/. Also in the Simpevarp region glacial striae as well as the orientation of eskers indicate a main ice movement direction from NW–NNW. Subordinate older striae indicate more westerly and northerly directions. In the Oskarshamn area striae formed from north-east have been observed on the islands outside the present coast /cf. Rudmark, 2000/, which indicates a period with an ice moving from the Baltic depression. According to the calibrated clay-varve chronology, the Oskarshamn area was deglaciated almost 14,000 years ago /Lundqvist and Wohlfarth, 2001/, during the Bölling chronozone.

The ice front had a north-east south west direction during the deglaciation, which is perpendicular to the latest ice movement (see above). Results from studies of clay-varves, along the coast of Småland, indicate that the ice margin retreated more or less continuously with a velocity of c. 125–300 m/year /Kristiansson, 1986/. There are, however, indications of an ice marginal oscillation in the Vimmerby area, 40 km north-west of the regional model area /Agrell et al. 1976/. The oscillation has resulted in a series of ice marginal deposits which can be followed to Vetlanda c. 50 km south-west of Vimmerby /Lindén, 1984/. This presumed oscillation may have taken place during or after the Older Dryas chronozone (c. 14,000 years ago).

The highest shoreline in the Oskarshamn region is located c. 100 m above sea level /Agrell, 1976/, and, thus the whole Simpevarp regional model area is situated below the highest shoreline. In the Simpevarp region, shoreline regression has prevailed and the rate of shoreline displacement during the last 100 years has been c. 1 mm/year /Ekman, 1996/.

The late Weichselian and early Holocene shoreline displacement in the Oskarshamn region has been studied with stratigraphical methods by /Svensson, 1989/. According to that investigation, and several other publications /e.g. Björck, 1995/, the shoreline dropped instantaneously c. 25 m due to drainage of the Baltic Ice Lake 11,500 years ago. The drainage was followed by the Yoldia Sea stage, which was dominated by freshwater condition but was influenced by brackish water during 100–150 years. The onset of the following Ancylus Lake stage was characterised by a transgression of c 11 m. This means that the land areas uplifted from the Yoldia Sea, was flooded by water. There are no studies from the Oskarshamn area dealing with the shoreline displacement during the Litorina Sea stage.

Results from a study c. 100 km north of Simpevarp /Robertsson, 1997/ suggest a regressive shore displacement during Litorina time. However, more detailed stratigraphical studies of sediments from areas north (Södermanland) and south (Blekinge) of the Simpevarp area has shown that three respectively six transgressions occurred during that period /Risberg et al. 1991; Berglund, 1971/. It is therefore likely that several transgressions have occurred in the model area during Litorina time.

The estimated shore line displacement since the last deglaciation has been reviewed and modified more recently by /Påsse, 2001,1997/ (Figure 3-5). Påsse's curve is similar to the curve presented by /Svensson, 1989/. Påsse suggests, however, that the reason for the fast shoreline displacement during the end of the Baltic Ice Lake was caused a fast isostatic component and not due to a sudden drainage as has been suggested earlier /e.g. Svensson, 1989; Björck, 1995/.

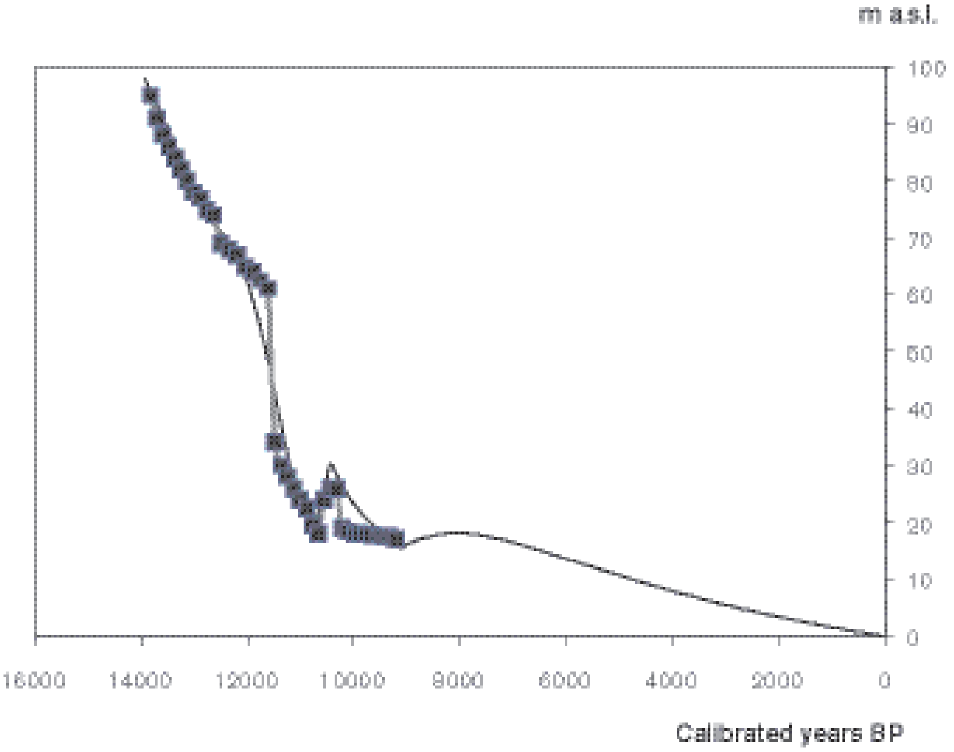


***Figure 3-5.** The shore line displacement in the Oskarshamn area after the latest deglaciation. The blue symbols show a curve established by /Svensson, 1989/ after a study of lake sediments in the region. The curve without symbols has been calculated by the use of a mathematical model /Påsse, 2000/.*

Pollen stratigraphical investigations from Blekinge show the succession of terrestrial plants in southeastern Sweden from the latest deglaciation to the present /Berglund, 1966/. The Simpevarp area was probably deglaciated before or during the relatively cold Older Dryas chronozone /cf. Lundqvist and Wohlfarth, 2001/, which was characterised by tundra vegetation dominated by herbs and bushes and a low coverage of trees. During the following Alleröd chronozone (Figure 3-1) a sparse *Pinus* and *Betula* forest dominated the vegetation.

The following cold Younger Dryas chronozone was characterised by tundra vegetation reflected by a high proportion of *Artemisia* pollen. At the beginning of the Holocene c. 11,500 years ago the temperature increased and southeastern Sweden was first covered by forests dominated *Betula* and later by forests dominated by *Pinus* (pine) and *Corylus* (hazel). 9,000–6,000 years ago a forests by *Tilia* (lime), *Querus* (oak) and *Ulmus* (elm) covered southeastern Sweden. Picea (*spruce*) reached the Simpevarp area only c. 2,000 years ago.

A pollen investigation, covering the last c. 1,500 years, have been carried out on sediments from two lakes situated 20 and 25 kilometres west of Fårbo /Aronsson and Persson, unpublished data/. The results show an increase of *Juniperus* (Juniper) and *Cerealea* (corn) c. 1,200 years ago, which indicates that areas used as arable land and for pasture increased during that time.

3.1.2 Human geography

Introduction

This section investigates the land-use; the settlement and the way people have used and affected the landscape in the investigated area. The study revolves around the historical land-use, the changes in settlement and how people have been working and using the landscape over the last centuries. Some results and examples from the region will be presented. This is however not a complete summary of the work, but will give an insight to a project in progress, for further details see /Jansson et al. 2004/. The sources used include historical maps, cadastral material, interviews and fieldwork. The first phase ended in the summer of 2004 and the remaining work is to be reported in spring 2005. When writing this text the field-investigations and interviews are still going on and the results have not yet been fully analysed. They will add additional value to the historical studies and also shed light on the present situation as far as the use of the land is concerned.

Input data

The methods for obtaining information from historical records follow the source critical tradition of historians, human geographers and others that have been investigating agrarian history and rural landscapes. The methods are not technically challenging but require a careful selection of sources since the written material is vast in certain periods.

The historical landscape study is based on medieval information, settlement information from cadastral books (*Sw. jordeböcker*) 1550–1880, information on population size from *Tabellverket* 1759–1855, registers on harvest (*Sw. tiondelängder*) and livestock (*Sw. boskaplängder*). In the detailed investigations registers on priest's interrogations (*Sw. husförhörslängder*) have been used.

The medieval sources are the most difficult historical material in Swedish history. In the local studies it has been possible to investigate the settlement and land owning structure during the Middle Ages. Sources from the medieval times are very scarce in Sweden, partly because of the fire in the Stockholm castle in the end of the 17th century when a lot of medieval documents were destroyed. In order to get a picture of the areas during the Middle Ages it is commonly used method to combine the land taxation register from the mid 16th century with the scarce medieval documents (see methodology).

The regional studies of the settlement and land owning structure are based on cadastral books, *kronans jordeböcker* and *årliga räntan*. Before the beginning of the 20th century the taxes in Sweden were based on land. The cadastral books were made by the Crown in order to control and manage the revenue in the country. Every farm in Sweden, except the demesnes of the aristocracy, was supposed to pay taxes. The amount of the taxes was decided by the size of the farm. The cadastral ledgers were made for each parish and show every single farm in the parish. If two or more farms are registered under the same name it is a village. It is therefore possible to study the settlement and its structure in these registers, and even pick out individual farms from farms in villages. The cadastral registers were systematically made in the middle of the 16th century during the reign of Gustav Vasa. In order to get control of the resources of the country he started to register the taxes paid by each farm in Sweden /Dovring, 1951/. At that time the medieval land owning structure was still in function. That means that even the land owned by the church was registered, even if Gustav Vasa later confiscated that land. The records give a reliable picture of the settlement and land owning structure on farm and village level. Households and settlement that were paying land based taxes, for example cottagers, craftsmen and others, is not registered in the registers. For these categories of people the "*Tabellverket"* and the "*husförhörslängder*" are more suitable.

Original cadastral ledgers from c. 1630, 1680, 1730, 1780, 1825 and 1880 have been used (copied) in the National Archive (*Sw: Riksarkivet*) and the Kammarkollegie Archive (*Sw: Kammarkollegiets arkiv*). DMS-material has been used to get access to cadastral register c. 1550. DMS, that stands for *Det Medeltida Sverige* was a project within the Bureau of national antiquities (*Sw: Riksantikvarieämbetet*)

The regional studies of the population are based on statistical material from Central board of statistics, founded in 1749, the so-called *Tabellverket* (later *Statistiska centralbyrån*). The material consists of pre-printed forms, which were filled in by the priests of the parishes every fifth year. On these forms there are columns for the numbers of different kind of people living in the parish during the period. The population is differentiated in several classes. These classes are changing over time, which are a problem when comparing the population structures of different times from 1749 and forward. In order to make such a comparison easier we have grouped classes of people. The statistical materials from the *Tabellverket* are often used as a source in historical studies and its value as a source for the population and the social differentiation of the population are good. The data from *Tabellverket* gives a good quantitative picture of the population and the growth of the population over time. It also gives a good picture of the social structure of the population and changes of the social structure over time /Palm, 2000/.

The geographer Torsten Lagerstedt's summaries on harvest and stock farming, gathered in the 1940s, have been used as source material /Lagerstedt, 1968/. The disadvantages about not using the original source material are that there could be mistakes made by Lagerstedt that is difficult to discover. There are however great benefits by using this material, as Lagerstedt's summaries are clear and easy to get access to. In all parishes Lagerstedt's summaries of registers on harvest from the year 1640 have been used. There have been some difficulties in deciding what kind of units that were used at this time, as different units were used in different areas of Sweden.

Registers on priest's interrogations have been used in the detailed study, and it is thus possible to illustrate household size and household structure. However, as going through these registers is a very time consuming activity, only selected parts of the parishes have been studied. These registers were made every fifth year when the parish priests visited every single household in the parish and made control of the religious knowledge of the people in the household. The registers therefore are a good source in order to catch all of the households, which are not farmers. The register covers craftsmen, sailors, salesmen and other people living in the parish. This material gives reliable and detailed information of different kind of households on a local level. In this material it is also possible to get information about the people and households which are not farmers.

Methodology

One of the greatest challenges was the data-capture of small-scale and large-scale historical and modern cadastral maps. The study is carried out in various levels of scale. Some investigations are of an overview character. The investigated areas consist of parishes. This is due to the fact that most of the sources for historical periods are organised in parishes. It is also a level that enables us to study the human activities, i.e. follow the use of forests in the context of a village. By studying a larger area we can also get o more comprehensive view of the society.

The method for the detailed analyses

The methods enabled us to digitise and geo-reference maps from the 17th, 18th and the 19th centuries so they could be treated and visualised together. The aim was to make the maps correspond to each other, so as to enable a comparison between different periods in time, e.g. settlement, land under cultivation, pastures and roads.

The method follows a line of work that has been developed at the Department of Human geography at Stockholm University over the last 10 years. The method uses only existing software and is fairly straightforward and follows a general model of how to handle digital data in a GIS. The work consists of different stages. The first one is data capture; it is often scanning a map or the photograph of a map. In this case the maps were of varying ages and supplied in different formats and at different scales. The maps that were not in a digital format from the beginning were photographed with colour positive film that was subsequently scanned. The second phase is often referred to as pre-processing; this includes work with the scanned image. We often want to reduce the image size by adjusting the resolution and reducing the colour depth. The next stage is to geometrically adjust or rectify the image to fit to a modern co-ordinate system. This also includes adjusting for the errors the surveyor made during his mapping. Generally the older the maps are, the worse the geometrical quality is. These images were imported into a raster based GIS, in this case both ENVI and ArcMap were used. The process of rectifying consists of a selection of points, often known as ground control points when we deal with aerial photos. The work consists of trying to find points on a modern map that correspond with objects in an older map. This transformation can be made more or less "severe", from a simple afine transformation to a polynomial warp of the image and makes the older map fit to a modern one as well as assigning it a coordinate system. When georeferencing old maps, it is important to find as many corresponding points, as possible. It is difficult to find points of similar location if the landscape has changed dramatically between the time periods that are to be compared. The next phase, if we want to extract information from the image, is to do a vectorisation the image. That includes manually drawing the contours of features in the geometrically corrected map. This can be done in many different "levels" from extremely detailed information of each parcel of land and adding all kinds of attribute data to a more superficial selection of features. The level must be decided by the analysis we want to conduct. The analysis phase is the next one. The types of analyses that can be done with digital information are almost endless and must also be guided by the research question at hand. The last phase is presentation of the information, this should not be forgotten, because it is important to communicate the analyses. It is not always a map that is the best way of representing the information. It could be a graph or a table with the information.

Method for processing large amounts of raster based information

The method used for the detailed maps is time-consuming and our goal to analyse a larger area required another technique. First all the maps had to be digitally re-sampled to fit to the coordinate system. This was relatively easy for the maps from the 20th century, but some of those were also of lesser quality. Some of the maps from the 19th century were however very hard to "conform" to the modern projection.

This method uses the colour information and extracts the land-use from the maps. Printed maps have however some problems. One is that the colours assigned to a certain feature are not as straightforward as one might think. Older maps have considerable variations in colour, both due to the manufacturing process and the ageing of paper and print. More modern maps as the Swedish economic maps have other problems. They use a backdrop of a photo that is overlaid with colours. This means that there is sometimes a blur of colours that has to be dealt with. A scanned map is a convenient way of obtaining digital geographic data. However maps often contain information that might not always be of spatial relevance, e.g. text and cartographic symbols. As these objects might range very much in size conventional filtering is not a very good approach when we want to get rid of these features. Instead we have found that using ordinary distance operators provides a very smooth and accurate way of solving the problem if two conditions are fulfilled; i) the objects to be removed do have a colour that is different from objects to be kept, and ii) the features to be kept are neither dithered or patterned.

Area of investigation

The physical landscape is the base for the cultural landscape. The physical setting to some degree always governs the land-use and sets the limits for human use in the present and through history. It is thus essential to understand for instance the topography, soils, vegetation and so on. Studies of this character is written and published within the framework of the SKB-investigations and will not be touched upon in the text in any detail, but the physical setting is often essential for an understanding of land-use, settlement, economy and so on throughout our history. One of the important traits in the Simpevarp-region is the location above or close to the marine limit. The tills are used for farming in some areas, but to a large degree in certain parts also limit the use because the presence of large boulders prevents any arable use of the land.

Ownership

In Misterhult and Kristdala the majority of farms were crown farms in the middle of the 16th century. In Misterhult there were nearly 80% crown farms and 20% noblemen farms in 1543. In Kristdala the amount of crown farms were not that dominating, around 44%, and the landed property categories (*Sw. jordnaturer*) were rather scattered. Here about 16% were freehold farms, c. 12% church farms and c. 21% unity farms (*Sw. sämjehemman*). Likewise in Döderhult the landed property categories (*Sw. jordnaturer*) was quite divided, but also somewhat different, since about 34% were king's heritage farm (*Sw: arv och eget hemman*) and c. 32% noblemen farms (*Sw: frälsehemman*), around 17% were church farms (*Sw: kyrkohemman),* c. 12% were freehold farms (*Sw: skattehemman*) and only c. 7% were noblemen farms. By the end of the 19th century c. 56% of the farms in Misterhult were tax farms and 22% were noblemen farms. Furthermore, c. 11% were noblemen manors and around 6% were subordinated farms (*Sw. rå- och rörshemman*). This implies that the noblemen were quite dominating in Misterhult in the late 19th century and the former crown farm domination had completely disappeared. In Döderhult the tax farms reached c. 39% and about 37% were noble farms. Here the crown farms had increased from only a few percent in the middle of the 16th century to c. 23% in the 1880s. In Kristdala there was a considerable domination of freehold farms in the 18th and 19th centuries, around 76%. The crown farms reached c. 12% and the total amount of farms in the hands of the nobility was about 11%.

The population

In 1571 the estimated population size in the three investigated parishes in Småland was all in all c. 1,266 persons (Figure 3-6). As for Uppland it is important to point out that this number is an approximation. The population growth was quite modest in Misterhult, Döderhult and Kristdala until the middle of the 18th century and particularly after c. 1800, when there was a strong population growth, especially in Döderhult. Kristdala and Misterhult show a quite similar population trend, although Misterhult's population size generally was larger. Döderhult follow the same trend, as Kristdala and Misterhult, until c. 1865, when a very large population growth began in Döderhult that lasted until c. 1900. This peak might be explained by the fact that the town Oskarshamn was established in 1856. Between 1856 and 1900 Oskarshamn and Döderhult were shown together in the statistics. After 1900 however, Oskarshamn was separated from Döderhult and hence the population size in Döderhult was reduced. During the 20th century there was a negative population trend in the three investigated parishes. After 1960 the trend has turned into a population growth in Döderhult, and the same thing happened in Misterhult after 1980. In 1990 the population size was calculated to all in all 10,640 persons in Misterhult, Döderhult and Kristdala.

In Misterhult the social structure was quite similar in 1850 as it was in 1785, see Figure 3-7. What are the reasons behind this relative stability? The major difference is that the share of works- and mine workers in 1785 has disappeared in 1850. Instead there is a small share of soldiers registered in 1850. Furthermore the share of crofters has decreased a little.

Farms and households

The number of farms has changed over the years in this area of Småland. There has been a partitioning of the farms. One example is Lilla Laxemar. There were seven small holdings in 1831. We can see the variety of landowners and that some of them not were residing in the village (Table 3-3). Bengt Andersson, who lived in Lilla Basthult owned 1/8, 1/16 was owned by Sven Olsson, another 1/16 was owned by Didrik Nilsson, that both apparently lived in the village. The rest of the owners were however not living in the village, among them one pilot called Alexander Persson. In Langö (1/16), Peter Olsson in "Westerbo" (1/16), the widow Lisa Magnidotter in Äverö (1/16) and the children of Lage Olsson (1/16) were not living or using the lands. In the investigated area in Småland a vast number of deserted farms are registered in the 1631 cadastral

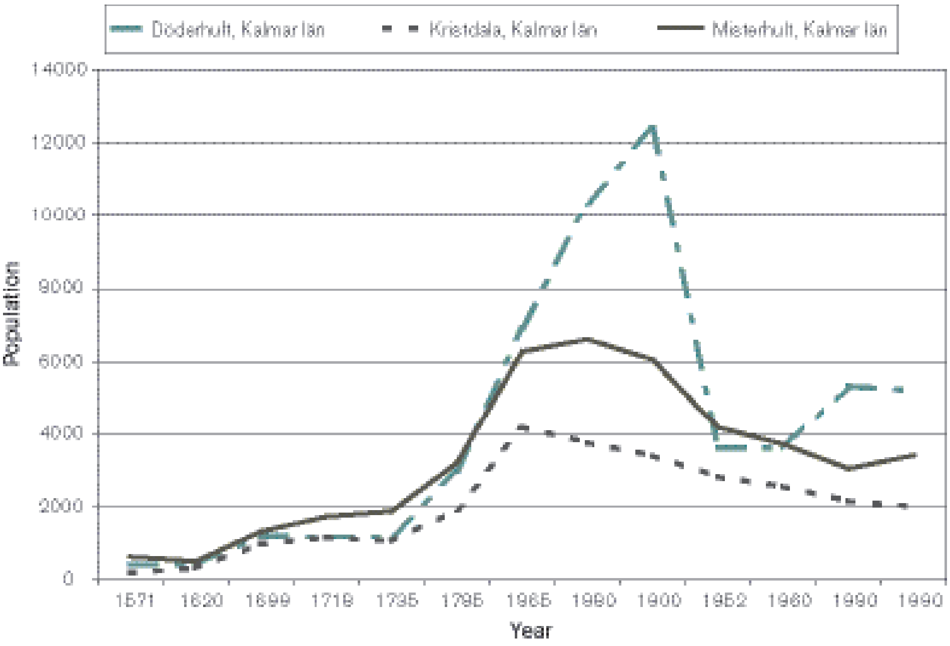


Figure 3-6. The population changes in the Oskarshamn area /Tabellverket; Palm, 2000/.

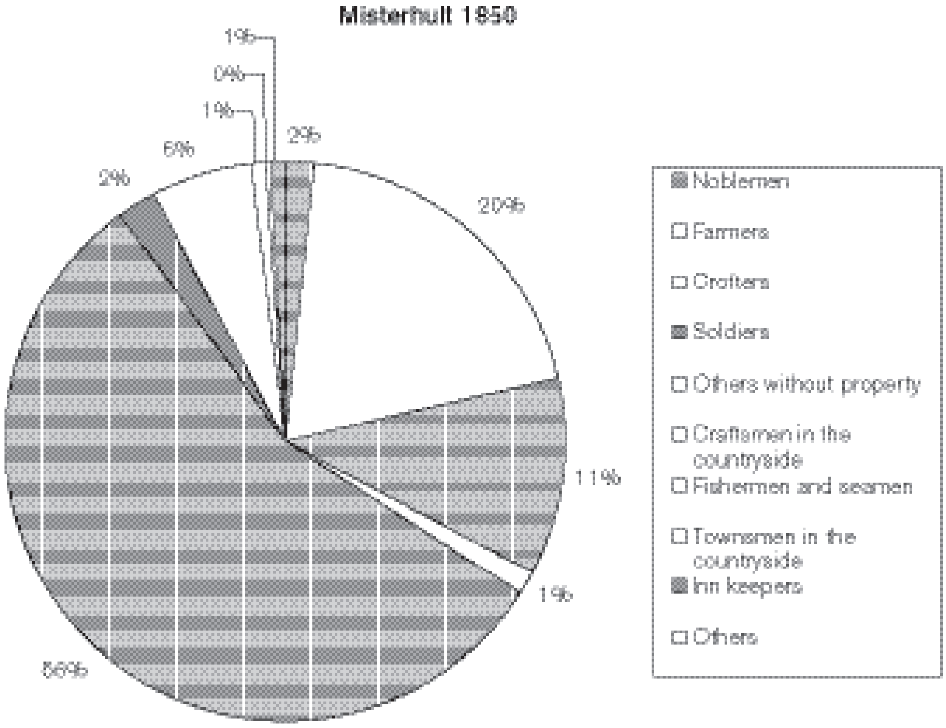


***Figure 3-7.** Social population structure in Misterhult /Tabellverket/.*

book. In Döderhult nearly 50% of the settlement units were wholly or partially deserted in 1631. In Kristdala the deserted farms reach c. 17% and in Misterhult c. 22% of the farmsteads were deserted at this time. Why were these farms deserted? A possible explanation can perhaps be found in the expensive Swedish wars that had a great impact on the population. An interesting question is where in the landscape these deserted farms were located.

In Misterhult the priest's interrogation registers have been used for two periods, 1851–60 and 1893–99 in order to study the household size (Table 3-2). Priest's interrogation registers are missing in Misterhult before 1812. The changes between 1851 and 1893 indicate an interesting pattern. In these c. 50 years the average household size decreased from almost 7 persons per household in 1851–60 to c. 5.5 persons per household in 1893–99. If farms are separated from crofter's holdings some differences can bee seen. In 1851–60 the farm household size can be estimated to almost 8 persons per household. Crofter's holdings however have an average household size of just over 5 persons. At the end of the 19th century the farm household size has increased to a little more than 6 persons and the crofter's holdings still is c. 5 persons per household.

The average household size has decreased over time. We can also observe that the farm's households seem to have been larger than the ones at the crofter's holdings. This is probably due to the number of farm-hands and maids in the farm households.

Table 3-2. Number of units in Misterhult. 1550, 1630, 1680, 1730 and 1871 are based on cadastral records whereas 1850 and 1895 are based on the priests records (husförhörslängder), more representative for households than cadastral units.

	1550	1630	1680	1730	1850	1871	1895
Basthult, Stora	2	1	1	1	11	1	7
Ekerum					18		9
Laxemar, Lilla	3	3	2	2	12	2	8
Simpevarp	1	1	1	1	8	1	7

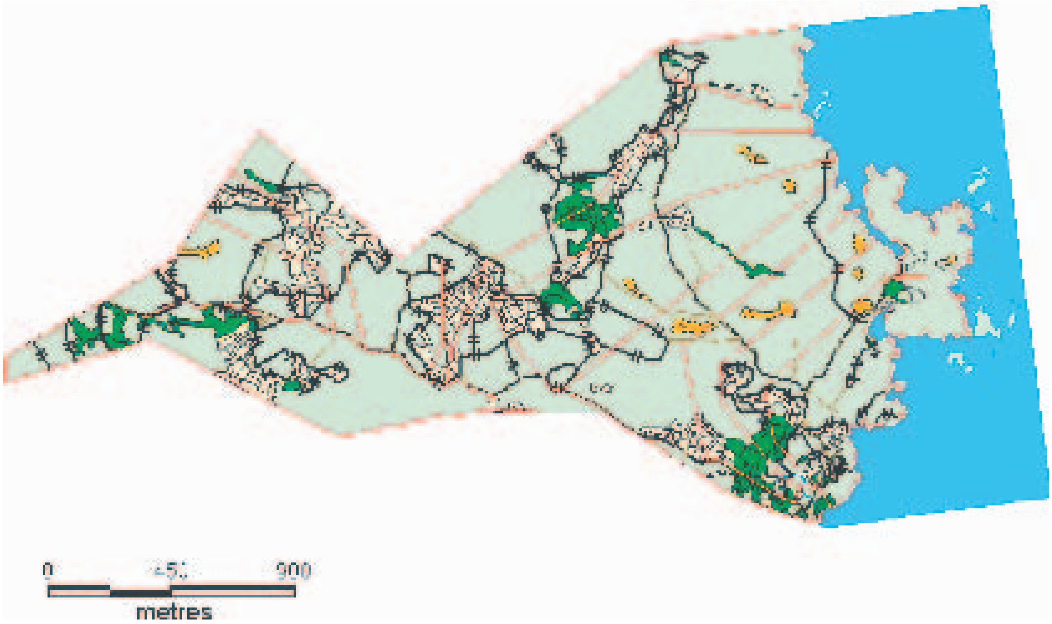


Figure 3-8. *In this map of the northern part, shows the subdivision of farms that occurred during the period ("Lantmäteriverkets forskningsarkiv": LSA G63-51:5, 1872).*

Table 3-3. Average household size (number of persons per household) in Misterhult and Valö. Farms and crofters holdings separated. Source: Parish catechetical meeting registers in Misterhult 1850 and 1895.

	c. 1750	c. 1850	c. 1895
Misterhult (all households)	–	6.7	5.5
Farms in Misterhult	–	7.9	6.7
Crofter's holdings in Misterhult	–	5.2	5.1

The reduction of arable land in the 20th century

In Oskarshamn the changes in the landscape were dramatic between the two time series that were studied, i.e. 1940 and 1980 (Figure 3-9). About 74 million square metres were abandoned between 1940 and 1980. According to the calculations only 3.8 million new square metres were ploughed in 1980. Of the original 114 million square metres of arable in 1940 only 41 million were kept in 1980. This is a dramatic change and if we study the changes spatially we can detect that some areas were more affected than others. A large part of the smaller fields have been completely abandoned.

Lilla Laxemar, Misterhult

Lilla Laxemar, together with the farms Ström and Ekerum, are situated by the coastline in Misterhults parish, just north of Simpevarp. About 1530 is a fishery mentioned in Lilla Laxemar /Rahmqvist, 1999/. At that time Gustav Vasa established crown fishery at Simpevarp. Simpevarp was also the centre for the whole area and fishery in the area took place with Simpevarp as a starting point. There was a fishery bailiff at Simpevarp during the later part of the 16th century. According to the record from the Simpevarp fishery at 1557 the main capture was small fish (*Sw. abborre, braxen, gädda id, mört, ål, knipor*), but also seal, the later captured during the summertime at *Simpevarps skär* (Rahmqvist, 1999). There are no document from the Middle Ages preserved for Lilla Laxemar and the other farms in the detailed studied area. The ancient monuments from the late Iron Age at Simpevarp indicate that Lilla Laxemar and Simpevarp were important places for fishery during the whole period from late Iron Age to the mid 16th century /Norman, 1993/. The field evidence

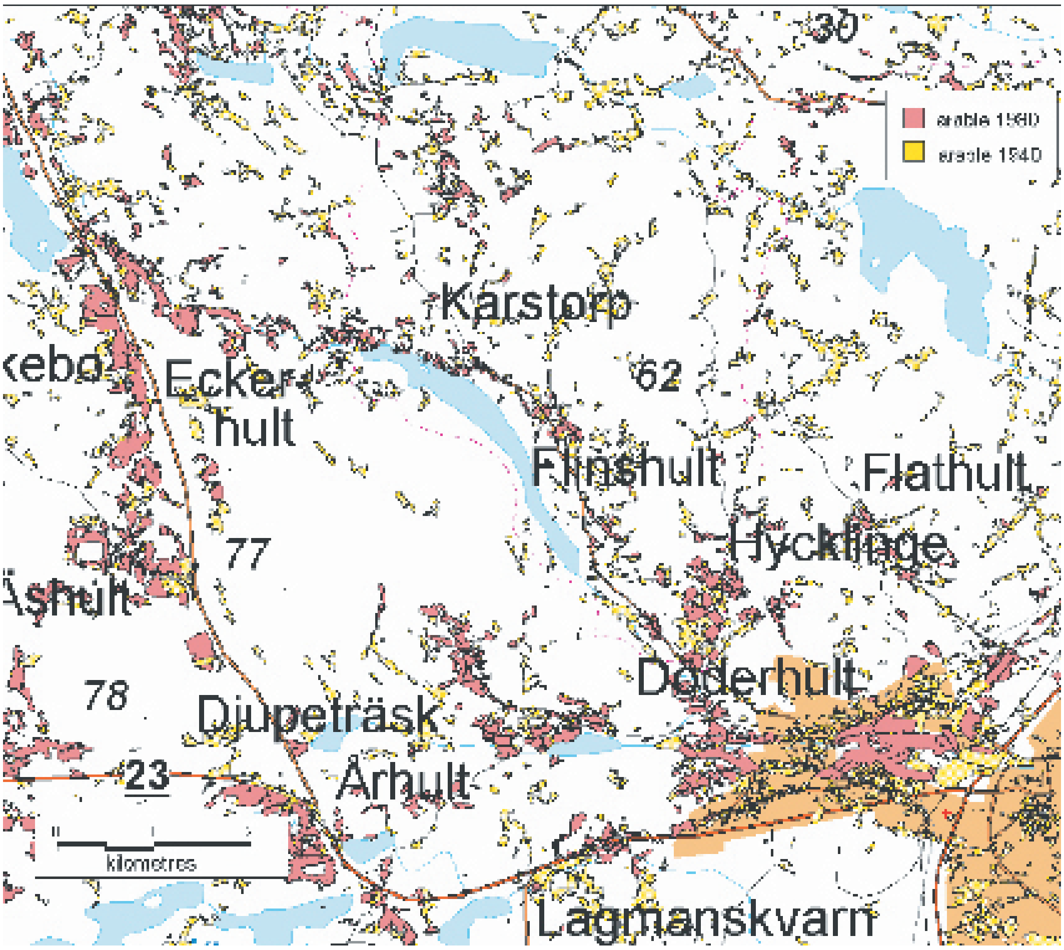


Figure 3-9. *This map shows the changes of arable land in the period between the 1940:s and 1980:s. Some areas have been abandoned for arable farming.*

containing remains of seasoned based fishery, the so called *tomtningar*, on the islands of the outer part of the archipelago in the Misterhult area from the early and high Middle Ages also indicate that fishery was as a main source of income for the people in the coast area /Norman, 1995/. Probably the people living in the area used agriculture just as a sideline during the whole period from at least late Iron Age to at least the 19th century.

The three farms were mapped together in the end of the 17th century. The reason for mapping them together was that the farms shared the forests. They constituted a so-called *skogelag*. The map (Figure 3-10) shows that the three farms were situated as single farms quite near to each other. Every farm has its own arable land but the three farms were sharing a large part of the meadowlands and the woodlands. The aim the map from 1689 was to separate the farms in the woodlands. The three farms are mentioned in the mid 16th century land taxation register of Misterhult. At that time Lilla Laxemar was two farms and Ström one farm owned by the crown. Regarding that Lilla Laxemar in the map 1689 was only one farm, the other farm in the mid 16th century probably was Ekerum.

According to the map 1689 the three farms had very little arable land. In spite of the small areas of arable land the farms were considered as full tax paying units (*sw. hemman*). These circumstances indicate that the main income for then farmers in the area came from other than agriculture. At the coastline in Misterhult it was fishery and other incomes from the sea that were most important.

During the 18th and 19th century the arable land and the meadow increased. Especially the number of meadows increased. It was wetlands in the forests that now were used as meadows. At the same time the old meadows near the settlement were transformed into arable land. The increase of population and the increase of the number of farms during the period may partly explain this. Another explanation may be that fishery and incomes from the sea decreased in relation to other incomes and that agriculture increased as the source for incomes at the same time. That does not mean that the incomes from the sea decreased to nothing, but that agriculture became relatively more important.

In the mid-18th century the enclosure (*Sw. laga skifte*) took place in Ekerum and Lilla Laxemar. At that time the number of farms in the area had increased. Ekerum consists of 7 farms and Lilla Laxemar consists of 7 farms (Figure 3-11). At that time the arable land had increased even more. A consequence of the enclosure in Ekerum and Lilla Laxemar was that some farms were forced to move from the former toft of the villages. In this area two farms from Ekerum moved to the crofters place Ärnhult. This forced the crofter at Ärnhult to move away. Another direct consequence of the enclosure was the establishment of the borderlines of the properties. From that time all the farms in the area were single farms managing the lands on their own.

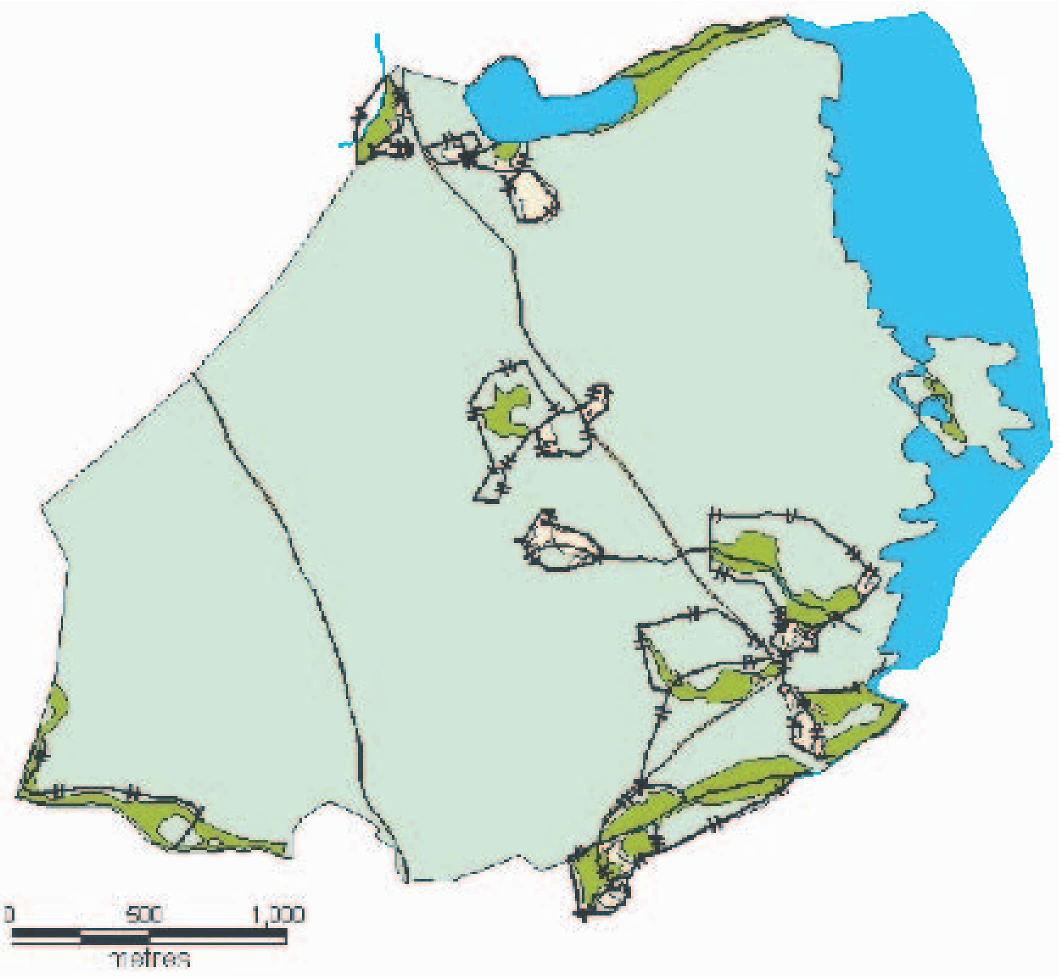


***Figure 3-10.** This is the earliest map of the area of Ekerum and Lilla Laxemar, made in 1689 (“Lantmäteriverkets forskningsarkiv”: LSA G63-51:1).*

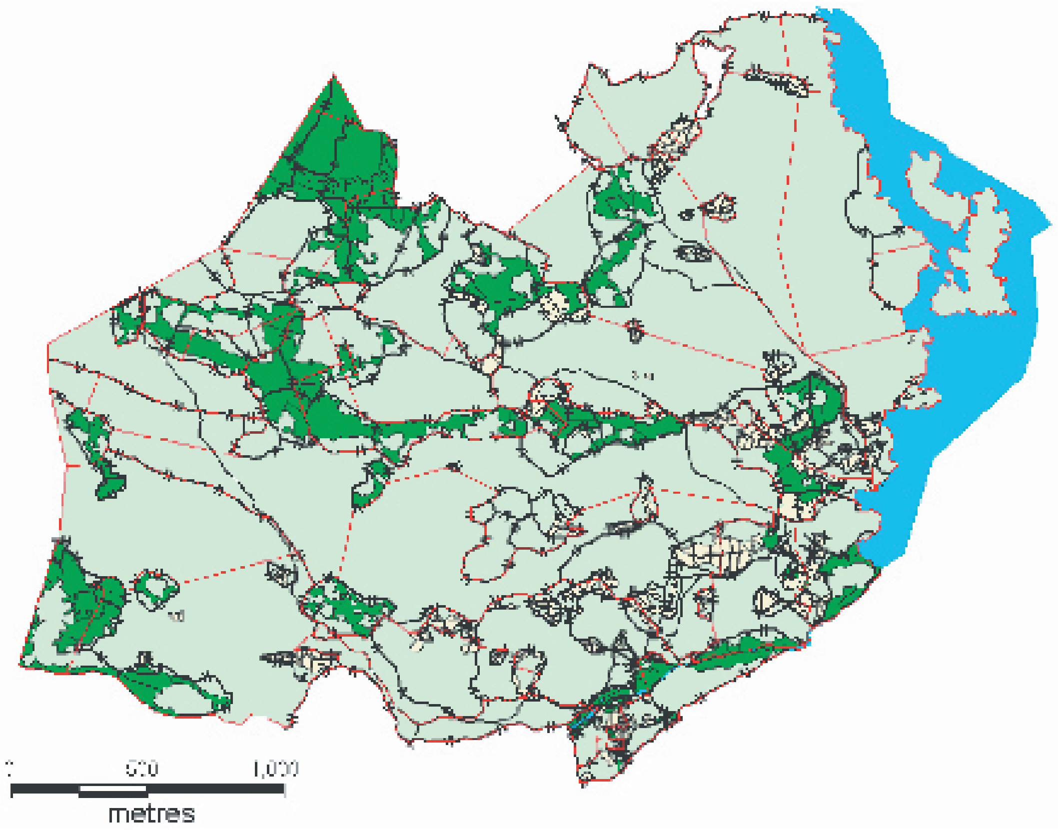


Figure 3-11. *In this image the effects of creating fences in the forest can be observed. This is often referred to as "förhagning" and is connected to an increase in livestock. Map from 1793 ("Lantmäteriverkets forskningsarkiv": LSA G63-51:2).*

3.2 Geometry model DEM

3.2.1 Introduction

Digital elevation models (DEM) are typically used to represent terrain relief. A DEM is a regular grid with elevation values at each point of intersection. This section gives an account of how the DEM is constructed, the quality of both input data and the DEM and how the DEM will be used as input data to different models in scientific areas such as Quaternary geology (3.3), Hydrology (3.4), Oceanography (3.5) and Terrestrial ecosystems (4.1).

A DEM is required as input data for many types of surface models such as hydrological models, geomorphometrical models etc. The DEM resolution is the size of the cells in a DEM. The DEM is constructed by interpolation from irregular spaced elevation data. In both these models the Kriging interpolation method were used. Kriging is a geostatistical interpolation method based on statistical models that include autocorrelation (the statistical relationship among the measured points). Kriging weights the surrounding measured values to derive a prediction for an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points.

Normally, a DEM have a constant value for sea surface (0 m.a.s.l) and also constant values for lake surfaces. The DEM's for Simpevarp area has negative values in the sea representing water depth, but constant positive values for lake surfaces representing the lake elevations. All lakes in both areas are depth sounded, so in future versions of the DEM's it is possible to let lakes be represented for the elevations of the lake bottoms instead of the lake surfaces.

Input data to the interpolation have many different sources, such as existing DEM's, elevation lines from paper topographical maps, paper charts and digital charts. All data are converted to point values with different techniques. The Kriging interpolation was performed in ArcGis 8 Geostatistical Analysis extension.

3.2.2 Methods

Data catch from land areas

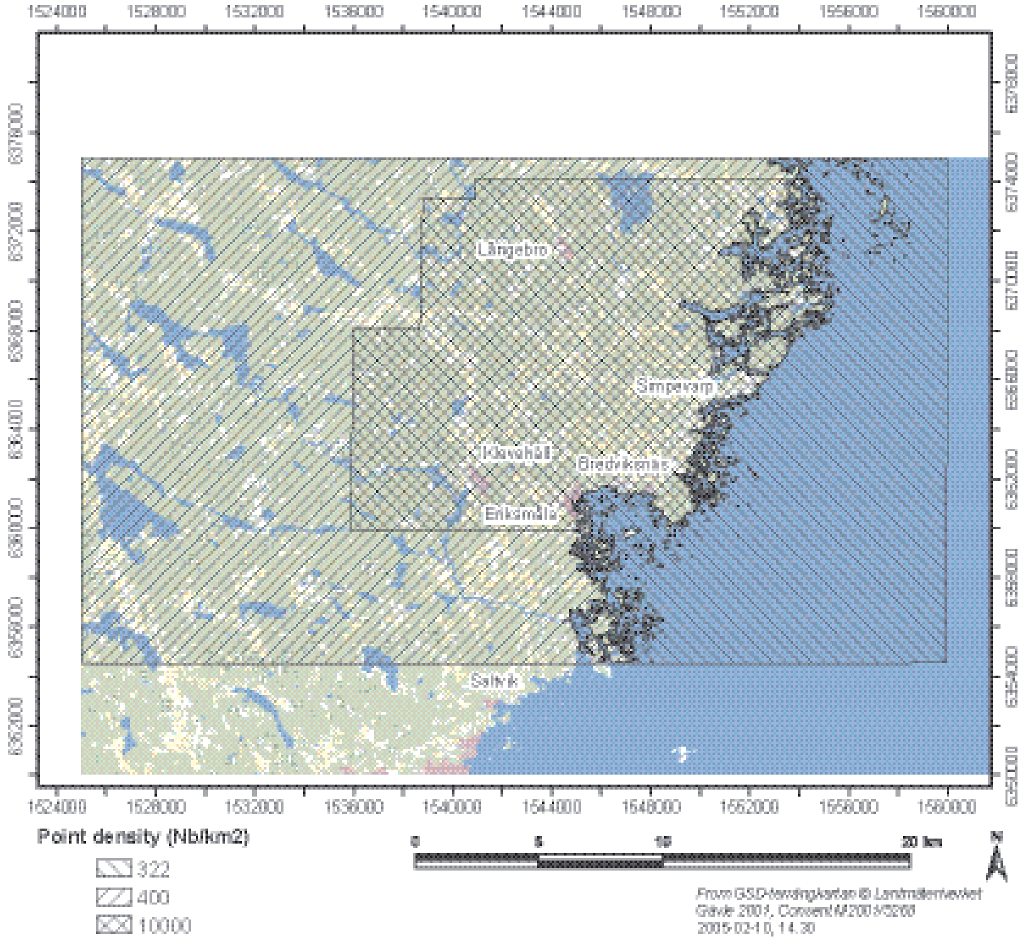
Three sources has been used for collecting elevation point data for land areas, the existing DEM from the Swedish national land survey with a resolution of 50 meters, the SKB DEM with a resolution of 10 meters (Figure 3-12) /Wiklund, 2002/.

The lines were transformed to points with an Avenue script in the GIS software ArcView version 3.2. The existing DEM's were converted to point layers in shape-format using ArcToolbox in ArcGis 8. All three point-layers were merged into one single point layer. All point placed on the sea surface polygon from the digital localities maps were deleted from the datasets. These layers are in the Swedish national grid projection (RT 90 2.5 Gon W) and in the Swedish national height system 1970 (RH 70).

Data catch from sea areas

A digital chart for the Simpevarp archipelago was not available in September 2002 so to catch depths for the sea, the archipelago paper chart number 624 Kråkelund – Blå Jungfrun was used. The chart has a Gauss projection and the geographical grid refers to WGS-84 and was corrected 1997.

The chart was scanned and rectified to WGS-84 in the GIS-program ArcGis 8. The depth information on the rectified chart was digitized on the screen. The depth curves for 3, 6, 10, 15, 20 and 50 meters water depth was digitized as lines and then converted to points with an equidistance



From GSD-terrängkartan © Lantmäteriverket Gävle 2001, Consent M2001/5268 2005-02-10, 14.30

Figure 3-12. *Number of points per square kilometre in the input data to the interpolation for the Simpevarp area.*

of approximately 10 meters. The point depths (single water depth values) and symbols for "Stone in water surface" (a plus sign with dots in each corner) and "Stone beneath water surface" (a plus sign) were digitized as points. The water depth for "Stone in water surface" was set to –0.1 meter and for "Stone beneath water surface" to –0.3 meter.

The sea shoreline was evaluated from the digital localities map (1:10,000). The sea water polygon was converted to lines and the lines converted to points with an equidistance of approximately 10 meters and the depth values was set to zero.

The depth values in the chart are reduced to mean sea level 1985. Elevation data on land are in the Swedish national height system 1970 (RH 70) so it was necessary to adjust water depth values to mean sea water level at 1970. The shoreline displacement rate in this area is only approximately 0.1 cm per year /Påsse, 1997/ so a constant of 0.015 meter was subtracted from the depth values.

All points with depth values were merged into one single point layer and the projection was changed from WGS-84 to RT90 2.5 Gon W using ArcToolbox in ArcGis 8. The total numbers of depth values in the Simpevarp area are 87,500 (Figure 3-12).

3.2.3 Results

Construction of the digital elevation models

All elevation point values were collected in one database and with this database a new digital elevation model was created. The DEM for Simpevarp area was created with a resolution of 10 meters. The interpolation from irregularly spaced point values to a regularly spaced DEM was done with the software ArcGis 8 Geostatistical Analysis extension. Kriging was chosen as the interpolation method /Davis, 1986; Isaaks et al. 1989/. The choosing of theoretical semivariogram model and the parameters scale, length and nugget effect was done with the extension.

The coordinates of the starting point (upper left corner) was chosen so that the values from the SKB 10 meters DEM was not changed by the Kriging interpolation process, i.e. the central points in the cells in the new DEM coincide with the central points in the SKB 10 meter DEM. The digital elevation model is illustrated in Figure 3-13. Finally, the DEM was transformed from ESRI Grid format to ArcInfo ASCII Grid format, a data format that most GIS software can read.

3.2.4 Quality of the digital elevation model

Different parts of the DEM area have different data density of the irregular point elevation values. In general, land areas have higher data density compared to sea areas, particularly in sea areas with great water depths. This implies that different parts of the DEM also have different quality.

Figure 3-12 illustrates the great differences in point densities depending on which data source the values belong to. The best quality is within the area of the SKB 10 meter DEM, much lower quality nautical chart area. The lowest data quality in the DEM is the area in the sea with high water depths.

A serious error exists in the grid at approximately 1555000 west and 6365000 north. A rectangular area of 500×500 metres size in the sea has incorrectly given a constant positive value of 0.35 metres. The reason for this error is unknown.

The final grid have a size of approximately 20×35 kilometres, a cell size of 10 metres, 2,001 rows and 3,501 columns, a total number of grid cells of 9 006 001 and a file size of approximately 26.8 MB (ESRI Grid format). The extension is 1524995 west, 1560005 east, 6375005 north and 6354995 south in the RT 90 coordinate system. As mentioned earlier the height system is RH 70.

The area is undulating; the range in elevation is approximately 186 metres with the highest point at 106 metres above sea level at the north-west part of the grid, and the deepest sea point at –80 metres in the south-east part of the grid. The mean elevation in the grid is 24.3 metres and 74% is land and 26% consist of sea.

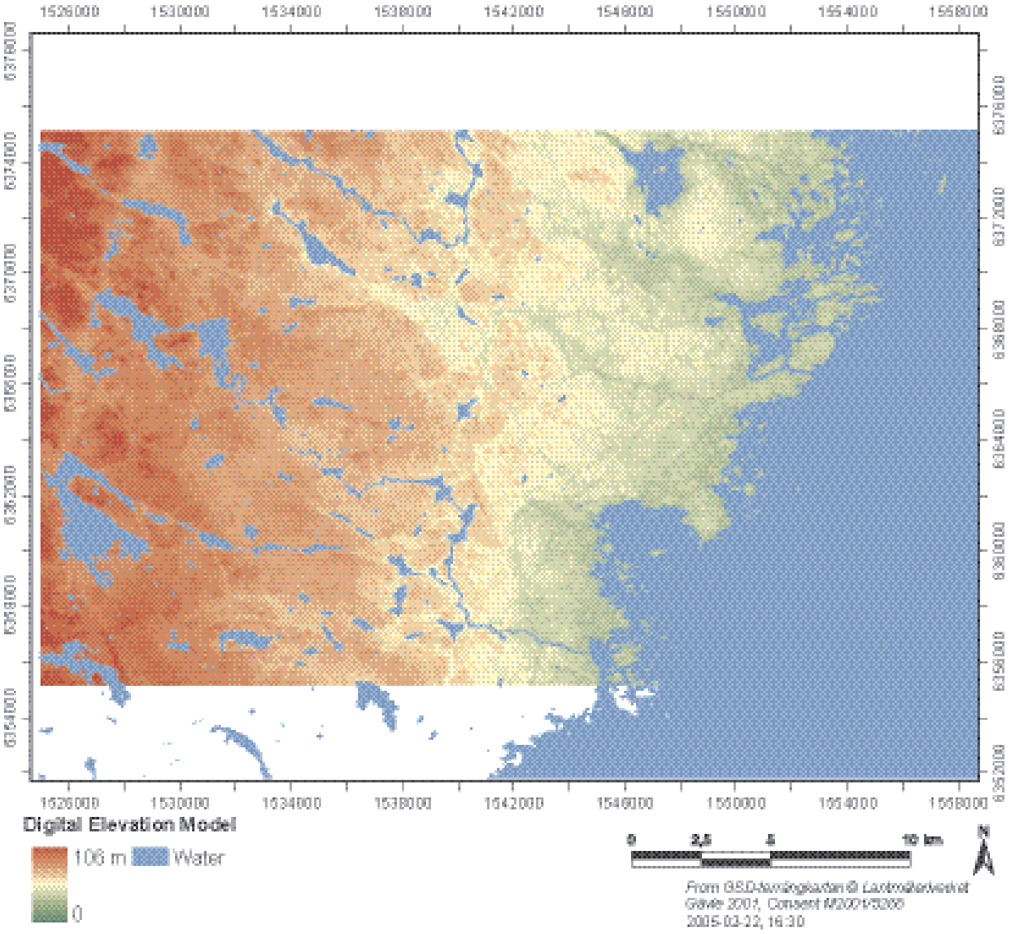


Figure 3-13. A digital elevation model of Simpevarp.

3.3 Regolith (overburden)

3.3.1 Input data and data evaluation

Data concerning the overburden has been gain during several activities and the overburden data used in this report is described below. Most of the present data comes from the Simpevarp subarea. Data available from the Simpevarp regional model area in general and the Laxemar subarea in particular will increase considerably after Laxemar 1.2.

All known overburden in the Simpevarp regional model area was formed during the Quaternary period, after or during the latest glaciation, i.e. during the last 100 000 years. The overburden is in the forthcoming text refereed to as QD (Quaternary deposits).

Data included in this report:

The QD within the Simpevarp regional model area has earlier been mapped by the Geological Survey of Sweden /Svedmark, 1904/. This map probably gives a fairly good view of the relative distribution of QD. It is, however, relatively old and the geographical positioning has low accuracy. This map is therefore not used further in this report. A recent map of the QD, interpreted from aerial photos, has been produced by /SGAB, 1986/ and was presented in /Bergman et al. 1998/. This map does not give any detailed information about the distribution of QD. It is, however, available in GIS format and more modern than the map produced by /Svedmark, 1904/. The map from /Bergman et al. 1998/ will therefore be used in the further model work until a more detailed map is available (after Laxemar 1.2).

/Rudmark, 2004/ has presented results from an investigation of QD in the Simpevarp subarea, which includes:

- A map that can be presented in scale 1:10,000 and showing bedrock exposures and QD with an area larger than 10×10 m. The map shows the overburden at a depth of 0.5 metres below ground surface. The superficial boulder frequency of the till and the effects of wave washing are also shown on the map.
- Stratigraphical data that has been compiled from studies of trenches and 17 auger boreholes (Figure 3-14) down to a depth of maximum 8.5 meters below the ground surface.
- The direction of glacial striae on rock outcrops, which gives information on the direction of the ice movements during the latest ice age.

The distribution of exposed bedrock in the central part of the regional model area has been interpreted from aerial infrared photos. This interpretation was done within the bedrock mapping activity (AP PS 400-02-015).

In the Simpevarp subarea stratigraphical information is available from weight sounding (23 sites, Figure 3-15) and soil/rock drillings (17 sites, Figure 3-16) /Ask, 2003; Johansson and Adestam, 2004b/. The soil/rock drillings also gives information regarding the total depth of the overburden. Results from two of these drillings were reported in the Simpevarp 1.1 report (SSM000001 and SSM00002). In the Laxemar subarea stratigraphical information was gained during two soil/rock drillings (SSM000009 and SSM000011). Two sites in the Simpevarp subarea were investigated with a backshoe excavator (SSM000004 and SSM000005).

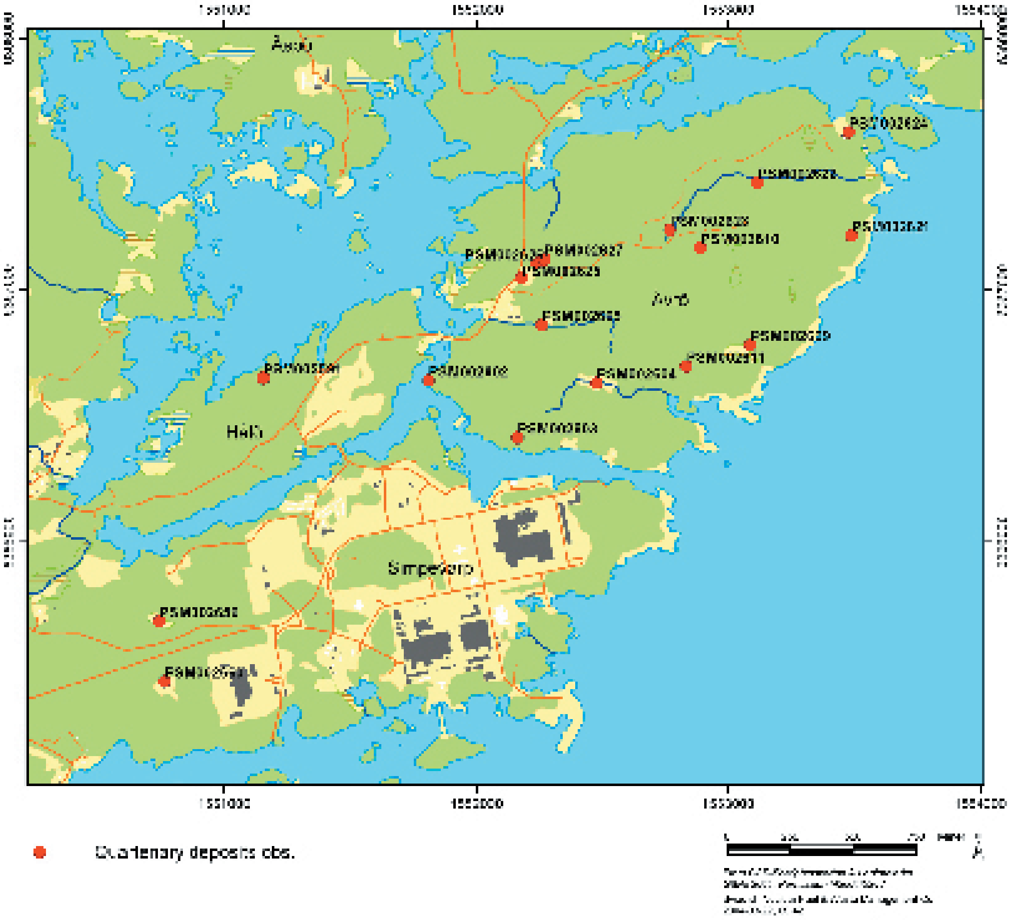


Figure 3-14. Location of sites in the Simpevarp subarea used during the mapping of QD to assess stratigraphical information.

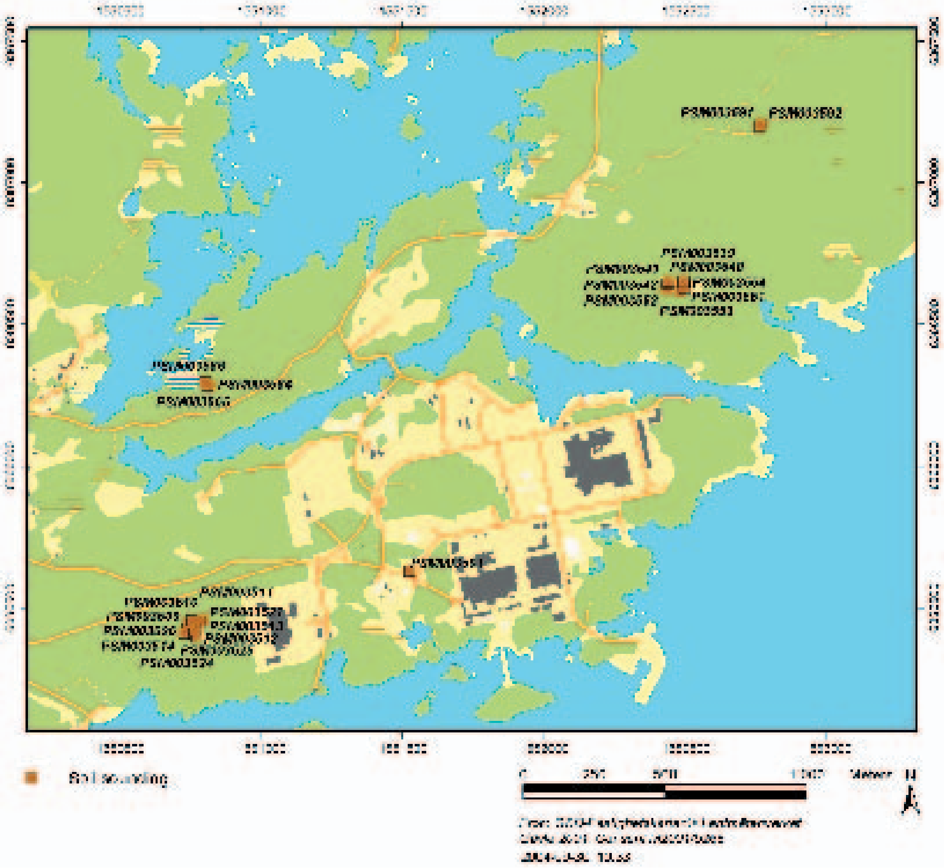


Figure 3-15. *The stratigraphy of the uppermost overburden in the Simpevarp subarea was gained from the weight sounding sites shown on the map.*

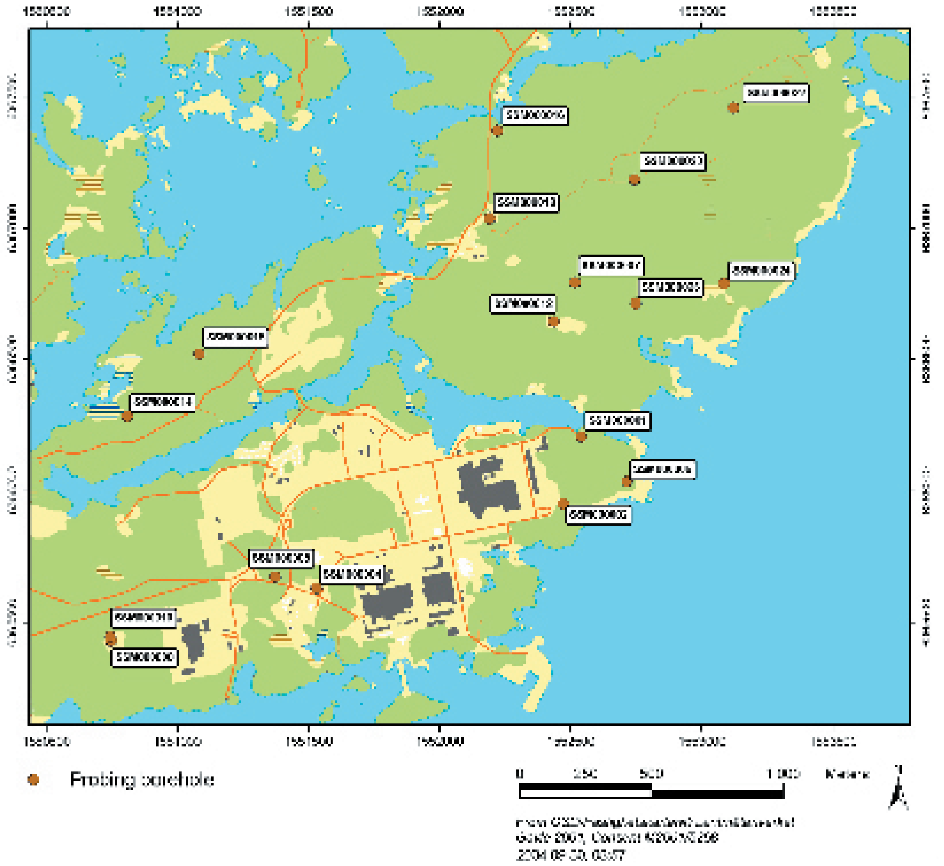


Figure 3-16. *The total depth and stratigraphy of the overburden in the Simpevarp subarea was gained from the soil/rock drilling sites shown on the map.*

Soils from ten different land types were investigated in the in the Simpevarp regional model area (Figure 3-17). The soils were classified in eight spade dug profiles at two sites from each land type (AP PS 400-03-26).

Data from the detailed marine geological survey of the sea bottom outside Simpevarp (AP PS 400-02-017) gives information regarding the horizontal and vertical distribution of QD on sea bottoms situated at water depths greater than 3 m. This information is presented in two maps (scale 1:100,000).

The data was collected from boat (Ocean Survey from SGU) in lines with a spacing of 100 m in the local Simpevarp area and with a spacing of 1 km further out in the regional Simpevarp area (Figure 3-18). Sediment samples were taken with 1 and 6 metre cores. The information gained during the marine geological survey contains details regarding geology and bathymetry, which can not be printed due to safety reasons. All maps in this report are therefore presented in the scale 1:100,000.

The helicopter borne geophysical survey includes large part of the Simpevarp regional model area. The data gained during that survey includes gamma ray spectrometry, magnetics and EM (electromagnetic) /Triumf et al. 2003/. The information from the EM measurements was used to calculate the relative depth of QD and the distribution of overburden with a low electric resistively (mostly clay).

Vertical Electrical Soundings (VES) was carried out on the ground to support inversion of helicopterborne EM-data /Thunehed and Pitkänen, 2003/. Results from that investigation gives information about the total depth of the overburden at altogether 22 sites (Figure 3-19).

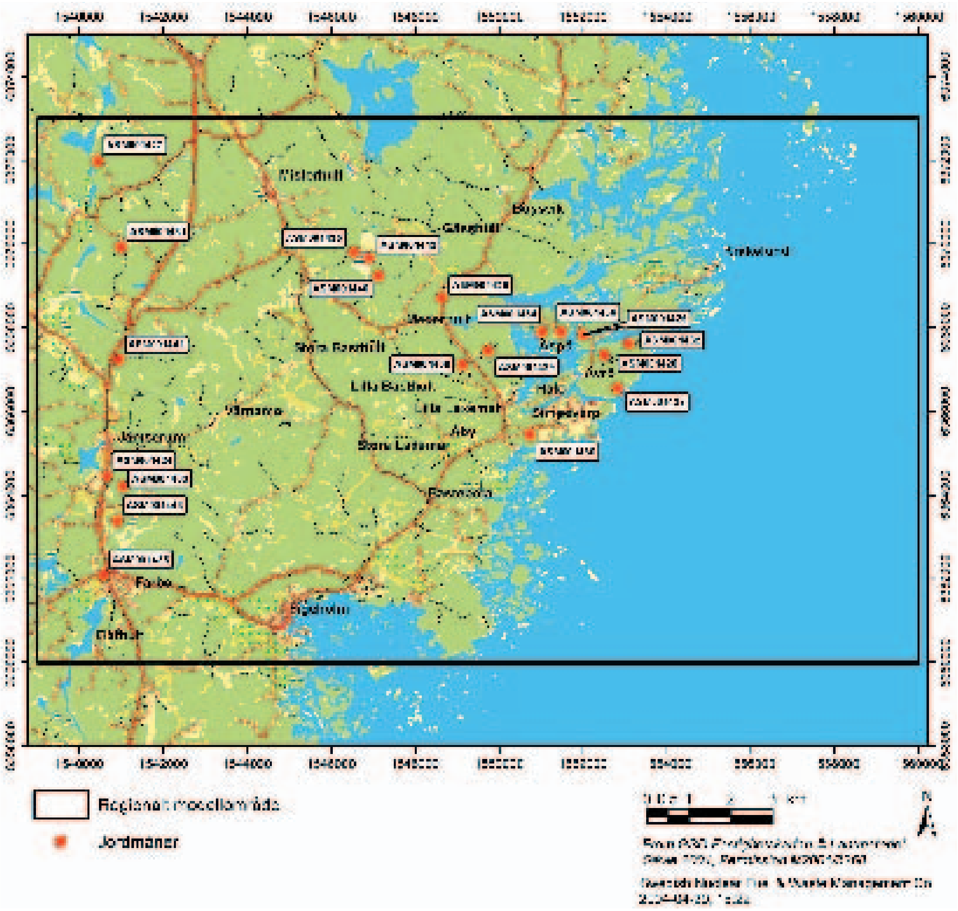


Figure 3-17. *Soil classification was carried out at altogether 20 sites in ten different land types.*

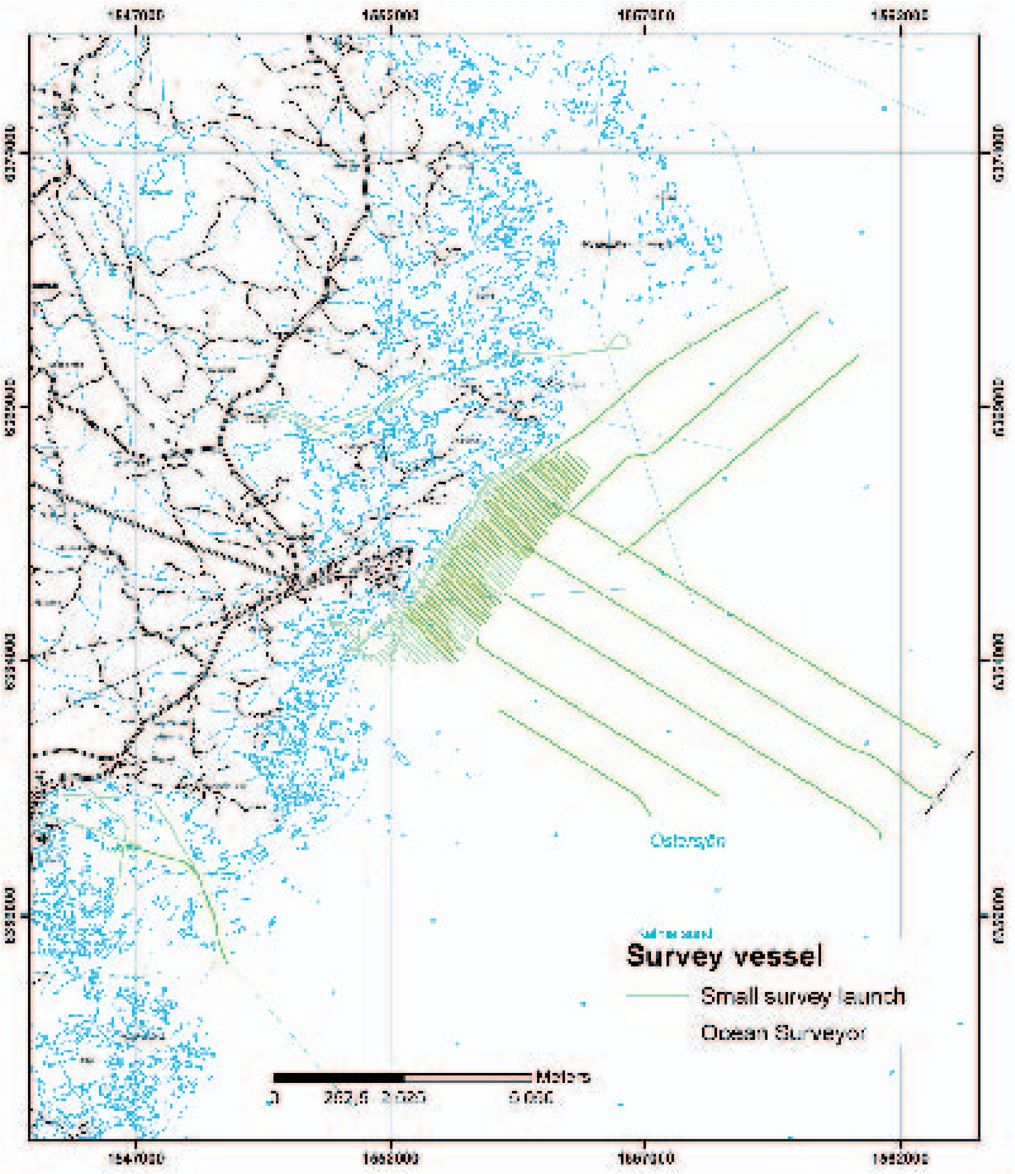


__Figure 3-18.__ The marine geological survey in the Simpevarp regional model area was carried out along the lines shown on the map. The area with dense investigation lines, close to the Simpevarp Peninsula, is referred to as the detailed investigation area, whereas the area further out is referred to as the regional investigation area.

Data available after Laxemar 1.2. The amount of data related to the overburden will increase considerably after Laxemar 1.2, which will include:

- An overview map of the QD in the whole Simpevarp regional model area.
- A Map of QD in the Laxemar river drainage area (scale 1:50,000).
- A detailed map of the QD in the Laxemar subarea (scale 1:10,000).
- More information regarding the total depth and stratigraphy of the QD in the regional model area, with focus on the Laxemar subarea.
- Stratigraphical information of peat and fine-grained sediments in lakes, shallow bays and wetlands.

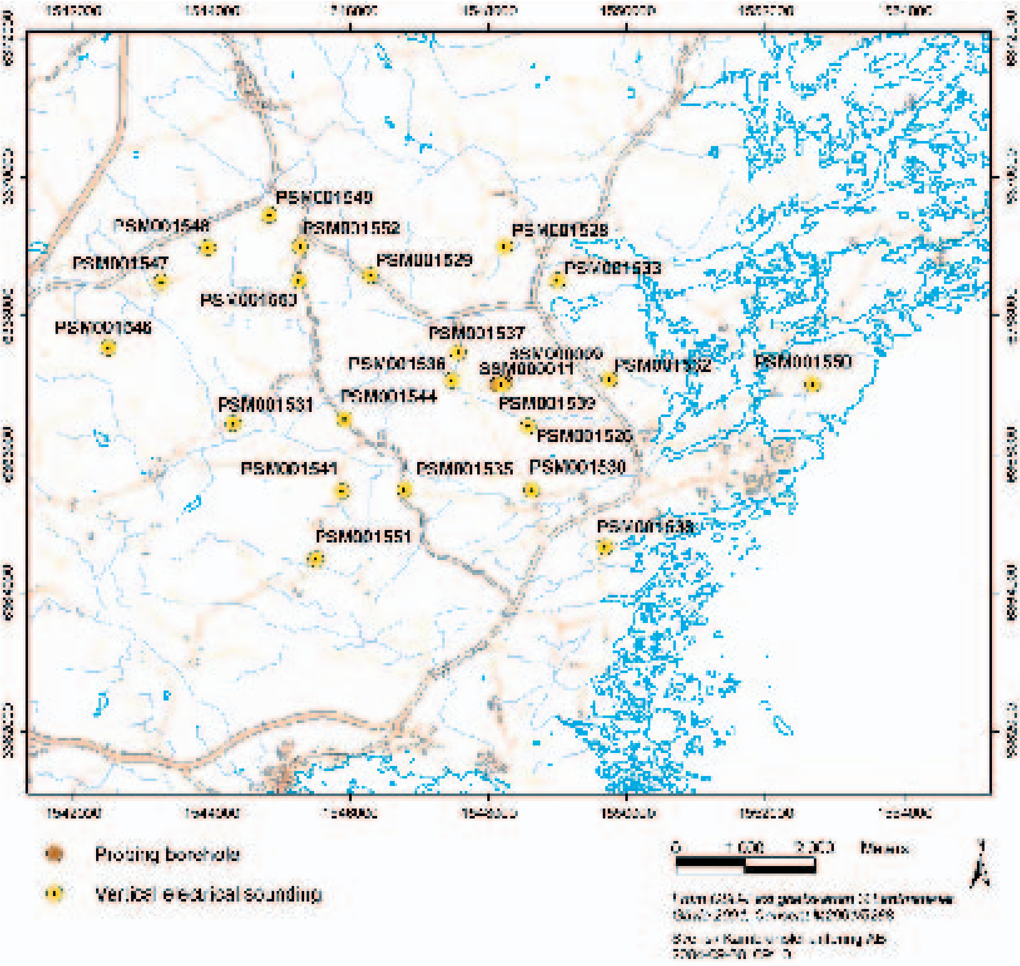


Figure 3-19. The total depth of the overburden in the Simpevarp regional model areas was gained from vertical electrical soundings (VES) and soil/rock drillings (two sites).

3.3.2 Methods for mapping of QD

The mapping of QD in the Simpevarp regional model area started during 2003 and will be finished during 2004. Data from the mapping of the Simpevarp subarea was reported by /Rudmark, 2004/. Results from the largest part of the regional model area will be reported during the autumn 2004 (L1.2). There is, however, an overview map of the QD in the regional model area, interpreted from aerial photos /Bergman et al. 1998/. This map was compared with modern land use maps. The result shows that the map from 1998 has a low geographical accuracy.

In the Simpevarp subarea the uppermost deposits were mapped using a spade and a hand driven probe /Rudmark, 2004/. GPS and aerial photos (infrared photographs taken from an altitude of 2,300 m, scale 1:15,000) were used for orientation. A mirror compass was used to measure the directions of the glacial striae. Before the mapping started, the aerial infrared photographs were interpreted and areas with exposed bedrock were marked (see below).

The different QD were marked directly on the aerial photographs during the field mapping. All QD that could be distinguished from other deposits and have an area larger than 10 by 10 metre were marked on the map as surfaces. The map shows the distribution of QD at a depth of 50 cm. Some surface layers, thinner than 50 cm, are also shown on the map (e.g. peat overlaying other deposits). The surface frequency of boulders is estimated in field and shown on the map.

Exposed bedrock

The distribution of exposed bedrock was interpreted from aerial infrared photos, taken from a height of 2,300 metres /Wiklund, 2002/. The investigation includes the central parts of the Simpevarp regional model area. This interpretation will be checked during the field mapping of QD (L 1.2). The results from the field mapping of QD in the Simpevarp subarea /Rudmark, 2004/ show, however, that there are only small discrepancies between the interpretation of exposed bedrock from aerial photos and the results obtained from the field investigations.

Stratigraphical information

Stratigraphical information was gained from weight sounding and soil/rock drillings /Johansson and Adestam, 2004a/. The soil/rock drillings give information about the stratigraphy and total thickness of QD. The weight soundings do not give information about the total thickness of QD but the results can be used to interpret the stratigraphy of the uppermost, often soft, overburden (e.g. sand clay and silt).

Weight soundings were made in profiles across depressions to gain information regarding spatial variations of the stratigraphy of the uppermost overburden.

During the soil/rock drillings sample of overburden were characterised in the field. The weight soundings give information about the physical properties of the deposits, which was used to identify different types of overburden. Samples were taken at 14 of the soil rock/ drillings locations. Some of these samples will be analysed for grain size composition and $CaCO_3$ content (L 1.2). Some samples will also be used for geochemical analyses, which will be performed to gain information regarding potential ore formations in the area. At thirteen of the drilled sites ground water monitoring wells have been installed, which will be used to sample and monitor the groundwater.

/Rudmark, 2004/ has also studied the stratigraphy during the mapping of QD in the Simpevarp subarea. That information has been gained from boreholes down to a depth of maximum 1.5 meters below the ground surface.

Soils

Soils from 10 different land types (Figure 3-17) were studied within the Simpevarp regional model area. The land types were defined based on vegetation, land use, and wetness. Classifications of soil and QD were carried out in eight spade dug profiles at two sites from each land type. Soil studies at the land type "rock outcrops" reefers to sites, which have a thin cover of overburden and are situated close to rock exposures. Glacial till is the most common Quaternary deposit at these sites.

The aim of the soil classification is to define soils with special properties, which then can be compared with soils from other areas. Samples were taken from the 2–3 uppermost soil horizons. The properties of the QD have a large effect on the soil forming processes. The forthcoming map of QD will therefore be used together with other information (e.g. land use and vegetation) to produce a map of soils in the Simpevarp regional model area.

Geophysical investigations

A helicopter borne geophysical survey was carried out during 2002 /Triumf et al. 2003/, which cover large parts of the Simpevarp regional model area. The geophysical investigations do, however, not include the large glaciofluvial esker in the eastern part of the regional model area.

The helicopter borne investigation includes measurements of gamma ray spectrometry, magnetic and EM (electromagnetic). It was not possible to use the EM measurements, which was carried out close to large power lines. One aim of the investigation was to gain information regarding the conductivity and relative depth of the QD. The magnetic properties were measured to determine bedrock properties and are therefore not used further in the present overburden model.

The gamma ray spectrometry reflects variations in the superficial distribution of K, U and Th /Triumf et al. 2003/. The Simpevarp regional model area constitutes mainly of exposed bedrock and glacial till /Svedmark, 1904; Rudmark, 2004/. The composition of the glacial till reflects that of the bedrock. It has been assumed that variations of the K, U and Th radiation in the Simpevarp area mainly reflect variations related to the bedrock /Triumf et al. 2003/. Some of the variations related to the gamma ray spectrometry have, however, been interpreted as being caused by variations in the composition of the overburden. This will be discussed in a forthcoming report when the results from the mapping of QD in the Simpevarp regional model area are available (after L1.2).

The EM data provides information about the electrical properties of the overburden and the bedrock. The penetration depth of the EM method is between 30 and 200 metres. It can therefore be assumed that these data includes the electrical properties of all the overburden in the area. The EM data were used to calculate the electrical resistivity of the overburden. Low resistivity is often related to areas where the overburden has high water content. Overburden with a high salinity in the pore water does also have a low resistivity. The result from EM measurements can often be used to define areas with high clay content or peat, since these deposits often have high water content. The water content is, however, also dependent on the depth of the groundwater table. The EM data has also been used to calculate the relative thickness of the overburden in areas with overburden thicker than 2.5 meter.

Vertical electrical soundings (VES) were carried out on the ground to gain information about the electrical resistively of the overburden /Thunehed and Pitkänen, 2004/. The purpose of that investigation is to support the EM data achieved from the helicopter born investigation. The results from the VES investigation were used to calculate the total depth of the overburden.

The electrical investigations (EM and VES) give information regarding the total thickness of the overburden. The results can, however, not be used for interpretation of the stratigraphical distribution of the QD.

It has yet not been possible to use the EM data, from the helicopterborne investigation, to calculate the absolute depth of the overburden. The forthcoming investigations (e.g. soil/rock drillings) will give more information about the total depth of overburden in the area. The EM data can then hopefully be useful when constructing a model, which will show the absolute thickness of the overburden in the area, investigated during the helicopter borne investigation.

Marine geological investigations

Surveying in areas with greater water depths than 6 m was made from S/V Oceans Survey, whereas at smaller boat was used at water depths between 3 and 6 m. The survey includes echo sounding, sediment echo sounding, reflection seismic and side scan sonar. Samples were taken to verify the interpretation from the acoustic measurements. Soft bottoms (clay) were sampled with a core and coarser deposits with a grab sampler. The results were used to produce maps showing the distribution and total depths of QD. The distribution of QD is mapped from a depth from approximately 0.5 m below the overburden-water interface (same as on land). Thin surface layers of e.g. sand are, however, also mapped.

3.3.3 Description and conceptual model

The aim of the data evaluation presented here is to construct models of the spatial surface and stratigraphical distribution of the overburden in the Simpevarp regional model area. However, most of the data comes from the Simpevarp subarea.

The overburden includes marine and lacustrine sediment and peat. Knowledge of the composition of the overburden is of crucial importance for the understanding of the hydrological, chemical and biological processes taking place in the uppermost geosphere.

All known overburden in the Simpevarp regional model area was formed during the Quaternary period. In the Simpevarp area the latest deglaciation occurred c. 14,000 years ago. Due to the pressure of the inland ice large parts of Sweden, including the whole Simpevarp regional model area, were covered by water after deglaciation. The highest altitude covered by water in an area is referred to as the highest coastline. The division of QD according to genesis and the environment in which they were formed consists of two main groups: glacial and post-glacial.

Glacial deposits were deposited either directly from the inland ice or from the water, derived from the melting of this ice.

a) The glacial till was deposited directly by the ice. The till is the most common type of Quaternary deposit in Sweden and often contains all grain sizes from clay particles to large boulders.

b) The melt water from the ice deposited the glaciofluvial deposits. These deposits comprise coarse material, often forming eskers but, also clay and silt, which often form flat fields. Compared to the glacial till the glaciofluvial deposits are often well sorted with respect to grain size. The glacial clay and silt were deposited at the deepest bottoms below the highest coastline. The glaciofluvial deposits often overlie the till.

Post-glacial deposits were formed after the inland ice had melted and retreated from an area. Post-glacial sediment and peat form the youngest group of overburden. In general, they overlie till and, locally, glacial clay or crystalline bedrock. The post-glacial deposits are dominated by organic sediment and re-deposited, wave washed clay, sand and gravel. Processes forming post-glacial deposits have continuously been active since the latest deglaciation.

a) The re-deposition of sediment often has a levelling effect on the topography of the post-glacial clay was deposited after erosion and redeposition of some of the previously deposited overburden materials, such as glacial clay. The post-glacial clay can often be found in the deeper parts of valleys below the highest coastline. These clay deposits may contain organic material and is then often referred to as gyttja or gyttja clay.

b) Post-glacial sand and gravel has been deposited by streams and waves, which have altered and reworked glaciofluvial deposits and till as the water depth in the sea successively decreased. The sand and gravel, is subsequently deposited at more sheltered localities.

c) Peat consists of remnants of dead vegetation, which are preserved in areas (often mires) where the prevailing wet conditions preclude the breakdown of the organic material.

There are no evidences of glacial deposits in the Simpevarp regional model area older than the latest glaciation. Older glacial till and fluvial sediment were, however, found during the SGU's mapping of QD in Västervik, c. 40 km north of Simpevarp /Svantesson, 1999/. It can therefore not be excluded that QD, older than the latest glaciations, exist also in the Simpevarp area. The typical stratigraphical distribution of QD in areas below the highest coastline is shown in Figure 3-20. The overburden in the Simpevarp area is probably distributed in a similar way.

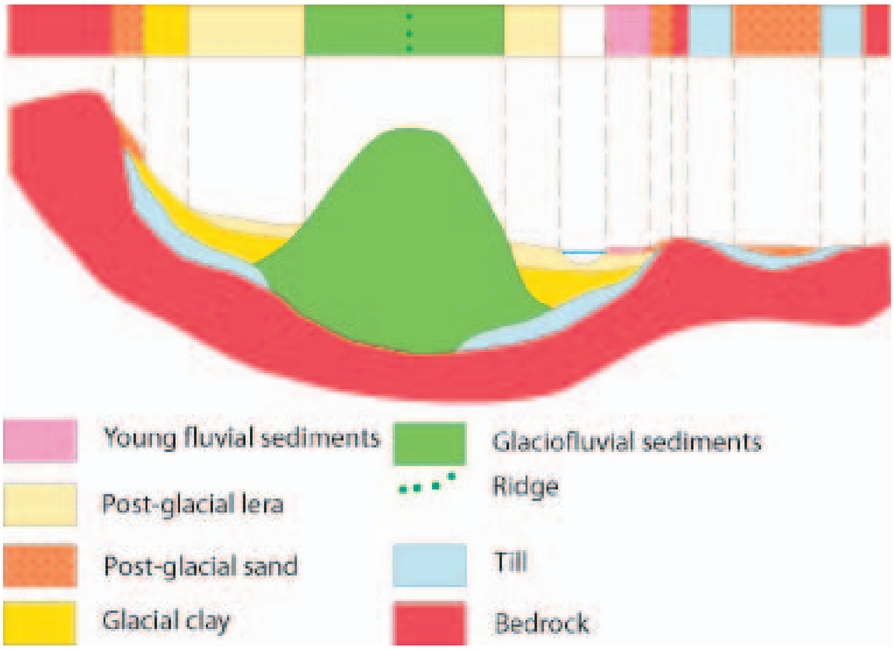


Figure 3-20. The stratigraphical distribution of QD below the highest coastline. It is assumed that the QD in the Simpevarp area have a similar stratigraphy. It is, however, possible that the results from forthcoming drillings and excavations will modify this model.

The bedrock

Large parts of the Simpevarp regional model area constitute of bedrock outcrops. The mineralogical composition of the local bedrock is probably reflected in the nearby composition of the till. The mineralogy of the bedrock is therefore of importance not only for the areas constituting of rock outcrops but also for the soil chemistry in the till. The sensitivity of soil minerals for chemical weathering is of importance for soil pH and concentrations of nutrients available for the plants. A high percentage of easily weathered minerals, e.g. calcite or amphibole, may consequently be favourable for the vegetation.

There is a detailed bedrock map covering the Simpevarp subarea. The density of bedrock information is lower in the Laxemar subarea and the rest of the regional model area. More bedrock data will, however, be available in the future.

The soil

The upper part of the overburden is referred to as the soil. Soils are formed during the interaction of the overburden, climate, hydrology and biota. Different types of soils are characterised by horizons with special chemical and physical properties. It often takes thousands of years for soil horizons to form. The properties of the soils are of crucial importance for the composition and richness of the vegetation. In Sweden the soils have been formed during the period following the latest deglaciation, which is a relatively short period of time for soil formation. The soils in Sweden are therefore relatively young compared to many other parts of the world. Many coastal areas in Sweden have been raised above the sea relatively recently. In such areas to little time has passed for significant soil horizons to form.

The entire Simpevarp regional model area is situated below the highest coastline. At the lowest altitudes the time available for soil forming processes has therefore been short.

In the Simpevarp regional model area the following soils were classified:

1) Histosol: is a soil type formed from materials with a high content of organic matter. The uppermost organic layer is at least 40 cm thick. Histosol is found in areas constituting of peat, which includes both open mires and areas covered by forest.
2) Leptosol: is a soil type present in areas with a thin layer of overburden overlying the bedrock. This soil type is formed at sites with less than 25 cm of overburden upon the bedrock. Leptosol occur at the highest altitudes of the landscape.
3) Gleysol: is a soil type that is periodically saturated with water. This soil type can be found in wetlands, which are not covered by peat but different types of clay (e.g. gyttja clay). The properties of Gleysol are caused by changes between reducing and oxidising conditions.
4) Podzol: is a soil type with low pH, which has a subsurface, often rust coloured, spodic horizon. The spodic horizon is rich in organic matter and amorphous aluminium oxides with or without iron. The spodic horizon is characterised by its dark colour. Podzol is the most common soil in Sweden and is typically found in areas constituting of glaciofluvial sediment or till.
5) Umbrisol: is a soil type, which often develops on arable land. The uppermost horizon is dark and rich in organic material.
6) Cambisol: is a soil type, which is young and fertile, and often develops on fine-grained sediments such as clay.
7) Arenosol: is a soil type, which often is formed on sandy material such as dunes or wave washed sand.
8) Regosol: is a soil type, which develops on coarse-grained material and is characterised by incomplete development of soil horizons. This is due to a short time of exposure to soil forming processes.
9) Unclassified (could be caused by e.g. too much water).

For a more thorough description of the characteristic of the different soil types the readers are referred to WRB, 1998.

Surface distribution of QD

The terrestrial parts of the Simpevarp regional model area

The map of QD presented in /Bergman et al. 1998/ is based upon interpretation of aerial photos and indicates that most of the Simpevarp subarea constitute of exposed bedrock. Also the results from the new interpretation of aerial photos show that large parts the Simpevarp regional model area is dominated by exposed bedrock. The new interpretation indicates, however, that smaller areas constitute bedrock exposures than indicated on the map by /Bergman et al. 1998/. Furthermore, the map by /Svedmark, 1904/ suggests that larger areas comprise till and smaller areas comprise exposed bedrock compared to the map from 1998. Also the information based on the ongoing site investigation shows that QD cover a considerably larger part of the Simpevarp subarea /Rudmark, 2004/.

The map from /Bergman et al. 1998/ is rather coarse but gives some general information regarding the distribution of QD in the Simpevarp regional model area (Figure 3-21):

1) The largest till areas are situated around Fårbo in the south-western corner of the regional model area. The area covered by till is, however, most probably underestimated in other parts of the regional model area /cf. Rudmark, 2004/.

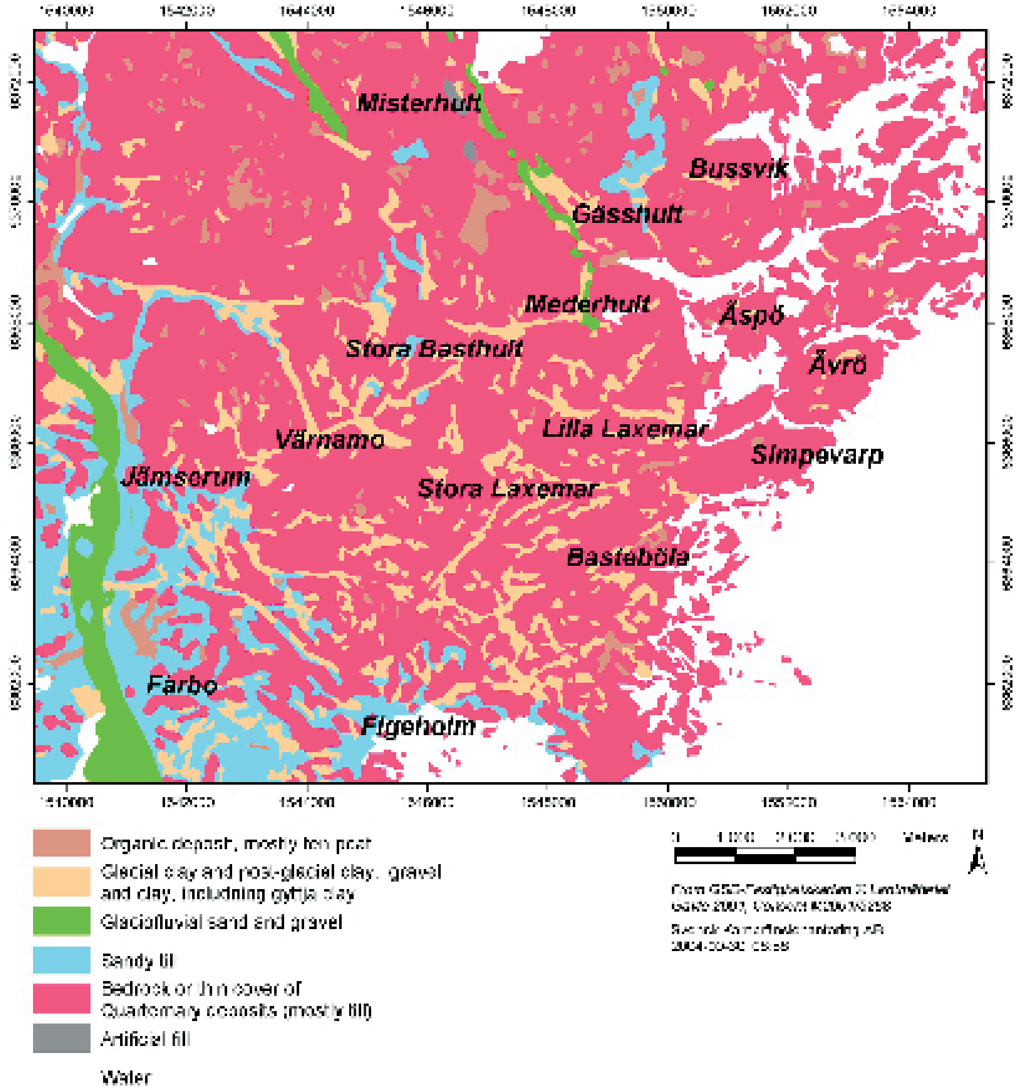


__Figure 3-21.__ The superficial distribution of QD and bedrock exposures in the Simpevarp regional model area /Bergman et al. 1998/. The information shown on the map is entirely based on interpretations from aerial photos.

2) Three glaciofluvial deposits are distinguished on the map. One large glaciofluvial deposits with a north-south direction can be followed from Fårbo. The esker has a north-west south-east direction north of Jämserum. There are two smaller glaciofluvial deposits with a north-west south-east direction in the northern part of the regional model area. One of these deposits has its southernmost extension, west of Lake Frisksjön, in the northern part of the Laxemar subarea.

3) Several of the narrow valleys are covered by fine-grained water laid sediments. The map does not give any information regarding the characteristics of these sediments. There are, however, results from the marine geological investigation (see below), which indicates that gyttja clay is a common sediment type at the floor of many the narrow bays. This is also supported by the results from an investigation of a sediment core from Borholmsfjärden south of Äspö /Risberg, 2002/. Furthermore results presented by /Borg and Paabo, 1984/ have shown that the gyttja layers are several metres thick on two fens situated ca 5 km east of Figeholm. It is likely that the distribution of water laid QD in the Simpevarp regional model area shows similarities with that of surrounding coastal areas. The SGU Ae maps from Västervik and Oskarshamn (scale 1:50,000) /Rudmark, 2000; Svantesson, 1999/ show that the valleys in these areas to a large extent consist of post-glacial clay or gyttja clay. The results from all these older investigations suggest that the valleys in the Simpevarp regional model area to a large extent are covered with gyttja sediments (or post-glacial clay).

The results from the soil investigation (see below) show that many of the wetlands in the Simpevarp regional model area consist of peat.

The results from the helicopter borne EM measurements show areas with a high conductivity (Figure 3-22), which probably to a large extent are associated with areas covered by clay and/or peat. High water content and possibly high salinity of the pore water is the cause of the

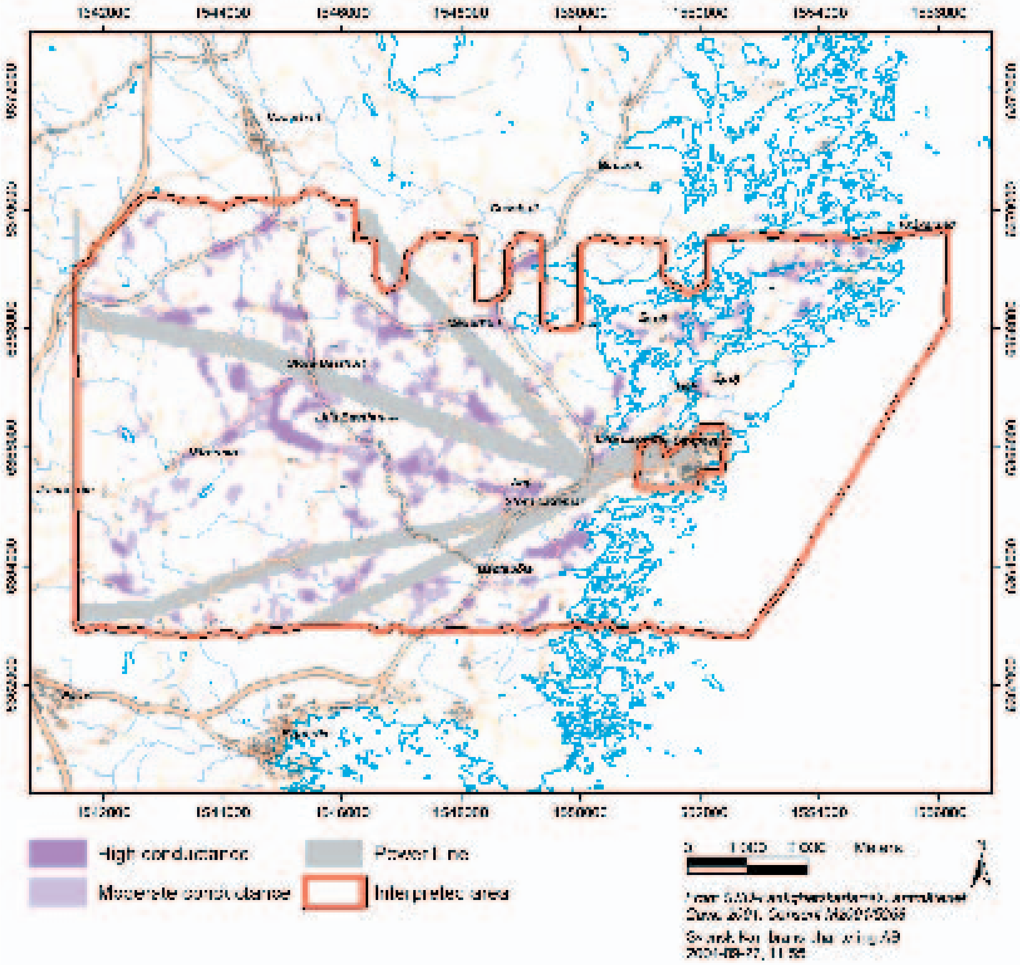


Figure 3-22. Results from the helicopter borne EM measurements. Areas with high electric conductivity are shown on the map. These areas probably constitute of clay and/or peat.

high conductivity of the overburden in these areas. These high conductivity areas correlate with areas, constituting of arable land and open fields. On the map presented in /Bergman et al. 1998/ most of these high conductivity areas are shown as areas constituting of fine-grained water laid sediments, i.e. mostly clay. The conductivity map does only show the largest areas constituting of clay and peat. The map of QD from the Simpevarp subarea (Figure 3-23) shows numerous small clay areas, which are not visibly on the conductivity map.

The conductive deposits are connected to long and narrow valleys. One of the longest valleys has an east- west direction and can be followed between the villages Stora Laxemar and Värnamo, a distance of altogether more than 5 km. Another distinct valley can be followed from Mederhult in the east to the western border of the investigated area.

Large parts the Simpevarp regional model area is dominated by exposed bedrock. These bedrock-dominated areas have probably a similar distribution of QD as that of the Simpevarp subarea /Rudmark, 2004/. It is therefore likely that areas without conductive deposits (clay) or exposed bedrock are dominated by glacial till (Figure 3-24).

It is not possible to conclude, from the geophysics, if the conductive clay was deposited during glacial or post-glacial time. It is, however, suggested in the discussion above that most of the uppermost clay in the valleys was deposited during post-glacial time.

The Simpevarp subarea

The map, which shows the surface distribution of QD /Rudmark, 2004/, is presented in Figure 3-23. The proportional distribution of overburden and exposed bedrock is shown in Table 3-4. For a detailed account of sampling point locations and detailed stratigraphy, reference is made to Figure 3-14 and Table 3-5, respectively.

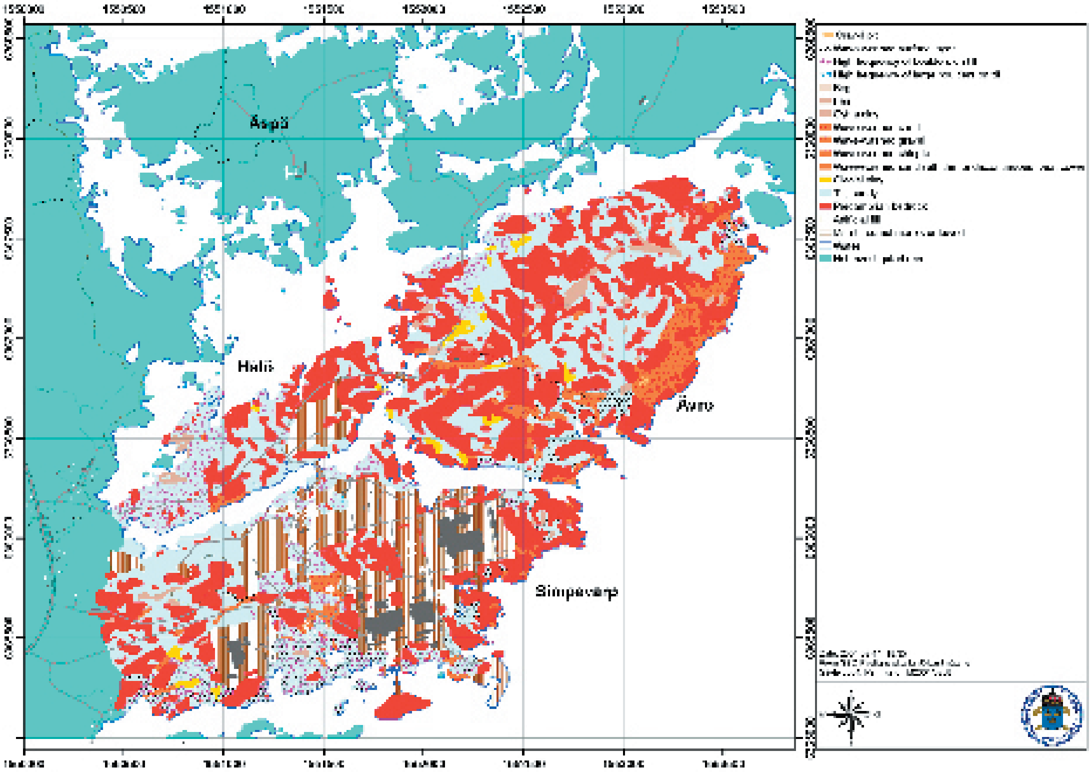


__Figure 3-23.__ The superficial distribution of QD and bedrock exposures in the Simpevarp subarea. Areas with wave washed surface layer and the superficial boulder frequency of the till are also shown. The map has been produced for the scale 1:10,000 and shows deposits with an area larger than 10×10 meters.

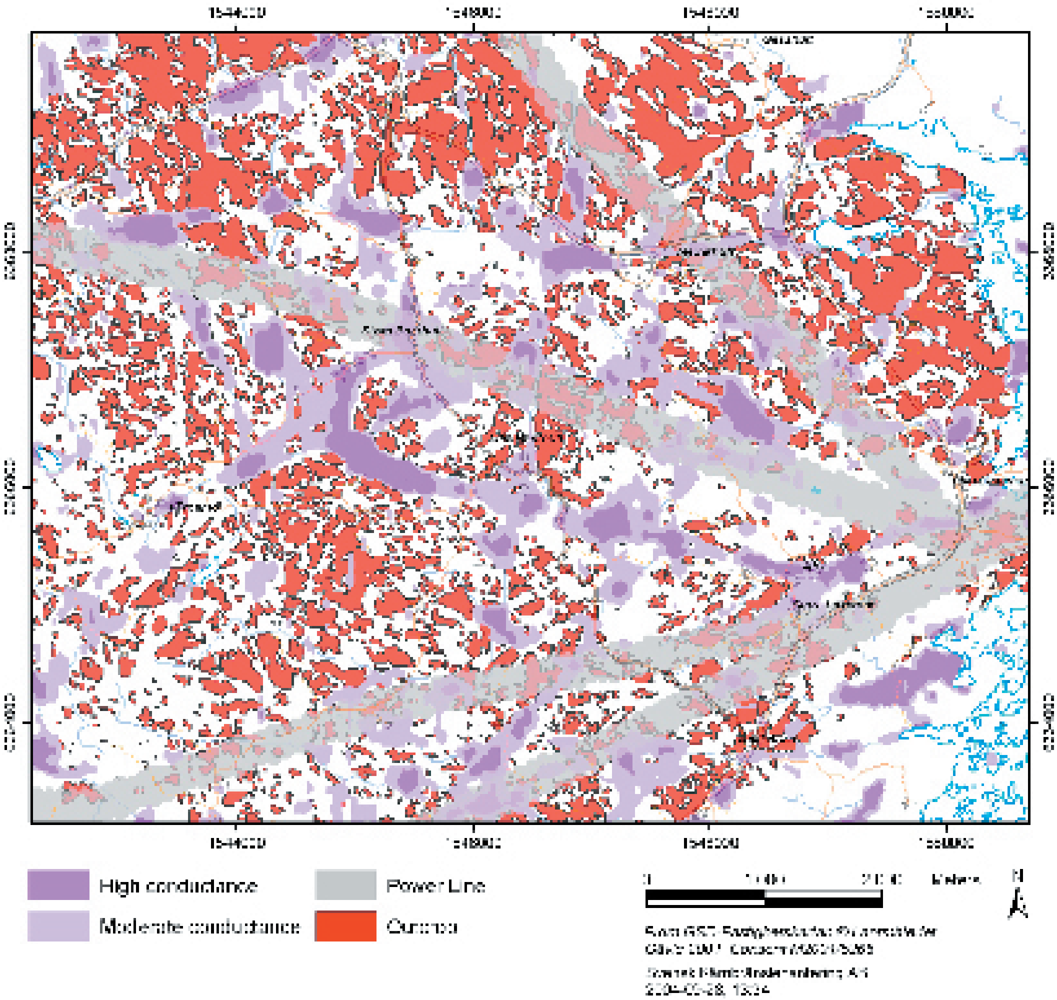


Figure 3-24. The distribution of bedrock exposures, interpreted from aerial photos, and areas with high electric conductivity (mostly clay and peat) in the Laxemar subarea with surroundings. The white areas are probably dominated by glacial till.

Table 3-4. The proportional surface distribution of QD and exposed bedrock in the terrestrial part of the Simpevarp subarea showed in the Figure 3-22.

Quaternary deposit	Coverage (%)
Peat	1.89
Gyttja sediment	0.05
Glacial clay	1.06
Postglacial sand and gravel	5.80
Glacial till	35.04
Man-made fill	17.93
Precambrian bedrock	38.22

The terrestrial part of the Simpevarp subarea is relatively flat, and is dominated by exposed bedrock and glacial till. In some places, there are distinct valleys, which partly are covered with water-laid sediments and/or peat. Glaciers have polished the bedrock surface to a large extent. The glacial striae can be found all over the area but they occur most frequently close to the shoreline. The striae probably reflect ice movement close to the ice margin during ice recession. The dominating ice movement in the area was, according to the striae directions, from N40–50°W. At the northernmost cape of Hålö (PSM002590), a more northerly, probably older, direction (N30°W) was observed.

Till is the dominating Quaternary deposit and covers about 35% of the mapped area (Table 3-4). The morphology of the till normally reflects the morphology of the bedrock surface. The thickness of the till is often between 0.5 and 3 m. In some areas, as on the western part of Hålö, the till may be thicker. The matrix of till is often sandy, but gravelly till was observed in some trenches (PSM002643, PSM002642). It was not possible to separate these two till types in the field. Therefore, all till areas have been shown as sandy till on the map (Figure 3-23).

The boulder frequency in the surface of the till is, in most areas, normal. There are, however, areas with a high boulder frequency, especially on the peninsula of Simpevarp and on the western part of the island of Hålö. There are also a few small areas with a high frequency of large boulders on northern Ävrö. The till is often rich in stones close to the ground surface.

Glacial clay occurs as a cover in many valleys and is often covered by post-glacial sediments, such as sand and gravel (Table 3-5). The thickness of the glacial clay is often approximately 1 metre. Three drillings on Ävrö and one on the Simpevarp peninsula (PSM002660) showed that the total thickness of glacial clay was more than 1.5 m.

Flat areas and small beach ridges consisting of gravel occur in many places in the investigated area, most frequently in the coastal zone on the north-eastern part of Ävrö. There is a well-developed, 200 m long, cobble field north of Korsbergen on Ävrö. There is a gravel pit close to the cobble field, which shows that the thickness of gravel is at least 3 m (PSM002609). Littoral sand is of small extent and occurs in depressions, where it often covers glacial clay.

The mires are divided in two types: bogs and fens. A coherent cover of Sphagnum-species characterises the bogs. There are few, small, not raised, bogs on the northern part of Ävrö. The thickness of the bog peat is about 0.5 m. The bog peat is underlain by fen peat and gyttja (Table 3-5). The fens are characterised by sedges of different species, reed, moisture-seeking herbs etc. The fens are small and are situated in depressions. The largest fen in the investigated area is Örnkärren/Stora mossen. The peat thickness in that particular fen is almost 1 m (PSM002622 and PSM002623).

Around the Oskarshamn nuclear power station the ground has been changed by human activities. These areas were mapped as artificial fill and cover a substantial part, 18% of the total investigated area, cf. Table 3-4. On the island of Hålö, there is a large area with artificial fill, which consists of bedrock material from the excavation of the access tunnel to the Äspö HRL.

It is likely that large parts of the Simpevarp regional model area show a similar distribution of QD as in the Simpevarp subarea. The long and narrow valleys covered by fine-grained water laid sediments are however not present in the terrestrial part of the subarea, where corresponding valleys are covered with water.

The sea floor

The map of QD on the sea floor is presented in Figure 3-25. The proportional distribution of overburden and exposed bedrock is shown in Table 3-6. The geology on the sea floor is similar to the Simpevarp regional and detailed areas. However, the sea floor of the narrow Kärrsvik Bay has a much higher proportion of post-glacial clay (mostly gyttja clay). More than half of the sea floor constitutes of exposed bedrock. Fine-grained, water laid, sediments (sand and clay) are present in narrow valleys which are surrounded by shallower areas dominated by exposed bedrock. The water depth in the valleys is often 15–20 m but the water depth is more than 30 m in certain areas (Figure 3-25). The narrow sediments covered depressions can in some cases be followed for several kilometres.

The areas covered with till is much smaller on the sea floor compared to the terrestrial parts of the Simpevarp subarea (1% compared to 35%). There is, however, no reason to believe that the conditions for deposition of till were less favourable at the present sea floor compared to the present land areas. On land, the layers of till are thin with a surface rich in stones and boulder /cf. Rudmark, 2004/. It is therefore likely that some till areas at the sea floor were interpreted as bedrock exposures with the methods used during the marine geological survey. There are no indications of any glaciofluvial deposits at the sea floor.

Glacial clay is the most common Quaternary deposit on the sea floor (almost 40%) and is often overlaid by a thin layer of sand. In the Simpevarp detailed area the surface of the sand is locally characterised by ripples. The proportion of areas covered with glacial clay is much larger on the sea floor compared to the terrestrial parts of the Simpevarp subarea. It is possible that erosion by waves and streams during the land upheaval have decreased the land areas, which formerly was covered by clay. Some areas of the sea floor are covered thicker layers of sand, which probably often are underlain by glacial clay. The deepest parts of the narrow bays, surrounded by land (e.g. Kärrsvik Bay), are covered with post-glacial gyttja clay. The wave erosion is low in these bays and there is probably accumulation of sediment at these bottoms also today. The depositional environment in the present bays was probably similar to the situation, which occurred when the clay areas on the present land were covered by shallow water.

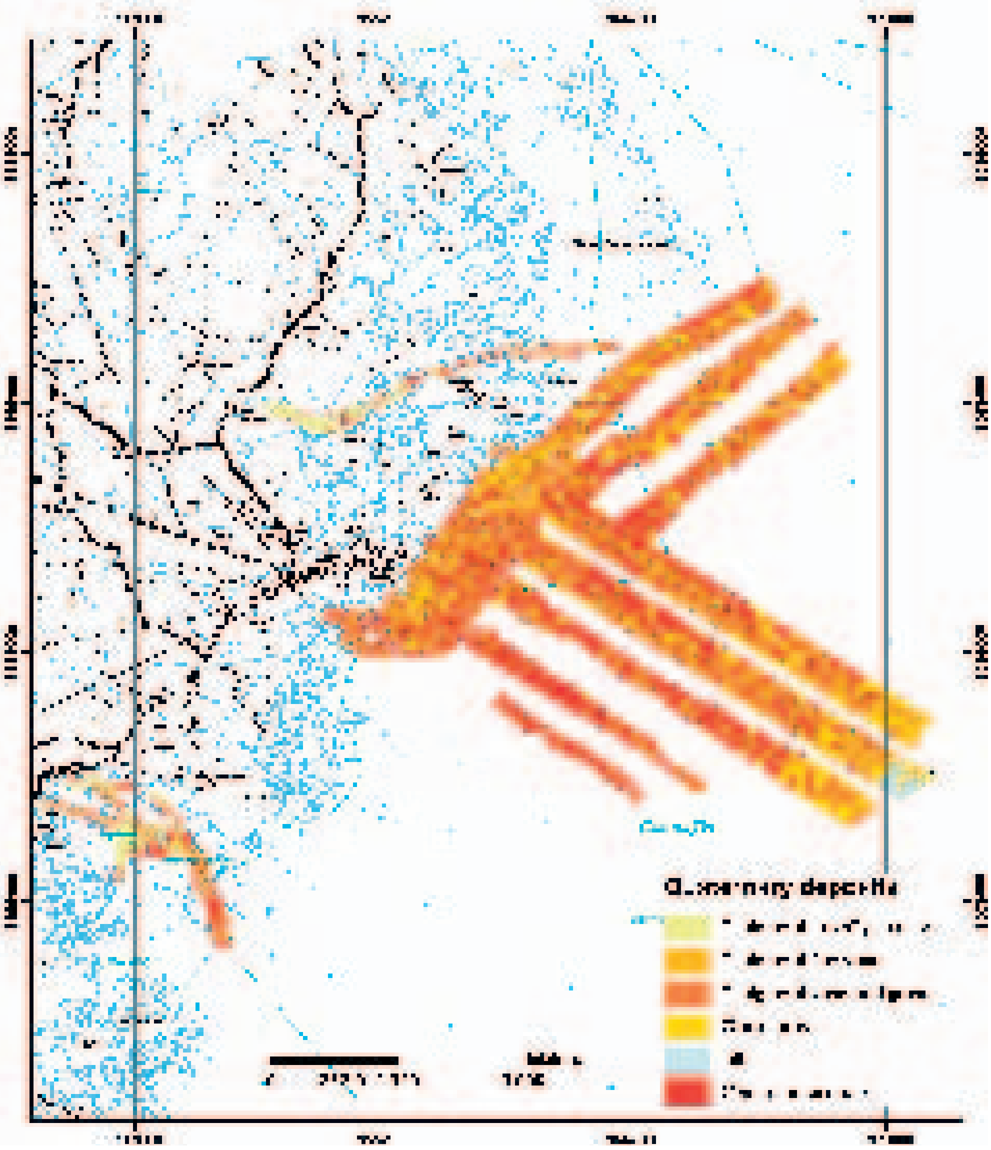


Figure 3-25. *The superficial distribution QD and bedrock exposures on the sea floor.*

Total depth of the overburden

Soil/rock drillings in the Simpevarp subarea

Results from 15 soil drillings and two weight soundings show that the total depth of overburden in the Simpevarp subarea varies between 0.8 and 8.6 metres (Figure 3-27, Table 3-5). The average thickness is 3.6 m. The thickest overburden covers are found in the middle of the depressions, which often conssist of water laid sediments such as clay and gyttja clay. These well-sorted deposits constitute, however, a relative small fraction (c. 7%) of the whole Simpevarp subarea /Rudmark, 2004/. Large parts of the Simpevarp subarea constitute of exposed bedrock (almost 40% of the land area). The results from the soil/rock drillings give information about the maximum thickness of the overburden cover since the drillings mainly were performed in depressions.

Results from two drillings in the Laxemar subarea, SSM000009 and SSM000011, show that the total depths of overburden at these two sites are 2.8 and 4 m respectively (Figure 3-28).

Geophysics in the Simpevarp regional model area

The results from the EM measurements show that the areas with the thickest overburden are more or less restricted to the same areas as the ones constituting of clay (Figures 3-22 and 3-29). These areas are situated in valleys where the environment probably has been favourable for the deposition of thick layers of clay. It is also possible that the glacial till is relatively thick in these valleys (Figure 3-27). Forthcoming, drillings and excavations will give more information about the absolute thickness and stratigraphy of the overburden.

The vertical electrical soundings (VES) give some information regarding the absolute thickness of the overburden. The results from the 22 stations show that the thickness of the overburden varies between 0 and 14.5 m (Figure 3-28). Only five of the investigated stations have an overburden thickness of more than 2 meter. Arable land and areas close to houses were avoided during this investigation. The results from the EM measurements suggest that the thickest overburden, however, is situated in areas used as arable land. It is therefore likely that areas with thick overburden are underrepresented in the VES investigation. One of the VES measurements (PSM001526) is, however, from a valley where the EM results suggest thick quaternary cover. This is also the VES-station, which have the highest recorded thickness of overburden (14.5 m).

Marine geological survey

The areas with the largest depth of QD are found in depressions at the sea floor (Figures 3-26 and 3-30). The total depth of overburden in the deepest parts of these depressions is typically between 5 and 8 m. The total thickness of overburden exceeds, however, 10 m locally and at one place the depth to bedrock was > 15 m. These results give a hint of the overburden depths, which can be expected, in the clay-covered valleys situated in the terrestrial part of the Simpevarp regional model area.

Stratigraphy of the QD

The results from mapping and soil/rock drillings show that the till rests directly upon the bedrock surface. The average thickness of the till, recorded during the soil/rock drillings, is 1.8 m and thickest observed till layer is almost 2.2 m (Table 3-5, SSM000022). Sand and gravel dominate the till in the Simpevarp subarea /Rudmark 2004; Johansson and Adestam, 2004a/. There are, however, observations of boulder clay and clayey till in samples from SSM000015 and SSM000018 respectively /Johansson and Adestam, 2004b/. There is no other reporting of clay rich till in the model area and it can therefore not be excluded that the clay in that till is caused by contamination from overlying clay during the sampling. Forthcoming grain size analyses and studies in machine cut trenches will give more information regarding the composition and stratigraphy of the till.

The till in the valleys is often covered by glacial clay /Rudmark, 2004/. At some places a layer of silt was found in-between the clay and till. A layer of sand and gravel overlies the clay at many sites. A corresponding sand layer, overlying the glacial clay, was observed during the marine geological survey. In the terrestrial part of the Simpevarp subarea the thickest observed clay layer is three meters (SSM000022; Table 3-5). The clay layers are, however, often less than one metre thick. A clay thickness of five meter have, however, been observed in a core from Borholmsfjärden south of Äspö /Risberg, 2002/ and clay layers thicker than six m was observed during the marine geological survey.

The layers of sand and gravel, at the drilled sites, are often a few dm thick and always thinner than one metre. The large gravel deposits on eastern Ävrö have, however, a thickness of at least 3 m /cf. Rudmark, 2004/.

There are no observations of post-glacial clay at any of the sites in the Simpevarp subarea. Post-glacial clay and gyttja has, however been, observed at the sea floor and in terrestrial part of the Simpevarp subarea /Borg and Paabo, 1984/. It is, also, suggested that the narrow valleys in the inland parts of the Simpevarp regional model area consist of post-glacial clay (see above). /Borg and Paabo, 1984/ studied the stratigraphy of fine-grained deposits in the coastal area between Karlskrona and Oskarshamn. The results show that post-glacial sediments underlain by a sand layer and thereunder glacial clay occur widely along the coast. This stratigraphy was also observed in Bornholmsfjärden /cf. Risberg, 2002/ and is probably valid in most of the Simpevarp regional model area.

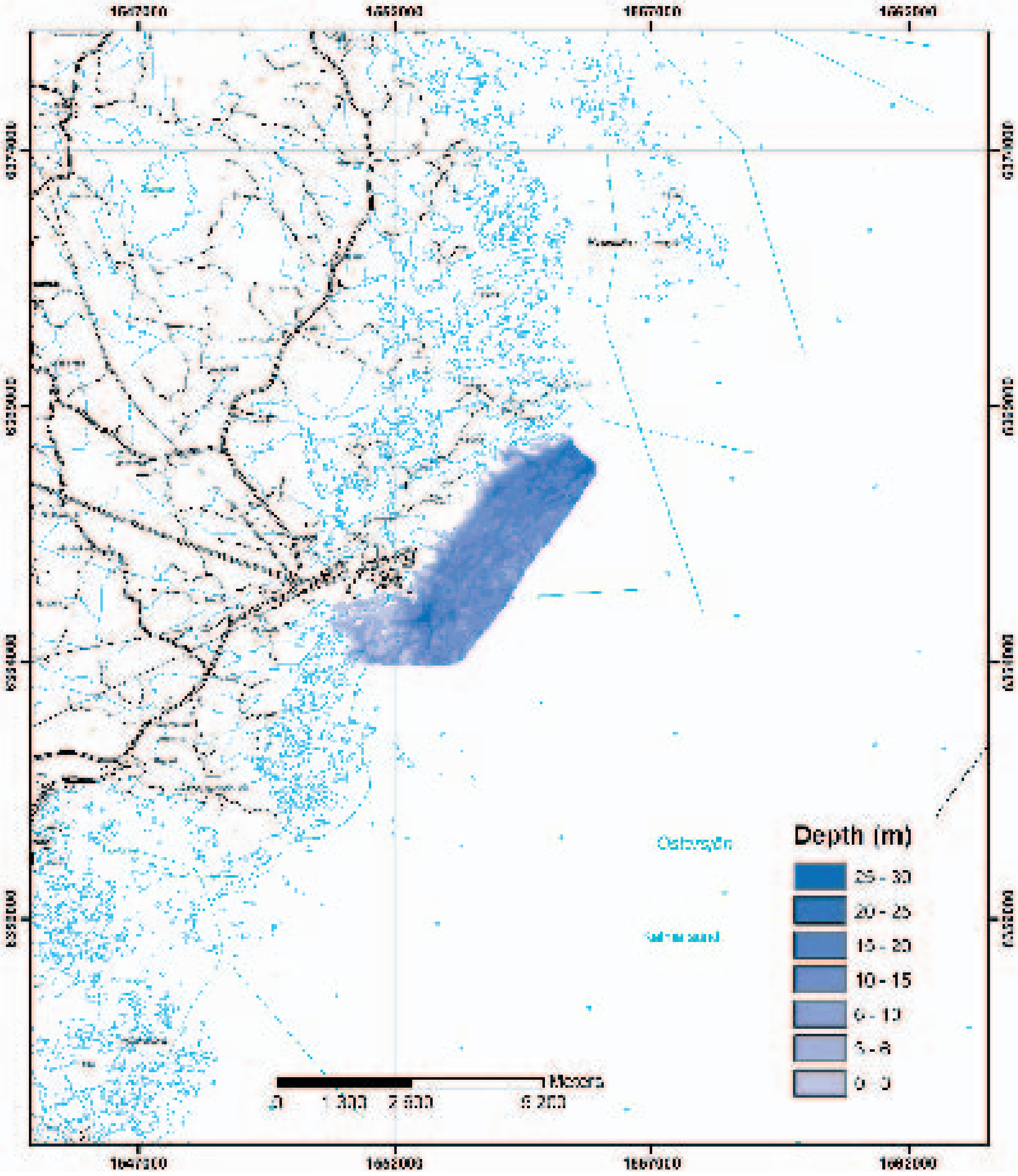


Figure 3-26. *The bathymetry of the sea floor in the detailed investigation area south west of the Simpevarp peninsula and Ävrö.*

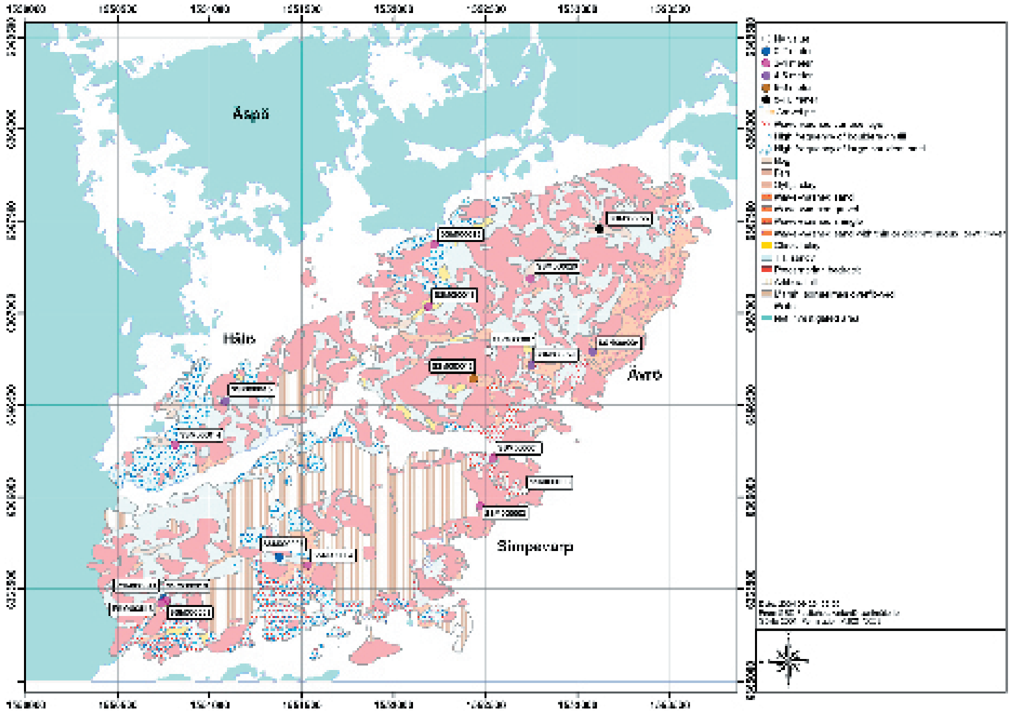


Figure 3-27. The total depth of the overburden gained from soil/rock drillings in the Simpevarp subarea.

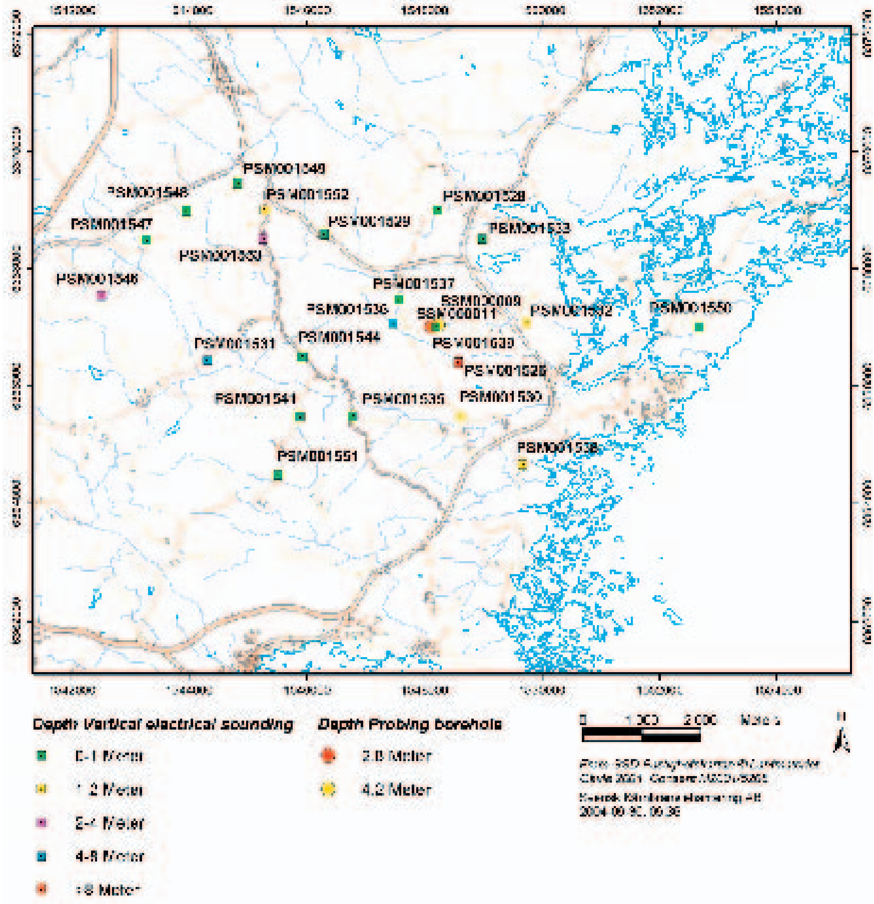


Figure 3-28. The total depth of the overburden gained from VES and soil/rock drillings in the Simpevarp regional model area.

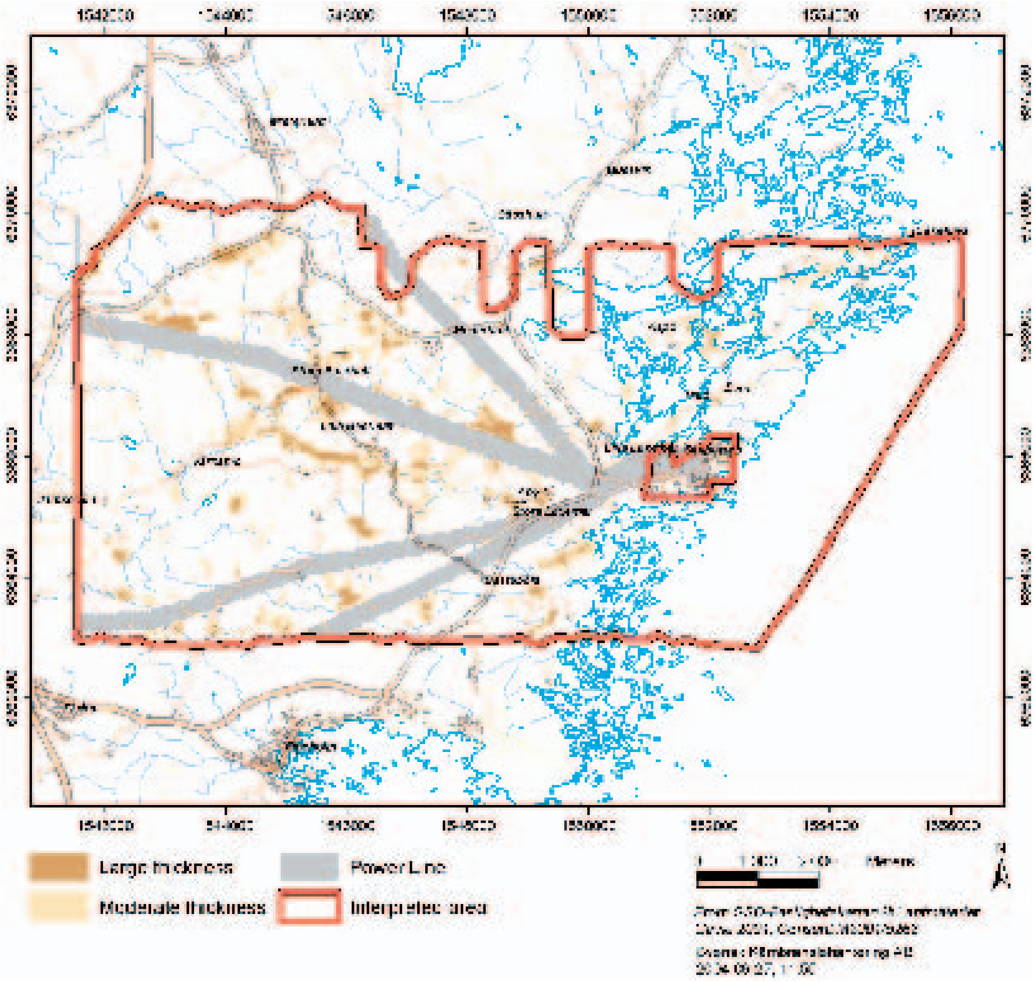


Figure 3-29. Results from the helicopter borne EM measurements. Areas with large and moderate thickness of overburden are shown on the map. These areas coincide with the areas constituting of clay and/or peat.

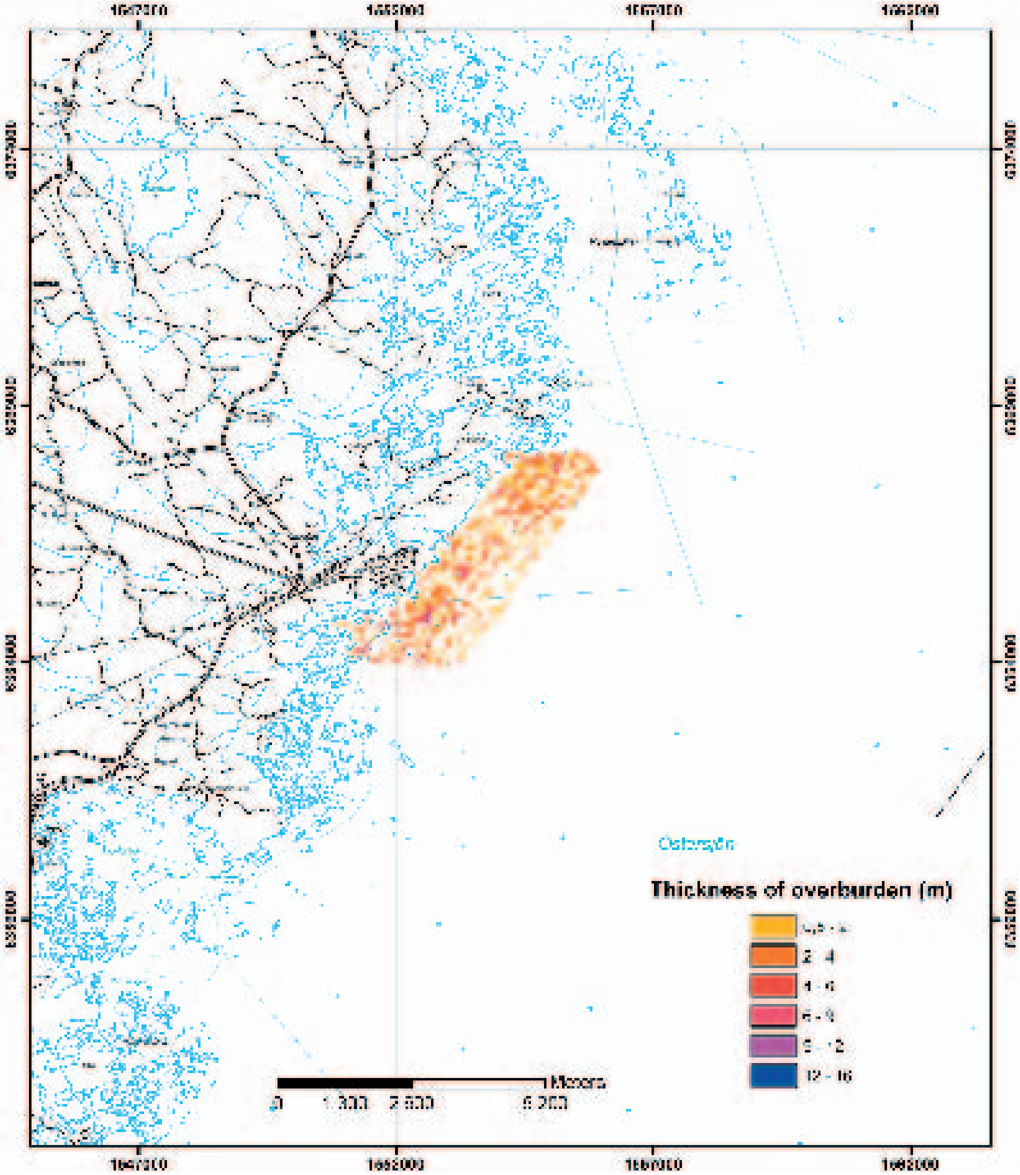


Figure 3-30. *The total thickness of QD (overburden) on the sea floor in the detailed investigation area south west of the Simpevarp peninsula and Ävrö.*

At two of the drilled sites, in the Simpevarp subarea the sand and gravel is covered by peat (SSM000020 and SSM00022). The peat is often thinner than one meter /Rudmark, 2004/ and thickest observed peat layer is 1.5 meter (SSM000022). The wetlands constituting of peat has been ditched. It is therefore likely that drying and oxidation have made the peat coverage thinner.

Table 3-5. Some results from the stratigraphical investigation of Quaternary deposits in terrestrial part of the Simpevarp subarea. The positions of the investigated sites are shown in Figures 3-14, 3-15 and 3-16.

Site	Depth below ground surface (m)	Quaternary deposit	Depth to bedrock (m)	Method
PSM003565	0.0–0.2	Top soil	> 2.4	Weight sounding
	0.2–0.9	Gravelly sand		
	0.9–1.0	Clay		
	1.0–1.2	Clayey, gravelly sand		

Site	Depth below ground surface (m)	Quaternary deposit	Depth to bedrock (m)	Method
	1.2–2.4	Sandy gravelly till		
SSM000022	0.0–1.5	Peat	8.6	Soil/rock drilling
	1.5–1.6	Gravelly sand		
	1.6–4.6	Clay		
	4.6–4.8	Silty clay		
	4.8–7.0	Silty sandy till		
SSM000026	0.0–0.2	Top soil	4.2	Soil/rock drilling
	0.2–0.8	Gravelly sand		
	0.8–1.7	Clay		
	1.7–4.0	Sandy till		
PSM002604	0.0–0.3	Peat	> 1.5	Hand driven probe
	0.3–0.8	Post-glacial sand		
	0.8–1.5	Glacial clay		
PSM002621	0.0–0.5	Bog peat	> 0.8	Hand driven probe
	0.5–0.8	Fen peat		
PSM002622	0.0–0.8	Fen peat	> 1.3	Hand driven probe
	0.8–1.3	Gyttja		
PSM002660	0.0–0.1	Fen peat	> 1.5	Hand driven probe
	0.1–0.2	Post-glacial gravel		
	0.2–1.5	Glacial clay		

Table 3-6. The proportional surface distribution of QD at the sea floor. The stratigraphical information of the distribution of QD has been used as input to the conceptual land model, Figure 3-34.

	Kärrsvik Bay (%)	Simpevarp detailed (%)	Simpevarp regional (%)	Simpevarp total (%)
Precambrian bedrock	19.3	53.5	55	54.8
Glacial clay	3.1	42.4	37.5	38.4
Post-glacial clay (including gyttja clay)	75.7		5.2	4.2
Post-glacial sand and gravel	2.0		0.1	0.1
Post-glacial fine sand		3.4	0.9	1.4
Till		0.6	1.2	1.1
Artificial fill		0.1		0

Bedrock

The Simpevarp subarea mainly constitutes of Ävrö granite, quartz monzodiorite and fine-grained diorite (Figure 3-31). All over the Simpevarp subarea small areas with diorite to gabbro occur. Also in the Laxemar subarea the bedrock distribution seems to be dominated by granite and diorites with small areas constituting of diorite to gabbro. This last bedrock type has a higher content of easily weathered amphibole compared to the other bedrock types. It is therefore possible that the areas with diorite to gabbro have locally different soil chemistry (e.g. higher nutrient availability), which may have resulted in richer vegetation in these areas.

The possible relation between soil chemistry, vegetation and local bedrock composition, in the Simpevarp regional model area, has not yet been studied.

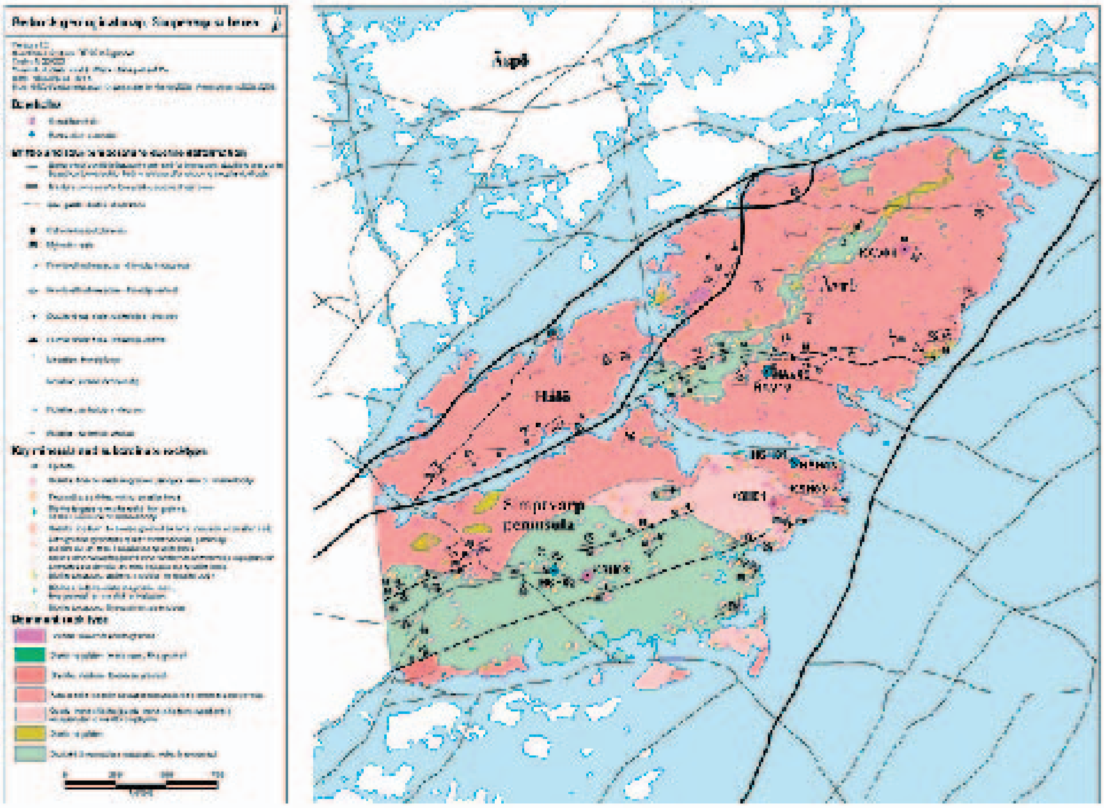


Figure 3-31. *Bedrock map of the Simpevarp subarea.*

Soils

The results from the soil classification are summarised in Table 3-7a. The glacial till and glaciofluvial esker are dominated by podzol and regosol. The land type referred to as rock outcrops are situated close to "real" outcrops and consist of thin layers of overburden. These sites are dominated by glacial till where podzol or regosol are the most common soil types. Umbrisol and gleysol dominate the fine-grained water laid sediments, which are used as arable land or meadows. Histosol is the most common soil type in the wetlands, which shows that many of the wetlands in the area are covered by peat.

Table 3-7a. Results from the classification of land types, QD and soil types in the Simpevarp regional model area.

Site	Land type	Quaternary deposit	Soil type Swedish system	Soil type International
ASM001424	Glaciofluvial deposit (esker)	Sand.	Järnpodsol	Podzol
ASM001425	Glaciofluvial deposit (esker)	Gravel and sand.	Järnpodsol	Podzol
ASM001426	Deciduous forest	Till dominated by gravel and sand.	Brunjord	Umbrisol (4)/ Regosol (4)
ASM001427	Deciduous forest	Till (silty).	Brunjord	Umbrisol (3)/ Regosol (5)
ASM001428	Rock outcrops	Till (4) and rock outcrops (4) (shingle and gravel dominates).	Järnpodsol (3) i morän	Podzol (3) on till Regosol
ASM001429	Rock outcrops	Till (7) sand dominates.	Övergångstyp (3)/ Järnpodsol (4)	Podzol (2)/ Regosol (5)
ASM001430	Meadow	Low sorted sediment, silt-fine sand.	Kulturjordmån	Gleysol (1)/ Umbrisol(7)
ASM001431	Meadow	Well sorted clay.	Kulturjordmån	Umbrisol

Site	Land type	Quaternary deposit	Soil type Swedish system	Soil type International
ASM001432	Small wetlands surrounded by exposed bedrock	Peat.	Sumpjordmån	Histosol
ASM001433	Small wetlands surrounded by exposed bedrock	Peat.	Sumpjordmån	Histosol
ASM001434	Wetlands covered by forest	Peat.	Sumpjordmån	Histosol
ASM001435	Wetlands covered by forest	Peat (6) and clay (2).	Sumpjordmån	Histosol
ASM001436	Shore	Peat.	Sumpjordmån	Histosol
ASM001437	Shore	Well sorted sand.	Ej B-horisont på grund av grov jordart	Regosol (6)/ Arenosol (2)
ASM001438	Arable land	Well sorted sediment, clay.	Kulturjordmån	Gleysol (5)/ Umbrisol (3)
ASM001439	Arable land	Well sorted sediment, clay.	Kulturjordmån	Umbrisol
ASM001440	Spruce forest	Clay (4) and peat (4).	Sumpjordmån	Histosol (7)/ Regosol (1)
ASM001441	Spruce forest	Peat.	Sumpjordmån	Histosol
ASM001442	Wetlands	Peat (6) and clay (2).	Sumpjordmån	Histosol
ASM001443	Wetlands	Peat.	Sumpjordmån	Histosol

3.3.4 Quantitative model

The surface distribution and stratigraphy of QD

All known QD in the Simpevarp region, were probably formed during the latest glaciation and after the latest deglaciation, which in the Simpevarp area occurred c. 14,000 years ago. The oldest QD are therefore of glacial origin and have been deposited either directly by the ice or by water from the melting ice. The whole model area is located below the highest coastline and fine-grained water laid glacial and post-glacial sediments have been deposited in sheltered positions. In more exposed positions the overburden has partly been eroded and redeposited by waves and streams when the water depth became shallower, as a consequence of the isostatic land uplift. The Simpevarp regional model area, in its present state, is a relatively flat area with a coastline well exposed to the Baltic Sea. Isostatic land uplift is still an active process and other coastal processes are continuously changing the properties and distribution of the overburden. Accumulation of gyttja clay is an ongoing process in the present narrow bays along the coast.

The glacial striae indicate a dominant ice movement from N40–50°W. This direction probably reflects ice movement shortly before the latest deglaciation. Some striae indicate an older more northerly ice flow direction from N30°W. The same or similar directions of ice flows have been recorded in Västervik and Oskarshamn /Svantesson, 1999; Rudmark, 2000/, which indicates a regional significance of the north-westerly ice flow direction.

The surface distribution of QD in the terrestrial parts of the Simpevarp subarea and Simpevarp regional model area are shown in Figures 3-23 and 3-21, respectively. The distribution of overburden on the sea floor is shown in Figure 3-25. A relatively large part of the Simpevarp regional model area comprises exposed bedrock. The areas situated at the highest altitudes are entirely composed of exposed bedrock. There are probably several reasons for the relatively low coverage of QD. One reason may be that a relatively small amount of glacial till was deposited in the area during the latest ice age. Another reason is the fact that large parts of the investigated area are exposed towards the open Baltic Sea. That has caused, and is still causing, erosion and redeposition of overburden by waves and streams. The map of QD in the regional model area indicates, however, that there is a more coherent till coverage in the south-western and western part of the model area.

The glacial till is the oldest known component of the overburden in the area and was deposited directly by the Quaternary glaciers. It may be assumed, but not concluded, that most of the till in the regional model area was deposited during the latest glaciation and rests directly on the bedrock surface. Till is the dominant Quaternary deposit and covers about 35% of the Simpevarp subarea (cf. Table 3-4). The morphology of the till in the subarea normally reflects the morphology of the bedrock surface. The thickness of the till varies between 0.5 and 4 m. Most of the till has a sandy matrix, but gravelly till does also occur. The areas covered by till are most probably underestimated on the maps showing the distribution of overburden in terrestrial and marine parts of the Simpevarp regional model area.

Glaciofluvial deposits are restricted to the western and northern parts of the regional model area. These deposits may have hydrological importance and will be a focus for studies during the forthcoming investigations. Special focus must be put on studying the properties and extension of the glaciofluvial deposit found in the northern part of the Laxemar subarea.

Directly after the deglaciation the water depth was c. 100 metres deeper than at present /cf. Agrell, 1976/. The melt water from the receding ice contained large amounts of suspended material, which were deposited as glacial clay on the deepest parts of the sea floor. Post-glacial clay was and still is successively deposited during the land upheaval. There is only one such known deposit with post-glacial clay (gyttja clay) within the Simpevarp subarea. Post-glacial gyttja sediments seems, however, to be a common deposit in the present bays along the coast and in the narrow valleys found in the inner parts of the Simpevarp regional model area.

Streams and waves have further altered and reworked the glaciofluvial deposits and the till as the water depth in the sea successively decreased. In wave-exposed positions, the fine-grained fractions have, therefore, often been washed out from the uppermost sequence of the deposits, which then has a stony and/or gravelly surface layer. The material eroded from the older deposits, e.g. sand and gravel, is subsequently deposited at more sheltered localities. Such deposits of sand and gravel are often covering the glacial clay within the investigated area (cf. Table 3-5). The marine geological map shows that the glacial clay is covered by sand also at deep bottoms, which indicates high capacity of streams also at large water depths (20–30 m).

Peat covers c. 2% of the Simpevarp subarea and is restricted to some of the narrow valleys. The peat is often found in mires, which are divided in two types: bogs and fens. The bogs are poorer in nutrients compared with the fens and are characterised by a coherent cover of Sphagnum species. Fen peat is the most common peat type in the Simpevarp subarea. There are, however, a number of small, not raised, bogs. The bog peat is often underlain by fen peat and a natural succession is that the areas present covered by fen peat in the future will be covered by bog peat. Results from the soil investigation shows that several wetlands in the rest of the Simpevarp regional model area consist of peat.

The results from the marine geological investigation show that the thickest overburden cover is restricted to long narrow valleys. This is further supported by results from soil/drillings in the Simpevarp subarea and geophysical investigation in the regional model area. The total thickness of overburden is often less than 10 metres in the valleys. The overburden cover in the higher topographical areas, characterised by numerous bedrock exposures, is probably one or a few metre thick. Further drillings, excavations and geophysical investigations will give more information regarding the thickness of overburden, especially in the Laxemar subarea.

Most stratigraphical information is at present concentrated to the Simpevarp subarea (Table 3-7b). A general tentative stratigraphy for the whole regional model area has, however, been constructed (Table 3-9). This stratigraphy is based on results from the marine geological survey and older stratigraphical investigations in the Simpevarp regional model area /e.g. Borg and Paabo, 1984; Risberg, 2002/ and its surroundings /e.g. Svantesson, 1999; Rudmark, 2000/. This stratigraphy may need modifications in the future, e.g. if QD older than the latest deglaciation are found. The glaciofluvial sediments have not yet been included in this stratigraphy due to the lack of information.

Table 3-7b. The stratigraphical distribution of Quaternary deposits in the Simpevarp regional model area.

Bog peat	Youngest
Fen peat	↑
Gyttja clay/clay gyttja	
Sand/gravel	↑
Glacial clay	
Till	↑
Bedrock	Oldest
Bog peat	Youngest

In Simpevarp, two main type areas, with QD can be distinguished based on the present knowledge. These two areas occur both on the present land and at the sea floor.

1) The highest topographic areas, which are dominated by exposed bedrock and till. Results from the Simpevarp subarea show that small peatlands are common in these areas. The overburden in these areas is generally one or a few metres thick. It is possible that small pockets with thicker overburden occur.
2) Narrow valleys dominated by clay, which is underlain by till. The total thickness of QD is several meters in this area.

The distribution of QD is mainly an effect of the local bedrock morphology. The highest areas have been subjected to erosion from waves and streams. Periods with erosion have occurred also in the lowest areas but it is evident that long periods with deposition of fine grained material have taken place in these areas. The processes of erosion and deposition are still active along the present coast and at the sea floor.

It will probably be possible to define more type areas when more data is available. One important aim will be to describe and delineate the glaciofluvial deposits, which may have a large hydrological importance.

Soils

The Simpevarp regional model area has successively been raised above the sea level due to the post-glacial land upheaval (see Figures in Section 3.1). The lowest investigated sites are situated more than one meter above the present sea level and have consequently been exposed to soil forming processes for at least thousand years.

The forthcoming soil map will give information regarding the relative distribution of the different soil types. It is, however, possible to make some preliminary suggestions regarding the distribution of soil types. Till is the most common Quaternary deposit in the Simpevarp regional model area /Svedmark, 1904; Rudmark, 2004/. Podzol and regosol are the most common soil types in areas covered by glacial till (Table 3-7a) it is therefore likely that these soil types also are the most common soil types in the whole Simpevarp regional model area. Regosol and podzol are also common in areas with coarse-grained glaciofluvial material.

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 (Table 3-7a). This soil type is probably common also in ditched wetlands. Land used as arable land and meadows seem to be dominated by gleysol and umbrisol. Gleysol is typically formed in areas with gyttja sediments, which seems to be common in the inner parts of the Simpevarp.

3.4 Climate, surface hydrology and near-surface hydrogeology

3.4.1 Background and general objectives

This section describes the modelling of climate, surface hydrology and near-surface hydrogeology in support of the Simpevarp 1.2 model. The methodology, primary data and results of the modelling are presented in a background report /Werner et al. 2005/. 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 report /SKB, 2004a/. The objectives of the modelling reported in this section 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 provide an overview of the site and to support the ecological systems modelling,
- summarize 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. 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. 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.

The methodology for the descriptive modelling of surface water hydrology and hydrogeology in the overburden was presented in the modelling strategy report for hydrogeology /Rhén et al. 2003/. The strategy report describes the input data, the modelling process and the resulting descriptive model, based on a systems approach in which the descriptive model of the surface and near-surface system is presented as a set of Hydraulic Soil Domains (HSD). The 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 groundwater flow 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. Therefore, the basic information required for developing this type of models is also provided, see /Werner et al. 2005/ for details.

3.4.2 Investigations and available data

Previous investigations

The site descriptive models (SDM) version 0 /SKB, 2002/ and version 1.1 /SKB, 2004a/ of the Simpevarp area 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 site descriptive model after S1.2, Laxemar 1.2, will be abbreviated L1.2.

The S0 model /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 (QD). In addition, 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.

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 one 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 below.

Other investigations contributing to the modelling

In addition to the investigations listed in above, the modelling in S1.2 was 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 QD.
- Data on the hydrogeological properties of the bedrock.

Summary of available data

Table 3-8 gives references to site investigations and other reports that contain meteorological, hydrological and hydrogeological data used in the S1.2 modelling. Table 3-9 provides the corresponding information with respect to other disciplines or types of investigations. Table 3-10 specifies the SKB-reports referred to in Table 3-8 and Table 3-9.

Table 3-8. Available meteorological, hydrological and hydrogeological data and their handling in S1.2.

Available site data Data specification	Ref	Usage in S1.2 analysis/modelling	Not utilised in S1.2 arguments/comments
Meteorological data			
Regional version 0 data			
Summary of precipitation, temperature, wind, humidity and global radiation up to the year 2000.	TR-02-03 R-99-70 SICADA	Basis for general description and quantitative modelling of surface water and near-surface groundwater flow.	
Site Investigation data			
Precipitation, temperature, wind, humidity, global radiation and potential evaporation Oct 2003–Sept 2004 from meteorological station on Äspö.	SICADA	Comparison with regional meteorological data.	
Hydrological data			
Regional version 0 data			
Regional discharge data.	TR-02-03 R-99-70	Characteristics of catchment areas. Specific runoff in GIS-based flow models.	
Site Investigation data			
Investigation of potential locations for discharge stations.	P-03-04		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 characterisation of catchment areas and lakes.	
Simple discharge measurements in water courses, lakes and the sea.	P-04-13 P-04-75 SICADA	General description of temporal variability in groundwater and surface water flow.	
Hydrogeological data			
Inventory of private wells.	P-03-05	Description of available hydrogeological information.	No attempt is made to infer hydraulic parameters from drilling data.
Manually measured groundwater levels.	SICADA	Basis for identifying depth of unsaturated zone.	
Data on installed groundwater monitoring wells.	P-03-80 P-04-46 P-04-121	General description and evaluation of hydraulic properties.	
Hydraulic conductivity of QD.	P-04-122 SICADA	Basis for assigning hydraulic conductivity of QD in descriptive and numerical models.	

Table 3-9. Input data from other disciplines and their handling in S1.2.

Available site data Data specification	Ref	Usage in S1.2 analysis/modelling	Not utilised in S1.2 arguments/comments
Topographical and other geometrical data			
Digital Elevation Model (DEM)	P-04-03 SICADA	Flow modelling (ArcGIS and MIKE SHE).	
Surface-based geological data			
Soil type investigation	P-04-243	Flow modelling (MIKE SHE).	
Geological mapping of QD	P-04-22	Basis for defining HSD (Hydraulic Soil Domains) in the Simpevarp subarea Flow modelling (MIKE SHE).	
Airborne geophysical data	P-03-17 P-03-100 SICADA	Basis for defining HSD (Hydraulic Soil Domains) in the Laxemar subarea.	

Available site data Data specification	Ref	Usage in S1.2 analysis/modelling	Not utilised in S1.2 arguments/comments
Geological data from boreholes			
Drilling and sampling in QD	P-03-80 P-04-46 P-04-121	Stratigraphical information in the Simpevarp subarea – used as input to descriptive and quantitative modelling.	
Hydrogeological properties of the rock			
Modelled hydraulic conductivity and pressure distributions in the upper part of the rock – DarcyTools Simpevarp 1.1	R-04-65	Flow modelling (MIKE SHE) – parametrisation and identification of boundary conditions.	
Vegetation data			
Vegetation map	P-03-83 SICADA	Flow modelling (MIKE SHE) – parametrisation for evapo-transpiration and unsaturated flow calculations.	

Table 3-10. Reports in the SKB P, R and TR series that are referred to in Tables 3-8 and 3-9.

P-03-04	**Lärke A, Hillgren R.** Rekognocering av mätplatser för ythydrologiska mätningar i Simpevarpsområdet.
P-03-05	**Morosini M och Hultgren H.** Inventering av privata brunnar i Simpevarpsområdet, 2001–2002.
P-03-17	**Thunehed H, Pitkänen T.** Simpevarp site investigation. Electrical soundings supporting inversion of helicopterborne EM-data. Primary data and interpretation report.
P-03-80	**Ask H.** Oskarshamn site investigation. Installation of four monitoring wells, SSM000001, SSM000002, SSM000004 and SSM000005 in the Simpevarp subarea.
P-03-83	**Boresjö Bronge L, Wester K.** Vegetation mapping with satellite data 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 QD 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, SSM 000006 and SSM 000007 in the Simpevarp subarea.
P-04-75	**Ericsson U, Engdahl A.** Oskarshamn site investigation. Surface water sampling in Oskarshamn – Subreport October 2003 to February 2004.
P-04-121	**Johansson T, Adestam L.** Oskarshamn site investigation. Drilling and sampling in soil. Installation of groundwater monitoring wells.
P-04-122	**Johansson T, Adestam L.** Oskarshamn site investigation. Slug tests in groundwater monitoring wells in soil in the Simpevarp area.
P-04-242	**Brunberg A-K, Carlsson T, Brydsten L, Strömgren M.** Oskarshamn site investigation. Identification of catchments, lake-related drainage parameters and lake habitats.
P-04-243	**Lundin L, Björkvald L, Hansson J, Stendahl J.** Oskarshamn site investigation. Surveillance of soils and site types in the Oskarshamn area.
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, Berglund S, Svensson U.** 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.

3.4.3 Description of primary data

This section provides a brief description of the primary data used in the S1.2 modelling. For a detailed presentation and evaluation of the primary data, the reader is referred to /Werner et al. 2005/.

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 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 in 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 metres above ground level, and air temperature, humidity, precipitation, global radiation and air pressure at 2 m.a.g.l. 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.

Hydrological data

The delineation of catchment areas and the description of size and land use of the catchments 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 /Brunberg et al. 2004/, see Figure 3-32. The relative areas of different types of wetlands have been calculated for each of the identified catchments. 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.

Hydrogeological data

Hydrogeological properties

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

In the S1.2 data freeze, results from so-called slug tests was 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 are to provide estimates of the hydraulic conductivity (K) of the QD and/or the soil/rock interface /Johansson and Adestam, 2004b/.

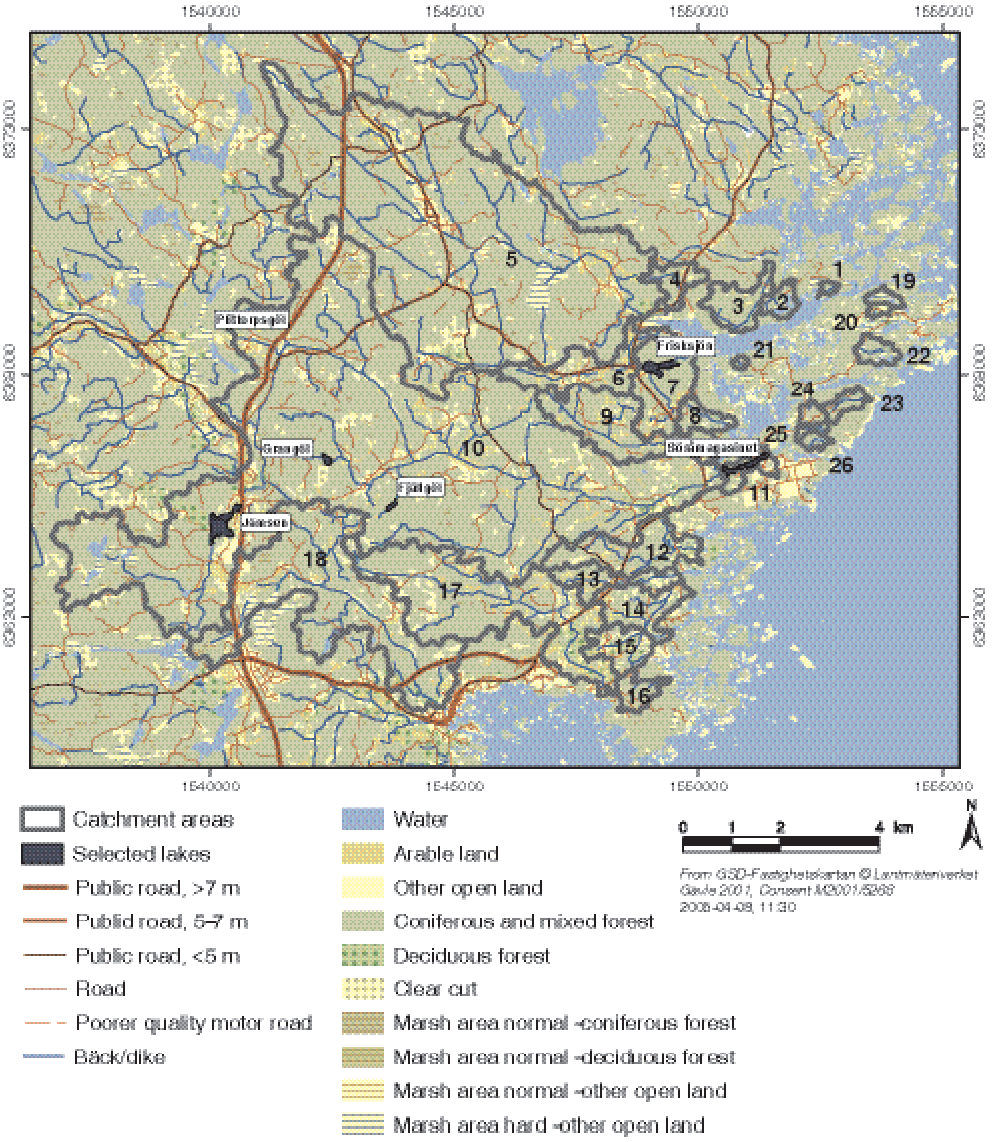


***Figure 3-32.** Delineation and numbering of the 26 catchment areas in the Simpevarp regional model area /Brunberg et al. 2004/. The map also shows the locations of the 6 identified lakes in the area.*

Groundwater levels

No site-specific data on groundwater levels in QD 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. In addition, data loggers for automatic measurements of the groundwater pressure have been installed in several groundwater monitoring wells. 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.

Private wells

Private wells in the regional area were investigated and described by /Morosini and Hultgren, 2003/. There are totally 218 private wells identified in the Simpevarp regional area, of which 213 have been checked in the field. The well capacity is not reported, but the pumped discharge is reported for 6 wells.

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, is responsible for most of the artificial water handling activities in the regional model area.

A brief overview of the water handling at OKG is presented in /Werner et al. 2005/. 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.

3.4.4 Conceptual and descriptive modelling

Methodology and objectives

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 section 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.

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. 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 uncertainties associated with the S1.2 descriptive model are discussed in Section 3.4.6.

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 Section 3.4.3), 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 3-33 illustrates SKB's systems approach to site descriptive hydrogeological modelling. The division into three types of hydraulic domains (overburden (QD), 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 overburden (QD) and the upper part of the bedrock, provide input to:

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

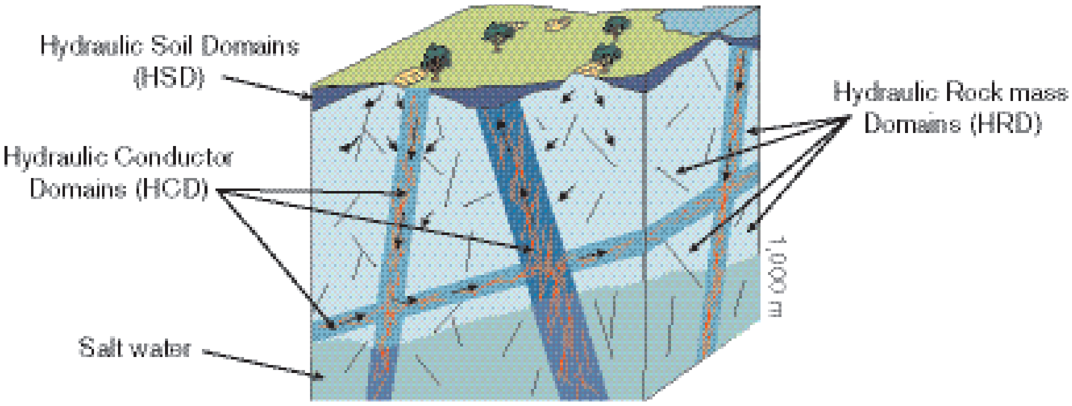


Figure 3-33. Division of the overburden and the bedrock into hydraulic domains representing the QD (HSD) and the rock domains (HRD) between fracture zones modelled as conductor domains (HCD). Within each domain the hydraulic properties are to be represented by mean values, or by statistical distributions /Rhén et al. 2003/.

In the present context, where the HSDs are investigated in detail, a further division is made of the near-surface system (in terms of type areas, domains and interfaces) than shown in Figure 3-33.

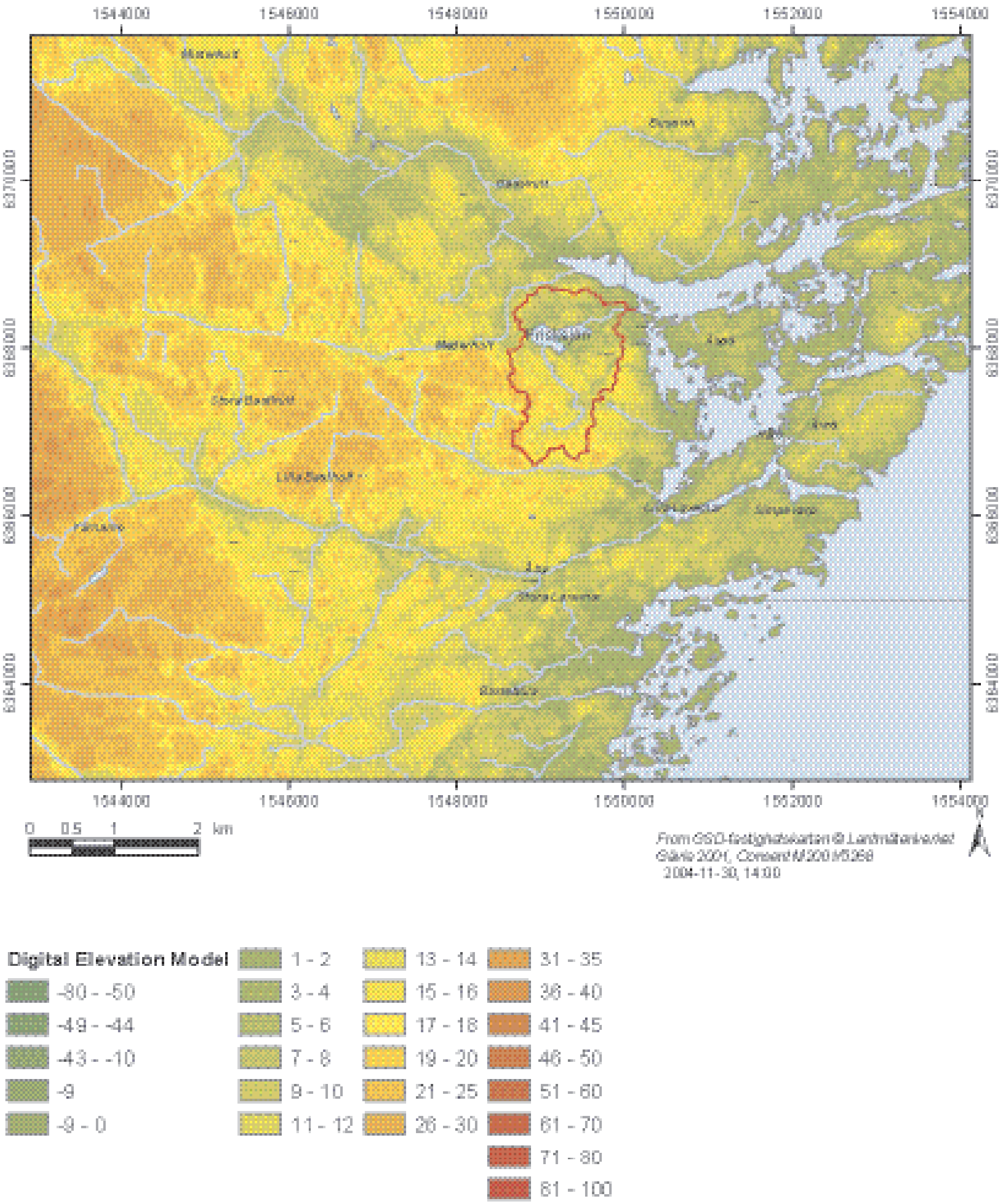
A complete descriptive model of the surface hydrology and the hydrogeology at a site involves the description of the integrated (continuous) hydrogeological-hydrological system, i.e. groundwater in bedrock, groundwater in QD and surface waters. The focus of the modelling presented here is on the surface and near-surface conditions. The hydrogeological properties of the bedrock and the lower boundary condition used in the quantitative modelling are therefore not presented in the descriptive model. However, the bedrock properties and the interaction between QD and bedrock, as handled in the quantitative flow modelling, are described in Section 3.4.5.

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×year^{-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 3-34) and by relatively shallow QD. Almost the entire area is below 50 metres 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 very small). A crude water balance for the regional model area, based on discharge measurements in selected representative hydrological stations outside the regional model area and hydrological modelling based on regional meteorological data, 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/.

The QD are mainly located in the valleys, whereas the higher-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 QD 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 the QD in the Laxemar subarea and in the regional area will be provided in the L1.2 data freeze.



From GSD-fastighetskartan © Lantmäteriverket Gävle 2001, Consent M2001/5268
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***Figure 3-34.** Digital elevation model (DEM) of the regional model area.*

According to the presently available large-scale maps covering the Laxemar subarea, there is a lower degree of exposed bedrock and more abundant QD in Laxemar than in the Simpevarp subarea (see Figure 3-35). 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 regional model area.

Descriptive model of surface hydrology and near-surface hydrogeology

Description of elements

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

- **Type areas.** These are areas that are considered to be more or less similar from a geological-hydrological perspective.

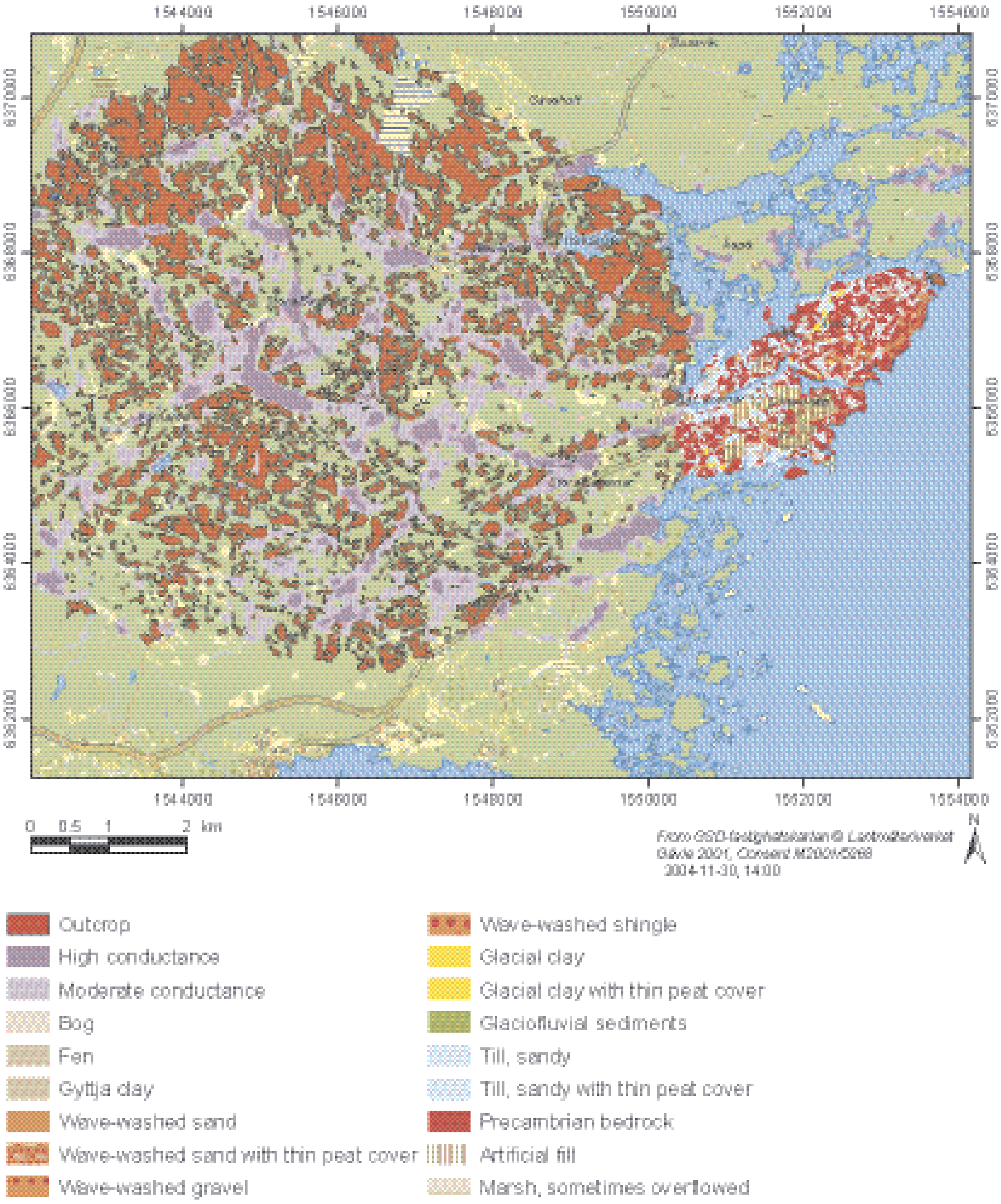

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Figure 3-35. *Detailed map of QD in the Simpevarp subarea combined with results of airborne geophysical measurements in the Laxemar subarea.*

- **Domains.** The overall SKB approach (Figure 3-33) 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 QD) are identified and described, based on the currently available data. This involves a simplification of the geological description, aiming at an identification of the characteristic hydrogeological units and a quantification of the parameters that describe their geometry and hydraulic properties.
- **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, see also /Werner et al. 2005/.

Type areas

At present, most of the available data on the QD (surface distribution and stratigraphy) are from the Simpevarp subarea; they were collected in connection with detailed geological mapping /Rudmark, 2004/ and drillings for groundwater monitoring wells /Johansson and Adestam, 2004a/. 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 QD and exposed bedrock is approximately 65% and 35%, respectively.

The QD mainly consist of till. The till can be characterized as sandy (at some locations sandy-gravelly), with a high surface frequency of stones and boulders. The thickest layers of QD are found in the low-lying areas (valleys), where the till often is covered with postglacial deposits (clay and/or gyttja clay). The glacial clay is often over laid by a sand/gravel 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 QD, three basic hydrogeological type areas are identified in the present descriptive model (Figure 3-36. 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 QD /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.

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 modelling, a much larger amount of site-specific data on the surface distribution and stratigraphy of the QD 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 3-33) as defined in S1.2 are listed in Table 3-11. 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, gyttja clay/clay gyttja, and peat) will be detailed when their occurrence and spatial distribution is better known. Table 3-11 shows the hydraulic properties of the QD (HSDs) that are used in the S1.2 modelling. The values within parentheses in the table are those used in the flow modelling of the "Simpevarp 7" catchment area (see Section 3.4.5).

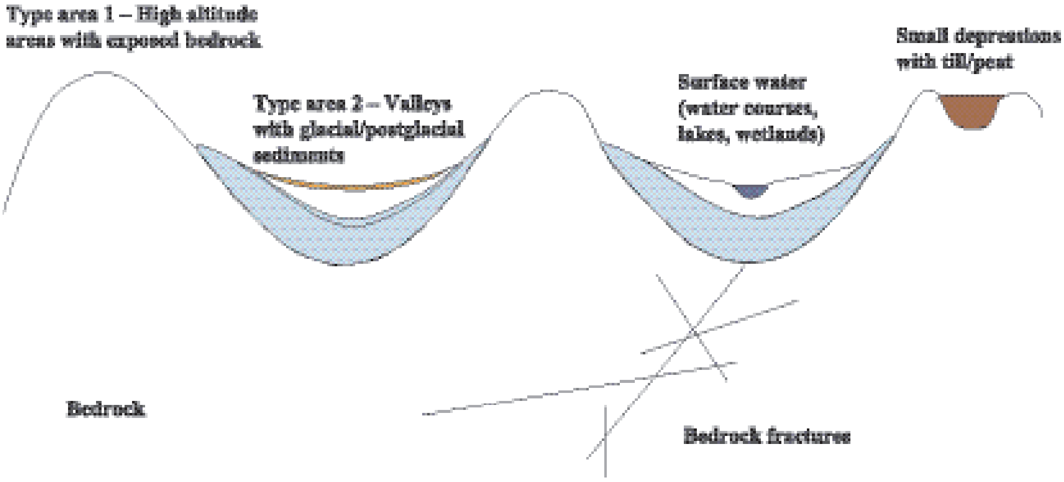

Figure 3-36. *Schematic cross section illustrating the descriptive model of HSDs.*

Table 3-11. Assignment of hydraulic properties for 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 post-glacial sedi-ments: 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	0.44	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/

The hydraulic conductivity for till in Table 3-11 is the average value from the slug tests performed in groundwater monitoring wells with their screens 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 values of the specific yield, S_Y, for the different types of QD are taken from the literature, whereas the same value of the storage coefficient is used for all QD.

For the bedrock (HCDs and HRDs), which is considered in the flow modelling but not in Table 3-11, the DarcyTools modelling team has provided input in terms of the spatial distribution of the hydraulic conductivity (see Section 3.4.5). Specifically, the hydraulic properties from the S1.1 hydrogeological modelling of the rock /Follin et al. 2004/ are used.

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. The occurrence of and reasons for anisotropic conditions in till have 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 the L1.2 model development. 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 sub-area, which implies that, e.g., different types of till may be identified during the continued 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 within 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. The surface runoff taking place in areas with exposed bedrock is diverted into the valleys. Thin QD 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 for each catchment, directed towards surface waters, lakes, wetlands, and other local near-surface drainage systems.

Interfaces between domains

Important factors in the characterisation of groundwater 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 Figure 3-37):

- **The interface between "near-surface" bedrock and "deep" bedrock.** In the S1.2 flow modelling, this interface is defined at the level –150 m.a.s.l.
- **The interface between QD and bedrock.** In the S1.2 modelling, the main flow of water across this interface is assumed to take place at locations where fractures and fracture zones are in contact with the QD.
- **The interfaces between groundwater and surface waters** (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.

Description of the surface and near-surface flow system

As described in Section 3.4.1, the present description is focused 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 the 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 the vegetation. The groundwater level rises during late autumn, and the highest levels are reached during the 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 above. 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 QD, or as overland flow into surface waters (water courses, lakes and/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.

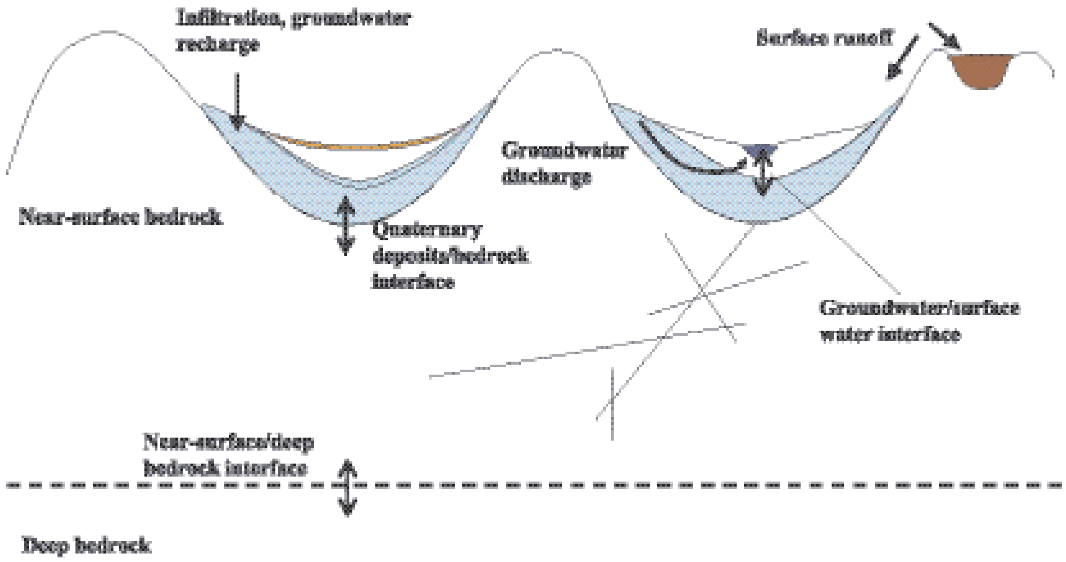

Figure 3-37. *Schematic cross section, illustrating the descriptive model of the surface-hydrological and near-surface hydrogeological conditions in the regional model area. The figure also shows the interfaces considered in the S1.2 modelling.*

These concepts are illustrated in Figure 3-37. 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 (see above).

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 in higher-altitude (recharge) areas and lower in low-lying (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 or 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 implies that groundwater recharge and 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.

As mentioned above, lakes can function both as discharge and recharge areas. A lake can be a recharge area during periods when the near-surface groundwater levels in its vicinity are low, and shift to be a discharge area when the groundwater levels are high. The hydraulic contact between lakes and near-surface groundwater is highly dependent on the hydraulic conductivity of the bottom sediments. In the Simpevarp area, drilling and soil sampling have not yet been performed in the lake sediments to investigate the depth and properties of the sediments. In the S1.2 modelling, the lake bottoms are assumed to consist of fine sediments with low hydraulic conductivity.

Wetlands (e.g., 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 above). Information needs to be collected to clarify the hydraulic contact between groundwater and the wetlands within the model area. At this stage, it is assumed that the bottoms are covered with fine-grained sediments with low permeability.

Interaction between near-surface groundwater flow in QD and groundwater flow in upper part of the bedrock takes place primarily where the more permeable parts of the bedrock are in contact with the QD (see the discussion on interfaces above). Discharge from the bedrock into the QD will probably mostly take place in the topographically defined major discharge areas. Based on hydrological measurements in identified representative catchments and hydrological modelling using meteorological data from SMHI stations otside the model area, the runoff in the regional model area has been estimated to 150–180 mm×year^{-1} /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 Section 3.4.5).

The manual groundwater level measurements show that the groundwater table is usually less than 1 m below the ground surface. A shallow groundwater table indicates that the identified boundaries of the catchment areas /Brunberg et al. 2004/ can be used as no-flow boundaries also for quantitative modelling of near-surface groundwater flow. Shallow groundwater also implies that the groundwater level can be assumed to follow the topography. Generally, groundwater levels in areas similar to the present model area are usually less than a few metres below ground level in recharge areas and less than 1 m deep in discharge areas /Knutsson and Morfeldt, 1993/. The annual groundwater level fluctuations are usually a few metres in recharge areas and about 1 m in discharge areas /Knutsson and Morfeldt, 1993/. As mentioned above, the extents of recharge and discharge areas can be expected to vary during the year. The sea-water level fluctuations will probably have insignificant influence on the groundwater levels and their fluctuations, at least in the more inland parts of the model area.

The groundwater flow in the three glaciofluvial deposits identified within the regional model area, and their interfaces with the surroundings, are not included in the conceptual model (cross section) in Figure 3-36. However, in its simplest form, the groundwater flow in the three identified eskers can be conceptualised as channel flow, taking place parallel to the esker orientation. Depending on their hydraulic contact with the surroundings, and the differences in groundwater levels between eskers and surroundings, the eskers may discharge groundwater to or receive groundwater from the surrounding QD.

Supporting evidence from other disciplines and models

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.

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

Mapping of QD, soil types and vegetation: Comparison of descriptive model or flow pattern and spatial distributions of QD, soil types and/or vegetation; the evaluation is based on assumed or observed correlations between geology/soil types/vegetation types and hydrological/hydrogeological characteristics.

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. 2004a,b/.

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 (e.g., "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, 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 Section 3.6 of this report and in the background report from the hydrogeochemical modelling /SKB, 2004d/.

In L1.2, a more extensive dataset on the hydrogeochemical parameters will be provided and evaluated to support 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, see /SKB, 2004d/. 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 flow in the present report are not obtained. However, the modelling illustrates a useful methodology that can be applied also when more data from the surface system is at hand. In addition, some results of the data evaluation in /SKB, 2004d/, such as the observed differences in water composition between different lakes, should be further investigated in future model versions.

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 3-38 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.

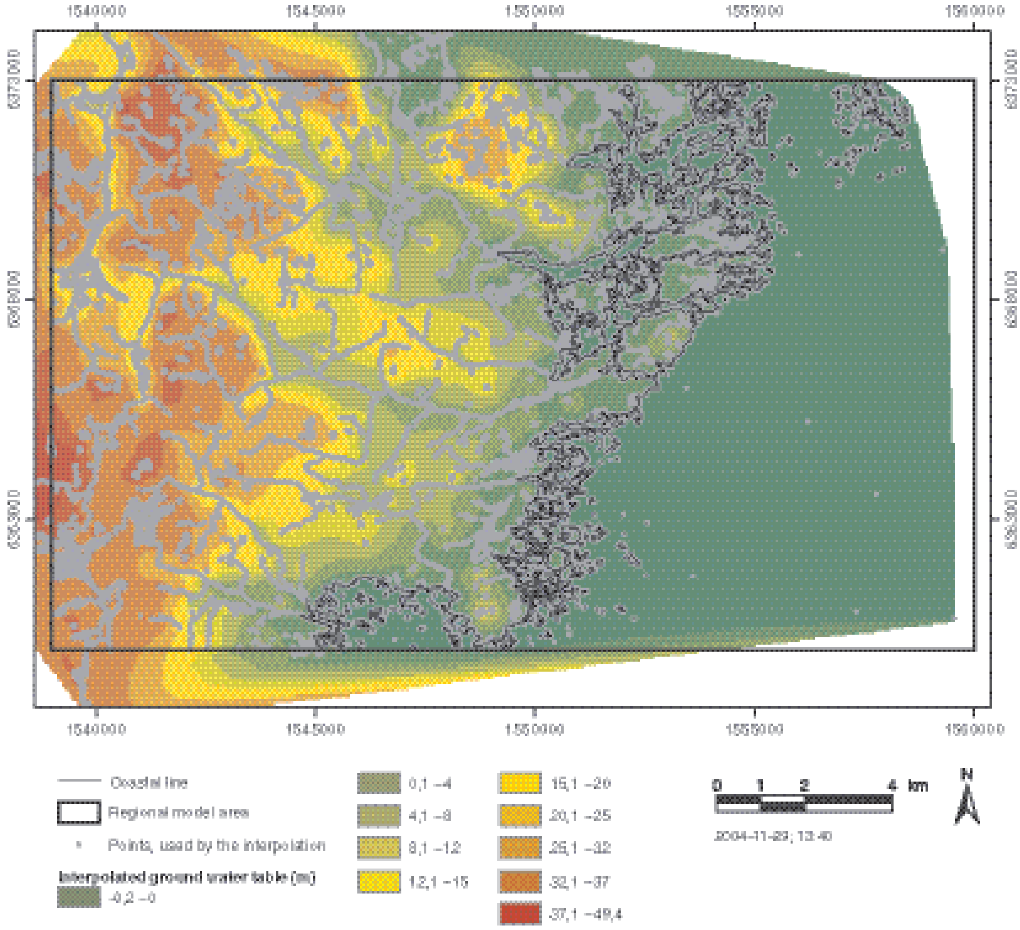

Figure 3-38. Interpolation of known water levels in the regional model area. The points used in the interpolation are indicated by grey dots.

Figure 3-39 shows a map where the interpolated "groundwater surface" in Figure 3-38 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.

Comparison of DEM and geological map

The purpose of this section is to show how evidence from other disciplines and models can be used as support of the conceptual and descriptive models. As an example, the Digital Elevation Model (DEM) is compared to a map integrating the currently available data on Quarternary deposits and bedrock outcrops for catchment area no 7. The rationale behind this comparison is that the definition of type areas (see above) is highly dependent on the coupling between the topography (high and low areas) and the locations of areas with QD and surface waters.

Figure 3-40 shows that the higher-altitude areas define the water divide (red line). Surface waters (lakes and water courses) are located in low-altitude areas. In Figure 3-41, areas with bedrock outcrops are red, whereas QD (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 QD.

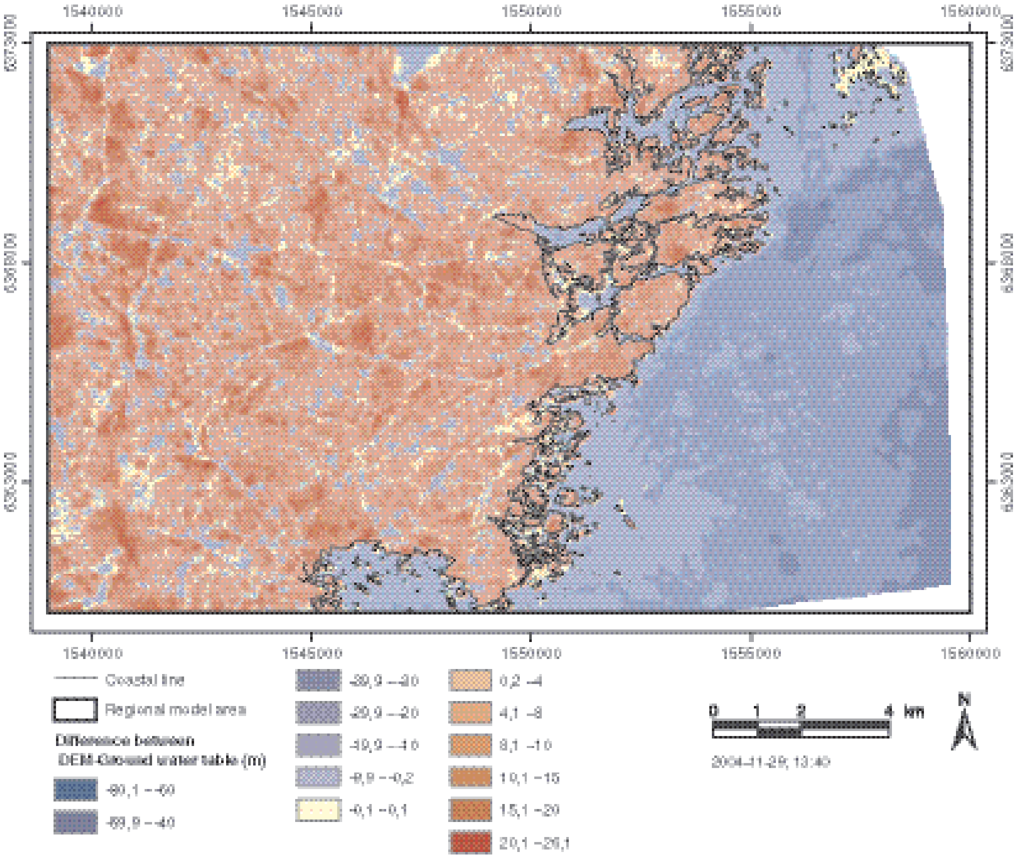

Figure 3-39. *"Groundwater depth" based on DEM and interpolated groundwater level in Figure 3-38.*

A comparison of Figure 3-40 and Figure 3-41 shows that areas described as bedrock outcrops (Figure 3-41) are modelled as high-altitude areas in the DEM (Figure 3-40). On the other hand, low-lying areas are mapped as areas with till (green colour in Figure 3-41) and/or areas with water-laid sediments ("high" or "moderate" conductance). Valleys and higher-altitude areas are readily identified and separated on both maps, although it is also realised that the differences on the QD map correspond to local variations in the topography; further analysis/classification of the topography is needed to enable a straightforward quantitative comparison. However, this simple comparison provides at least qualitative evidence in support of the definition of type areas associated with the descriptive model.

3.4.5 Quantitative flow modelling

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 geometric interpretations or boundary conditions, 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 related to initial and boundary conditions and hydraulic properties.

Description of flow paths and flow conditions: Model calculations aimed at improving the general understanding of the site-specific groundwater flow system.

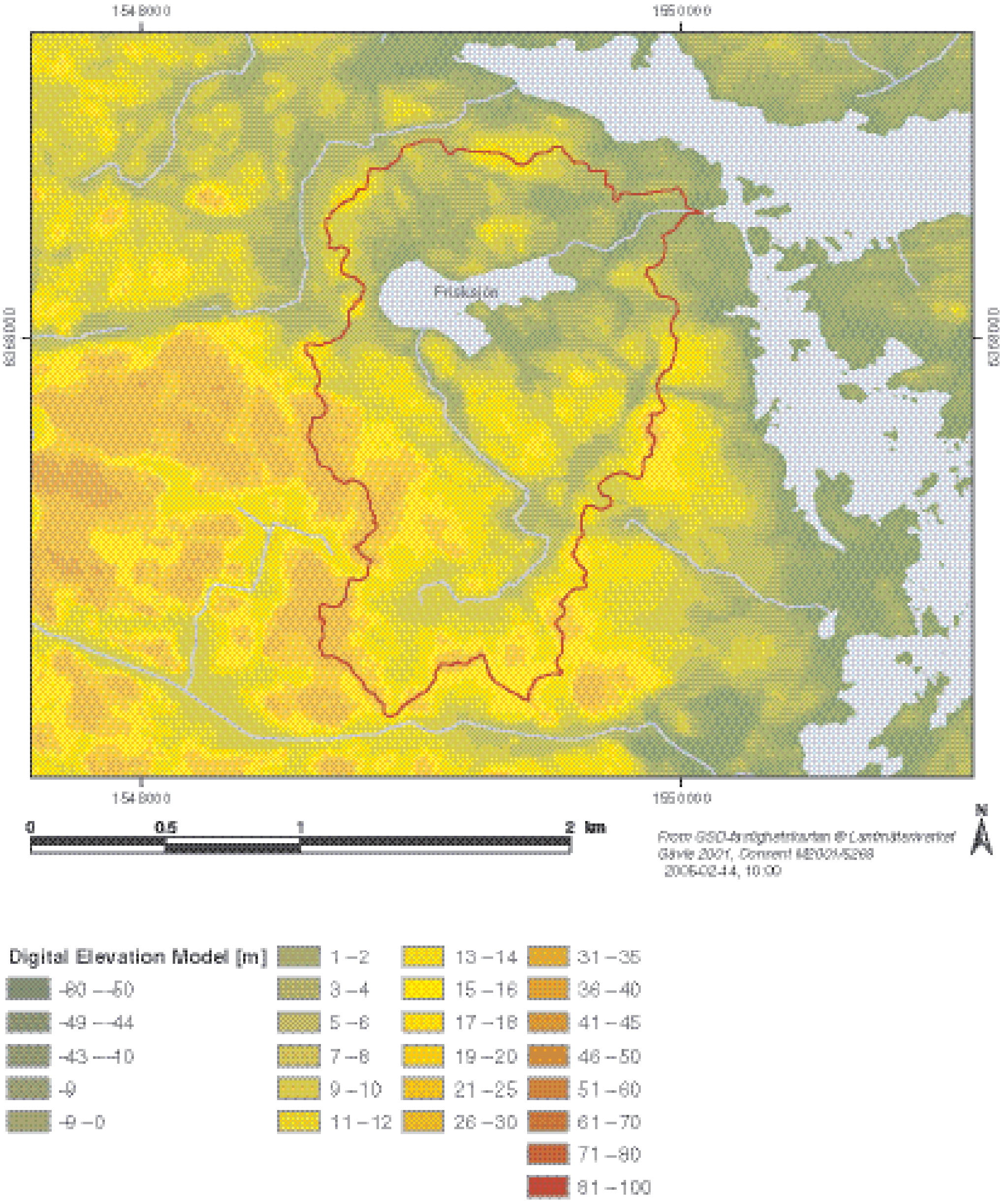

Figure 3-40. *Digital Elevation Model (DEM) of the "Simpevarp 7" catchment area.*

Due to the limited data available and the "immature" state of the surface and near-surface flow modelling in general, only a limited modelling effort has been made in S1.2. The overall objectives of the quantitative flow modelling in S1.2 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,
- 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, the activities related to conceptual/descriptive and quantitative modelling has 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 conceptual/descriptive and quantitative modelling than in a "complete" modelling process.

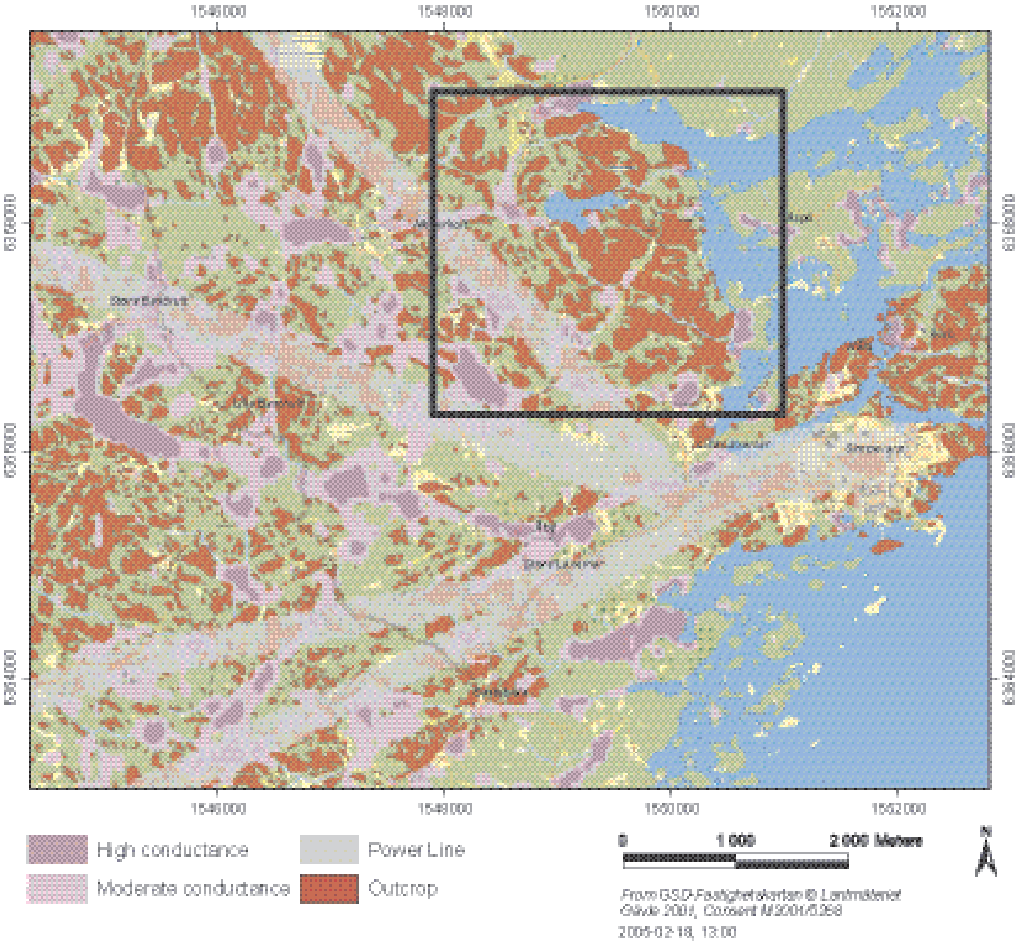

Figure 3-41. Detail of the map in Figure 3-35, showing QD (Simpevarp subarea) and results of airborne geophysical measurements (Laxemar subarea). The approximate corresponding coverage of the map in Figure 3-40 is indicated by a rectangle.

Short description of modelling tools and objectives

This section gives a brief description of the tools used in the S1.2 quantitative flow modelling, and the objectives of each model application. For a more detailed description of the tools, see /Werner et al. 2005/.

GIS-based modelling

Relatively simple, topography-driven hydrological models can be developed using the extension "Hydrological modelling" in ArcGIS 8.3. The tool requires a Digital Elevation Model (DEM) as the sole input to calculate water flow directions and so-called "flow accumulation". In addition, an estimate of the specific discharge (obtained from elsewhere) is required for calculating the mean annual discharge for a specific cell in the model.

The main objective of the GIS modelling in S1.2 is to provide input to the ecological systems modelling in terms of the spatial distribution of the total runoff. Furthermore, the GIS modelling aims at illustrating the overall water flow pattern within the Simpevarp regional model area and to estimate the mean annual discharge in the main water courses in the area. Another objective is to evaluate uncertainties related to the DEM.

Hydrological process modelling with MIKE SHE

MIKE SHE (Système Hydrologique Europeen) is a physically based, distributed model that simulates surface hydrological and hydrogeological processes, including subsurface unsaturated and saturated flow and evapotranspiration processes. For simulation of surface water flow, MIKE SHE is integrated with the channel-flow program MIKE 11. The exchange of water between MIKE SHE and MIKE 11 takes place continuously during the simulation. MIKE SHE is primarily developed to model groundwater flow in porous media. However, the S1.2 modelling also considers groundwater flow in the near-surface bedrock. Deep rock and near-surface groundwater flow models are here coupled through a head boundary condition at the bottom of the MIKE SHE model (at 150 m below sea level).

The main objective of the MIKE SHE modelling is 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. Other objectives are to deliver output data on the components of the water balance to the ecological systems modelling, and to test the MIKE SHE tool within the SKB environment.

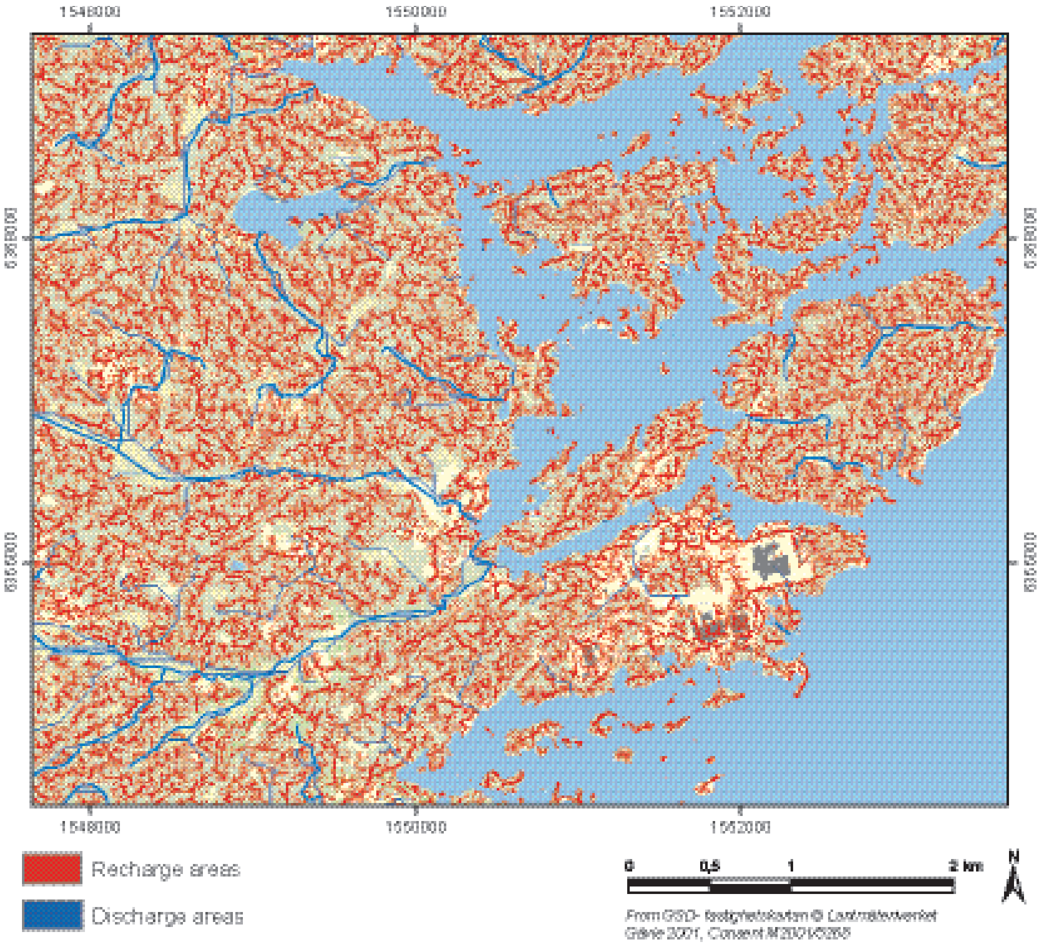

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Figure 3-42. *Identification of recharge and discharge areas using the GIS model. In the model, areas receiving water from an area larger than 0.05 km^2 are defined as discharge areas.*

Results from GIS modelling

Recharge and discharge areas

Recharge and discharge areas have been identified with the GIS model. In this modelling, a zero value in the accumulation grid defines a recharge area. Areas with an accumulation values equal to zero are marked with red in Figure 3-42 whereas areas with a value higher than 500 are marked with blue. As the grid cells have a size of 10 m by 10 m, this implies that cells receiving water from an area larger than 0.05 km^2 are defined as being within discharge areas.

Figure 3-42 illustrates the local flow systems described in the conceptual and descriptive modelling (cf. Section 3.4.4). 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 also be noted that the locations of recharge and discharge areas are strongly influenced by the local topography.

The modelled flow pattern in catchment no 7, which includes Lake Frisksjön and its catchment area, is illustrated in Figure 3-43. The arrows are flow weighted, which means that a long arrow represent a higher value in the accumulation grid, and hence a larger discharge. The accuracy of the GIS model can be tested by comparing the modelled flow pattern with the field-controlled water divides (the red lines in the figure). It can be seen that the arrows cross the field-controlled water divide in some areas. These errors can be related to accuracy of the DEM. The modelled flow pattern also shows that water at the outflow from Lake Frisksjön has been redirected by the opening of a man-made outlet. The blue line shows the present outlet, whereas the arrows show where the outlet would have been located without human interference.

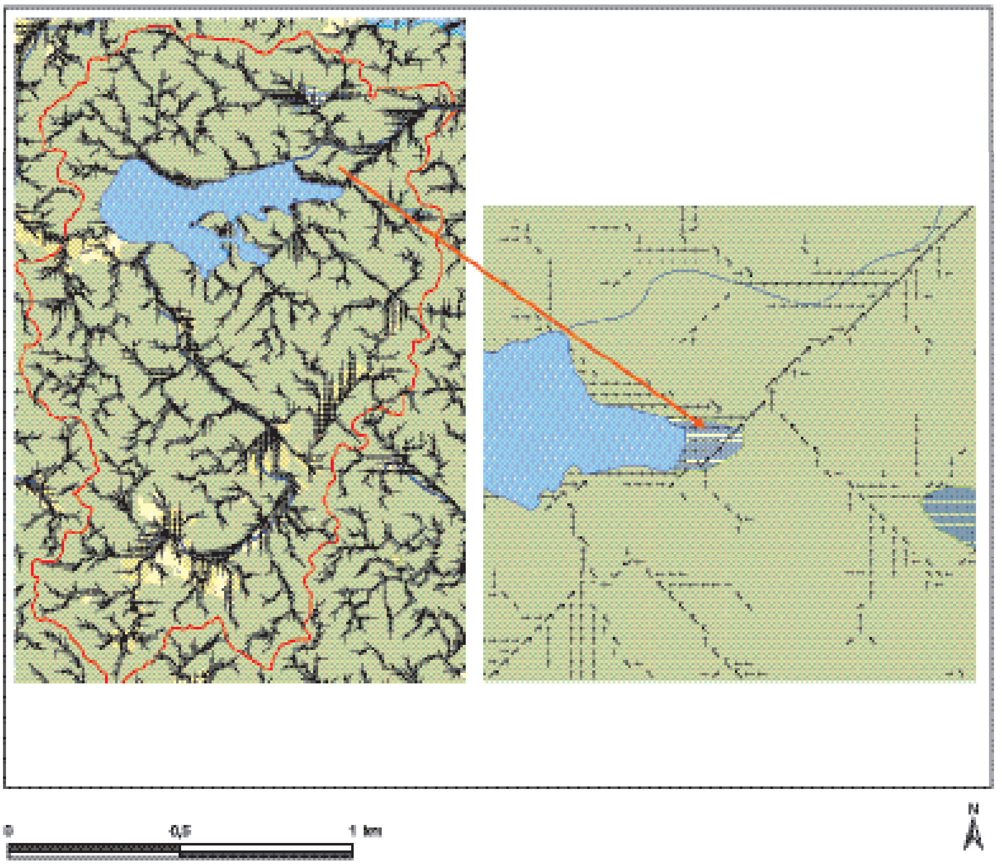

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Figure 3-43. Flow pattern in the catchment area of Lake Frisksjön.

Identification of catchment area boundaries

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 catchment area of a specific wetland area. In the main part of the model area, the modelled catchments coincide with the field-controlled catchment boundaries, cf. Figure 3-44. In the figure, the field controlled boundaries are indicated by dashed lines and the number of each catchment is marked in the figure. The modelled catchments are marked with different colours.

A detailed comparison of each field-controlled catchment area and the corresponding modelled catchment area is presented in /Werner, et al. 2005/. 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, 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 errors in the modelling of these two large catchments 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 affect the overall flow pattern and the predictions of discharges in coastal outlets.

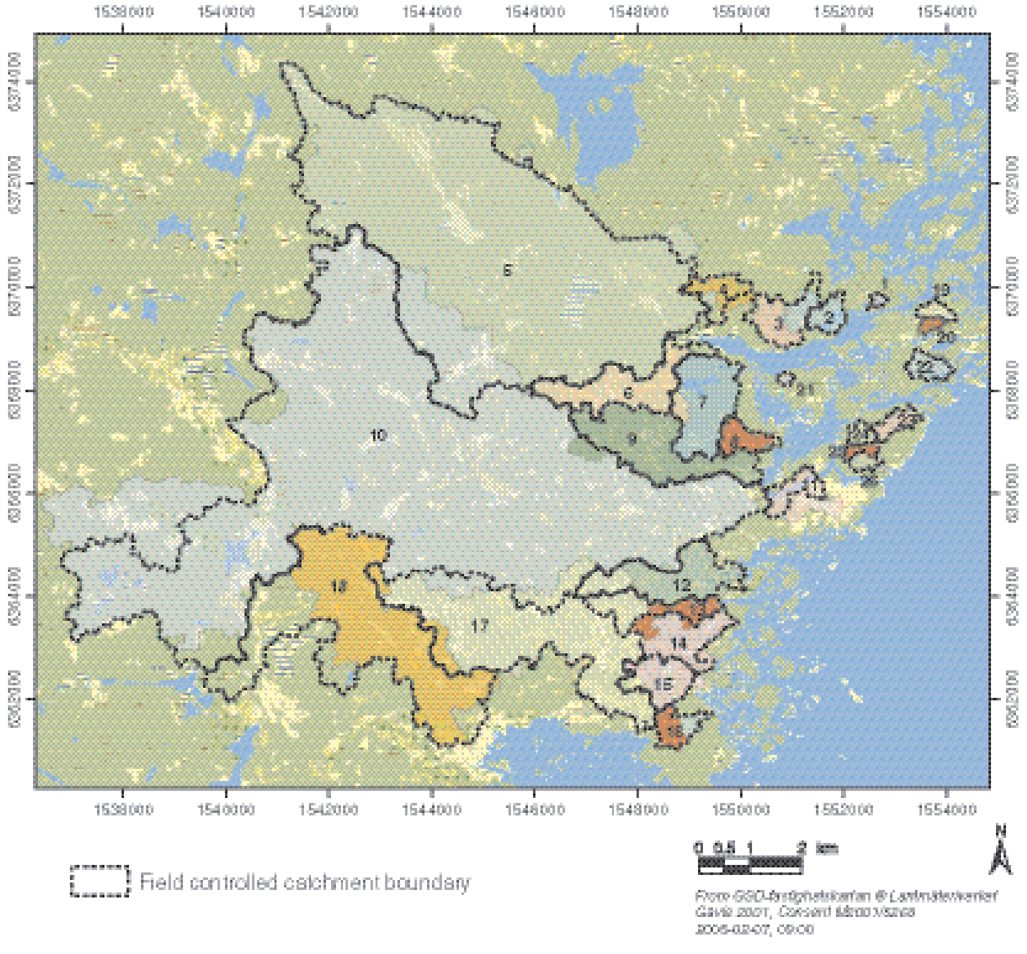

Figure 3-44. Modelled and field-controlled catchment area boundaries.

Results from MIKE SHE modelling

The meteorological input data to the process modelling with MIKE SHE are taken from the SMHI station nr 7722, Ölands norra udde. Data are 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 evaporation. Thus, it should be noted that all references to "dry" and "wet" periods concern different periods of this single year, and not long-term extremes. The input data used in the MIKE SHE modelling are described by /Werner et al. 2005/.

Water balance

The regional average runoff in the area has been estimated to 5.7 l×s^{-1}×km^{-2} /Larsson-McCann et al. 2002/, which corresponds to 180 mm/year. The modelled specific runoff in the MIKE SHE model of the "Simpevarp 7" catchment is 4.9 l×s^{-1}×km^{-2} which corresponds to 154 mm. Since there is a mass balance error in the unsaturated zone component of the model and a net flow at depth across the model boundary at the coastline (which may or may not be included in the runoff), the calculated runoff should be expressed as an interval; the runoff is here estimated to 150–160 mm/year. The total actual transpiration was calculated to almost 430 mm/year. Hence, the overall water balance agrees with previous estimates and the conceptual and descriptive modelling of the water flow system presented above.

Figure 3-45 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 evapotranspiration 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 the 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 actual discharge and water levels in the water course.

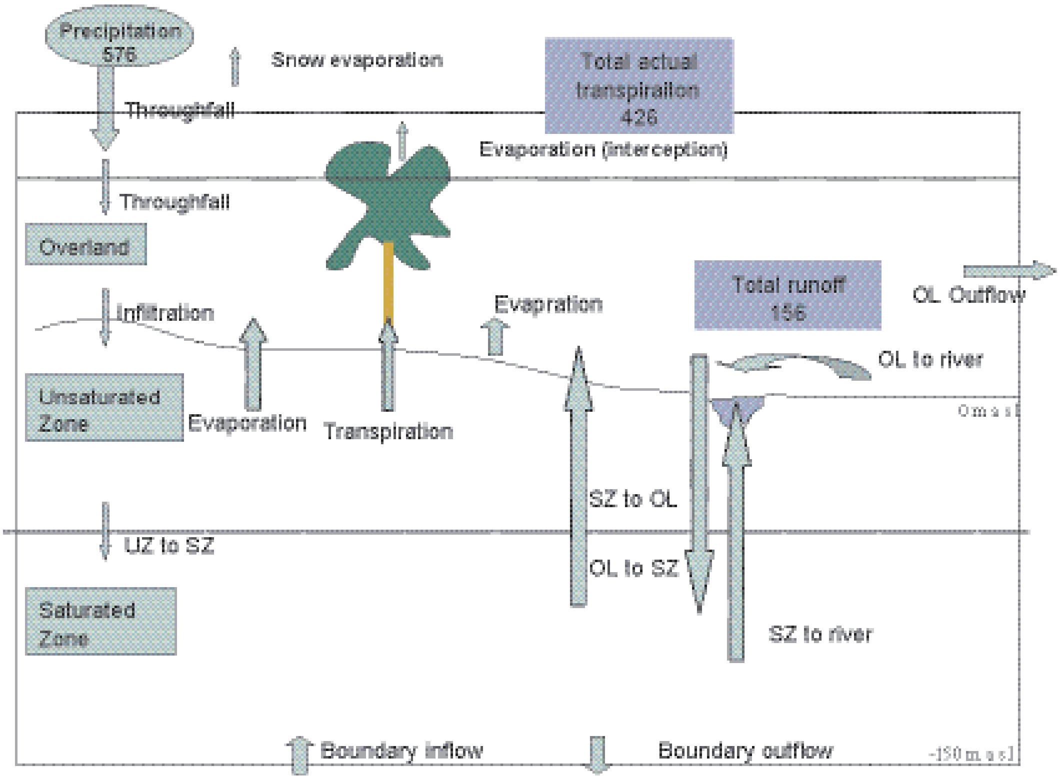

Figure 3-45. *Water balance for the catchment and water exchange between the different compartments in MIKE SHE.*

The discharge in the water course, Kåreviksån, varies during the year and is highly dependent of the precipitation (Figure 3-46). 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 3-46, 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 in the same time; 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.

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. As shown in Figure 3-47, which shows the depth to the groundwater table in the end of May, the depth to the groundwater table varies within the model area. 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 3-47 indicates ponded water (overland water) on the ground surface. The depth of ponded water is illustrated in the figure. 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. Except from Lake Frisksjön, there are two areas, in the eastern part of the catchment area, where there is ponded water. 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 3-47 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.

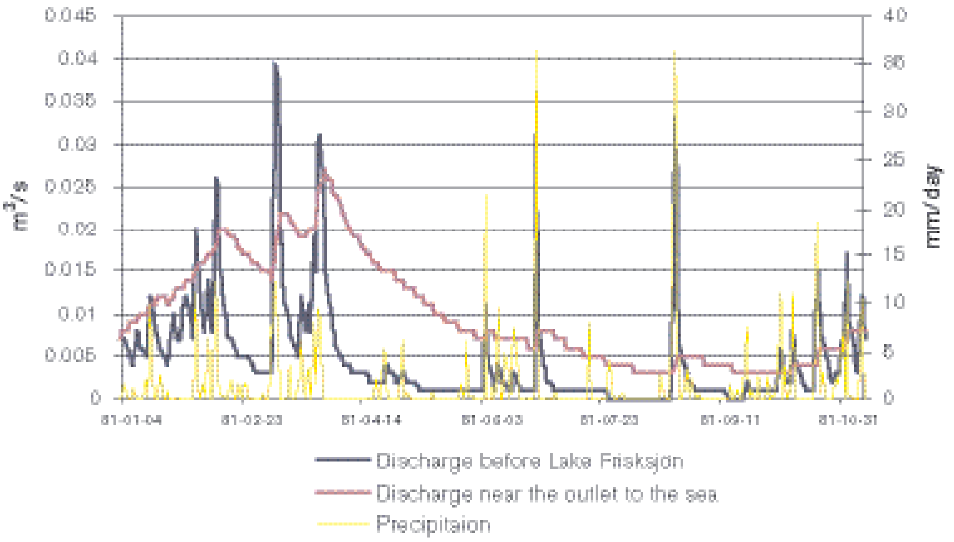

Figure 3-46. *Calculated discharge in Kåreviksån (left vertical axis) and precipitation (right axis).*

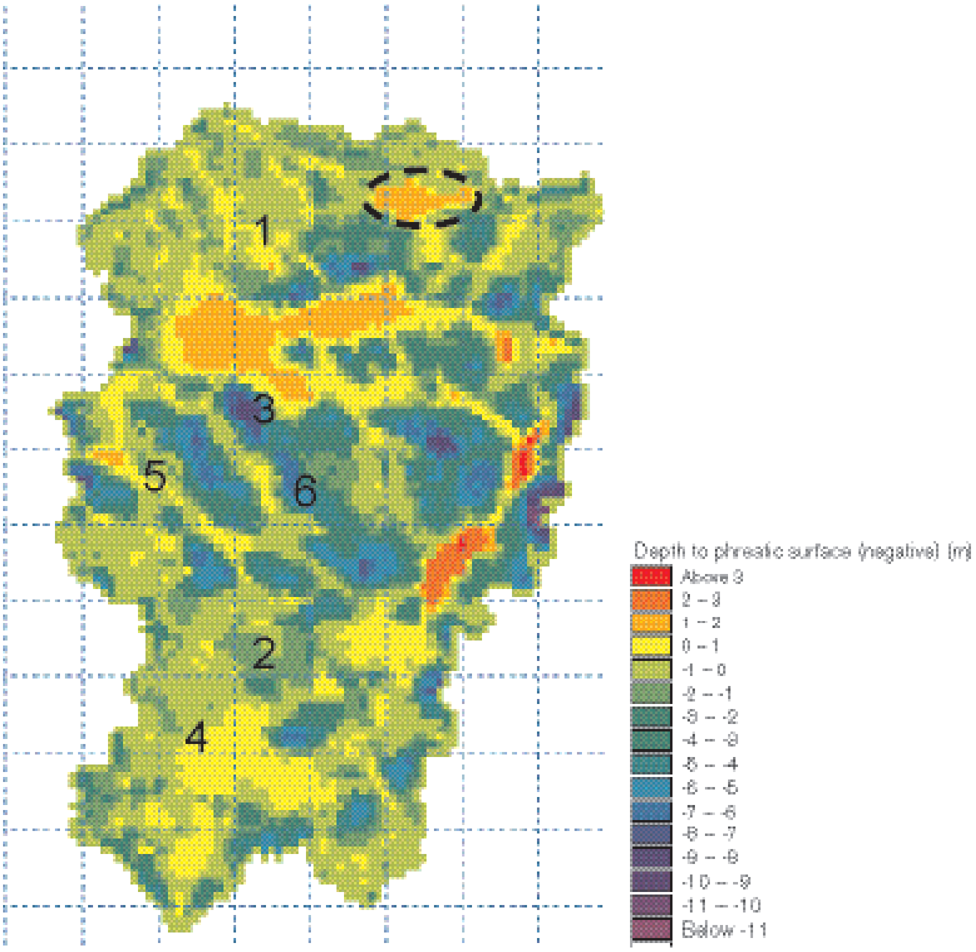

Figure 3-47. *Depth to the ground water table (in metres below ground surface).*

Time series showing the fluctuations of the groundwater level (expressed relative to the ground level) in the numbered points in Figure 3-47 are shown in Figure 3-48 and Figure 3-49. 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. Comparing the results, it can be noted that the two groups of observation points show somewhat different patterns of temporal variability.

In the points of shallow groundwater, the levels are sensitive to variations in the meteorological conditions. Figure 3-48 shows that the groundwater level is above or very close to the ground surface during spring and autumn, and lower during the summer; these points also show short-term variations that are not observed where the groundwater depth is larger. The curves for the groundwater levels below the topographic heights are smoother (Figure 3-49). 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 hydraulic head in the saturated zone (calculation layer 1, i.e. the uppermost layer) is illustrated in Figure 3-50. The red and yellow areas are typical recharge areas. The light green areas are recharge areas during most of the year. The extent of recharge and discharge areas is controlled by temporal variations of precipitation/snow melt and temperature. The blue areas are typical recharge areas, and the lake and the water course are discharge areas throughout the year.

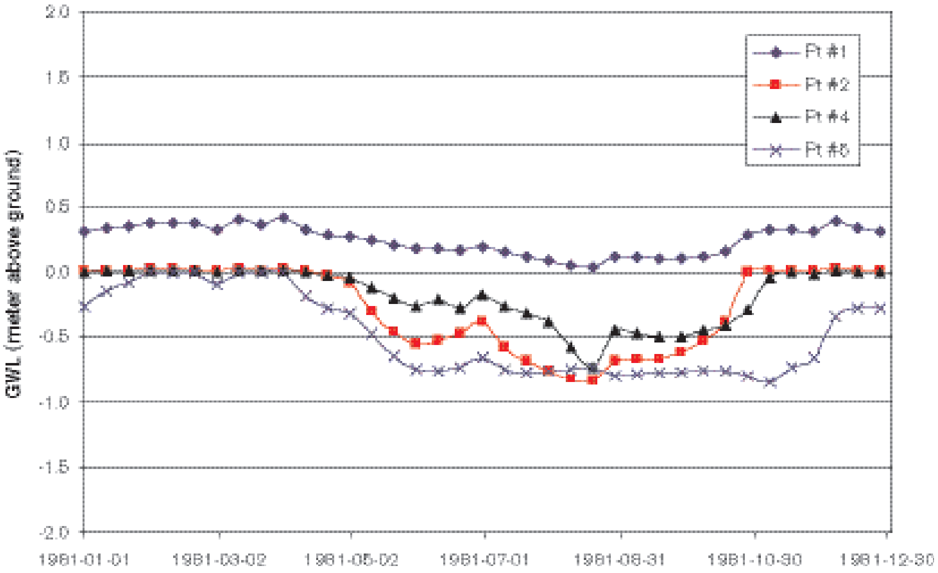

Figure 3-48. *Time series of calculated groundwater levels in points 1, 2, 4 and 5.*

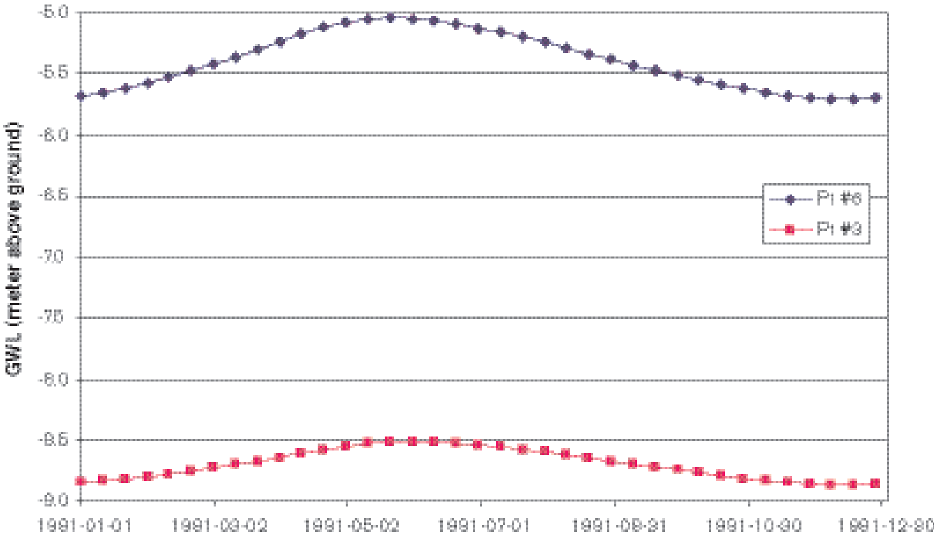

Figure 3-49. *Time series of calculated groundwater levels in points 3 and 6.*

Figure 3-51 shows the calculated hydraulic heads in different layers along the section indicated by the green line in Figure 3-50. The colours of the lines indicate the depths of the layers they represent; light green lines are shallow layers, dark green lines deep ones. The location of Lake Frisksjön is marked in the figure. It can be seen in Figure 3-51 that the hydraulic head generally is higher at the topographic heights, and that there is a hydraulic gradient and groundwater flow from high to low altitudes in all layers.

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 shallowest 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.

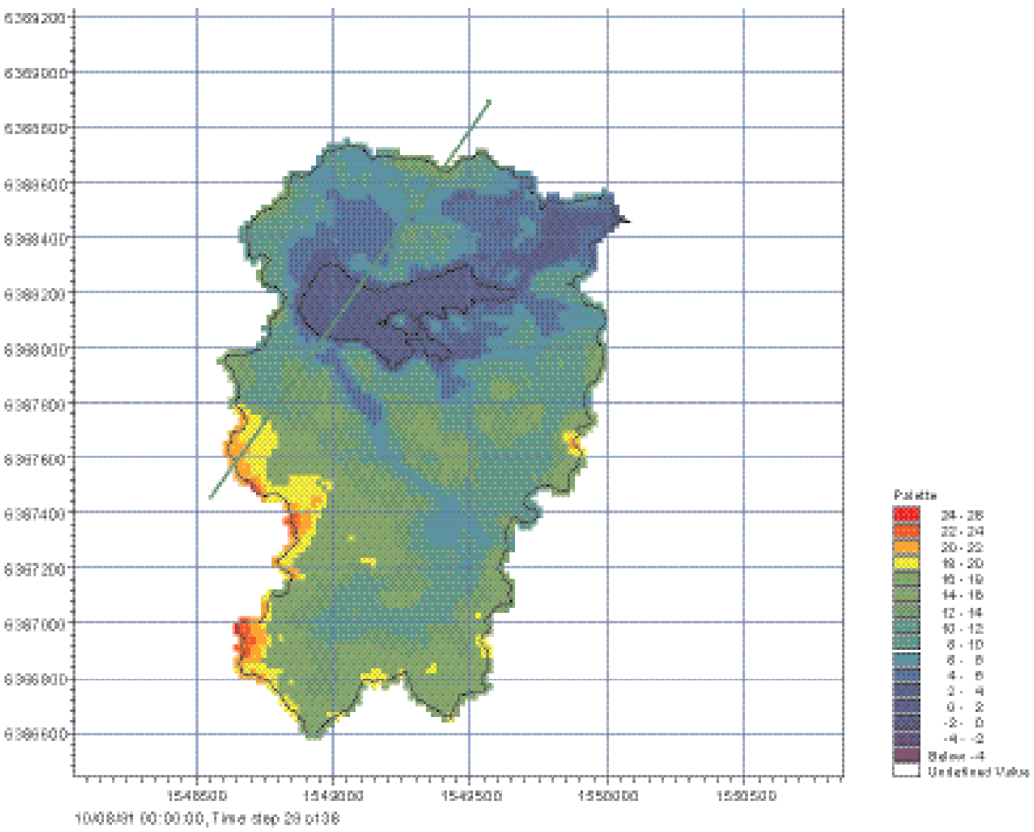

Figure 3-50. *Head elevation in saturated zone, calculation layer 1 (uppermost layer).*

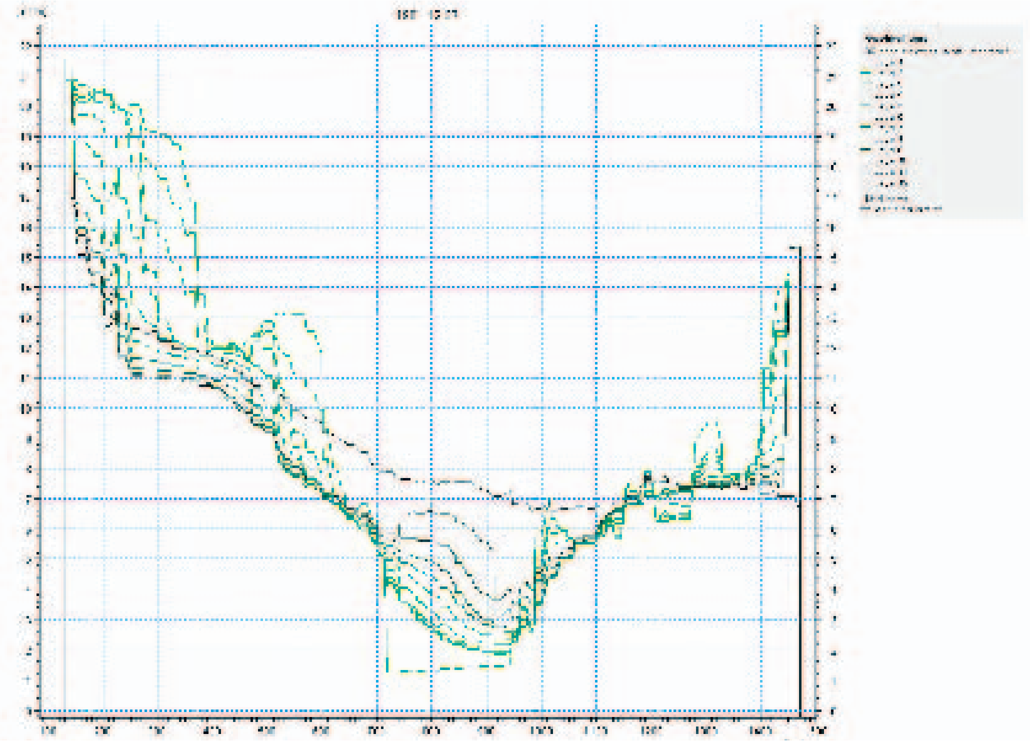

Figure 3-51. *Cross-sectional representation of calculated hydraulic heads in different layers; the lighter green the line, the more shallow the layer it represents. The position of the section is indicated by the green line in Figure 3-50.*

Recharge, discharge and exchange with deep rock

Figure 3-52 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 areas marked with yellow to beige and red colours in the figure have upward flow in the uppermost saturated layer, and can therefore be considered as discharge areas.

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 modelled year, which is in agreement with the description in Section 3.4.4.

The simulation results show that most of the water turnover takes place in the QD. In comparison, the water exchange between QD 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 QD 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/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 /Follin et al. 2004/. In Darcy Tools, the mean groundwater flow between –150 m.a.s.l. and –60 m.a.s.l. is 2.4 mm/year and has an upward direction. The net inflow over the bottom boundary at –150 m.a.s.l. 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 3-53 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, thereby indicating where the section goes through fracture zones. It can be seen that the flow rates generally are much higher in the uppermost layers in the QD 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.

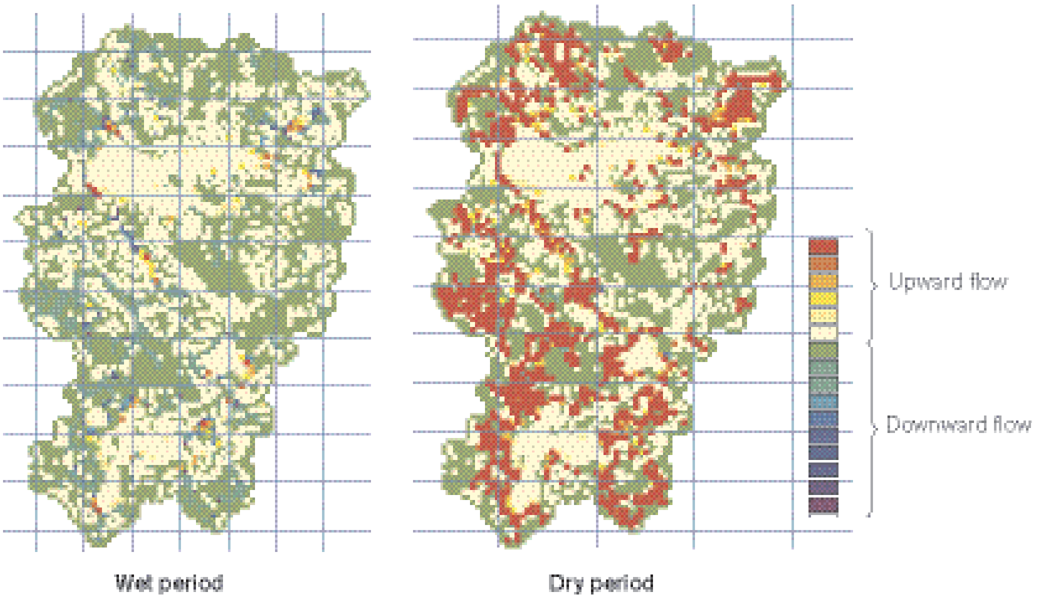

Figure 3-52. Calculated distribution of recharge and discharge areas during a wet (left) and a dry period. In the interpretation of the results, yellow and red areas are defined as discharge areas.

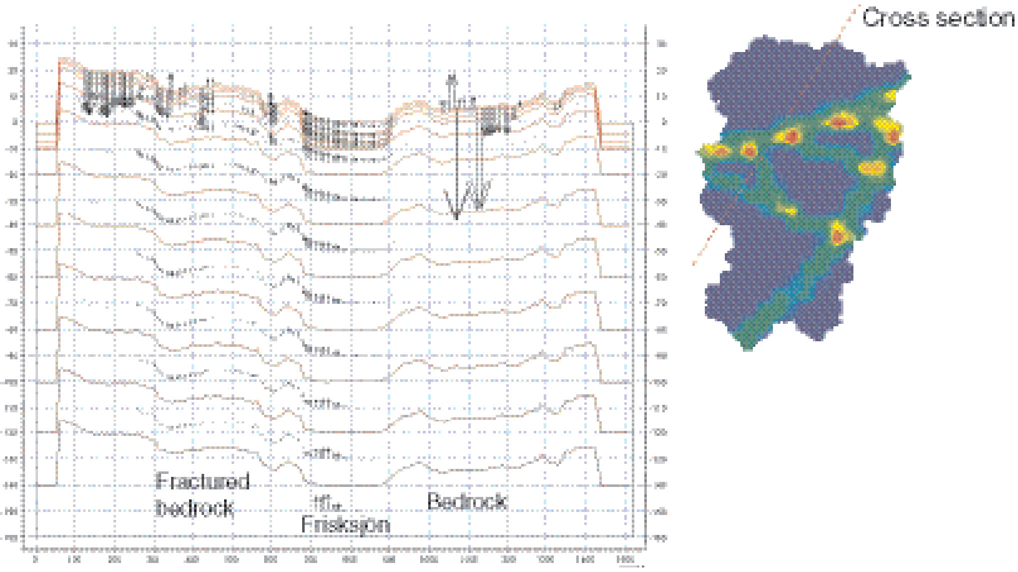

__Figure 3-53.__ Vertical flow in all calculation layers.

3.4.6 Resulting description of the Simpevarp site

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 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.

Summary of present knowledge

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 small catchment areas, and 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 QD is generally small. The thickest QD 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 QD, 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 QD 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 was possible to identify the following types of “elements”: 3 *type areas* (higher-altitude areas with exposed bedrock, valleys with QD, and areas with glaciofluvial deposits), 5 *domains* (till, glacial and postglacial clay and gyttja clay, sand/gravel, peat, and glaciofluvial deposits), and 3 important *interfaces between domains* (“near-surface”/“deep” bedrock, QD/bedrock, and groundwater/ surface waters). In the S1.2 modelling, the HSDs are assigned properties in accordance with Table 3-11.
- 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.

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 catchment area no 7, 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 150–160 mm and a total actual evapotranspiration of nearly 430 mm. These values are considered 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 catchment no 7), 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 QD, from high altitude areas 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 below sea level). Looking at a vertical cross-section through the model domain, there is groundwater flow 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). 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 QD and large areas with exposed bedrock implies that the storage capacity for water is small. The discharge in the water course within the modelled catchment 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 the lake in the modelled catchment (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 model simulates higher-altitude areas as recharge areas, and water courses in valleys and 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.

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:*** These include uncertainties in the DEM, the geological description (especially the surface distribution and stratigraphy of QD 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, hydraulic parameters are not 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 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, significant uncertainties remain regarding the quantitative aspects of the model. The identified type areas, domains and interfaces need to be developed, detailed and parameterised 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 have been calculated /Werner et al. 2005/, 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.

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.

3.5 Oceanography

3.5.1 Methodology

The Baltic coastal waters act as an intermediary link to successive advective and diffusive processes by which waterborne material released from the geosphere may eventually end up in the world oceans, passing through the Baltic (Figure 3-54) on its way. The primary connection with the geosphere can be made directly by leakage through the sea bottom of the coastal zone or via water run-off (discharged diffusely by ground currents, or discretely by localized watersheds such as streams or rivers) entering into surface layers of the coastal zone. The coastal waters also comprise aquatic ecosystems in which entered material can be transformed via food chains. For aquatic ecosystems the rate of water exchange is an indisputable basic parameter that sets the externally forced pace of the material turnover. The overall objective of this coastal oceanographic analysis is to quantify the water exchange of the coastal area in the vicinity of the planned depositories in

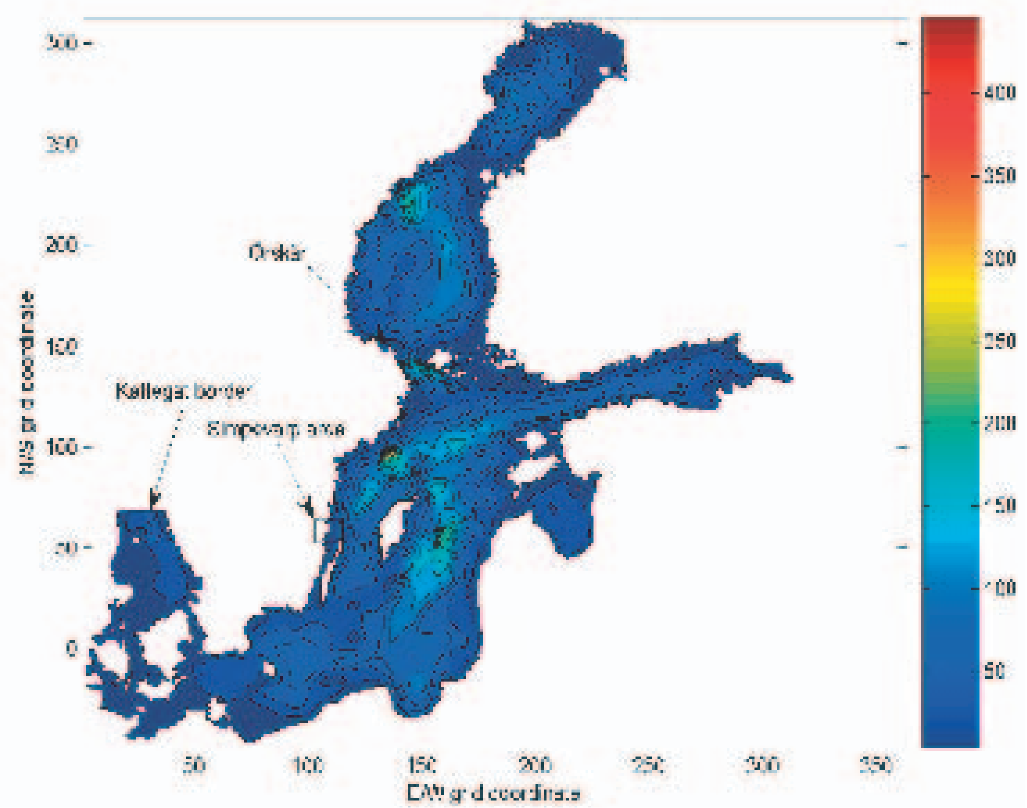

Figure 3-54. *The Baltic model grid displaying the Warnemünde hypsographic data. The approximate location of the Simpevarp area is indicated as is the Kattegat model border to the Skagerak.*

such terms that projection into the distant future is made possible. To this purpose various water circulation models driven by reasonably simplified but adequate forcing are employed, and the massive resulting hydrographic data generated over a one-year cycle of a typical year are condensed into a conceptual form that can serve as a basis for communication with other involved disciplines. For the Simpevarp coastal area (Figure 3-55), the year 1981 was chosen as the most representative year /Larsson-McCann et al. 2002/.

To obtain a quantitative estimate of the water turnover, the concept of Average Transit Residence (ATR-) time defined by /Bolin and Rodhe, 1973/ is used. This well-defined concept was adapted to water circulation models by introducing its volume-specific counterpart /Engqvist, 1996/. ATR-time denotes the length of time a particular water parcel on the average has spent within a specified connected area and can thus equally well be interpreted as an ATR-age (or simply ‘age’) counted from its (or parts thereof) entry into this area. Computationally the scalar variable ‘age’ of exogenous water (whether it enters though boundaries or is administered by discharge) to is initially set to zero (days/m^3), and the internally contained water is allowed to be aged one (1) time step unit for each time step it resides in the actual domain. Treated as an ordinary passive tracer in the model, the advection and diffusion of this variable will then attain a quasi-steady equilibrium between renewal by entering through the boundaries and aging of the water parcels. Because the exchange of the stratified coastal waters normally follows isopycnals and thus is mainly horizontal, averages in this direction represent a valid data reduction, retaining information on how the various vertical strata are renewed /e.g. Engqvist and Andrejev, 1999/. Vertical mixing, up-/down-welling and other baroclinic processes will act to equalize the age of adjacent strata, but this information is lost so that the full three-dimensional flow structure cannot be recovered. This loss is, however, deemed acceptable since the most intense and lasting vertical mixing takes place in the upper surface layers that will also be well-mixed when entering through the border. The up-/downwelling instances occur with a period time that is normally longer than the ATR-time, mitigating the temporal impact it will have on the long-term average.

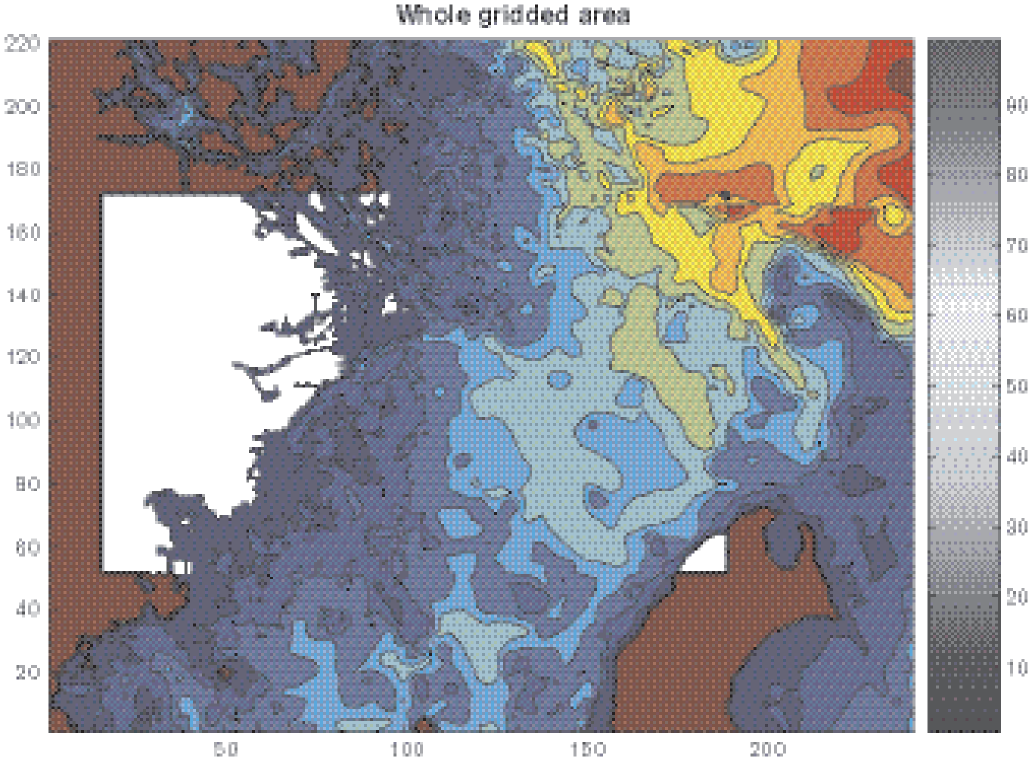

Figure 3-55. The entire gridded Simpevarp area with the location of the finally chosen grid indicated as white coloured land. Along the northern boundary the transition zone to the adjacent chart is noticeable which facilitated the actual choice.

Given information of the mixing time scales in relation to the advective time scales, it is possible to interpret the ATR-age concept for estimating the water exchange over long-term periods, typically one year, by computing its average, maximum and minimum values (together with an appreciation of the variance, e.g. the standard deviation, S.D.) based on computed instantaneous ensembles of the best resolved spatial unit (i.e. grid cell for 3D-models, Figure 3-56). These ATR-age snapshots should be sampled with a shorter time period than the induced inherent temporal variation due to the forcing. An appreciation of the corresponding water exchange would then be

$$Q_i = \gamma\, V_i/A_i\,; \qquad (3.1)$$

where Q, V and A denote volume flux, volume of the strata and the ATR-age respectively, while the index indicates the stratum's order number. The parameter γ takes a value of unity for more secluded landlocked areas. In such regimes the water passage is restrained by narrow and shallow straits. This means that the time scales of horizontal mixing are increased relative the advective time scale so that horizontally well-mixed conditions ensue. For plug-flow regimes with insignificant mixing – which would be the typical situation in the open coastal zone – in comparison to the well-mixed regimes, the parameter γ would tend be closer to 0.5. For pulsating flow regimes, with water being slushed back and forth across the boundaries with the same intensity, a kernel in the centre of the region could in principle age indefinitely, making the estimated Q progressively smaller with time, which is in accordance with the decrease of the effective exchange rate. Any level of diffusive mixing in the interior will under these circumstances make the appreciation of Q attain a plateau level. Thus the ATR-age concept must be used with some caution if ATR-times in parity with the designated one-year cycle time scale (derived from ecological modeling considerations) result from the computations. The highest *a priori* likelihood for this eventuality concerns the decisively landlocked areas, which will thus consistently be modelled separately.

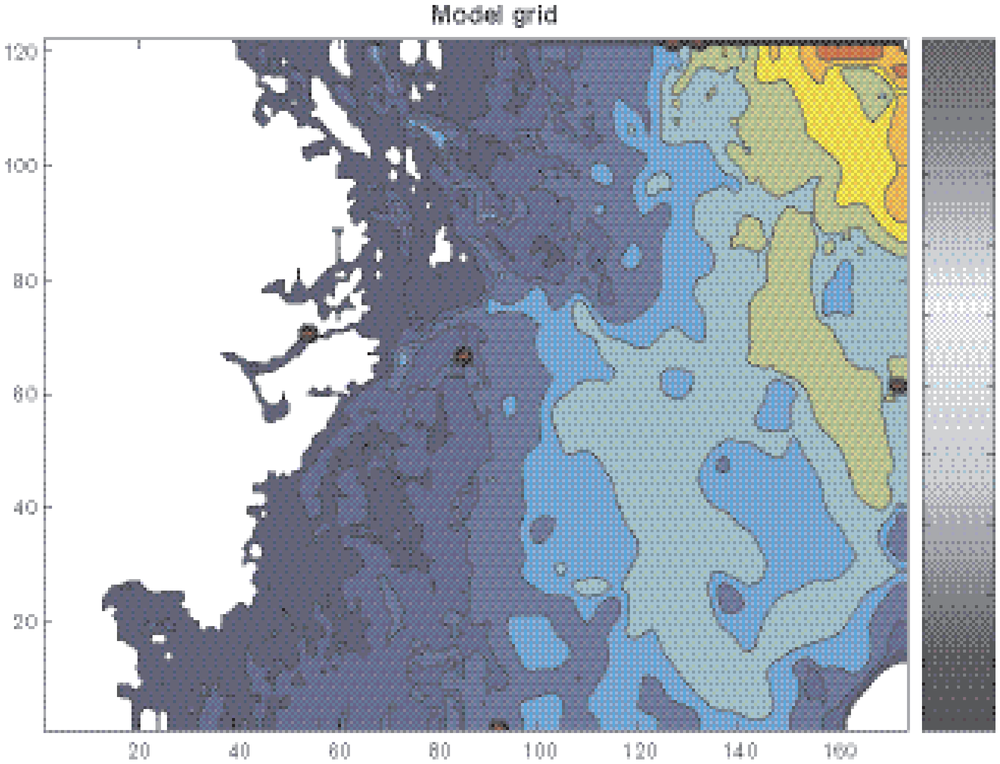

Figure 3-56. *The chosen model area with some of the grid cells manipulated manually. In the southeast corner a bit of the Öland island can be seen. The sites of the six measurement stations where oceanographic instruments are deployed for the 2004 field program are indicated a red spot against black background.*

The coastal area has been partitioned into a number of non-overlapping sub-basins (SBs) based on consideration of present underwater structures that potentially in the future with the current land rise will progressively accentuate the confinement of the water movements to a higher degree. One of these areas is considerably greater than all the others combined, and represents the open coastal section that is regarded as an intermediary stage for the eventual water exchange to the Baltic; this will be referred to as the major coastal SB, Figure 3-57. The computation of ATR-times will be performed with the major coastal SB both excluding and including all the sub-basins to obtain information of how these differ.

The bottom along the Simpevarp coast gradually slopes in the offshore direction so there are few topographic features that naturally indicate a well-defined delimitation line. In the absence of evident bathymetrical delimitation the average internal Rossby radius of convergence has been used which delineates a near-shore distance where up- and downwelling takes place. This means that a distance 5 km off the coast /Fennel et al. 1992/ defines this larger area.

The exchange of any of the SBs with the Baltic waters can then be estimated by staging this two-fold exchange in series, an approximation that is valid to the extent that the area of an SB is small in comparison to the total area of the larger computational domain. Some of these SBs are also coincidental, with anticipated leakage points connecting to geosphere. The water exchange of such a particular sub-basin area relative the Baltic Sea, then comes focus and is achieved in two steps. First, each of these SBs is subjected individually to estimation of their ATR-time, counting all ambient waters including other sub-basins as exogenous. Second, the ATR-time of the major coastal SB relative the Baltic is computed. The uncertainty of this appreciation may be confined within the values using the exclusive and inclusive representation of the coastal basin.

3.5.2 Description of conceptual models

The hydrography of the Simpevarp coastal area can be categorized as a rugged bottom next to the coast with an archipelago-like structure continued under the present sea level, intermittently sloping in the NE-direction towards increasing depths, reaching 80 m in the NE corner of the domain, Figure 3-56. In the southeast direction, the coast is shielded by the Öland island that progressively narrows the water passage until it reaches its minimum cross-sectional area at Kalmarsund with an average depth less than 6 m except for a small dredged channel. Only a few studies of water exchange in this area are known to have been performed and these are restricted to technical reports /e.g. Svensson and Erlandsson, 1978/, in which the influence of baroclinically induced ventilation was disregarded, however.

For contemporary coastal oceanography of an open (in contrast to landlocked) coastal section, three-dimensional (3D) models represent the state of the art. When the aspect ratio (vertical scale to horizontal scale quotient) is sufficiently smaller than unity, the hydrostatic approximation applies, and the numerically more efficient shallow water equations can be employed. When more articulated horizontal resolution is demanded, this simplification may eventually need to be abandoned, resulting in considerably increased computational effort. The forcing of the coastal zone model also necessitates providing information about the sea level and density fluctuations at the boundary toward the Baltic. Since only few such measurements are available, this problem can be handled by coupling two 3D-models in a cascade arrangement along simple geometrical interfacial lines so that information of the large-scale Baltic events are transferred into the better resolved fine-scale coastal areas. In any such cascaded coupling arrangement some information must necessarily be lost. A common method also presently employed is to create a buffer zone over which the incoming and outgoing surface waves and similarly two-way internal density wave modes are permitted to be relaxed.

The Baltic model (AS3D) employed in this study /Andrejev and Sokolov, 1989,1990/ has been developed for the main purpose of providing insight into the circulation of the central Baltic. Its present horizontal resolution is 2'×2' (nautical miles) based on the Warnemünde hypsographic data. The horizontal eddy diffusivity is nominally set to 30 (m^2/s), consistent with assuming the grid cells to be well mixed. This model is presently involved in several ongoing Baltic hydrographic studies /e.g. Andrejev et al. 2004a,b/. A thorough testing of this model in comparison to measured data /Engqvist and Andrejev, 2003/ revealed that along an interface to a model area comprising the Stockholm archipelago, the measured salinity and temperature profiles were acceptably well reproduced, with the main difference being an offset in salinity. This evaluation thus strongly increased confidence in the AS3D-model. The heat exchange with the atmosphere is mainly determined by the air temperature; likewise the ice formation and melting processes are formulated in a simple but straightforward manner. This would be a liability if the main concern were to correctly predict the ice situation, but this is not the case, and for projection into a distant future, climate scenarios could more likely produce a prognosis of shifting air temperatures, while other factors determining the heat exchange (insolation, relative humidity and nebulosity) would be more difficult to predict.

The 3D-domain grid has been computed from DEM based on national digitized charts, and complemented with shoreline information from economical maps. The grid has been specified in spherical coordinates WGS84 (sweref 99 long lat ellh) with the constraint that to be considered as a wet grid cell, at least 50% of the covered area should consist of water. The Simpevarp coastal area was resolved horizontally into 0.1×0.1 nautical mile grid cells (Figure 3-55). The final choice of the actual model area (Figure 3-56) includes a part of the Öland mainland in the southeast corner. The grid resolves the main underwater features of this coastal section, but does so more poorly for near-shore areas of the island clusters and for the landlocked waters around the Äspö island. In fact, when using the objective gridding criterion that at least 50% of an area must consist of water, meant that the connection to the sea for these interior waters was interrupted on a few locations. In order to attach these to the main computational domain, manual corrections were performed.

The water exchange of semi-enclosed landlocked waters is different from that of the open offshore waters because the confinement to channels entails a reduced degree of freedom of current directions. When quantifying the exchange of landlocked basins, two principally different

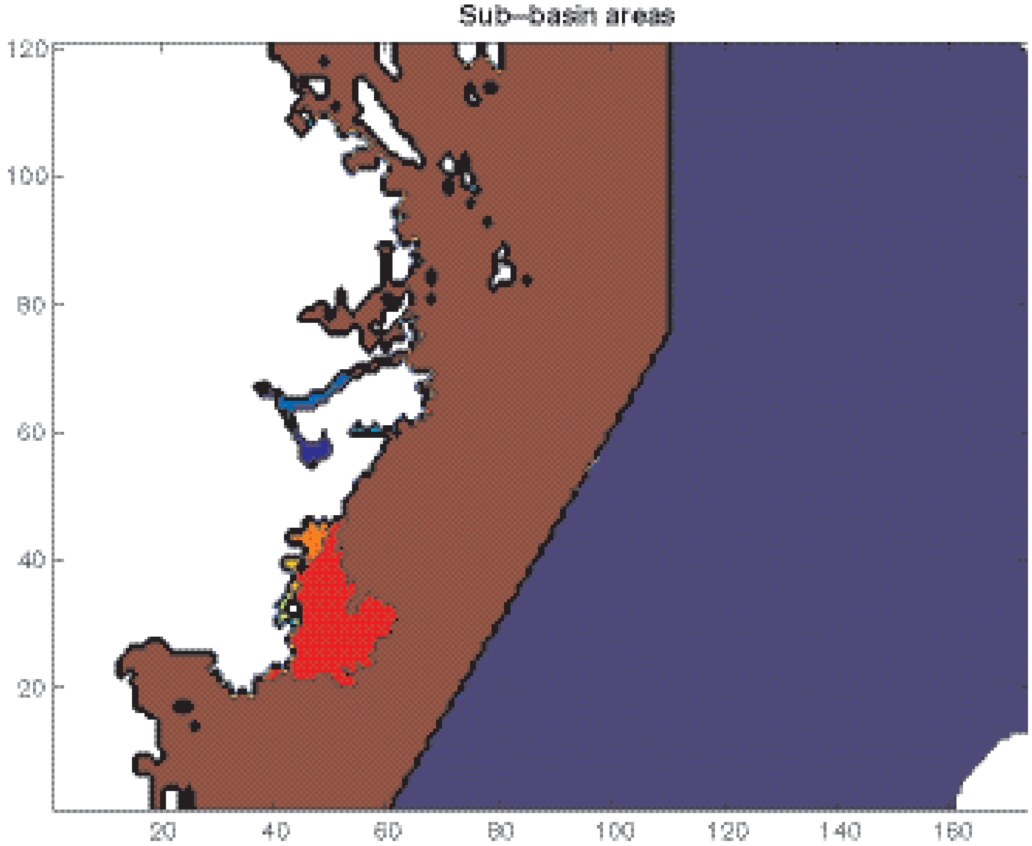

Figure 3-57. *The sub-basins' location indicated in other colors than dark blue. The coastal major sub-basin is depicted in dark red. It has been delimited by one internal Rossby radius off the coast, which approximately corresponds to 5 km or about 30 grid cells perpendicular to the major coastline direction.*

approaches are available: the first is to employ another three-dimensional (3D) model with even better horizontal resolution, the second is to resolve the area into hydraulically coupled, vertically resolved, discrete 1D-basins interconnected by straits /Engqvist, 1996,1997; Engqvist and Andrejev, 2003/. This can be accomplished in various ways, depending on the demand for horizontal resolution, Figure 3-56. The 3D-based method may potentially necessitate more sophisticated (non-hydrostatic) numerical models when applied to landlocked areas, making the second approach more attractive. However, this approach demands a refined description of the geometrical characteristics of the straits. In particular the existence or absence of a sill will strongly influence the water exchange /e.g. Dalziel, 1992/. A central condition is that the volume of the straits should be small compared to that of the basins and that the basins should to a high degree of approximation be horizontally well mixed. The response of the basins to the exchanged water adds to the local forcing, of which wind normally is the major cause of vertical mixing /Stigebrandt, 1985/. Basins that receive freshwater discharge also display a notable estuarine circulation mode. Even with an established estuarine circulation flow regime, the varying density stratification in the offshore waters is often the dominant cause of ventilation of coastal basins /Stigebrandt, 1990; Engqvist and Omstedt, 1992/. The choice of appropriate models to simulate the water exchange thus depends on the external forcing, the hypsography, and how the various model areas are hydrographically connected. For the same reason as for the Baltic model, the heat dynamics is presently based on prescribed surface temperatures and observations of ice formation and melting. If this would be regarded as inappropriate for making it possible to base the heat exchange with the atmosphere on more detailed forcing, this can be included in the model following, for example /Omstedt, 1999/.

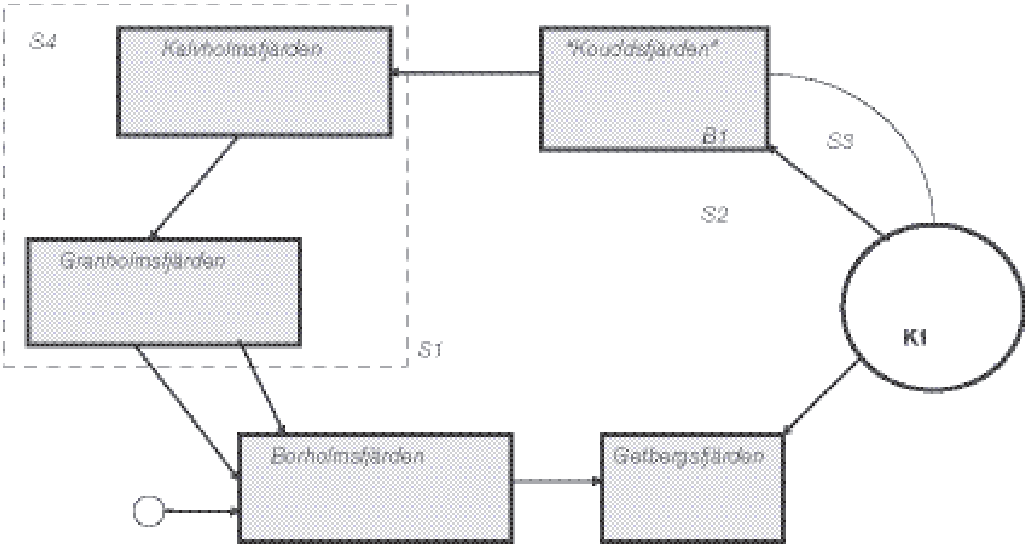

Figure 3-58. *Configuration of the DB-model of the three sub-basins (SB) in the vicinity of Äspö island, adapted from /Engqvist, 1997/. Sub-basin 2 (SB2) is for ecological purposes presently consisting of Granholmsfjärden and Kalvholmsfjärden conjoined. The resulting SBs are connected by seven straits S1 through S8, disregarding S4 that now has become an interior strait in SB2. The measurement station K1 was not in operation during the type-year 1981. Corresponding salinity and temperature data have been computed by the local 3D-model, Figure 3-60.*

3.5.3 Input data and data evaluation

Atmospheric forcing

Synoptically gridded (1°×2°) so-called Mueller-data are consistently used from which wind components, air pressure and temperature are extracted every 3 h. One instance of checking the wind against local measurements did not given any reason for concern; on the contrary the local wind measured at Örskär (Figure 3-54) was well represented in the actual synoptic wind /Engqvist and Andrejev, 1999/. Neither has there been any reason to doubt the accuracy of this data set: a numerical experiment comparing the outcome for the DB-model driven by wind data of the nearest coastal measurement station (Ölands Norra Udde) with the local wind of the Mueller synoptic data revealed the differences in computed ATR-times were so minute that such excerpts of Mueller data could be used confidently. For estimates of distant future coastal water exchange, more refined and explicit atmospheric thermal forcing (e.g. humidity, insolation and nebulosity) cannot be relied upon since these will also mainly be unknown. In the place of three unknown parameters, it is preferred to have only one unknown, i.e. the surface temperature.

Kattegat boundary data

For the Baltic model the sea level, salinity and temperature of the Kattegat model border also need to be appreciated. The sea level data are gauged both on the Swedish side (Göteborg) and on the Danish side (Fredrikshavn). The difference between those levels is an important model parameter providing the geostrophic adjusted flow. The absolute vertical position of these gauges is not possible to reliably reconstruct from accessible data; instead the long-term average has been used for obtaining this information. The salinity and temperature profiles are mainly determined by North Sea dynamics and display a repeated pattern from year to year /Gustafsson, 2000/; these averages a have been used. Aberration from these used averages will have the consequence that a slow drift in the average salinity will be induced which will only marginally affect the dynamics of the surface layers constituting the better resolved local model domain. If sufficient data are available, then procedures of data assimilation can be performed.

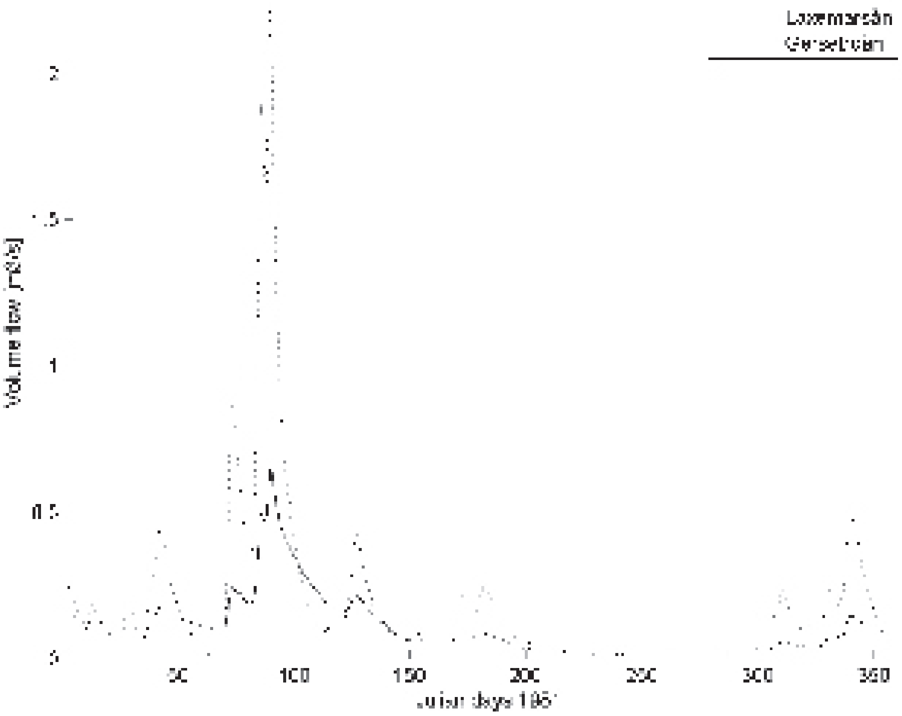

Figure 3-59. Discharge of the two major streams Laxemarsån and Gerseboån 1981.

Freshwater discharge data

The freshwater discharge of the two streams Laxemarsån and Geseboån (retrieval ID: Sicada_04_77) have a discharge capacity (Figure 3-59) that could contribute significantly to the water exchange of the coastal region by inducing estuarine circulation, at least in the spring when the volume fluxes peak. These fluxes have been calculated from the HBV-model /Jenny Ryman, SMHI, pers. comm./ for the actual type-year 1981. Since these data are from Sicada the corresponding QC-issues are deferred to the person responsible for this database. There were no surface temperature records nor observations on ice formation and melting events available for 1981, so these data have been based on observations from an interior coastal embayment (Kvädöfjärden) that is located a few kilometres to the north recorded by Fiskeriverket /J Andersson, pers. comm./.

3.5.4 Quantitative models

The complete set of equations of the AS3D-model including boundary formulation and numerical scheme is given in /Andrejev and Sokolov, 1997/, making it superfluous to reiterate them here. In the present version, the Baltic area including the section of its Kattegat boundary is resolved by a 315×363 cell grid. The integration time step is normally 1 hour, except on storm occasions when it has been lowered to 0.5 hour. This model is under continual development and is presently used in several ongoing Baltic hydrograpic studies: /Engqvist and Andrejev, 2003/ and /Andrejev et al. 2004a,b/.

The first coupling of two cascaded AS3D-models was performed by /Engqvist and Andrejev, 1999/. The Simpevarp area (Figure 3-54 and 3-56) with the planned depository is located centrally in the north/south direction in a grid that contains 174×121 grid cells. The horizontal eddy diffusivity has been set to 20 (m^2/s) and the integration time step has necessarily been set to as low as 1.2 minutes. The basic equations are essentially identical to those of the Baltic model, but one difference is that the interfacial border to the Baltic is affected by the computed sea level, salinity and temperature data of the Baltic model. Computational results from this model are both ATR time for some of the SBs (presented in Table 3-12) and forcing data corresponding to station K1 (Figure 3-60), which is used for forcing of the DB-model. The 1-year mean of the ATR times are depicted in Figure 3-61.

The landlocked sub-model areas are not well suited to be adequately subjected to 3D-modelling. The basins adjacent to the Äspö islands are included in the 3D-domain but the resolution is poor, which is also the case for the other southernmost SBs. These areas are instead resolved into SBs delimited by straits according to /Engqvist, 1997/, Figure 3-58. For flow regimes with feeble river discharges and only moderately intense sea level fluctuations, it is plausible that the exchange of the comparatively shallow individual straits can be modeled using a simplified formulation by /Stigebrandt, 1990/. If this results in not being the case, a more refined strait exchange formulation /Engqvist and Stenström, 2004/ can be employed. ATR-age computations for the first three sub-basins (with hitherto available provisionary hypsographic data) are given in Table 3-12 and Figure 3-62.

Table 3-12. ATR-time (days) estimates for five of the nine SBs. The vertically integrated volume-averaged statistics for SB1 through SB3 are computed with the coupled discrete basin model based on earlier extracted hypsographic data, while for SB8 and SB9 these volume averages are calculated directly from 3D-model results, which have a temporal resolution of one hour. SB4 through SB7 are not sufficiently resolved by the 3D grid and the corresponding calculation must be postponed until their basin and strait hypsographies are available.

		Min	Mean – S.D.	Mean	Mean + S.D.	Max
SB1	Borholmsfjärden	7.0	8.1	9.0	9.9	10.7
SB2	Granholms- and Kalvholmsfjärden	24.5	25.5	26.4	27.4	29.5
SB3	Getbergsfjärden	3.1	3.6	5.5	7.3	11.7
SB8		0.03	0.13	0.19	0.26	0.43
SB9	Major coastal sub-basin	0.04	0.95	1.61	2.28	3.0

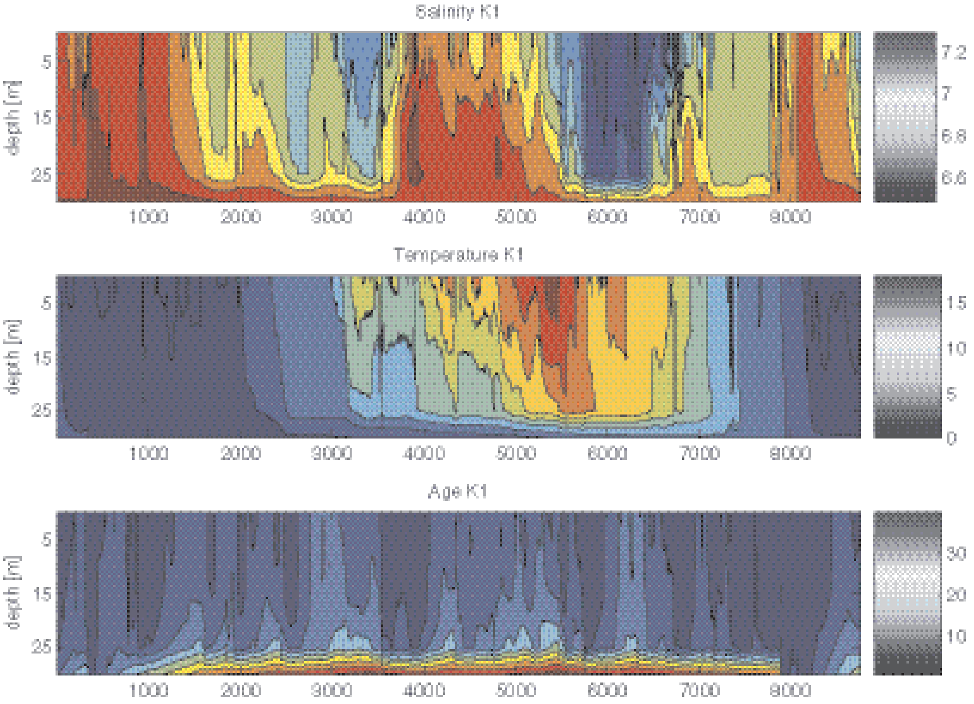

Figure 3-60. *Computed salininity, temperature and ATR-age profiles during the type-year 1981 at a location corresponding to the K1 measurement station. The incidences of up- and down-welling occasions are clearly seen as is the stabilizing thermal stratification during the summer period. The elevated ATR-age near the bottom is due to the circumstance that on the location of K1 in the model, there is a bottom cavity that retains the contained water which has to leave mainly by being replaced by up-welled denser water. This is of no consequence for the baroclinic forcing of the DB-model since the connecting straits are considerably shallower.*

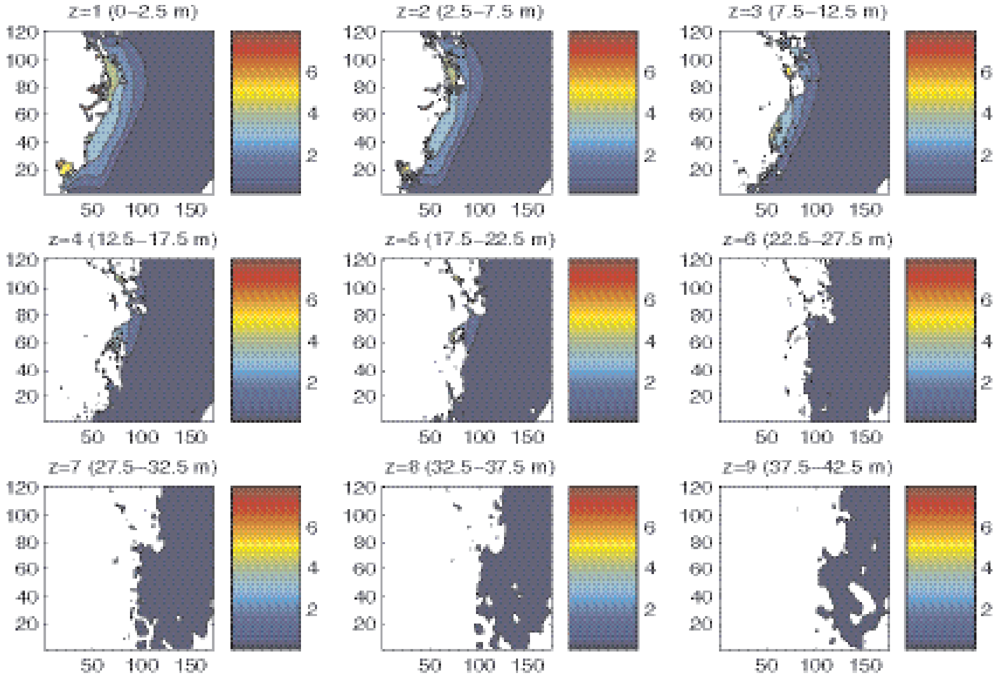

Figure 3-61. *ATR times calculated as a yearly average of the type-year 1981 considering all the SBs conjoined to obtain a conservative estimate. Exogenous water is entering from outside the 5 km offshore boundary and also as discharge from the two streams, Figure 3-57. The calculation is based on bi-monthly samples of the ATR times for the different strata down to a depth (42.5 m) that exceeds the deepest part of this area. Even for the innermost SBs that are separately modelled for reasons cited, the average ATR times are safely smaller than one year.*

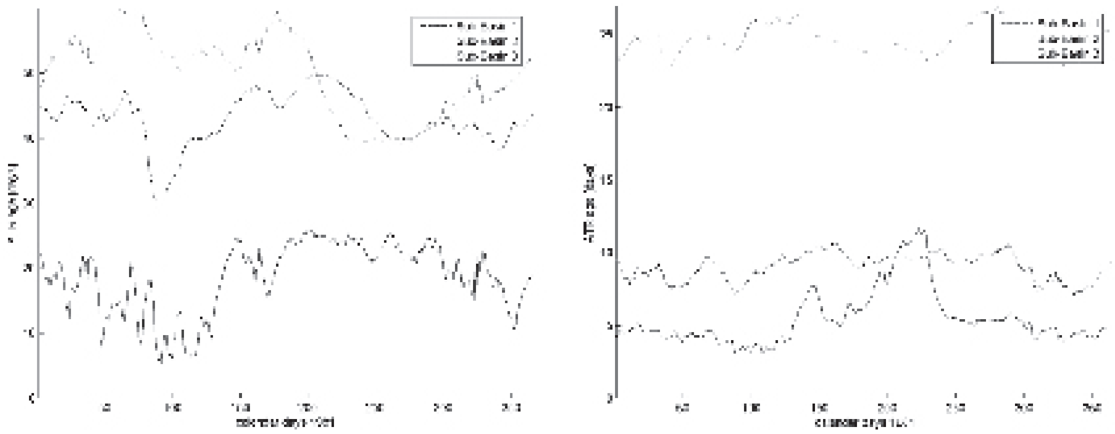

Figure 3-62. *Calculations of ATR times during 1981 of SB1 through SB3 with the major coastal basin counted as exogenous (left panel) and all adjacent basins counted as exogenous waters with an upheld ATR-age set to zero (right panel), which is referred to as relative ATR-times. These volume averaged data form the basis of the statistics presented in Table 3-12.*

3.5.5 Confidence and uncertainties

No model run is complete without a sensitivity analysis. An encompassing such analysis with regard to sensitivity of ATR-times variations to the forcing factors was performed in /Engqvist and Andrejev, 2000/. An ongoing thorough field data program with the sole aim of collecting systematic validation data entailing six measurement stations (Figure 3-55) over a full-year cycle in the Simpevarp area will determine decisively the level of confidence with which these models can be invested. Two general limitations can be pointed out, however:

Scarcity of Baltic salinity and temperature data for initialization or assimilation purposes limits the prospect of differentiating the interannual Baltic hydrography. For longer time scales, sensitivity analyses of the Baltic dependence on its forcing /Gustafsson, 2004/ may possibly be used.

Sea level computed by local 3D-model at K1 must be adjusted with added short-term fluctuations, since the 3h temporal resolution of the wind forcing does not suffice to reproduce the measured variance according to /Engqvist, 1997/.

3.6 Chemical properities

3.6.1 Introduction

A comprehensive description of the chemical properties in surface ecosystems will include a wide array of parameters (elements and compounds) and processes, varying both in time and space in several different media (water, regolith and biota). Water is by far the most important medium for transport of elements and matter, and the site investigations concerning chemical properties in the surface system have so far been concentrated to analyses of samples from surface water and near-surface groundwater. The site investigation programme for 2005 is planned to include analyses of chemical properties also in the regolith and in biota.

The results presented in this report represent only a part of the total data produced within the programme, and the aim is mainly to give a first characterisation and understanding of the site based on site data. Chemical properties and processes in the surface system in the Simpevarp and Laxemar subareas will be thoroughly discussed in forthcoming reports, when more data is available.

3.6.2 Input data and data evaluation

Data on **surface water** chemistry has been collected biweekly to monthly from October 2002, and the sampling programme includes 18 streams, 4 lakes and 4 sea sampling sites (see Figure 3-63). The stream and lake sampling sites represent 7 different drainage areas in the regional model area. The number of sampling occasions for each sampling site varies between 14 and 29, mainly due to weather conditions (storm, unsafe ice-cover, dried up or frozen streams) occasionally preventing sampling of some sites. Analysed parameters include, for most samples, major cations and anions, nutrients, organic compounds and O_2 (Table 3-13). Water temperature, pH, conductivity, salinity and turbidity were determined in the field. Moreover, trace elements were analysed at one sampling occasion (June 2003), whereas stable and radiogenic isotopes were analysed at 1-4 sampling occasions per year.

The surface water sampling programme is described in detail in /Ericsson and Engdahl, 2004a,b/, together with a compilation of primary data from the first year of sampling. In the present report, all available data at data freeze 1.2 has been included in the analyses when nothing else is stated. However, since no thorough evaluation of the surface water chemistry in the regional model area has been performed yet, some of the result presented here rely on the report by /Ericsson and Engdahl, 2004a/.

Data on **near-surface groundwater** has been collected from 13 wells (shallow boreholes), all situated in the Simpevarp subarea. The analysed water was sampled from levels situated in the glacial till or in the transition zone between till and bedrock. Each well has been sampled once, in the springs of 2003 or 2004. The forthcoming groundwater program will include a series of analysed samples from each well, and an evaluation of the seasonal variation in groundwater chemistry will be performed later when longer time series are at hand.

Data on water chemistry in **precipitation** has regularly been collected from one sampling site, however, no evaluation of the chemical composition of the precipitation has been performed yet. No data on the chemistry in regolith or in biota has so far been collected in the site investigations.

Figure 3-63. *Map showing the sampling sites for stream, lake and sea water in the Simpevarp regional model area. The delineated catchment areas and sub-areas are indicated on the map.*

Table 3-13. Parameters analysed in the site investigation programme for chemical properties in surface waters and near-surface groundwater.

Main cations and anions	Na, K, Ca, Mg, Si, Cl HCO_3^-, SO_4^{2-} and S^{2-}
Nutrients and organic compounds	NO_2–N, NO_3–N, NH_4–N, N–tot, P–tot, PO_4, POP (Particulate organic P), PON (N), POC (Particulate organic C), DIC, DOC, TOC, Chlorophyll–a, Chlorophyll–c and Pheopigment
Trace elements	U, Th, Al, As, Sc, Cd, Cr, Cu, Co, Hg, Ni, Zn, Pb, V, Rb, Y, Zr, Mo,In, Cs, Ba, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu
Stable isotopes	^{18}O, ^{2}H, ^{13}C, ^{37}Cl, ^{10}B, ^{34}S
Radiogenic isotopes	^{226}Ra, ^{222}Rn, ^{238}U, ^{235}U, ^{234}U, ^{232}Th, ^{230}Th,^{14}C age, ^{3}H and ^{87}Sr
Other data	Temperature, pH, conductivity, salinity, turbidity and O_2

3.6.3 Description and conceptual model

Surface water

The lakes and streams in the Simpevarp regional model area are, similar to most surface waters in the northern parts of the Kalmar County, relatively poor in nutrients while they are rich in organic matter, mainly humic compounds, which gives the water a brownish colour. The catchment areas in the model area are generally small, which means that some of the streams periodically show very low discharge or even get dry. Most of the surface water from the regional model area drains into a few, relatively confined, coastal basins, and the water chemistry of these basins will therefore differ considerably from the water chemistry of the outer parts of the archipelago.

Streams

The 18 stream sites in the regional model area represent 7 different drainage areas. Catchment areas for the stream sites vary from less than 1 km^2 to more than 40 km^2. One might expect concentrations of main constituents and nutrients to be lower in the smaller tributaries upstream and higher in downstream sites, but this pattern is only partly reflected in the results (Table 3-14). The lowest concentration of most major ions is found in the two small tributary sites at Lillekvarn (PSM002072) and Sillebäcken (PSM002078). However, some of the other small tributaries, e.g. Basteböla (PSM002086), show relatively high concentrations of both ions and nutrients. This is likely a combined effect of agricultural activities nearby the site and the close distance to the sea. It can also be noted that the site at Jämserum (PSM002069), situated just downstream Lake Jämsen, show low concentrations of nutrients (C, N and P), and that the chemical characteristics of this site is very similar to that of the surface water in Lake Jämsen (cf. Table 3-15).

Generally, the stream sites in the regional model area show only minor differences from average values for the 26 stream sites in Kalmar County which were included in the National Survey of lakes and streams, performed in 2000 (Table 3-14). Mean values for major ions and conductivity are somewhat lower for sites in the model area, which is somewhat surprising in light of the relative close distance to the sea. On the other hand, mean values for C/N/P-fractions, and especially for total nitrogen, are somewhat higher for sites in the model area than for the National Survey sites. As mentioned above, this is partly due to high nutrient concentrations in some sites situated near farming areas. Mean values of alkalinity and pH for stream sites in the Simpevarp area are low, especially for upstream sites with small sub-catchment areas (Table 3-14). However, total absence of carbonate alkalinity has only been noted for one site (four sampling occasions at Lillekvarn, PSM002072).

Lakes

Only a few lakes are situated within the regional model area. Four of these, Lake Frisksjön (PSM002065), Lake Jämsen (PSM002067), Lake Söråmagasinet (PSM005964) and Lake Götemar (PSM002066), are included in the programme for surface water chemistry. Nutrient concentrations in the three first lakes are moderate and they can be characterized as mesotrophic with brown water (Table 3-15). Lake Götemar shows considerably lower concentrations of nutrients and can be classified as an oligotrophic clearwater lake. Most of Lake Götemar is situated outside the northern part of the regional model area and it drains outside the model area. However, its inclusion in the programme is well motivated since it represents a type of lake that in the future may develop in the model area due to shore displacement, and knowledge of this type of lake is important for the safety analysis.

Compared to average values for 106 lakes in Kalmar County which were included in the National Survey of lakes and streams in year 2000, the Simpevarp lakes show higher concentrations of ions associated with marine water and of total nitrogen (Table 3-15). The buffering capacity of the investigated lakes, measured as HCO_3-concentration, is generally good and the pH values are close to neutral and stable over the season. Accordingly, there are no signs of anthropogenic acidification affecting the lakes.

Since three of the lakes are highly coloured and relatively deep, and since the clear Lake Götemar is as much as 16 m deep, all the lakes have a profundal zone, i.e. a zone where the light conditions are too poor to enable any primary production. In the summer, a thermal stratification evolves in all four lakes. Due to the decomposition of organic matter, oxygen levels become low in the bottom water during stagnant conditions, both in summer and in winter. This is most pronounced in Lake Jämsen, where the oxygen level was below 1 mg/l during the period July–September 2003. Although oxygen levels during stagnant periods become low also in the other lakes, levels below 1 mg/l has not been noted in any of these lakes.

Table 3-14. Compilation of selected chemical parameters for stream sites in the regional model area of Simpevarp. The table shows mean values based on 1-2 samplings per month during the period October 2002 to April 2004 (N for the different sites vary between 14 and 28). The summary in the shaded part of the table is based on calculated mean values for each site, and the data for Kalmar County stream sites originates from the National Survey of lakes and streams 2000.

IDCODE	Name		Na (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	Cond (mS/m)	Tot–N (mg/l)	Tot–P (µg/l)	TOC (mg/l)	DOC (mg/l)	pH	Catchment	
															Number	Area (km^2)
Stream sites																
PSM002080	Misterhult		8.3	9.2	1.8	18.7	9.7	7.3	11.3	1.27	42.1	23.0	22.5	6.3	5	4.9
PSM002081	Perstorpet		4.8	12.0	1.8	24.0	4.7	9.3	10.3	1.36	47.1	24.9	23.8	6.4	5	8.3
PSM002082	Misterhultsbäcken ö		7.5	11.7	2.1	25.2	8.7	9.1	12.4	1.57	41.7	23.2	22.4	6.4	5	17.3
PSM002083	Smedstorpet		9.8	10.4	2.2	17.3	11.6	13.1	13.5	1.38	50.1	22.3	21.4	6.4	5	27.2
PSM002084	Kärrsvik		10.2	16.8	3.6	29.0	10.7	27.3	18.0	1.59	43.9	20.2	19.5	6.6	6	1.9
PSM002085	Ekerum		8.1	29.0	3.5	67.7	6.8	25.3	21.3	2.05	42.3	20.1	19.7	7.3	9	2.5
PSM002072	Lillekvarn		10.5	4.8	1.2	2.5	13.6	3.0	9.6	1.17	33.8	32.6	31.7	5.6	10	3.4
PSM002078	Sillebäcken		4.3	6.7	1.6	3.4	4.3	14.7	8.1	1.00	22.4	18.8	18.4	5.7	10	3.5
PSM002068	Köksmåla		4.9	8.3	2.0	15.4	5.1	7.4	8.9	1.23	24.5	22.0	21.1	6.4	10	5.1
PSM002069	Jämserum		8.4	8.3	2.2	13.8	11.6	8.8	11.4	0.98	17.5	18.4	17.9	6.6	10	7.0
PSM002071	Plittorp		11.4	9.6	2.6	16.6	17.6	11.7	14.3	0.97	24.7	16.7	15.6	6.4	10	13.5
PSM002077	Brolund		10.1	9.5	2.5	15.4	14.4	12.3	13.6	1.08	37.2	19.8	18.3	6.3	10	30.2
PSM002079	Kvarnstugan		9.9	9.7	2.5	14.8	14.3	13.8	13.5	1.12	33.7	19.0	17.7	6.3	10	34.6
PSM002087	Ekhyddan		10.1	10.8	2.7	17.0	14.1	15.6	14.2	1.22	37.2	19.4	18.3	6.5	10	40.8
PSM002086	Basteböla		14.1	18.8	4.2	17.4	17.5	43.2	21.7	2.70	67.9	27.7	26.8	6.1	13	0.7
PSM002076	Övrahammar		7.8	14.0	2.5	20.9	8.3	16.8	13.6	2.26	79.8	33.8	32.3	6.2	17	4.7
PSM002070	Flohult		10.9	12.6	2.8	30.1	15.7	6.8	14.8	1.10	30.5	19.6	19.3	6.6	18	2.4
PSM002075	Figeholm		9.9	12.2	2.9	26.1	12.8	10.1	14.2	1.36	38.5	23.2	22.5	6.5	18	8.2
Summary, Simpevarp stream sites		Min	4.3	4.8	1.2	2.5	4.3	3.0	8.1	0.97	17.5	16.7	15.6	5.6	–	–
		Mean	8.8	12.2	2.5	21.0	10.9	15.3	13.7	1.43	39.6	22.4	21.6	6.4	–	–
		Max	14.1	29.0	4.2	67.7	17.6	43.2	21.7	2.70	79.8	33.8	32.3	7.3	–	–
Mean, Kalmar County stream sites (n = 26)			11.3	13.0	3.6	21.3	18.8	21.0	16.6	0.94	23.6	17.4	–	6.7	–	–

Table 3-15. Compilation of selected chemical parameters for the surface water (0.5 m depth) of lake and sea sites in the regional model area of Simpevarp. The table shows mean values based on 1-2 samplings per month during the period October 2002 to April 2004 (N for the different sites vary between 14 and 28). The summaries in the shaded parts of the table are based on calculated mean values for each site, and the data for Kalmar County lake sites originates from the National Survey of lakes and streams 2000.

IDCODE	Name		Na (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	Cond (mS/m)	Tot–N (mg/l)	Tot–P (µg/l)	TOC (mg/l)	DOC (mg/l)	pH	Catchment	
															Number	Area (km²)
Lake sites																
PSM002065	Frisksjön		9.5	7.2	2.3	12.6	10.4	12.2	11.7	1.11	24.0	16.5	16.2	6.7	7	1.8
PSM002066	Götemar		10.9	9.9	2.9	11.3	15.0	21.9	15.2	0.60	8.1	9.1	9.0	7.0	–	–
PSM002067	Jämsen		8.6	8.4	2.2	13.9	12.1	9.0	11.6	0.98	16.6	18.4	17.8	6.7	10	7.0
PSM005964	Söråmagasinet		14.2	11.1	3.6	35.2	18.6	14.9	17.5	0.85	19.3	12.1	12.0	7.2	11	0.5
Summary, Simpevarp lake sites		Min	8.6	7.2	2.2	11.3	10.4	9.0	11.6	0.60	8.0	9.1	9.0	6.7	–	–
		Mean	10.2	8.8	2.6	16.3	13.2	13.7	13.4	0.92	18.0	14.8	14.5	6.9	–	–
		Max	14.2	11.1	3.6	35.2	18.6	21.9	17.5	1.11	24.0	18.4	17.8	7.2	–	–
Mean, Kalmar County lake sites (n = 106)			4.8	8.3	2.3	17.5	5.5	10.3	8.6	0.58	19.4	13.4	–	6.5	–	–
Sea sites																
PSM002060	Kråkelund		1,977	94.5	235	91.2	3,576	531	1,122	0.28	20.6	4.0	3.9	7.9	–	–
PSM002061	Ekö		1,994	95.3	236	92.2	3,624	527	1,134	0.3	21.3	4.0	4.0	8.0	–	–
PSM002062	Borholmsfjärden		1,172	60.6	141	59.0	2,117	304	676	0.74	21.9	10.3	10.1	7.5	–	–
PSM002063	Fågelöfjärden		1,907	89.8	227	89.2	3,484	500	1,093	0.34	21.0	4.3	4.4	7.9	–	–
PSM002064	Granholmsfjärden		1,443	71.9	175	72.6	2,704	389	868	0.61	19.7	8.50	8.2	7.6	–	–
Summary, Simpevarp sea sites		Min	1,172	60.6	141	59.0	2,117	304	676	0.28	19.7	4.0	3.9	7.5	–	–
		Mean	1,675	81.6	200	79.9	3,059	444	966	0.47	21.0	6.4	6.3	7.8	–	–
		Max	1,994	95.3	236	92.2	3,624	531	1,134	0.74	21.9	10.3	10.1	8.0	–	–

Sea

The five investigated sea sites can be divided into two different types. The first type represents the open sea and outer archipelago and consists of three sites; Kråkelund (PSM002060), Ekö (PSM002061) and Fågelöfjärden (PSM002063). These sites are situated quite close to the open sea and show similar conductivity and similar concentrations of most analysed parameters (Table 3-15).

The other type of site is situated in relatively confined bays close to the mainland and consists of two sites; Borholmsfjärden (PSM002062) and Granholmsfjärden (PSM002064). These sites show lower concentrations of ions than the open sea sites, while the concentration of organic compounds and nutrients, especially the nitrogen fractions, are considerably higher (Table 3-15). As a consequence of the relatively high concentration of organic compounds (humus), water transparency in these bay sites was rather low throughout the year /Ericsson and Engdahl, 2004a/.

The oxygen concentration in the bottom water was high throughout the year in the three more open sites, while almost anoxic conditions were noted in the bottom water of both bay sites in late summer 2003.

Near surface groundwater

The chemical composition of the groundwater is an effect of both present and past processes. The Simpevarp area is situated in a coastal area, which has been completely covered with brackish water and still is subjected to the crustal land upheaval (cf. Section 3.1). Relict saline groundwater may consequently remain, especially in areas with QD which have a low hydraulic conductivity /cf. Aastrup et al. 1995/. The chemical composition of the groundwater may also be affected by chemical weathering, which leads to leaching of metals and other elements to the water. This is especially evident in areas where the overburden and/or bedrock contain calcite, which often causes high concentrations of Ca and high alkalinity in the groundwater /Aastrup et al. 1995/. Antrophogenic emissions can cause high groundwater concentrations of some elements both on a local and a regional scale.

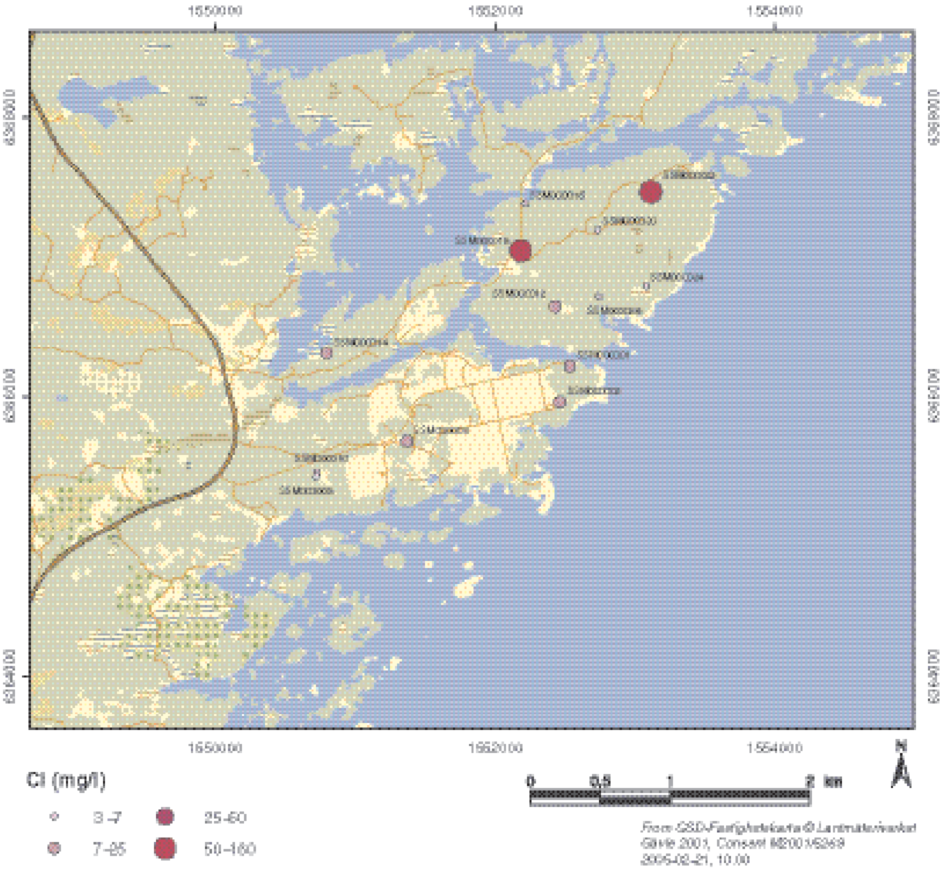

Figure 3-64. *Cl concentration in ground water wells from the Simpevarp subarea. The samples were taken during the springs of 2003 and 2004.*

Results from the investigation of ground water chemistry in the Simpevarp subarea are summarised in Table 3-16. The results for Mg, Ca, HCO_3, Cl, SO_4, Mn and pH was compared with the median values for groundwater from open aquifers in till or wave washed sediments situated at the west and south coast of Sweden /Naturvårdsverket, 1999/. The results from Simpevarp was also compared with values for the whole of Sweden /Aastrup et al. 1995/. These comparisons show that the chemical composition of the ground water is normal in most of the wells, except for Mn which show ten times higher median concentrations than the normal /cf. Naturvårdsverket, 1999/. The reason for the high Mn concentrations is not known.

Water from some of the wells has a relatively high salinity due to water remaining since the area was situated completely below the brackish Baltic Sea. The highest electric conductivity Cl (Figure 3-64) and Na concentrations were measured in two wells (SSM000018 and SSM000022), which are situated in areas where the uppermost overburden constitutes of clay, 1.5 and 3 meter respectively. The clay cover may have obstructed the water movement and can therefore explain the presence of relict saline water at these two sites. Also the alkalinity (Figure 3-65) is relatively high in water from several wells (Table 3-16, above 200 mg/l), which may be an effect of relict saline water /cf. Naturvårdsverket, 1999/. The alkalinity and pH (Figure 3-66) are positively correlated.

The normal Ca concentrations show that the groundwater has not been affected by calcite dissolution (Figure 3-67), which indicates that the QD in the Simpevarp subarea contain only minor amounts of $CaCO_3$.

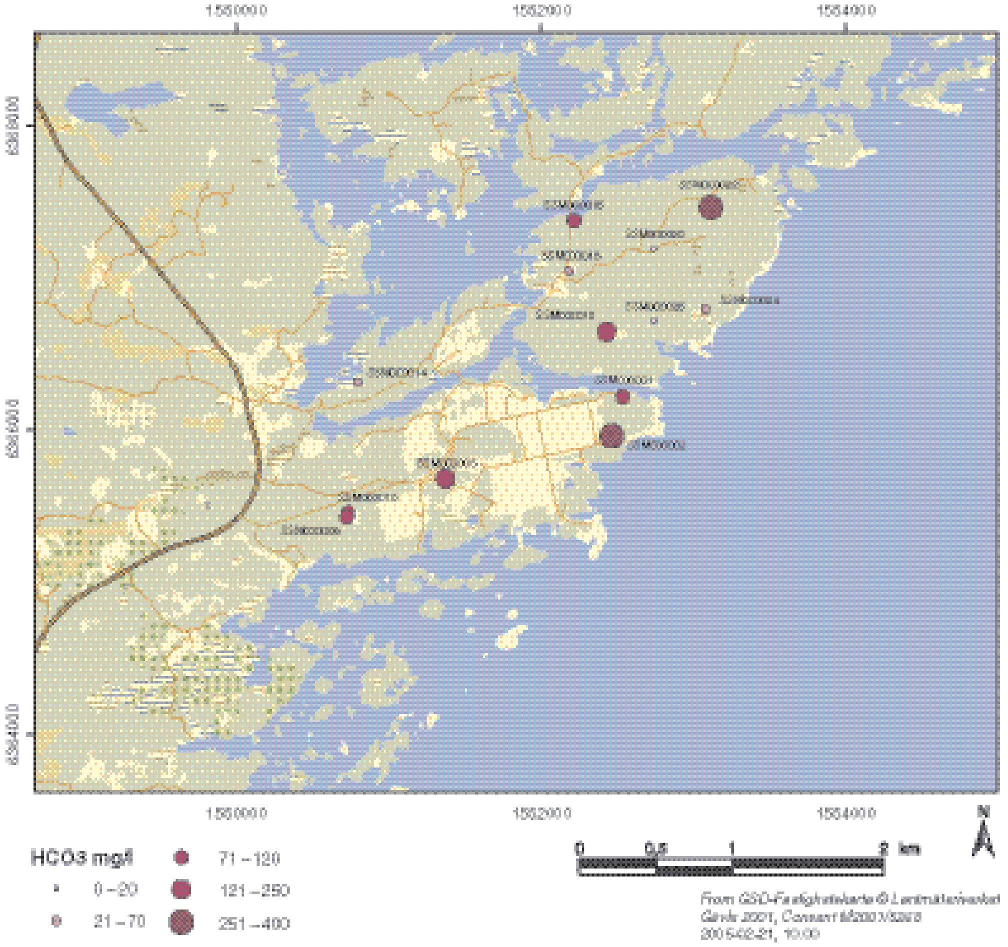

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Figure 3-65. *HCO_3 concentration in ground water wells from the Simpevarp subarea. The samples were taken during the springs of 2003 and 2004.*

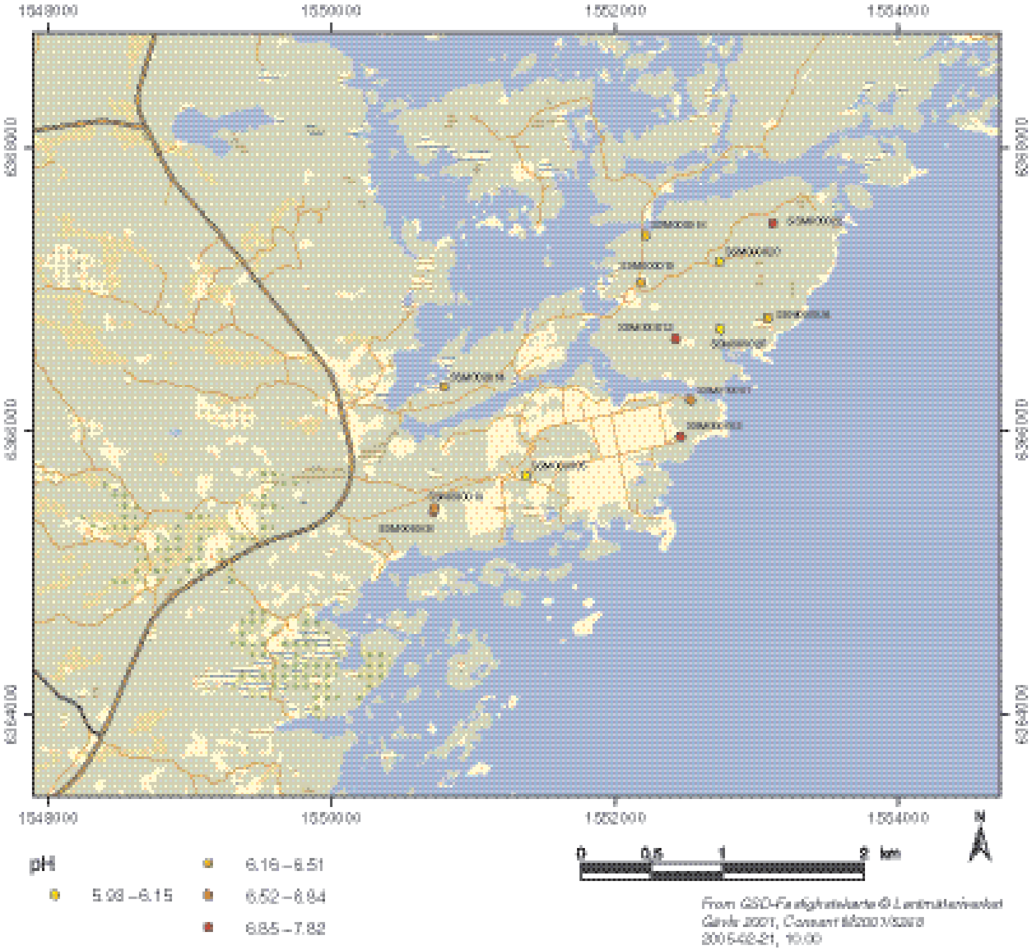

Figure 3-66. *pH in ground water wells from the Simpevarp subarea. The samples were taken during the springs of 2003 and 2004.*

No emissions from local antrophogenic sources have affected the composition of the groundwater. The data presented here do, however, not include any measurements of trace elements. The groundwater concentration of sulphate may be affected by the relatively high antrophogenic deposition from precipitation, which is characteristic for southern Sweden /Aastrup et al. 1995/.

Table 3-16. Chemical composition of ground water in the Simpevarp subarea. The samples were taken during the springs of 2003 and 2004.

	Average	Median	Max	Min	N
Na (mg/l)	34.4	10.1	232	4.6	13
Ca (mg/l)	33.2	30.2	91.2	9.1	13
Mg (mg/l)	10.1	9.2	28.8	2.3	13
HCO_3 (mg/l)	113	82	371	2	15
Cl (mg/l)	25.3	7.1	157	3.2	13
SO_4 (mg/l)	35.1	15.4	130	4.1	13
Si (mg/l)	11.4	10.8	22.2	4.9	13
Mn (mg/l)	0.80	0.3	6.0	0.09	13
Li (mg/l)	0.018	0.015	0.041	0.009	11
Sr (mg/l)	0.13	0.10	0.28	0.03	13
Cond. (mS/m)	38.8	25.7	121	11.9	13
pH	6.8	6.51	7.91	6.28	13

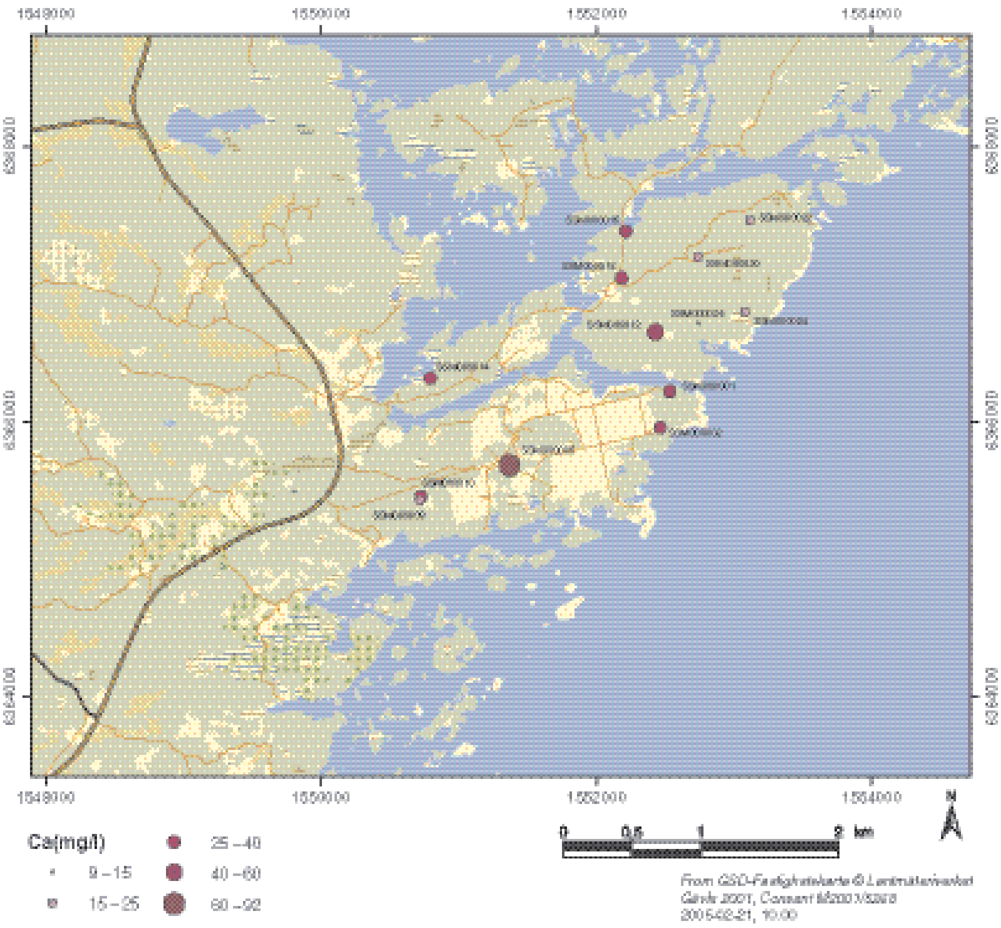

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Figure 3-67. Ca concentration in ground water wells from the Simpevarp subarea. The samples were taken during the springs of 2003 and 2004.

Chemical properties of the regolith, of biota and of atmospheric deposition

No new information concerning chemical properties of the regolith (overburden), of biotic components, or of atmospheric deposition in the Simpevarp area is available for this version of the site descriptive model.

3.7 Terrestrial biota

This section describes the terrestrial biota divided into producers and consumers at Simpevarp site.

3.7.1 Primary producers

The primary producers are here described in general terms, such as dominating vegetation and species composition, and in specific terms using quantitative data, such as biomass. It is a description of the taxa found at the site, consisting of species lists for various organism groups belonging to the plant kingdom, such as vascular plants, bryophytes, algae and lichens, and fungi that are found in the area. The purpose of this property is to assist in the classification of functional groups, such as tree, bush, field and ground layer species, and the identification of dominant taxa, and not to provide a complete list of all species in the area.

General description

Vegetation

The vegetation is very much influenced by the bedrock, quaternary deposits and human land management. Bedrock does mainly consist of granites. The quaternary deposits are mainly wave washed till while silt and clay have been deposited in the valleys. This pattern is clearly manifested in the vegetation where pine forests dominate on the till and all the arable land and pastures (abandoned arable land) are found in the valleys. Human management has been restricted to agriculture activities in the valleys while forestry has been the dominating activity elsewhere. The spatial distribution of different vegetation types is presented in the vegetation map /Figure 3-68, Boresjö Bronge and Wester, 2002/.

The forests are dominated by dry pine forests situated on bedrock or nutrient poor thin soils with shrubs, mostly *Calluna vulgaris*, and grasses, such as *Deschampsia flexuosa*, *Agrostis vinealis* and *Festuca ovina*, and with lichens and mosses dominating in the ground layer. When these pine forests get moister *Vacinium vitis-ideae* and *Vacinium myrtillus* gets more common in the field layer. The spruce becomes abundant were a deeper soil cover is found, however the deciduous tree species are an important constituent near the coast, i.e. mainly *Quercus robur* but also *Corylus avelana*, *Sorbus acuparia*, *S. intermedia* and *Acer platanoides*, making the mixed forest the second commonest forest type. *Q. robur* is often the dominant tree species when more or less pure deciduous forests are found. The character of these forests is a function of boulder frequency, nutrient availability and earlier history of management at the specific spot.

Arable land, pastures and clear cuts dominate the open land. Arable land and pastures are found in the valleys close to settlements. The pastures were earlier intensively used but are today a part of the abandoned farmland following the nation wide general regression of agriculture activities.

The dominating wetland type is the nutrient poor mire that is accumulating peat /Rühling, 1997; SNV, 1984/. A special type of semi wetland is found in the pine-dominated bedrocks where water filled depressions ("hällkar" in Swedish) are formed /Lundin et al. 2004a,b/. These obtain all their water from precipitation and have therefore a *sphagnum*-dominated community, much bog like, with *Ledum palustre* and *Pinus silvestris*, with a peat layer accumulating on the bedrock. These may vary a lot in size and may in some cases be large.

As a consequence of the forestry activities in the area there are a lot of clear-cuts to be found in different successional stages (Table 3-17). *Betula pendula* is the dominating species in many of the earlier successional stages until it is replaced by young *Picea abies* or *Pinus silvestris* depending on soil type and/or management.

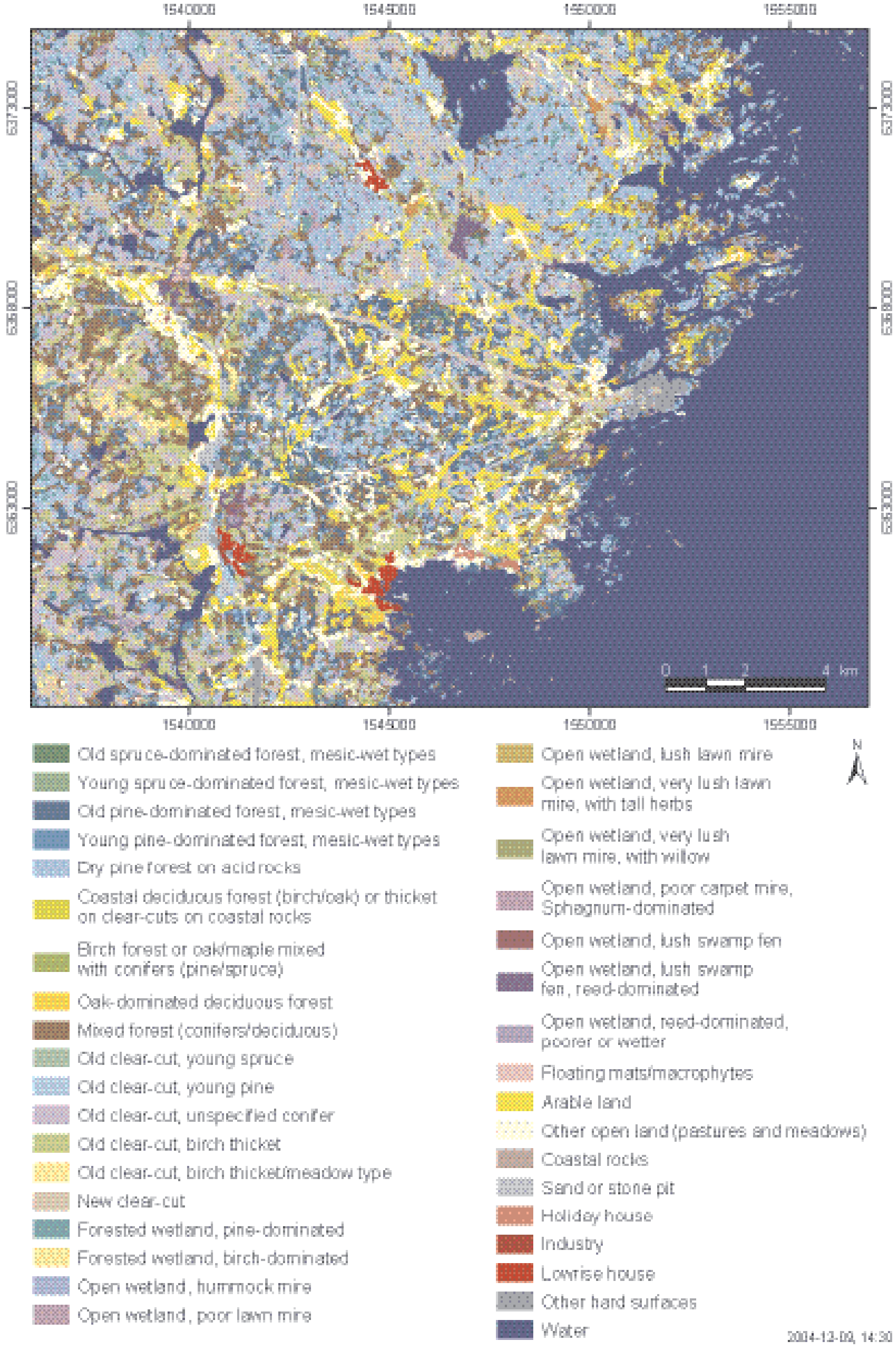

Figure 3-68. *Vegetation map covering the Simpevarp area from /Boresjö Bronge and Wester, 2002/.*

Table 3-17. The spatial coverage of the different land use/vegetation classes in relation to the total land area.

Land use/vegetation classes	Gridcode	N	Area (m^2)	MIN	MAX	%
Old spruce forest, mesic-wet types	11	1,646	6,336	16	331	2.5
Young spruce forest, mesic-wet types	12	1,158	5,457	17	88	2.2
Old pine forest, mesic-wet types	13	5,829	55,726	16	878	22.2
Young pine forest, mesic-wet types	14	2,251	4,974	25	33	2.0
Dry pine forest on acid rocks	15	4,755	31,193	16	3,641	12.5
Coastal deciduous forest (birch/oak) or thicket on clear-cuts on coastal rocks	23	621	3,276	17	112	1.3
Birch forest or oak/maple mixed with conifers (pine/spruce)	24	1,770	6,571	16	82	2.6
Oak-dominated deciduous forest	25	877	3,852	16	141	1.5
Mixed forest (conifers/deciduous)	30	5,358	36,306	16	692	14.5
Old clear-cut, young spruce	41	464	1,064	25	32	0.4
Old clear-cut, young pine	42	4,596	23,747	16	374	9.5
Old clear-cut, unspecified conifer	43	3,737	21,903	16	561	8.7
Old clear-cut, birch thicket	44	3,308	11,338	16	142	4.5
Old clear-cut, birch thicket/meadow type	45	651	1,889	16	113	0.8
New clear-cut	50	1,293	5,767	16	159	2.3
Forested wetland, pine-dominated	62	362	1,983	16	137	0.8
Forested wetland, birch-dominated	63	223	1,235	17	99	0.5
Open wetland, hummock mire	71	109	324	25	29	0.1
Open wetland, poor lawn mire	72	255	728	17	58	0.3
Open wetland, lush lawn mire	73	89	300	25	20	0.1
Open wetland, very lush lawn mire, with tall herbs	74	52	403	25	63	0.2
Open wetland, very lush lawn mire, with willow	75	26	91	798	36	0.0
Open wetland, poor carpet mire, Sphagnum-dominated	76	7	34	629	11	0.0
Open wetland, lush swamp fen	77	150	544	25	57	0.2
Open wetland, lush swamp fen, reed-dominated	78	194	1,523	16	317	0.6
Open wetland, reed-dominated, poorer or wetter	79	202	960	17	65	0.4
Floating mats/macrophytes	80	38	134	25	32	0.1
Arable land	81	599	9,085	16	240	3.6
Other open land (pastures and meadows)	82	1,056	9,436	16	242	3.8
Coastal rocks	83	382	1,425	16	61	0.6
Sand or stone pit	85	11	576	25	137	0.2
Holiday house	91	8	142	4,643	32	0.1
Industry	92	2	111	45,785	65	0.0

Species composition

The flora in this region has been investigated within the project "The flora of Oskarshamn" /Rühling, 1997/ that is a description of the distribution of vascular plants that is found within the municipality of Oskarshamn. The flora has also been investigated within the "National survey of forest soil and vegetation" that has located 38 sample plots in the area. Their methods include abundance data for 230 species of vascular plants, lichens and mosses. Moreover, is an additional 24 sample plots located by SKB within the area using the same methodology for taxa as "National survey of forest soil and vegetation" /Andersson, 2004b/.

Red listed species

All information concerning redlisted plants from the site have been obtained from the Swedish Species Information Centre (*Sw: Artdatabanken*) and are presented in Table 3-18. Further information concerning the actual species is presented in /Berggren and Kyläkorpi, 2002/.

Table 3-18. Summarized information of observations of redlisted species within the regional model area of Simpevarp from the register at Swedish Species Information Centre /Kyläkorpi, 2005/.

Taxa	No. of observations	No. of species
Vascular plants	146	21
Lichens	17	4
Fungi	10	8
Mosses	5	3

Protected areas

A number of sensitive areas of conservational interest are located within the site. Some areas have an extensive protection while others are so far unprotected but are under planning. These areas are extensively listed in /Kyläkorpi, 2005/. There are today three areas that are legally protected as nature reserves.

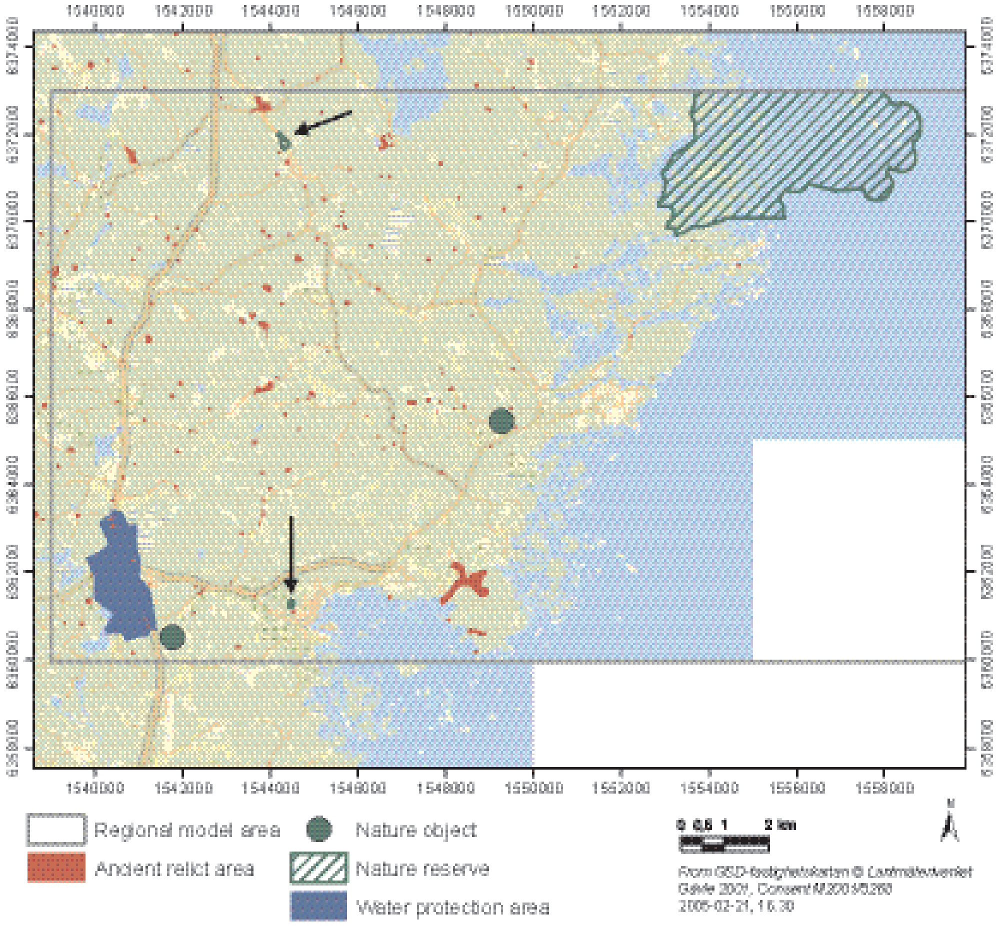

Figure 3-69. *Map illustrating areas of conservational interest in Simpevarp from /Kyläkorpi, 2005/. Arrows indicate the location of two small nature reserves (Figure 3-69, Table 3-19).*

Table 3-19. Legally protected areas of conservational interest at the site from /Kyläkorpi, 2005/.

Value	Name	Characteristics	No. of objects	Area (ha)
Nature reserve (Naturreservat)	Stenhagen	Area with hardwood forest (ädellövskog)	1	1.42
Nature reserve (Naturreservat)	Talldungen	Boulder ridge with old pine forest	1	4.61
Nature reserve (Naturreservat)	Misterhults skärgård	Archipelago with interesting cultural history and fauna	1	8,500.18
Nature object (Naturminne)	–	Single object or very small areas, protected by law	2	N/A
Ancient relict area (Fornlämnngsområde)	–	Areas with ancient cultural remains	294	173.29
Water protection area (Vattenskyddsområde)	–	Fresh water reserves	2	269.26

Forest Key Habitats

Forest key habitats are areas where red listed animals and plants exist or could be expected to exist /Nitare and Norén, 1992/. A nationwide survey of these habitats has been conducted in Sweden administrated by the Swedish Board of Forestry /SBF, 1999/. As a complement to this survey SKB initiated a deepened survey at the site. 46 habitats were identified with the total area of 61 ha /Sturesson, 2003/. The dominating key habitat type, both in number of objects and total area, at the site is old semi-natural grasslands or meadows with old pruned (*Sw: hamlade*) deciduous trees in close proximity to old settlements (Table 3-20). Generally are the woodland key habitat found in habitats dominated by deciduous trees. These habitats are often a relict of an older and more open landscape created by intensive management.

Table 3-20. The woodland key habitats found in the Oskarshamn area after /Sturesson, 2003/. Swedish names within brackets.

Habitat	Number	Area (ha)
Deciduous trees on semi-natural grasslands (Lövängsrest)	11	18.4
Deciduous trees on poor ground (Hedädellövskog)	8	13.5
Old pine forest on thin soil layer (Hällmarkstallskog)	5	10.7
Aspen forest (Aspskog)	7	5.8
Conifer forest with a high content of deciduous trees (Lövrik barrnaturskog)	7	5.3
Hazel forest (Hassellund)	1	2.2
Decidous forest (Ädellövskog)	3	2.1
Old conifer forests (Barrnaturskog)	1	1.6
Old deciduous forest (Ädellövnaturskog)	1	0.7
Decidouos rich forest edges (Lövrika skogsbryn)	1	0.3
Large deciduous trees (Grova ädellövträd)	5	0.2

Wetlands

The wetlands in this area is characterised by nutrient poor mires /Rühling, 1997; SNV, 1984/. A number of interesting wetlands have been identified within the area. The Environmental Protection Agency has identified 10 object of particular interest (Figure 3-70; Table 3-21)

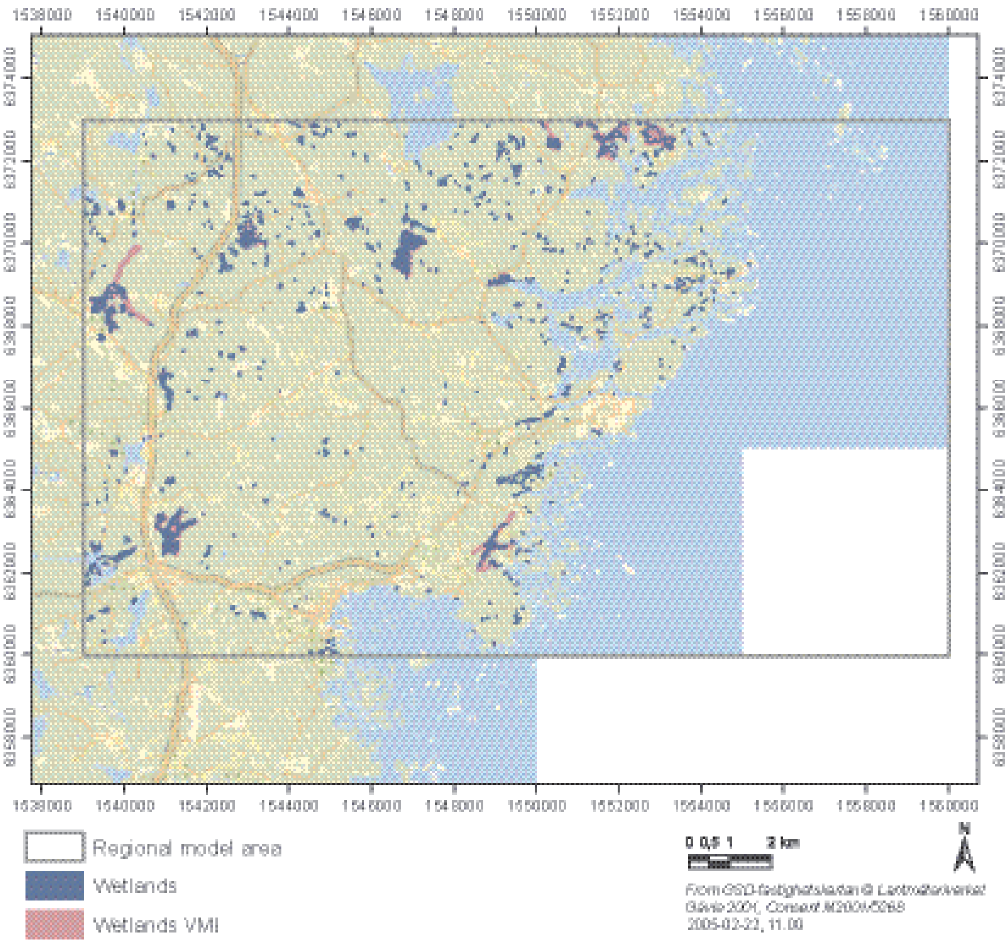

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Figure 3-70. Wetland areas within the regional model area after /Kyläkorpi, 2005/. Wetlands in pink are classified by the Environmental Protection Agency.

Table 3-21. Information of wetlands within the regional model area of Forsmark after /Kyläkorpi, 2005/. The Environmental Protection Agency uses four classes to classify wetlands according to their estimated nature value. Class 1 is regarded to have the largest nature value.

Characteristics	No. of objects	Area (ha)
Class 2	4	169.35
Class 3	4	175.38
Class 4	2	59.78
Derived from the vegetation map	1,007	497.17

Descriptive biomass and NPP models – introduction

The vegetation constitutes a major part of living biomass and comprises the main primary producers in terrestrial ecosystems. The biomass and necromass will therefore be an important measure of how much carbon that may be accumulated in a specific ecosystem. Similarly, the net primary production (NPP) will be an estimate of how much carbon (and other elements) that is incorporated in living tissue. Thus, combining net primary production and decomposition rates will give a rough estimate of the carbon turnover in the ecosystem. The primary producers covering the terrestrial landscape are described using biomass and NPP in order to feed a conceptual ecosystem model with data (see Section 4.1). This section describes the components, the resolution and the methodology that is used to build the quantitative descriptive models of biomass and NPP that are further treated in Section 4.1.

Biomass

The plant biomass in an area consists of a number of different components that all have to be measured or estimated to correctly estimate the total biomass (Figure 3-71). Some of these components are well studied while others are poorly investigated which make total biomass difficult to estimate. There are several reasons for the differences in knowledge. Some of the components are extremely labour intensive to study, e.g. root turnover. In the case of mycorrhizae there are few investigations available and have therefore not been included in biomass calculations until quite recently.

NPP

Photosynthesis provides the carbon and the energy that are essential for many important processes in ecosystems. Photosynthesis directly supports plant growth and produces organic matter that is consumed by animals and soil microbes. The photosynthesis at an ecosystem level is termed gross primary production (GPP). Approximately half of the GPP is respired by plants to provide the energy that supports the growth and maintenance of biomass /Chapin et al. 2002/. The net carbon gain is termed net primary production (NPP) and is the difference between GPP and plant respiration. However, GPP can not be measured directly and total respiration is difficult to measure, especially in multi-species forests /Gower et al. 1999/.

The different components, constituting the NPP for a certain ecosystem may be measured separately /Clark et al. 2001/ (Figure 3-72). NPP is here the sum of all materials that have been produced and are retained by live plants at the end of the interval and the amount of organic matter that was both produced and lost by the plants during the same interval /Clark et al. 2001/. NPP can then be calculated directly using eq.:

$$\text{NPP} = \sum P_i + H \tag{3.2}$$

where P is the net production of dry biomass for each of the plant tissues (i), including wood, foliage, reproductive tissue, roots (including mycorrhizae) and H is the consumption of organic matter by herbivory.

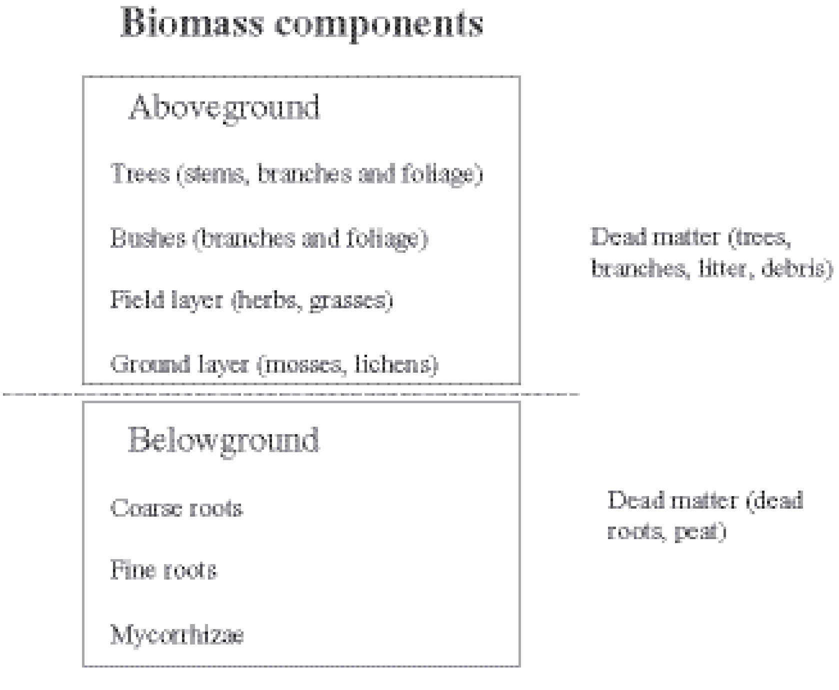


***Figure 3-71.** The different components of biomass in a forest.*

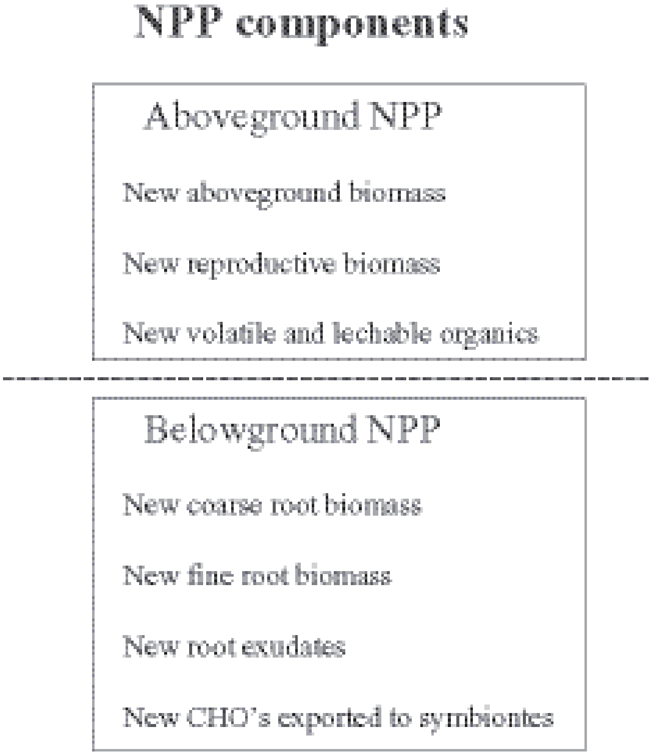


Figure 3-72. *The changes in biomass components that together constitutes the NPP during a specific time interval /after Clark et al. 2001/.*

A number of components have been omitted that so far are considered to be less important. Studies concerning volatile and lechable components above ground suggest that these components constitute an insignificant loss of the forest NPP /Clark et al. 2001, Persson and Nilsson, 2001/. Root exudates and transport to symbionts are poor studied fields but some studies have shown that the loss may be significant at the individual level with up to 30% of the NPP. No estimates of root exudates and transport to symbionts are known at the forest stand level, and this flux is therefore left for further investigations. A general review of herbivory showed that herbivory generally is less than 10% of NPP in forests except during insects outbreaks when it can be up to 50% of NPP /Schowalter et al. 1986/. Herbivory by insects on Scots Pine (*Pinus sylvestris*) was estimated to be 0.7% of the total needle biomass and 2.5% of the total needle production during one year /Larsson and Tenow, 1980/, while root consumption by phytophagous nematodes was estimated to 0.3% of the annual production of fine roots /Magnusson and Sohlenius, 1980/. Herbivory is, due to the low documented effect on total NPP in boreal systems, excluded from the calculations of NPP in equation. Herbivory by other animals is discussed in Section 3.7.2.

The stock of dead plant tissue and the yearly flux of dead organic matter are important for both the input of organic matter to the soil organic matter pool and for the calculation of NPP. However, we have no data of losses of larger branches and coarse roots or mortality of living trees. No data are available f the estimated ingrowth, which is the recruitment of new trees.

The components

The tree is divided into stem, branches and foliage. The green tissue is of particular importance as it continuously is replaced while the dead tissue will remain until the death of the entire tree. The trees are often the major component of the total biomass if present. This biomass component has a long history of interest because of its value to the forest industry. For example, /Marklund, 1988/ developed allometric functions describing the distribution of biomass (dry weight) among the different parts of a tree for Scots pine, Norway spruce and Birch. These functions are based on 1,286 sampled trees of various dimensions covering the whole of Sweden from a wide variety of stand and site conditions. The National Forest Inventory (NFI) calculates the volume of trees for Norway spruce, Scotch pine, Contorta, Birch, and other deciduous trees in the forest. This volume can be partitioned into dead, green and non-green biomass /Marklund, 1988/. These figures can be used to estimate the total biomass and the biomass partitioned into dead, green and non-green biomass for each habitat type in the area.

The shrub layer lack per definition a stem but may nevertheless gather a considerable biomass over time and may in some habitats be a major constituent e.g. *Salix sp.* on mires or *Betula pendula* on clear-cuts.

The field layer constitutes of herbs, grasses and dwarf shrubs (e.g. *Vacccinium vitas-idaea*). The significance of this layer to the total plant biomass vary between habitat and may in grasslands be the major constituent while being of low importance in some types of mires and forests.

The ground layer includes all plants that are directly attached to the ground or litter e.g. lichens and mosses. Lichens may be the dominating plant in dry pine forests while the mosses may be of significance in moist Norway spruce forests and is the dominating plant in mires.

Roots are often defined after their function, where fine roots has the major function of absorbing water and nutrients from the surrounding soil while the coarse roots may have multiple functions where the size has an important role /Persson, 2002/. There is no conventional definition of fine roots, but many forest biomass studies have defined fine roots as having a diameter less than 5 mm /Vogt and Persson, 1991/ and correspondingly are coarse roots having a diameter more than 5 cm in diameter. However, it is important to notice that this distinction is more or less arbitrarily and is crudely related to their function.

The fine roots of forest trees are almost always infected by mycorrhizal fungi /Persson, 2002/. Their total contribution to the total biomass is low (≈ 1%, /Vogt et al. 1982/). However, few studies have incorporated this component into biomass calculations. A conceptual model for the terrestrial environment is presented in Figure 3-73.

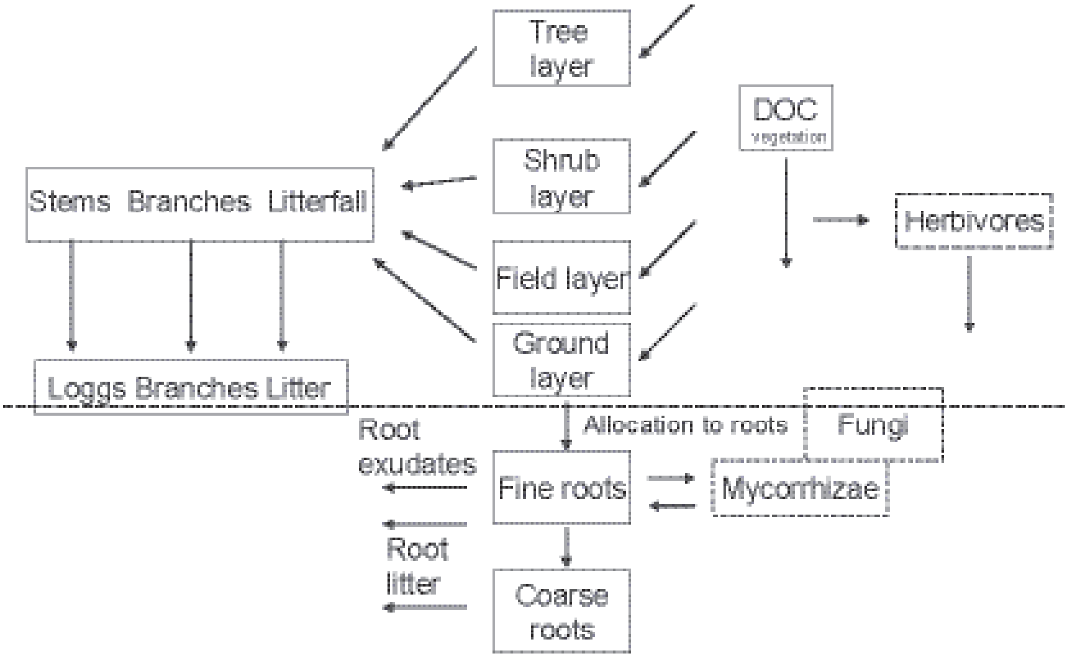


Figure 3-73. *An illustration of the different pools and fluxes of matter in a terrestrial ecosystem with the focus on the producers. Boxes with broken line are consumers but are here partly included in this section. Herbivores are also described in Section 3.7.2.*

Descriptive biomass and NPP models – methodology

Input data

The descriptive model contains a large number of components that describe biomass (Table 3-22), NPP (Table 3-23) and turnover of plant tissue (Table 3-24). These tables also present information concerning site specificity of the data, where it is published and some information about the method used to estimate/calculate results. NPP is sometimes (e.g. for trees) only available as the net accumulation of biomass during one year. In those cases are the NPP and the turnover different. Sometimes are the NPP and turnover set to equal, as a simplification, meaning that there is no net accumulation of biomass between years.

All the results are presented in carbon per square metre (dw gCm^{-2}) for biomass components and in carbon per square metre and year (dw gCm^{-2}year^{-1}) for NPP and turnover components.

Table 3-22. The different functional units and their components that describe the biomass of the vegetation. All components are presented in dw gCm^{-2}. Data is taken from the three categories L/R/G, which is Local/Regional/Generic. Data may also come from Forsmark and is then denoted accordingly. The source is showing from where the data is taken. Method describes how the result in this report was calculated. BEF is biomass expansion factor.

Functional unit	Component	Data L/R/G	Source	Method ref
Tree layer	Woody parts (AG)	L/R	NFI	Measured, Allometric eq.
	Needles/Foliage	L/R	NFI	Allometric eq.
	Coarse roots	L/R	NFI	BEF
	Fine roots	L/R	NFI	BEF
Shrub layer	Woody parts	G	/Gower et al. 2001/	Measured, allometric eq.
	Green parts	G	/Gower et al. 2001/	Measured
	Coarse roots	G	/Gower et al. 2001/	Allometric eq.
	Fine roots	G	/Gower et al. 2001/	Allometric eq.
Field layer	Green parts	Forsmark	/Fridriksson and Öhr, 2003/	Measured
	Non-green parts	Forsmark	/Fridriksson and Öhr, 2003/	Measured
	Below ground	Forsmark	/Fridriksson and Öhr, 2003/	BEF
Ground layer	Mosses	Forsmark	/Fridriksson and Öhr, 2003/	Measured
	Lichens	Forsmark	/Fridriksson and Öhr, 2003/	Measured
Fungi	Mycorrhizae/mycelia	G	/Vogt et al. 1982/	Measured
Dead organic material	Loggs	Forsmark	/Andersson, 2004/	Measured
	Branches	R	/Berggren et al. 2004/	Measured
	Litter layer	Forsmark	/Fridriksson and Öhr, 2003/	Measured
Rotzon	Depth	L	/Lundin et al. unpubl./	Measured

Table 3-23. The different functional units and their components that describe the NPP of the vegetation All components are presented in dw gCm^{-2}year^{-1}. Data is taken from the three categories L/R/G, which is Local/Regional/Generic. Data may also come from Forsmark and is then denoted accordingly. The source is showing from where the data is taken. Method describes how the result in this report was calculated. BEF is biomass expansion factor.

Functional unit	Component	Data L/R/G	Source	Method ref
Tree layer	Woody parts (AG)	L/R	NFI	Measured, equations
	Needles/Foliage	L/R	NFI	BEF
	Coarse/fine roots	L/R	NFI	BEF
	Ingrowth	No data	–	–

Functional unit	Component	Data L/R/G	Source	Method ref
Shrub layer	Woody parts	G	/Gower et al. 2001/	Measured, allometric eq.
	Green parts	G	/Gower et al. 2001/	Measured
	Coarse roots	G	/Gower et al. 2001/	Allometric eq.
	Fine roots	G	/Gower et al. 2001/	Allometric eq.
Field layer	Green parts	Forsmark	/Fridriksson and Öhr, 2003/	Measured
	Below ground	Forsmark	/Fridriksson and Öhr, 2003/	BEF
Ground layer	Mosses	G	/Bisbee et al. 2001/	Measured
	Lichens	No data	–	–
Fungi	Mycorrhizae/mycelia	G	/Vogt et al. 1982/	Measured

Table 3-24. The different functional units and their components that describe the turnover of the vegetation. All components are presented in dw gCm^{-2}year^{-1}. Data is taken from the three categories L/R/G, which are Local/Regional/Generic sources. The source is showing from where the data is taken. Method describes how the result in this report was calculated. BEF is biomass expansion factor.

Functional unit	Component	Data L/R/G	Source	Method ref
Tree layer	Needles/Foliage (litter fall)	L/R	/Berggren et al. 2004/	Measured
	Fine roots	G	/Majdi, 2001/	BEF
Shrub layer	Green parts	G	/Gower et al. 2001/	BEF
	Fine roots	G	/Gower et al. 2001/	BEF
Field layer	Green parts	G	/Fridriksson and Öhr, 2003/	BEF
	Below ground	G	/Fridriksson and Öhr, 2003/	BEF
Fungi	Mycorrhizae/mycel	G	/Vogt et al. 1982/	BEF
Dead organic material	Branch fall	R	/Berggren et al. 2004/	Measured

Conversion factors

Stem volume was presented in the data from The National Forest Inventory (NFI) for the net accumulation per year and was converted into biomass using Table 3-24. When carbon content was not presented as a part of each study, it was calculated using the factors presented in Table 3-25 if not otherwise stated.

Table 3-25. Biomass expansion factors for conversion from volume (m^3) to biomass (Ton dry matter) /after Fink et al. 2003/. Stem refers to stem and bark above stump height. One m^3 stem wood corresponds to the value in column 2 as ton dry matter.

Ton DM	Stem biomass including tops
Pinus sylvestris	0.407
Picea abies	0.404
Broad-leaved	0.501
All trees	0.402

Table 3-26. Carbon content in some common tree species in percent of the dry weight.

Tree species	Stem	Branch	Needles	Root
Norway Spruce	48.0	58.8	48.6	48
Scotch Pine	48.8	51.2	51.2	48
Birch	48.0	58.8	48.6	48
Other deciduous trees	49.0	49.0	49.0	48*

*Same value as *Betula pendula.*

Quantitative descriptive models

The quantitative descriptive model is the quantification of the components listed in Table 3-22, 3-23 and 3-24, and further transferred into GIS giving the data a spatial distribution.

Tree layer

This layer was created using information from the vegetation map /Boresjö Bronge and Wester, 2002/. The Swedish Terrain Type Classification (TTC)was used to cover the lower left and right corners of the model area, not covered by the vegetation map, to make the regional model area map spatially complete. The classification is presented in Table 3-27.

Table 3-27. The classes used to describe the tree layer and the GIS sources from where the information is obtained to construct the classes. TTC is the Swedish Terrain Type Classification map.

Class	Gridcode in vegetation map /Boresjö Bronge and Wester, 2002/	Gridcode in TTC
Young coniferous forest (< 30 y) mesic-moist	12, 14, 41, 42, 43	76
Dry coniferous forest	15, 31	–
Old coniferous forest (> 30 y) mesic-moist	11, 13, 30, 61, 62	71, 72
Deciduous forests	21, 23 26, 63 (23, 24, 25, 63)	73
Water	100	–

The biomass for the tree layer was described using the four fractions; woody parts (above ground), green parts, coarse roots and fine roots (≤ 1 cm).

Data for the above ground (AG) biomass was extracted from The National Forest Inventory (NFI) (Table 3-28). Deciduous forest is defined as a forest where the broad-leaved component is above 70% otherwise it is classified as a conifer forest. Below ground (BG) biomass for conifers were calculated using data from /Berggren et al. 2004/ from a nearby locality Asa (57°08’N 14°45’E). /Berggren et al. 2004/ used Marklund’s equations /Marklund, 1988/ to calculate the BG biomass (0.15 of the AG biomass was found BG). They also found that 0.08 of AG biomass was found as fine root biomass using a soil corer. Marklunds’ equations for fine roots (< 5 cm) are considered less accurate in describing the fine root biomass, due to the methodology used to estimate it /Marklund, 1988/ and therefore is the fine root biomass from Berglund (≤ 1 cm) added to Marklunds fraction. This resulted in a value of 11% for fine roots as a function of the AG biomass (corrected for field layer rot biomass representing 38% of the fine roots /Berggren et al. 2004/).

Data for annual biomass increment in stems was extracted from NFI as a volume and was then converted to dry matter per unit area using Table 3-31. Annual biomass increment allocated to needles was calculated using a BEF of 48% of stem increment. /Gower et al. 2001/. Total root increment was estimated from total AG biomass increment using a BEF of 67% /Gower et al. 2001/.

The data for deciduous forests was extracted from NFI, using the selective criteria of at least 70% broad leaved trees in the stand. The green part is 0.02 of the total AG biomass (/Li et al. 2003/, using data from *Fagus sylvatica* in Sweden). BG biomass for deciduous trees were calculated using figures (0.15 of above ground biomassa is below ground) from /Nihlgard et al. 1981/ presenting figures from four *Fagus sylvatica* stands in southern Sweden. The fraction fine roots of the total rot biomass was taken from a study by /DeAngelis et al. 1981/ in a *Fagus sylvatica* stand in southern Sweden (0.12 of the root biomass is fine root biomass).

Table 3-28. Mean biomass of different fractions in dw gC m^{-2} of the trees in Oskarshamn.

Class	Number of NFI plots	Woody parts	Green parts	Coarse roots	Fine roots	Total Biomass
Young coniferous forest (< 30 y) fresh-moist	69	1,339.5	135.9	221.1	117.9	1,814.3
Dry coniferous forest	46	2,422.6	150.3	385.7	205.7	3,164.2
Old coniferous forest (> 30 y) fresh-moist	151	5,331.7	356.1	852.5	454.7	6,995.0
Deciduous forests	16	6,141.5	124.4	939.7	112.8	7,318.3

The above NPP for the green fraction is set equal to the leaf mass in deciduous trees. The above ground net annual biomass increment is related to the below biomass increment in a 4.37 to one in deciduous forests (N = 18 studies, /Gower et al. 2001/).

Table 3-29. Annual biomass increment in dw gC m^{-2} year^{-1} for different fractions of the tree.

Class	Number of NFI plots	Stem	Green parts	Coarse and fine roots	Total
Young coniferous forest (< 30 y) mesic-moist	69	69.4	33.3	68.8	171.6
Dry coniferous forest	46	50.8	24.4	50.4	125.6
Old coniferous forest (> 30 y) mesic-moist	151	110.7	53.1	109.8	273.7
Deciduous forests	16	105.1	124.4	52.8	282.2

Data for litter fall and larger components such as cones and branches were taken from /Berggren et al. 2004/. However, these figures are used without recalculating them using a BEF.

Table 3-30. Annual amount of litterfall and other falling components, such as cones and branches. These values are taken from Berggren *et al.* 2004 were three 40 years old *Picea abies* forests with different moisture regimes were investigated in Asa.

Class	Class in /Berggren et al. 2004/	Other comp. gCm^{-2}year^{-1}	Litterfall gCm^{-2}year^{-1}	Root litter from trees gCm^{-2}year^{-1}
Young coniferous forest (< 30 y) mesic-moist	Moist	52.0	201.2	68.8
Dry coniferous forest	Dry	45.0	147.4	50.4
Old coniferous forest (> 30 y) mesic-moist	Moist	52.0	201.2	109.8
Deciduous forests	–	–	124.4*	52.8

* Is set equal to foliage biomass taken from Table 3-28.

Shrub layer

This layer was created using information from the bush layer and the vegetation map /Boresjö Bronge and Wester, 2002/. The Swedish Terrain Type Classification/ was used to cover the lower left and right corners of the model area, not covered by the vegetation map, to make the regional model area map spatially complete. However, TTC does only cover the class birch (*Betula sp*., gridcode 74) and this class was non-significant in this area. A comparison of the field layer type that is associated with willow (*Salix sp.*) suggested that the willow cover in the corners not covered by /Boresjö Bronge and Wester, 2002/ also were non-significant. The classification is presented in Table 3-31.

A significant shrub layer is associated with specific habitats such as *Juniperus communis* in certain pastures, *Salix sp.* on certain types of mires or *Rubus idaeus* on clear-cuts. The shrub layer can also be important in certain successional forests. However, field inventories /Andersson, 2004a/ indicated that the shrub layer most often is insignificant when a tree layer is present in this area. A habitat that had a very significant shrub layer was clear cuts of varying age where *Betula pendula* is very dominant. *Salix sp.* can be abundant on mires and was identified by /Boresjö Bronge and Wester, 2002/ in their shrub layer. Therefore is the focus on *Betula* and *Salix* in the shrub layer. However, due to lack of biomass and NPP data for *Salix sp.* the values for Birch are used. Values representing *Betula pendula* was taken from a Finnish study on *Betula pubescens* /presented in Gower et al. 2001/. These were from a 50 year old stand but are here used to represent much younger stand in lack of better data so far. The estimates of biomass and NPP for the different fractions are presented in 3-38 and 3-39. The fine root fraction was set to 0.12 in accordance with values used for deciduous trees (below). Turnover of fine roots per year were set to 1 (Table 3-33).

Table 3-31. The classes used to describe the bush layer and the GIS sources from where the information is obtained to construct the classes.

Class	Gridcode in vegetation map /Boresjö Bronge and Wester, 2002/	Gridcode in bush layer /Boresjö Bronge and Wester, 2002/
Willow	–	12
Birch	44, 45	–
Water	100	–

Table 3-32. The values of biomass in dw gC m^{-2} after /Gower et al. 2001/.

Class	Wood	Foliage	Coarse roots	Fine roots	Total biomass
Willow	1,262	93	359	49	1,767
Birch	1,262	93	359	49	1,767

Table 3-33. The values of NPP in dw gC m^{-2}year^{-1} after /Gower et al. 2001/.

Class	Wood	Foliage	Coarse roots	Fine roots	Total NPP	Litter fall	Root litter
Willow	76	93	10	35	214	93	35
Birch	76	93	10	35	214	93	35

Dead wood

The total amount of dead wood is divided with the total area inventoried for each class. Transformation factor from volume to dry weight is taken from /Fink et al. 2003/, which makes a difference between *Pinus sylvestris*, *Picea abies* and broadleaved trees (Table 3-25). For classes that make no difference between tree species we have used a mean value of the trees comprised in the class. Transformation from dry weight to carbon for decaying wood is difficult and is very much dependent on the decay stage of the wood. Here we have used general conversion factor of 0.5 for the carbon content in the dead wood.

Table 3-34. Biomass values of dead organic material as logs in dw gC/m^2. Figures are means calculated from /Andersson, 2004a/. Gridcode from /Boresjö Bronge and Wester, 2002/.

Class	Gridcode	Total area (ha)	Conversion of m^3 to g dw	Standing dead wood dw gC/m^2	Laying dead wood dw gC/m^2	Total dw gC/m^2
No tree layer within forest area	1	6.28	570,000	17.1	28.4	45.5
No tree layer outside forest area	2	86.74	570,000	2.2	6.7	9.0
Old spruce	11	145.53	600,000	20.3	82.2	102.5
Old pine	13	55.44	510,000	13.5	59.0	72.5
Young pine	14	30.96	510,000	0.6	3.1	3.6
Unspecified young conifer	17	16.20	560,000	2.2	3.1	5.4
Birch	21	7.68	640,000	8.2	28.0	36.1
Young birch (thicket on clear-cut)	22	12.93	640,000	2.5	5.0	7.6
Ash	26	4.14	640,000	8.7	30.5	39.2
Mixed forest	30	14.43	570,000	30.6	61.5	92.1

Field and ground layer

This layer was created using information from the soil map constructed by /Lundin et al. 2004a,b/ and the ground layer map /Boresjö Bronge and Wester, 2002/. No information has been gathered to cover the corners to make the regional model area map spatially complete. This may be done using information from the quaternary deposit map (Swedish Geological Survey, SGU) and the Swedish Terrain Type Classification (TTC). The classification is presented in Table 3-35.

Data for biomass AG for the different field layer types in Table 3-36 was taken from a study done in Forsmark /Fridriksson and Öhr, 2003/. However this study had fewer classes (lower resolution) than the one presented in Table 3-43. It was therefore necessary to use the same values for some of the classes (Table 3-43, column 2). BG biomass for mires and wetlands was taken from an investigation of an ombrotrophic bog in Canada /Moore et al. 2002/. They found an average ratio of above- to belowground biomass of 0.16:1. However, they had a somewhat lower aboveground biomass than /Fridriksson and Öhr, 2003/ ranging from approximately 175 to 225 gCm^{-2}.

Table 3-35. The classes used to describe the field layer in Oskarshamn. The classes correspond to Lundins fortcomming report describing the soil in Oskarshamn. In lack of this report the map describing the field and ground layer was constructed using information from the different vegetation layers denoted in column 3 to 5.

Class	Code in soil map /Lundin et al. in prep./	Gridcode in ground layer /Boresjö Bronge and Wester, 2002/	Gridcode in field layer /Boresjö Bronge and Wester, 2002/	Gridcode in tree layer /Boresjö Bronge and Wester, 2002/
Mires	HI	23	20–23	Without trees
Forested wetlands	GL	–	20–23	And trees
Herb dominated moist soils on fine texture parent material	GL/CM	–	16, 25	And 21, 24, 25
Pasture and seminatural grasslands	RG/GL-a (agriculture land excluded)	32	16	Without trees
Woodland, well drained, herbs, grasses and dwarf shrubs	RG/GL + RG	–	13, 14, 15	11, 12, 17, 22, 30
Thin soils with lichen rich heath vegetation	LP	–	14	13, 27
Shore line* (bedrock excluded)	AR/GL	excluded		
Agriculture land	RG/GL-a	81		

*This class is not assigned any data in this report version

Below ground biomass for Grasslands, Seashore and Herb dominated moist soils are calculated using values from /Saugier et al. 2001/. They found that the root biomass was 67% of the total biomass in temperate grasslands. The biomass of the arable land was calculated based on the standard yield figures of oat, which is the main crop cultivated in the area /Berggren and Kyläkorpi, 2002/. To the standard yield of 338 g oat/m^2 /Berggren and Kyläkorpi, 2002/ was added generic values of treshing loss (x 1.05) and straw yield (x 1.4). Root biomass was calculated as 0.43 of AG biomass /Jerling et al. 2001/. The total value was then translated to carbon content using the factor 0.453 in accordance with /Fridriksson and Öhr, 2003/.

Production for ground layer in mires and forested wetlands was set to equal the biomass. These figures are in the lower part in comparison with other investigations in the northern hemisphere /Rochefort et al. 1990/.

Table 3-36. Assigning biomass values in dw gC/m^2 for the different field, ground and litter layer classes in the Oskarshamn area. Figures are medians (N = 6) recalculated from /Fridriksson and Öhr, 2003/.

Class	Class in /Fridriksson and Öhr, 2003/	Litter gCm^{-2}	Ground layer gCm^{-2}	Field layer green gCm^{-2}	Field layer total AG gCm^{-2}	Below ground gCm^{-2}
Mires	Wetlands	321.6	62.3	201.7	201.7	1,260.6
Forested wetlands	Wetlands	321.6	62.3	201.7	201.7	1,260.6
Herb dominated moist soils on fine texture parent material	Seashore area	153.1	0.0	61.4	61.4	41.1
Pasture and seminatural grasslands	Grazing area	47.6	16.5	108.4	112.1	75.1
Woodland, well drained, herbs, grasses and dwarf shrubs	Picea area	153.9	401.2	0.0	0.0	0.0
Thin soils with lichen rich heath vegetation	Pinus area	258.6	180.7	24.6	3.1.3	40.4*
Shore line (bedrock excluded)	Seashore area	153.1	0.0	61.4	61.4	41.1
Agriculture land	–	0.0	0.0	225.0	225.0	97.0

*From /Berggren et al. 2004/ were mean total root biomass was taken from the dry plots in Knottåsen and then substracting tree roots (62% from /Majdi and Andersson, 2004/). That figure was used to create a fraction (1.29) describing the BG biomass as a function of AG.

Table 3-37. Assigning NPP values in dw gC m^{-2}year^{-1} for the different field, ground and litter layer classes in the Oskarshamn area. Figures are medians (N = 6) recalculated from /Fridriksson and Öhr, 2003/.

Class	Class in Fridriksson and Öhr, 2003	Ground layer gCm^{-2} year^{-1}	Field layer green gCm^{-2} year^{-1}	BG gCm^{-2} year^{-1}	AG litter fall	BG root litter gCm^{-2} year^{-1}
Mires	Wetlands	62.3	201.7	403.4	201.7	403.4
Forested wetlands	Wetlands	62.3	201.7	403.4	201.7	403.4
Herb dominated moist soils on fine texture parent material	Seashore area	–	61.4	122.8	61.4	122.8
Pasture and seminatural grasslands	Grazing area	5.0	108.4	216.8	108.4	216.8
Woodland, well drained, herbs, grasses and dwarf shrubs	Picea area	34.0	0.0	0.0	0.0	0.0
Thin soils with lichen rich heath vegetation	Pinus area	34.0*	24.6	49.2	24.6	49.2
Shore line (bedrock excluded)	Seashore area	–	61.4	122.8	61.4	122.8
Agriculture land	–	–	225.0	97.0	0.0	97.0

*In lack of other data the ground layer NPP for the “Woodland” category was used. This is most certainly an underestimation of the actual NPP.

Production for the ground layer in forests was taken from /Bisbee et al. 2001/. They found the NPP of the dominating moss species in the ground layer, Hylocomium splendens, covering in mean 70% of the ground layer, to be 24 gCm-2 year-1. Consequently, H. splendens, represents the ground layer and was recalculated due to the large cover in the sample plots (100%, /Fridriksson and Öhr, 2003/) to represent 100% cover. The ground layer production for grasslands is calculated using the same production estimate but recalculated using coverage of 13 % /Fridriksson and Öhr, 2003/.

Data covering BG production for the field layer are scarce. A generic value taken from a summary of temperate grasslands /Saugier et al. 2001/ was used for all habitats except agriculture land /0.151, Saugier et al. 2001/ to calculate the BG production from the AG production. The input of carbon to the soil as turnover of roots was set equal to the BG production, implying that there is no net accumulation BG between years in the field layer.

Fungi/mycorrhizae

Carbon transfer from vegetation through roots to fungi that are symbiotically associated with the roots is of significant importance when describing the flow of carbon. There are two dominating types of plant – mycorrhizal associations, the arbuscular mycorrhiza (AM) and the ectomycorrhiza. A third type the ericoid mycorrhiza is exclusively formed by plants in the Ericales. These are an important component of high altitude boreal forests. Except in boreal and some temperate forests in heatlands are the AM symbiosis the normal state of the root system of most plant species /Fitter et al. 2000/. We have no data covering biomass and NPP for the arbuscular and ericoid mycorrhiza.

Data for ectomycorrhiza is extracted from an investigation made in USA, Washington State, estimating mycorrhizal fungal biomass and production from two *Abies amabilis* stands of different age (23 and 180 years old) /Vogt et al. 1982/. Conifer fine roots (including mycorrhizal roots) and *Cenococcum graniforme* (Sow.) Fred. and Winge sclerotia were hand sorted from soil cores. Epigeous and hypogeous sporocarps were collected from permanent sub plots during one year. However, the tree root biomass calculations from NFI includes ectomycorrhizal sheath so that amount is here subtracted (16% of total fungal component) from the total to avoid accounting for that biomass twice. Similarly is that part excluded from the NPP calculations. Here we use data from the plot covered with 23-year-old trees, which seems to better approximate the age classes of the forests in focus. A conversion factor of 0.5 was used to convert dry weight to carbon weight. The deciduous forest gets the same values as coniferous forest in lack of other data. Turnover of mycel is calculated using an assumption of steady state in between years, which gives a turnover equal to NPP.

Table 3-38. Biomass and NPP for fungi in forest habitats.

Class	Biomass gCm^{-2}	NPP gCm^{-2} $year^{-1}$	Litter $gCm^{-2}year^{-1}$
Young coniferous forest (< 30 y) mesic-moist	117	137	137
Dry coniferous forest	117	137	137
Old coniferous forest (> 30 y) mesic-moist	117	137	137
Deciduous forests	117	137	137

Root zone depth

Describes the depth of the root zone. The estimation of the root depth was done by /Lundin et al. 2004a,b/ at two localities for each class in Table 3-39. The statistics presented in the Table 3.45 are taken from the locality that had the deepest mean root zone value.

Table 3-39. Statistics describing the depth of the root zone for a number of vegetation types.

Class	Code in soil map /Lundin et al. 2004a,b/	Mean (sd) (m)	Min–Max (m)	N
Mires	HI	0.34 (0.07)	0.30–0.47	7
Forested wetlands	GL	0.31 (0.05)	0.25–0.43	8
Herb dominated moist soils on fine texture parent material	GL/CM	0.42 (.0.09)	0.26–0.58	8
Pasture and seminatural grasslands	RG/GL-a (agriculture land excluded)	0.26 (0.13)	0.17–0.54	8
Woodland, well drained, herbs, grasses and dwarf shrubs	RG/GL + RG	0.26 (0.04)	0.18–0.32	8
Thin soils with lichen rich heath vegetation	LP	0.28 (0.07)	0.16–0.37	8
Shore line (bedrock excluded)	AR/GL	0.25 (0.06)	0.17–0.35	7
Agriculture land	RG/GL-a	0.19 (.0.07)	0.09–0.027	8

Confidence and uncertainties

The largest stocks and flows are associated with trees (except the soil organic carbon that is not treated here). This means that a low confidence in these would have a large effect on the overall confidence of the descriptive models. The estimates of tree properties are, however, the best estimates we have (compared with all the data used) in the sense of number of replicates, coverage of the region and the allometric functions used within the NFI to calculate biomass for the fractions above ground. There is a large variation depending on a number of factors such as nutrient status and wetness. Nutrient status is known to have a large effect on the biomass of roots /Persson, 2002/. However these variations depending on local factors are supposed to be evened out when viewing a larger area /Svensson, 1984, see also Banfield et al. 2002/. The average error for the estimate of the tree biomass in NFI (for the area 217 km^2 forest) should be approximately 6% /Svensson, 1984/. We have introduced errors by joining continuous data into a number of categories, but these are on the other hand averages of a large sample covering most forest types. The use of biomass expansion factors to distribute biomass and NPP properties among tree fractions (where such has not been found in the NFI data) also introduces errors. BEF's are known to be sensitive to tree age /e.g. Lehtonen et al. 2004/.

An assumption of a steady state has repeatedly been used when quantifying turnover of plant tissue. This assumption is in some cases an overestimation of the actual turnover as the perennial taxa in the field layer do accumulate biomass. In other cases the assumption is more justified e.g. fine root turnover /Majdi, 2001/.

Interestingly, few or no single studies have been able, or chosen, to estimate all the properties that have been treated above. Partly, because of the laborious work but also because many of the pools and fluxes are small in comparison and therefore expected to have a small influence on the overall carbon budget.

3.7.2 Consumers

Input data

Site-specific and generic data that have been obtained from different reports are shown in Table 3-46. Other data that have been used, such as the weight of species and consumption data, have been gathered from internet sites, for example Swedish Association for Hunting and Wildlife Management (*Sw: Svenska Jägareförbundet*), The National Association of Huntsmen (*Sw: Jägarnas Riksförbund*), BBC- Nature wild facts and the Mammal society.

A new mammal report with more detailed information about weights, feeding- and migration habits, reproduction, carbon content etc. is in preparation, as well as a new bird report with site specific density data. Those data are, however, not yet available.

Table 3-40. References and data for the description of consumers in Simpevarp area.

Fauna family	Species	Data	Source
Mammals	Moose	Density (site specific)	/Cederlund et al. 2004/
		Carcass weights (site specific)	/Svensk Viltförvaltning, 2003/
	Roe deer	Density (site specific)	/Cederlund et al. 2004/
		Carcass weights (generic)	/Cederlund, 1995/
	Red deer (kronhjort)	Density (site specific)	/Cederlund et al. 2004/
	Hare in field (European hare) and Hare in forest (mountain hare)	Density (site specific)	/Cederlund et al. 2004/
	Small mammals in field (mainly water vole, field vole) and in forest (mainly yellow necked mouse, wood mouse and bank vole)	Density (site specific)	/Kjell Wallin and Göran Cederlund, personal communication, 2004/
	Marten	Density (site specific)	/Cederlund et al. 2004/
	Fox	Density (generic)	/Svenska Jägareförbundet, 2004, website/
	Wild boar	Density (site specific)	/Cederlund et al. 2004/
		Population structure (age-distribution -generic)	/Jonas Lemel, personal communication, 2004/
Birds	–	No site-specific density figures, only no. of birds/km and no. of territories/km^2	/Green, 2004/
Amphibians and reptiles	–	Species that occur in the Simpevarp area	/Andrén, 2004a/
	Snakes (Adder/huggorm, Grass snake/vanlig snok and Smooth snake/hasselsnok)	Density, weight, consumption (generic)	/Andrén, 2004b/
	Newts (Smooth newt/mindre vattensalamander and Great creasted newt/stor vattensalamander)	Density around a water pond, weight, consumption (generic)	/Andrén, 2004b/
	Common toad (vanlig padda)	Density, weight, consumption (generic)	/Andrén, 2004b/
	Moor frog (åkergroda)	Density around a water pond, weight, consumption (generic)	/Andrén, 2004b/
	Lizards (Sand lizard/sand ödla, Common lizard/skogsödla and Slow-worm/kopparödla)	Density, weight, consumption (generic)	/Andrén, 2004b/
Soil fauna	–	Density in a deciduous forest, a moor pine and a grass land.	/Lohm and Persson, 1979/

Metodology

General

The ambition concerning consumers has been to calculate the carbon flow among the terrestrial consumers, expressed as gC/m^2/y and total gC/y, in Simpevarp 7 (the drainage area of Lake Frisksjön) within Simpevarp area. This has not been possible for all species, as the input data is incomplete.

When calculating the consumption of carbon for herbivores the carbon content in the vegetation is assumed to be 46.1% (mean value) of the dry weight as for the green fieldlayer in /Fridriksson and Öhr, 2003/. The carbon content in mammals is assumed to be 10%, based on personal communication. Information about the carbon content will be included in the new mammal report from *Svensk Naturförvaltning*. The carbon content in reptiles and amphibians are assumed to be equal to the carbon content in mammals.

The herbivore faeces (vertebrate) have been calculated as 50% of the energy input (consumption) and the carnivore faeces (vertebrate) as 20% /Jerling et al. 2001/.

Moose

The moose (*Sw: älg*) density was investigated in the Simpevarp area in 2003 through pellet (fecal) counts and an aerial survey. The methodology is described in /Cederlund et al. 2004/. A control area for the pellet counts was placed in Blankaholm.

The carcass weights from Ankarsrum, close to Simpevarp /Svensk Viltförvaltning, 2003/, has been divided with 0.55 in order to get the live weight /G Cederlund, Svensk Naturförvaltning, pers. comm./. A sex ration of 0.5/0.5 has been assumed when calculating the average weight. The production is proposed to be 30% of the biomass /G Cederlund, pers. comm./. Consumption figures for moose were found at /Svenska Jägareförbundet, 2004(1), website/. A mean value of the winter- and summer consumption was calculated.

Roe deer

The roe deer (*Sw: rådjur*) density was investigated in the Simpevarp area (and Blankaholm) in 2003 through pellet (fecal) counts. The methodology is described in /Cederlund et al. 2004/. Roe deers were also observed during the aerial survey in Simpevarp. However, no attempts were made to calculate the density since the observations were too few.

An average weight was calculated based on the distribution of fawns (*Sw: kid*), goats (*Sw: get*) and bucks (*Sw: bock*) that are given at The National Association of Huntsmen /Svenska Jägareförbundet, 2004(2)/ and the live weights for fawns, goats and bucks that are given in /Cederlund and Liberg, 1995/. The production is 50% of the biomass /G Cederlund, pers. comm./. Consumption figures for roe deers in enclosure were found at /Svenska Jägareförbundet, 2004(3), website/. A mean value of the winter- and summer consumption was calculated.

Red deer and Fallow deer

The red deer (*Sw: kronhjort*) density was investigated in the Simpevarp area (and Blankaholm) in 2003 through pellet (fecal) counts. The methodology is described in /Cederlund et al. 2004/. Red deer was also observed during the aerial survey in Simpevarp. However, no attempts were made to calculate the density since the observations were too few.

An average weight has been calculated based on the weight values for stags (male) and hinds (female), and a sex ratio of 0.5/0.5 /Svenska Jägareförbundet, 2004(4), website/. No values for consumption have been found, but the red deer was assumed to consume 5% of the average live weight, which is the consumption for moose in Simpevarp. The production is assumed to be equal with the moose production, i.e. 30% of biomass.

The fallow deer (*Sw: dovhjort*) density was investigated in the Simpevarp area (and Blankaholm) in 2003 through pellet (fecal) counts. The methodology is described in /Cederlund et al. 2004/. Fallow deer was only found in Blankaholm.

Hare

The hare density was investigated in the Simpevarp area (and Blankaholm) in 2003 through pellet (fecal) counts. The methodology is described in /Cederlund et al. 2004/. Data sets from the fields and from the forests were separated. Normally, the mountain hare (*Sw: skogshare*) is associated with forest and European hare (*Sw: fälthare*) with fields, but there is no absolute border in habitat use between the species. Since it is hard to discriminate pellets from the two species, calculations refer to the two main habitat types, where the density in forests is applied to the mountain hare and the density in fields to the European hare.

When calculating the total number of individuals in Simpevarp 7, the density figures have been multiplied with the forest area and the field area (grassland, arable land and wetland), respectively.

The live weight for an adult mountain hare and an adult European hare have been obtained from /Svenska Jägareförbundet, 2004(5–6), website/. The production is 30% of the biomass /G Cederlund, pers. comm./. A consumption figure for mountain hare was found at /Svenska Jägareförbundet, 2004(7), website/.

Small mammals

The density for small mammals have been modified after /Cederlund et al. 2004/, and after /G Cederlund, pers. comm./. When calculating the total number of individuals in Simpevarp 7, the density values have been multiplied with the forest area and the field area (grassland, arable land and wetland), respectively.

Average weights for small mammals in field and in forest were proposed by Kjell Wallin, *Svensk Naturvårdsförvaltning*, pers. comm. According to /Anticimex, 2004, website/ a house mouse consumes 2–3 g food per day, ie.13% of its biomass. The production is proposed to be 10 times the biomass for all rodents (10 generations per year) /G Cederlund, pers. comm./.

Cattle

There is no active agriculture in Simpevarp 7, but the grasslands and arable fields in the area, gives a prerequisite for milk production from five dairy cows (age 1–5). These five cows could produce three calves per year of which two are slaughtered each year together with the oldest cow. The production is therefore calculated as the biomass of two calves and one cow.

A dairy cow consumes yearly approximately 3 500 kg grass, 2 000 kg crops and 1,000 kg concentrated fodder, in total 6,500 kg food (17 kg per day) /LivsmedelsSverige, 2004, website/. The carbon content is assumed to be 25% of the total weight. The living weight of a cow and a calf have been calculated from the utilized carcass weight in /Miliander et al. 2004/. The utilized carcass weight is assumed to be 44% (0.55×0.8) of the living weight as for the game meat /Miliander et al. 2004/. The average living weight has been calculated.

Marten

The marten (*Sw: mård*) density was investigated in the Simpevarp area in 2003 by using line transects in the snow according to the Buffon method. The number of tracks per transect length can be converted into number of animals per km^2.The methodology is described in /Cederlund et al. 2004/.

The live weight has been obtained from Swedish Association for Hunting and Wildlife Management /Jägarnas Riksförbund, 2004(1)/. No consumption data has been found for marten. Its consumption is therefore assumed similar as the consumption for lynx, also a carnivore. The consumption for lynx is 5.3% of its biomass (1 kg per day /Järvzoo, 2004, website/ and an average weight of 19 kg /Jägarnas Riksförbund, 2004(2), website/). The production for marten is thus proposed to be 30% of the biomass /G Cederlund, pers. comm./.

Fox

There are no site-specific density data for fox. A generic density value as well as a weight value have been found at /Jägareförbundet, 2004(8), website/. No consumption data is available for fox. Its consumption is therefore assumed to be in similar proportion as the consumption for lynx (5.3% of its biomass). The production is assumed to be 30% of the biomass, as proposed for marten /G Cederlund, pers. comm./.

Wild boar

The wild boar (*Sw: vildsvin*) density was investigated in the Simpevarp area in 2003 through pellet counting. The methodology is described in /Cederlund et al. 2004/.

The live weight has been obtained from /Jägareförbundet, 2004(9–10), website/. The mean weight has been calculated based on demographic data: 55% of the population are six months (0–1 year), 25% are 1.5 years old (1–2 years) and 20% are full sized, according to the population structure given by /J Lemel, pers. comm./. Consumption figures during the summer for an adult wild boar and a piglet was found at /Jägarförbundet, 2004(11), website/. An average consumption was calculated approximating that 50% of the population is piglets (0–1 year). The carbon consumption has been calculated based on a 100% vegetarian diet. Normally a wild boar consumes animalia to 15% /Lemel, 1999/.

The production is assumed to represent 1% of the energy input (consumption) according to Table 2-4 in /Jerling et al. 1999/. This gives a production equal to almost 50% of the biomass.

Birds

One bird survey has been performed in Simpevarp, mainly to evaluate the possible effects of the site investigation on the numbers of breeding birds and in some cases also on their breeding success /Green, 2004/. The number of birds registered per kilometre during the line transects as well as numbers of territories per km^2 are presented in /Green, 2004/, but no density values are presented here.

Since no density data were available, the biomass for birds has not been calculated. It is important to notice that the most common species (in terms of number) are quite small, and a calculation of total biomass for each species might give quite a different picture from the relative abundance estimated based on numbers.

Amphibians and reptiles

A short field study was performed in 2003 mainly to verify the presence of suitable habitats for the species that are likely to occur in Simpevarp /Andrén, 2004a/. Generic densities for the species that occur at Simpevarp area have been estimated by /Andrén, 2004b/. Average weight figures as well as feeding habits and the number of egg/offspring per individual are also included /Andrén, 2004b/. No attempt has been made to calculate the production from the number of eggs/offsprings per female. Instead, the production of the amphibians and the reptiles have been calculated based on Table 2-4 in /Jerling et al. 2001/, showing that the production of vertebrates (ectothermal, *Sw: växelvarma*) represent 8% of the energy input (consumption).

Amphibians and reptiles are carnivores and their diet (small mammals, other amphibians and reptiles, insects and invertebrates) is, as the mammals, assumed to contain 10% carbon.

Soil fauna

The three examples of soil fauna densities and biomass data are obtained from T Persson, SLU, pers. comm. The three examples come from a pine moor in Gästrikland, a deciduous forest in Uppland (Andersby-Ängsbacka in Dannemora) and a grassland in Uppland /Lohm and Persson, 1979/. The dry weight consist of 50% carbon according to /T Persson pers.comm./. There are no data concerning the consumption and production.

Description of consumers

Moose

The aerial survey in 2003 gave a mean density of approximately 0.8 moose/km^2 in Simpevarp. The pellet counts indicate that the winter population is lower (approximately 0.5 moose/km^2). The dominance of female (75%) is due to a long-term effect of high hunting pressure on adult bulls. The unusually high proportion of calves (37%) indicates a high fecundity among adult females and/or low hunting pressure /Cederlund et al. 2004/.

The average carcass weights from Ankarsrum, close to Simpevarp, are 151 for a bull and 146 kg for a cow /Svensk Viltförvaltning, 2003/. These figures are lower than the carcass weights that are given by /Svenska Jägareförbundet, 2004(12)/; 180–230 kg for a bull and 170–200 kg for a cow. The carcass weights in Simpevarp correspond to live weights of 275 kg and 265 kg, respectively.

An adult moose consumes 6–10 kg food per day during the winter and 2–3 times more during the summer /Svenska Jägareförbundet, 2004(1), website/. That gives a yearly consumption average of 14 kg fresh weight per day (3.5 kgC per moose and day).

During summer the moose eats leafs from deciduous trees, such as birch (*Sw: björk*), aspen (*Sw: asp*), willow (*Sw: vide*) and sallow (*Sw: sälg*). They also eat herbs like meadow-sweet (*Sw: älgört*), rose bay willowherb (*Sw: mjölkört*)**,** clover and some water plants. During the autumn the diet changes to berry shrubs, heather (*Sw: ljung*), oat and wheat. Twigs and sprouts of pine, common juniper (*Sw: en*) as well as of deciduous trees and scrubs are the winter diet, together with bark from primarily aspen, rowan and pine /Svenska Jägareförbundet, 2004(12)/.

The moose cow becomes fertile at the age of two and she gives birth to her first calf at the age of three. The cow gives birth to one or two calves in may-june, after a gestation period of eight months /Svenska Jägareförbundet, 2004(13)/.

A moose has a so called "home range", which is a specific area that the moose chooses to live in during a temporary time period (a winter, a summer or a whole year). The size of the home range varies. Generally, the bulls have larger regions than the cows. At Grimsö research station in Bergslagen, the home range is in average 1,400 ha for cows and 2,600 ha for bulls /Svenska Jägareförbundet, 2004(14), website/.

Roe deer

The roe deer density was 4.9 deers/km^2 in Simpevarp and 5.2 deers/km^2 in Blankaholm. Although it is well known that roe deer density varies considerably between adjacent, local areas, there is now reason to believe that the densities found in this study are exceptional /Cederlund et al. 2004/.

The live weights for roe deer are 22–28 kg for a buck, 21–27 kg for a goat and 12–16 kg for a fawn /Cederlund and Liberg, 1995/. According to /Svenska Jägareförbundet, 2004(2),website/, the population is composed by 30% fawns and 70% adults, of which 60% are goats. This gives an average weight of 21.3 kg.

A roe deer diet during the summertime consists of berry scrubs, heather (*Sw: ljung*), three leafs, grass and herbs; primary rose bay willowherb (*Sw: mjölkört*), wood anemone (*Sw: vitsippa*) and cow-wheat (*Sw: kovall*). Mushrooms are also an important part of the diet and sometimes also crops. Berry scrubs and heather are also an important part of the winter diet as long as they are not completely covered by snow. If so, the roe deer change over to twigs of coniferous and deciduous trees. An adult roe deer in enclosure consumes in average 3 kg food per day during summertime and in average 1 kg per day in wintertime according to /Svenska Jägareförbundet, 2004(3), website/. This means an average consumption of approximately 2 kg fresh weight per roe deer and day, i.e. 0.5 kgC/roe deer and day.

The roe deer goat becomes fertile at the age of one and she gives birth to her first fawn at the age of two. The goat gives birth to one to three fawns in May–June. According to /Svenska Jägareförbundet, 2004(15), website/, a roe deer lives at the most in 10–12 years.

A roe deer has, like a moose, a home range that may vary in size. Generally, the bucks have larger regions than the goats. Goats can also have overlapping ranges and share ranges with other goats and a buck. The roe deer migrate in dusk and dawn, see Svenska Jägareförbundet, 2004(16), website.

Red deer and fallow deer

Fallow deer was only found in Blankaholm (control area).

The red deer density varied considerable between Simpevarp and Blankaholm, which the clustering of deers can create. There are 0.03 red deer/km^2 in Simpevarp and 0.15 in Blankaholm according to pellet counts. Local managers consider these data to be too low. According to them the populations are increasing, as is the entire population in Sweden /Cederlund et al. 2004/.

Hare

Hare density in the field was rather high in Simpevarp with 3.5 hares/km^2, and somewhat lower in Blankaholm, 1.9 hares/km^2. The density was much lower in the forest, between 0.52 in Simpevarp and 0.32 in Blankaholm.

The live weight is 3–5 kg (mean 4 kg) for an adult mountain hare and 4–6 kg (mean 5 kg) for an adult European hare according to /Svenska Jägareförbundet, 2004(5–6), website/.

Mountain hares graze on heather, blueberry scrubs, twigs of deciduous trees, grasses, herbs, small coniferous plants and occasionally farm crops, see /Svenska Jägareförbundet, 2004(5), website/. The European hare eats almost the same, but is more bound to farm crops. The smallest amount of food that a mountain hare need to survive during the winter is 500 gram per day, see /Svenska Jägareförbundet, 2004(7), website/, i.e. 125 gC/hare and day.

A female mountain hare gives birth to a litter of 1–7 leverets after a gestation period of 50 days. Two litters per breeding season is most normal, but three can occur /Svenska Jägareförbundet, 2004(6), website/. The European hare has a somewhat shorter gestation period (45 days) and get 1–5 leverets in three litters /Svenska Jägareförbundet, 2004(5), website/.

The hares are mainly solitary, but they do not avoid each other. The home range of the mountain hare is approximately 200 ha (2 km^2) on a yearly basis /Svenska Jägareförbundet, 2004(17)/.

Small mammals – forest

The small mammals in forest are mainly bank vole (*Sw: skogssork*), yellow-necked mouse (*Sw: större skogsmus*) and wood mouse (*Sw: mindre skogsmus*). The density of small mammals in forests in Simpevarp is 3,110 per square kilometre /G Cederlund, pers. comm./ A yellow-necked mouse weights 22–44 g and a wood mouse (and house mouse) weights 10–28 g according to /Svenskt Naturlexikon, 2000/. The bank vole weights 12–35 g according to /ARKive, 2004(1), website/. The mean weight of small mammals in forest has been estimated to 20 g /K Wallin, pers. comm./.

The bank vole inhabits broadleaved woodlands, scrub, parks, hedgerows and banks, where there is plenty of herbaceous cover. Their diet is broad and mainly herbivorous, including fruit, soft seeds, leaves, fungi, roots, grass, buds and moss. Occasionally, they feed on invertebrates such as snails, worms and insects. 4 to 5 litters are produced in a year, each one consisting of 3–5 young. Gestation takes around 21 days. Predators such as owls, kestrels, foxes and weasels take their toll on vole populations; the maximum life span for the species is 18 months /ARKive, 2004(1), website/.

The wood mouse is a highly adaptable species exploiting a wide range of habitats. They feed on seeds, invertebrates, fruits, nuts, seedlings, moss and fungi. Females give birth to 2–9 young, after a gestation of 25–26 days. They tend to have 4–7 litters a year. The maximum life span is up to 20 months /ARKive, 2004(2), website/.

The yellow-necked mouse usually occurs close to arable land. It may also inhabit orchards, field margins, wooded gardens, hedgerows and buildings in rural areas. They feed on fruit, seedlings, buds and invertebrate. Females give birth to 2–11 young, but usually 5, after a gestation of 25 or 26 days. Around three litters are produced each year. Yellow-necked mice are adept climbers, thus feeding in trees and shrubs and enter houses more often than wood mice /ARKive, 2004(3), website/. The life span is up to one year /BBC, 2004(1), website/.

Small mammals – field

The small mammals in field are mainly field vole (*Sw: åkersork*), water vole (*Sw: vattensork*) and common shrew (*Sw: vanlig näbbmus*). The density of small mammals in the field in Simpevarp is 2,200 per square kilometre /G Cederlund, pers. comm./. A common shrew weights 5–12 g, according to /BBC, 2004(2), website/. The field vole weights 20–40 g and the water vole 150–300 g according to /The Mammal society, 2004(1–2), website/. The mean weight of small mammals in the field, dominated by field vole, has been estimated to 30 g /K Wallin, pers. comm./.

The field vole occurs typically in un-grazed grassland or in the early stages of forestry plantations, but may also inhabit forest or moor land (*Sw: ljunghedar*), wherever grass is available. Grass is the field voles' only food source. The females produce 5–6 litters of 4–6 young each year. The average life span of a field vole is less than a year /The Mammal society, 2004(2)/.

The water voles inhabit the banks of ditches, dykes, slow-moving rivers and streams, and grassland. The water vole feed mainly on grasses or other plant material. It produces up to five litters of in average six young each year. The life span of a water vole is up to 2 years /BBC, 2004(3), website/

Common shrews are insectivorous and carnivorous, feeding on insects, slugs, spiders, worms and carrion. They need to eat 80–90 percent of their own body weight in food daily. The shrew females rear 2–4 litters a year of typically 6 young. The life span of a common shrew is up to 23 months /BBC, 2004(2), website/.

Cattle

See Section 3.10.

Marten

The track indexes indicate that marten is common in both Simpevarp and Blankaholm. The density was in 2002 estimated to 0.13 marten/km^2 in Simpevarp (and 0.05 in Blankaholm). The density estimates are relatively uncertain (high confidence intervals, but seems quite reasonable /Cederlund et al. 2004/.

The live weight is 0.8–1.5 kg according to the website of /Svenska Jägareförbundet, 2004(1)/. The marten prefer well wooded areas with plenty of cover. They feed on squirrels, birds, small mammals, rabbits/hares, eggs, insects and berries. They also eat carrion of cervids /Svenska Jägareförbundet, 2004(18), website/. No consumption data is available for marten.

The marten population growth rate is low. The first litter comes normally when the female is 2–3 years old. Females give birth to 1–4 young, which become fully independent after six months.

Fox

There are in general 0.8 foxes/km^2 in Southern Sweden, but the density depends on the amount of food /Svenska Jägareförbundet, 2004(8), website/.

The male weights approximately 7.5 kg and the female 6.5 kg. Rodents are the main diet, but they do eat hares, roe deer fawns, birds, frogs, berries, insects and scraps left by humans. The female fox becomes fertile at 9–10 months of age and gives birth to five to six cubs, after a gestation period of approximately 52 days. The fox lives normally in 10 years /Svenska Jägareförbundet, 2004(19–21), website/.

Foxes forage alone in different parts of their territory, which may extend from 20 to 2,000 ha (0.2–20 km^2) depending on the food supply /Svenska Jägareförbundet, 2004(22), website/.

Wild boar

According to local game managers, the wild boar population is fairly new in the region and in many areas still at low density. However, a rapid increase is expected. The population growth of wild boar is 13% in central Sweden, on a year basis /Lemel, 1999/. The pellet counts showed a density of 0.26 boars/km^2 (0.12 in Blankaholm) /Cederlund et al. 2004/.

The sows weight normally 80–90 kg, while the boars are heavier and can weight 150 kg /Svenska Jägareförbundet, 2004(9), website/. A piglet weights 20 kg after six months and 60–65 kg after one year /Svenska Jägareförbundet, 2004(10), website/. According to /Lemel, 1999/, the population structure is: 50–55% of the population is 0–1 years old, 25% is 1–2 year, 10% is 2–3 year, 5% is 3–4 year and 2.5% is 4–5 year. The mean weight has been estimated to approximately 57 kg.

An adult wild boar consumes 4 kg per day during the summer while a piglet consumes half of that amount, according to /Svenska Jägareförbundet, 2004(11), website/. The mean consumption is assumed to be approximately 0.75 kgC per wild boar and day, as 50% of the wild boars are 0–1 year. A wild boar is to 85% herbivorous (vegetation and mushrooms) and to 15% carnivorous /Lemel, 1999/. The animal diet consists mainly of earthworms, insect larvaes and invertebrates. Small mammals are occasionally a part of the diet /Svenska Jägareförbundet, 2004(11), website/.

A young sow gives birth to one litter of 3–4 piglets. A sow of three years or older can get a larger litter of 5–6 piglets /Svenska Jägareförbundet, 2004(10), website/.

The size of a wild boar home range varies. An adult wild boar uses in night time in average a region of approximately 100 ha (1 km^2). The total area that a wild boar uses is at least three times that size. A group of sows with piglets can use a home range of 2,000 ha /Svenska Jägareförbundet, 2004(23), website/.

Birds

In total, 126 species were found in the regional model area, and 28 of these are noted in the Red List as endangered bird species in Sweden. The most common species on land were Chaffinch and Great Tit (Table 3-41). A major part of the nesting species was small birds, associated with the open or semi-open landscape. For detailed information on each species found in the Simpevarp area /Green, 2004/.

Table 3-41. The ten most common nesting species in the Simpevarp regional area, presented as the total number of birds registered and the number of birds per km during transect surveys /Green, 2004/. Swedish names within brackets.

Species English (Swedish)	Latin	Total number (2003)	Abundance (n/km) 2003	Abundance (n/km) 2002
Chaffinch (Bofink)	Fringilla coelebs	2,505	12.03	7.10
Great Tit (Talgoxe)	Parus major	1,635	7.85	1.55
Willow Warbler (Lövsångare)	Phylloscopus trochilus	1,264	6.07	7.15
Robin (Rödhake)	Erithacus rubecula	1,127	5.41	2.22
Blue tit (Blåmes)	Parus caeruleus	1,039	4.99	0.58
Blackbird (Koltrast)	Turdus merula	978	4.70	2.24
Song Thrush (Taltrast)	Turdus philomelos	436	2.09	1.89
Wood Pigeon (Ringduva)	Columba palumbus	418	2.01	1.63
Yellow hammer (Gulsparv)	Emberiza citrinella	278	1.34	0.87
Hooded crow (Kråka)	Corvus corone cornix	275	1.32	0.56

Reptiles and amphibians

The information that was given in /Andrén, 2004b/ is compiled in Table 3-42.

Table 3-42. Ecological data concerning amphibians and reptiles /Andrén, 2004b/.

Species	Weight (g)	Density (ind/km^2)	Diet.	Energy needs	Reproduction
Adder (*huggorm*)	150	100	Primarily mice and voles	330,000 mg dry weight per year (900 mg/day)	In average 5 young per year
Grass snake (*vanlig snok*)	175	100 (200 in wetlands)	Frogs and toads, fish, newts.	350,000 mg dry weight per year (960 mg per day)	Approx. 13 eggs per year
Smooth snake (*hasselsnok*)	70	20	Other reptiles such as slowworm.	140,000 mg dry weight per year (380 mg per day)	In average 6 young per year
Slow-worm (*kopparödla*)	15	1,000	Earthworms and snails.	60,000 mg dry weight per year (165 mg per day)	8 young per year
Common lizard (*skogsödla*)	5	500	Spiders and insects.	21,000 mg dry weight per year (58 mg per day)	7 young per year
Sand lizard (*sandödla*)	8	15 (in Simpevarp)	Spiders and insects.	27,200 mg dry weight per year (75 mg per day)	10 eggs per year
Moor frog (*åkergroda*)	20	3,000 (0–100 metres from pond) 1,000 (100–300 metres from pond) 100–500 (300–500 metres from pond)	Insects, spiders and worms.	20,000 mg dry weight per year (55 mg per day)	1,500 eggs per year
Common toad (*vanlig padda*)	60	4,000	Insects, spiders and worms.	123,200 mg dry weight per year (338 mg per day)	4,000 eggs per year
Smooth newt (*mindre vattensalamander*)	3	2 per m^2 water area, the population size can be up to 10,000 individuals. They stay within 300 metres from the pond.	Larger zooplankton, waterinsects, waterspiders, earthworms, snails and larvae of insects.	3,000 mg dry weight per year (8.2 mg per day)	350 eggs per year
Great creasted newt (*stor vattensalamander*)	9	1 per m^2 water area, the population is never larger than a few thousand individuals They stay within 500 metres from the pond.	Insects, earthworms, snails, waterinsects, waterspiders, larvae of frog and smooth newt.	7,650 mg dry weight per year (21 mg per day)	200 eggs per year

Soil fauna

The density and biomass in three different biotopes are listed in Table 3-43. The biomass is approximately six times lower in the pine more than in the deciduous forest. The highest biomass is found in the grassland.

In general the deciduous forest has a humus layer of mould (*Sw: mull*) with mineral earth, which indicates that the soil contain larger species that burrow. The coniferous forest has a humus layer without mineral earth (*Sw: mår*), suggesting that there are no burrowing fauna. The total amount of soil fauna is larger in coniferous forest, because the organisms are microscopic, such as nematodes (*Sw: rundmaskar*), mites (*Sw: kvalster*) and springtails (*Sw: hoppstjärtar*), which can be seen in Table 3-43. In coniferous forests the decomposition is mainly carried out by fungi, not soil fauna, while it is mostly a bacterial decomposition in deciduous forests /SkogsSverige, 2004, website/.

Table 3-43. Biomass and density in the soil fauna in three different biotopes /Lohm and Persson, 1979/.

	Decidious forest (Uppland)			Pine moor (Gästrikland)			Grassland (Uppland)		
	Number per m²	Dry weight per m² (mg)	mgC per m²	Number per m²	Dry weight per m² (mg)	mgC per m²	Number per m²	Dry weight per m² (mg)	mgC per m²
Earthworm (daggmask)	180	6,100	3,050	< 1	16.9	8.45	130	5,900	2,950
Enchytraeidae (småring-mask)	3,800	370	185	17,000	420	210	24,000	850	425
Wood louse (gråsuggor)	2	9	4.5	< 1	2.25	1.125	< 1	4	2
Centipede (tusenfotingar)	1,200	70	35	25	3	1.5	2	30	15
Springtails (hoppstjärtar)	66,000	110	55	65,000	100	50	110,000	140	70
Protura (trevfotingar)	3,800	2	1	1,000	1	0.5	40	0.5	0.25
Thrips (tripsar)	100	0.5	0.25	1,400	6	3	720	3	1.5
Homoptera (växtsugare)	70	2	1	270	11	5.5	70	1	0.5
Hemipteron (skinnbaggar)	10	7	3.5	190	10	5	10	3	1.5
Beetles (skalbaggar)	600	480	240	500	170	85	1,400	2,800	1,400
Steklar, tex myror	50	50	25	40	15	7.5	110	3	1.5
Wiggler (mygglarver)	1,300	50	25	700	20	10	4,400	320	160
Fly-maggot (fluglarver)	30	80	40	70	9	4.5	1,100	330	165
Spiders (spindlar)	220	70	35	340	70	35	200	40	20
Mite (kvalster)	190,000	600	300	620,000	400	200	110,000	130	65
Sum	267,362	8,000.5	4,000.25	706,535	1,254.15	627.1	252,182	10,554.5	52,77.3

The soil fauna stands for 10% of the carbon turn over in soil, while the fungi and bacterial flora stands for approximately 90% /T. Persson, 2004, pers. comm./. The soil fauna has instead a larger importance to the soil structure and soil properties. Among the soil organisms fungi has most likely the largest storing capacity of radionuclides /T. Persson, SLU, pers. comm./ As mammals, such as moose, consume the fungus they should be an important part of the safety assessment.

The main part of the soil fauna is microbivores (they consumes microorganisms), while some species are primary decomposers /T. Persson, 2004, pers. comm./. According to /Jerling et al. 2001/ the production of microbivores is 12% of the energy input (consumption), while the respiration stands for 18%. The rest goes out as faeces (70%).

Quantitative model

The calculations are compiled in Table 3-44 and the carbon flow is visualised in Figure 3-74 and 3-75.

The density of mice and voles are much higher in Simpevarp than in Forsmark. As the production of the small mammals has been calculated to be 10 times the biomass, the total production of herbivores becomes approximately twice as high as in Forsmark. Excluding the amount prayed by fox, marten and man, there is a large amount left of the production that is assumed to go to other carnivores (see Figure 3-74).

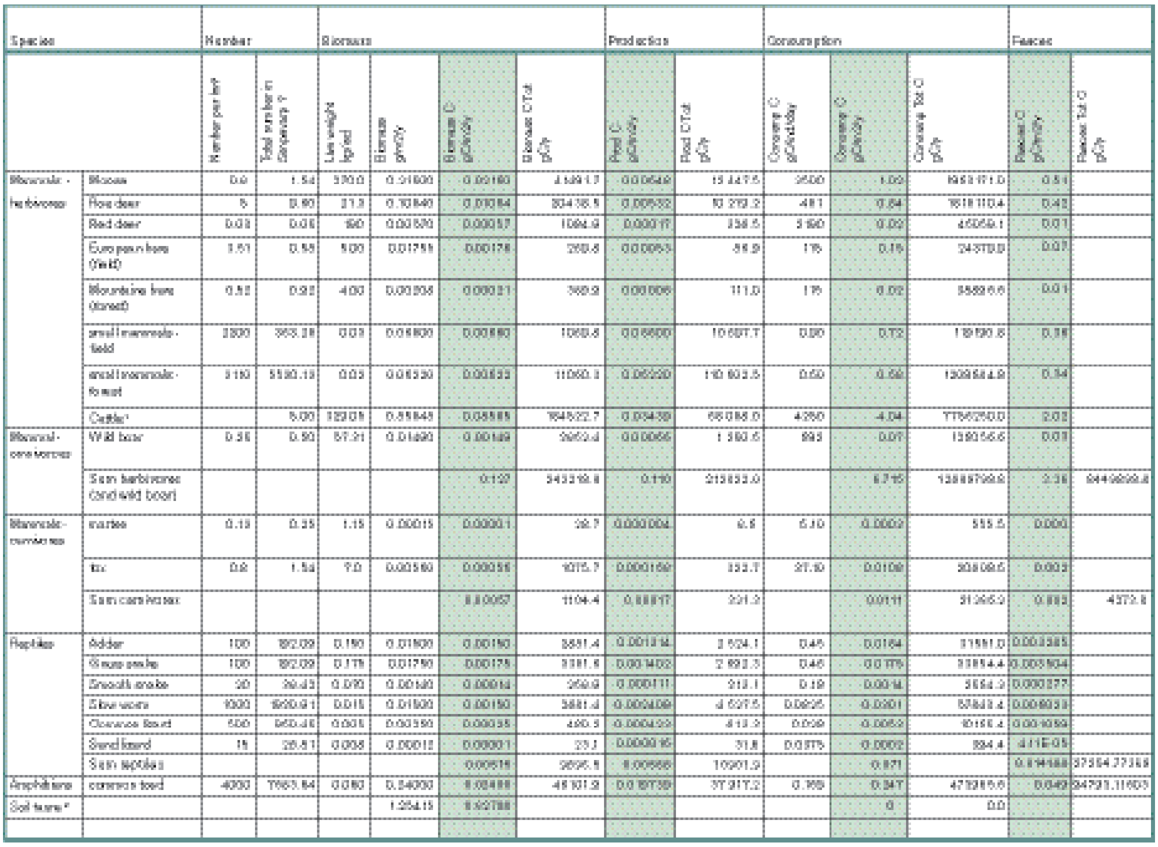
When comparing human (see Table 3-63) and fauna values, it is notable that the moose production is less than the output of moose through hunting. According to the values more than half of the moose population in Simpevarp is harvested, which is not very likely. One explanation is that the hunting values are a mean value for 1997–2003, while the density is calculated for 2003.

The moose harvest was lower in the season 2002/2003 (0.35 moose/km^2), which can be compared to the density of 0.8 moose/km^2. It should also be noted that the harvest values comes from Oskarshamns Norra jaktvårdskrets and an area much larger than the Simpevarp area. The moose is of course not evenly harvested within this area. Besides, the moose do migrate within a large home range. If we, besides the hunting values from 2003, use the production values presented in /Jerling et al. 2001/, which is 1% of the energy input (consumption), the moose production will be larger than the output through hunting.

The density values for hare and the hunting values for hare are not corresponding, and the calculated production of roe deer is almost equal to the human output.

Almost half of the herbivorous production goes to other carnivores besides humans, foxes or martens (Figure 3-74). The fictitious cattle population constitutes a major part of the carbon flow, which can be seen in Figure 3-75.

Table 3-44. Calculations of biomass, production, consumption and faeces in Simpevarp 7, expressed as gC/y and gC/m²/y.



Species		Number		Biomass				Production		Consumption			Faeces	
		Number per km²	Total number in Simpevarp 7	Live weight kg/ind	Biomass g/m²/y	Biomass C gC/m²/y	Biomass C Tot gC/y	Prod C gC/m²/y	Prod C Tot gC/y	Consump C gC/ind/day	Consump C gC/m²/y	Consump Tot C gC/y	Faeces C gC/m²/y	Faeces Tot C gC/y
Mammals - herbivores	Moose	0.8	1.54	370.0	0.29600	0.00180	45691.7	0.00549	15447.5	3500	1.02	1963171.0	0.51	
	Roe deer	5	9.60	21.3	0.10640	0.01064	20438.5	0.00532	10 219.2	481	0.84	1618110.4	0.42	
	Red deer	0.03	0.06	190	0.00570	0.00057	1094.9	0.00017	328.5	3190	0.02	45059.1	0.01	
	European hare (field)	3.51	0.58	5.00	0.01755	0.00176	260.6	0.00053	55.9	175	0.15	24370.0	0.07	
	Mountain hare (forest)	0.52	0.92	4.00	0.00208	0.00021	369.2	0.00006	111.0	175	0.02	55825.6	0.01	
	small mammals - field	2200	363.28	0.03	0.06600	0.00660	1089.8	0.06600	10 897.7	0.90	0.72	119190.8	0.36	
	small mammals - forest	2110	5530.13	0.03	0.06330	0.00633	11060.3	0.06330	110 603.5	0.60	0.69	1209584.9	0.34	
	Cattle¹		5.00	123.05	0.55845	0.05585	184522.7	0.03439	65 088.0	4250	4.04	7756250.0	2.02	
Mammal - omnivores	Wild boar	0.36	0.90	57.31	0.01690	0.00169	2950.4	0.00056	1 380.6	895	0.07	132056.6	0.03	
	Sum herbivores (and wild boar)					0.127	343219.8	0.110	213833.0		6.716	13888799.8	3.36	6449899.8
Mammals - carnivores	marten	0.13	0.25	1.15	0.00015	0.00001	28.7	0.000004	6.6	6.10	0.0002	555.5	0.000	
	fox	0.8	1.54	7.0	0.00560	0.00056	1075.7	0.000168	332.7	37.10	0.0108	20809.6	0.003	
	Sum carnivores					0.00057	1104.4	0.00017	331.3		0.0111	21365.0	0.003	4372.8
Reptiles	Adder	100	192.09	0.190	0.01900	0.00190	3651.4	0.001314	2 524.1	0.45	0.0164	31551.0	0.008385	
	Grass snake	100	192.09	0.175	0.01750	0.00175	3361.6	0.001402	2 693.3	0.46	0.0175	33854.4	0.008804	
	Smooth snake	20	38.42	0.070	0.00140	0.00014	269.9	0.000111	213.1	0.19	0.0014	2664.3	0.000277	
	Slow worm	1000	1920.91	0.015	0.01500	0.00150	2881.4	0.002409	4 627.5	0.0205	0.0301	57843.4	0.008033	
	Common lizard	500	960.46	0.005	0.00250	0.00025	480.3	0.000423	813.3	0.059	0.0053	10155.4	0.001059	
	Sand lizard	15	28.81	0.008	0.00012	0.00001	23.1	0.000016	31.8	0.0375	0.0002	394.4	4.11E-05	
	Sum reptiles					0.00515	9896.5	0.00566	10901.9		0.071		0.014188	27294.27369
Amphibians	common toad	4000	7683.64	0.060	0.24000	0.02400	46101.9	0.019738	37 917.2	0.169	0.247	473385.6	0.049	94721.11603
Soil fauna²					1.25415	0.02788					0	0.0		

¹ Fictitious numbers since there is no cattle in Simpevarp 7. In theory there could be five milkcows in the area as there are some agricultural habitats within Simpevarp 7.

² Dry weight. The figure demonstrate the results from a pine moor in Gästrikland.

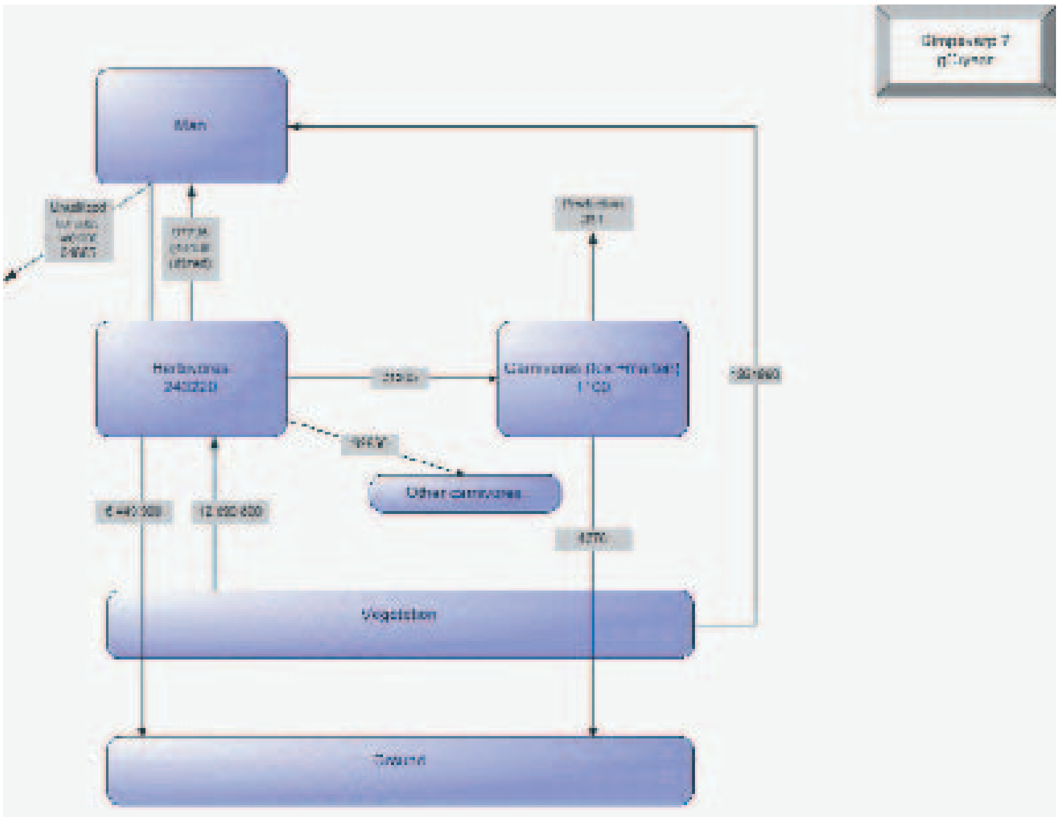


Figure 3-74. *Carbon budget for the terrestrial fauna in Simpevarp 7, expressed as total carbon (gC/year).*

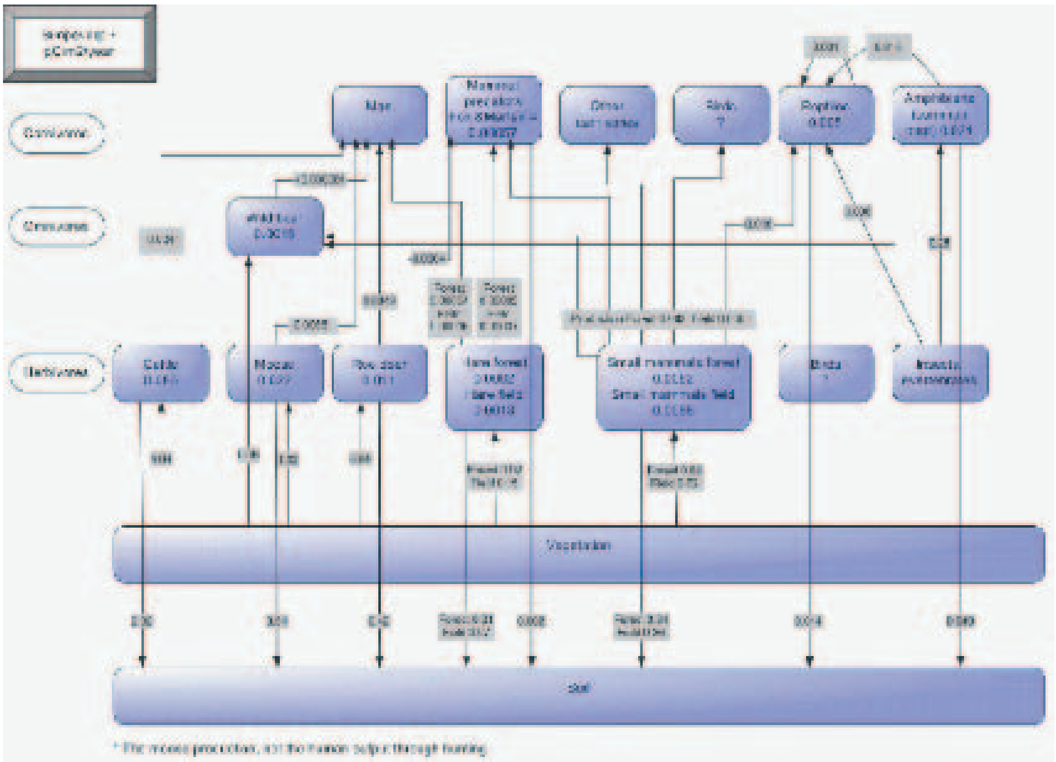


Figure 3-75. *Detailed carbon budget for the terrestrial fauna in Simpevarp 7, expressed as gC/m²/year.*

3.8 Limnic biota

The regional model area of Simpevarp contains relatively few lakes. Totally six lakes, situated partly or entirely within the regional model area, have been investigated for habitat characterisation during the site investigations, and for some of the lakes there are also other biotic data collected, e.g. plankton, fish and invertebrates. Much of the data has been collected during 2004, and the results from some of the investigations have not been reported yet. The most comprehensive dataset available today concerning limnic biota in the area is from Lake Frisksjön, and in this report we will give an account of data only from Lake Frisksjön. Future versions of the report will compile all available data also from the other lakes and from stream sites in the area.

3.8.1 Producers

Input data

The lake habitats have been characterised and the borders between different habitats within the lakes have been defined /Brunberg et al. 2004/. Furthermore, phytoplankton sampling for biomass estimation has been performed in Lake Frisksjön during one year /Sundberg et al. 2004/.

Table 3-45. Data sources concerning primary producers in lakes in the Oskarshamn regional model area.

Parameter	Lake	Year	Reference
Habitat borders	6 lakes in the Oskarshamns area (e.g. Lake Frisksjön)	2003	Brunberg et al. 2004
Phytoplankton biomass	Lake Frisksjön	July 2003–June 2004	Sundberg et al. 2004

Metodology

The *lake characterisation* included identification of watershed, data collection and field investigations /Brunberg et al. 2004/. Identification of watersheds was performed using a GIS-program. The borders of the watersheds were then controlled in field. The lake morphometric parameters were recording using a DGPS and echo-sounder equipment. From these data, bathymetric maps, as well as depth grids, were constructed for each lake. Using the same equipment, the distribution of different habitats was determined in field.

Phytoplankton was sampled 12 times during the period July 2003–June 2004 /Sundberg et al. 2004/. Three of the samples were analysed (July and December 2003, April 2004). Phytoplankton samples were taken with a "Rambergrör" (a 2 m tube sampler with a diameter of 3.5 cm). Five sub-samples were taken within a radius of 50 meters. The samples were preserved in the field with a solution of Lugol. Species composition and biomass of phytoplankton were determined using an inverted phase-contrast microscope.

Description/models

The lakes in Oskarshamn have been divided into five different habitats; the Littoral type I, II and III, the Pelagial and the Profundal /Brunberg et al. 2004/.

Littoral type I: The littoral habitat with emergent and floating-leaved vegetation. This habitat is developed in wind-sheltered, shallow areas where the substrate is soft and allows emergent and floating-leaved vegetation to colonise.

Littoral type II: The littoral habitat with hard substrate. This habitat develops in wind-exposed areas of larger lakes, but also in smaller lakes, where the lake morphometry includes rocky shores. The photosynthesising organisms colonizing these areas include species that are able to attach to the hard substrate, e.g. periphytic algae.

Littoral type III: The littoral habitat with submerged vegetation. This habitat is found in deeper areas of the lakes, where light enough to sustain photosynthetic primary production penetrates down to the sediment.

The profundal habitat: This habitat develops at the sediments of the lakes where light penetration is less than needed to sustain permanent growth of primary producers. Non-photosynthesising organisms dominate this habitat. The profundal organisms are dependent on carbon supplies imported from other habitats of the lake or from allochtonous sources.

The pelagic habitat: This habitat includes the open lake water, where a pelagic food-web based on planktic organisms is developed. Depending on the light availability, these plankton are dominated by either photosynthetic production (i.e. by autotrophic phytoplankton) or, if the water is strongly coloured or turbid, by heterotrophic carbon processing (e.g. by heterotrophic or mixotrophic bacterioplankton and phytoplankton). The pelagic habitat covers the same area as the sum of littoral type II, littoral type III and profundal habitats within a lake.

Below the habitat characterization of Lake Frisksjön is presented. The same type of data is available for the other 5 investigated lakes, i.e. Lake Fjällgöl, Lake Plittorpsgöl, Lake Jämsen and Lake Söråmagasinet.

Lake Frisksjön

All five major habitats are represented in Lake Frisksjön (Table 3-46; Figure 3-76). Despite the relative shallowness of this lake (maximum depth 2.8 m), the brown colour of the water prevents light from penetrating some parts of the lake. Thus, the profundal habitat covers a substantial part of the bottom area (41%). The dominating littoral habitat is of type III.

The highest phytoplankton biomass in Lake Frisksjön was recorded in July 2003 (5.2 mg ww L^{-1}). In December 2003 the biomass was 0.1 mg ww L^{-1} and in April 2004 biomass was 0.4 mg ww L^{-1}. Compared to other humic lakes, phytoplankton biomass in July was very high, whereas the values for December and April were very low (Table 3-47). Dinophytes dominated phytoplankton biomass in July, whereas diatoms dominated in December 2003 and in April 2004 (Figure 3-77). *Perdinium willei* was the dominating species in July. *Merismopedia warmingiana*, *Cryptomonas spp*., *Monoraphidium dybowskii* and *Trachelemonas sp*. were also common. In December 2003 the phytoplankton community had changed to be dominated by the diatom genera *Aulacoseira spp*. In April 2004, *Aulacoseira spp* was still the most common genera, followed by species of *Cryptomonas*. Several species found in Lake Frisksjön are typical for humic lakes. Several species of bluegreen algae (cyanophyceae) were recorded from the lake, although in very low biomasses, and none of the observed species has been documented as potentially toxic.

Table 3-46. Distribution of major habitats in Lake Frisksjön /Brunberg et al. 2004/.

Habitats	Area (%)	Area (m^2)
Littoral type I	18	24,200
Littoral type II	< 2	1,430
Littoral type III	38	49,130
Pelagial	82	107,270
Profundal	41	52,250
Sum		127,010

Table 3-47. Total biomass (gC/m^3) of phytoplankton in station PSM002065 Frisksjön.

Date	Sampling depth (m)	Biomass (mg ww/L)
2003-07-15	0–2	5.2
2003-12-10	0–2	0.1
2004-04-14	0–2	0.4

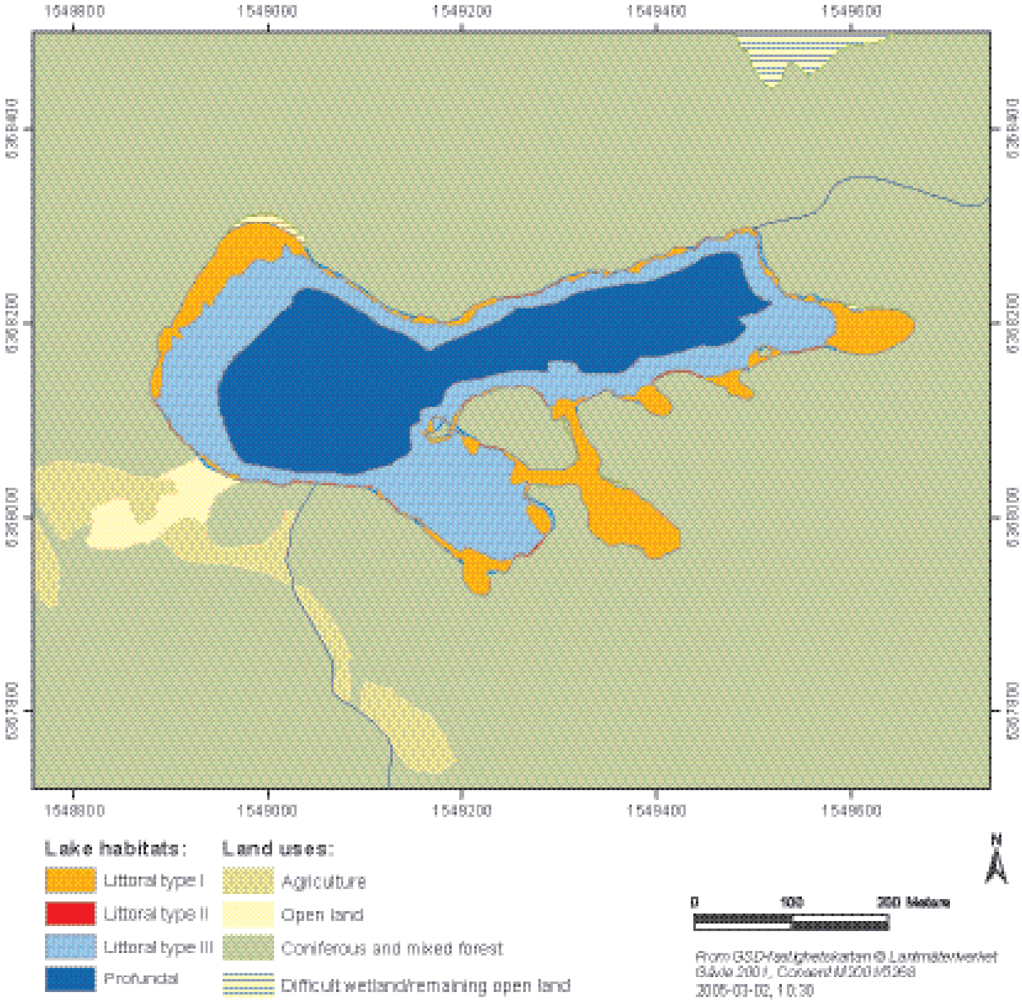


Figure 3-76. *Distribution of major habitats in Lake Frisksjön /Brunberg et al. 2004/.*

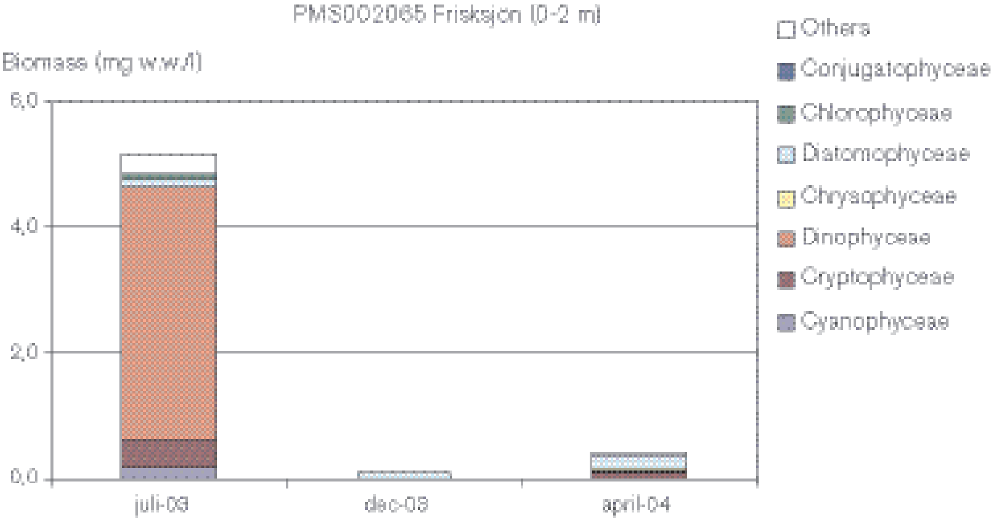


Figure 3-77. *Biomass (gC) of phytoplankton in Frisksjön (0–2 m), separated into different taxonomic classes.*

3.8.2 Consumers

Input data

Zooplankton sampling for biomass estimation has been performed in Lake Frisksjön at 12 occasions during the period July 2003–June 2004 /Sundberg et al. 2004/. Benthic macro invertebrates has been investigated in two watercourses and four lakes in the Simpevarp area /Ericsson and Engdahl, 2004/, while fish data has been collected from four lakes in the area (Lake Jämsen, Lake Söråmagasinet, Lake Frisksjön and Lake Plittorpsgöl) in August 2004 /Engdahl and Ericsson, 2004/. In this report we will only give an account of data from Lake Frisksjön.

Table 3-48. Data sources concerning consumers in the limnic systems of Oskarshamn.

Parameter	Lake	Year	Reference
Zooplankton biomass	Lake Frisksjön.	July-2003–June 2004	/Sundberg et al. 2004/
Benthic fauna biomass	Lake Jämsen, Lake Söråmagasinet, Lake Frisksjön, Lake Plittorpsgöl, stream from Frisksjön, Laxemarsån.	2004	/Ericsson and Engdahl, 2004/
Fish biomass	Lake Jämsen, Lake Söråmagasinet, Lake Frisksjön, Lake Plittorpsgöl.	2004	/Engdahl and Ericsson, 2004/

Metodology

The composition and biomass of *zooplankton* was analysed from three sampling occasions (July and December 2003, April 2004). Samples of the whole water column, from surface to bottom, were taken with a tube sampler and were sieved through a plankton net with a mesh size of 64 µm. The samples were preserved in the field with a solution of Lugol. Zooplankton were analysed and counted in a Leitz Diavert inverted microscope /Sundberg et al. 2004/.

Benthic fauna in lakes was sampled in April 2004 from different depth zones. In the lake littoral zone the samples were taken using kick sampling technique. In the deeper parts of the lakes, the samples were taken with an Ekman grabber with the size 0.0125 m^2. Samples were sieved through a 0.5 mm sieve and then preserved in 70% etanol /Ericsson and Engdahl, 2004c/.

The *fish survey* was performed using benthic multi-mesh gillnets of Nordic type according to standardised procedures /Engdahl and Ericsson, 2004/. For the conversion of weight values per unit effort into biomass per hectare, a factor of 33 have been used (1 kg fish in the net represents 33 kg fish/ha in the lake) as proposed by Per Nyberg at the National Board of Fisheries in Örebro (pers. comm.). Here, the data set has also been classified into functional groups; zooplanktivorous fish (Z-fish), benthivorous fish (M-fish) and piscivorous fish (F-fish), based on the weight of individual fishes and assumed feeding preferences according to /Holmgren and Appelberg, 2000/ (Table 3-48).

Table 3-49. Classification of fish species into functional groups according to /Holmgren and Appelberg, 2000/. The colour code for the functional groups is used in the following section.

Functional group	Included species
Planktivorous fish	Small perch (< 8 g)
Benthivorous fish	Ruffe, bream, roach, rudd and medium-sized perch (8–64 g)
Piscivorous fish	Pike, large perch (> 64 g)

Description/models

Lake Frisksjön

The *zooplankton* community in Frisksjön is typical for a small lake at the east coast of southern Sweden. Cladocerans dominated the summer sample in July 2003 (Figure 3-54). At this time, biomass was very high, 1.68 mg dw L^{-1}, mainly due to high densities of the filter-feeding *Daphnia cucullata* and the predatory *Leptodora kindti.* The small copepod *Thermocyclops sp.* was also common.

In December 2003 and April 2004, zooplankton biomass was much lower than in July (0.158 and 0.138 mg dw L^{-1}, respectively), but high as compared to most of the samplings in the Baltic Sea. At both these dates the zooplankton communities were dominated by copepods, especially the large calanoid *Eudiaptomus sp.*

Several species of rotifers were identified in the samples, however, no other zooplankton groups than cladocerans and copepods contributed significantly to the zooplankton community biomass in Lake Frisksjön.

The seasonal changes of the zooplankton community in Frisksjön indicate a rapid turnover in summer (July 2003), and a slower in winter (December 2003) and spring (April 2004). Cladocerans, as the efficiently filter-feeding *Daphnia* sp*.,* are usually able to recycle nutrients and other chemical substances faster than slowly growing large copepods, such as *Eudiaptomus.*

The substrate in the littoral of Lake Frisksjön is dominated by detritus, while macrophyte vegetation is sparse. The most abundant functional groups among *benthic fauna* in the Littoral type I were detritus feeders and predators, but also shredders contributed significantly to total biomass (Table 3-56).

Also in the Littoral type III (the area between the littoral with emergent and floating-leaved vegetation and the profundal) is the substrate dominated by detritus, and there is no vegetation. Numerically, detritus feeders were by far most abundant, but the biomass was totally dominated by filter feeders (Table 3-51). The reason for the dominance of filter feeders was a single specimen of the large mussel *Anodonta anatina*. If that mussel was excluded from data, the biomass was dominated by predators.

In the profundal zone, the most abundant group was predators, both numerically and in biomass (Table 3-52).

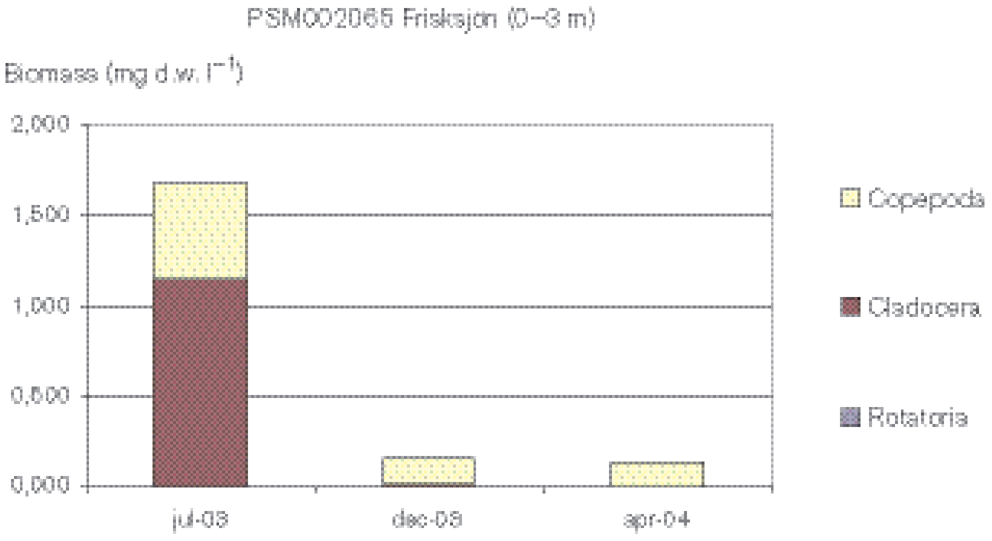


Figure 3-78. *Biomass of different zooplankton groups in the water column of Lake Frisksjön (0–3 m).*

Table 3-50. Abundance and biomass of different functional groups of benthic fauna in the Littoral type I of Lake Frisksjön (mean values, N = 5) /Ericsson and Engdahl, 2004c/.

Functional groups	Abundance (number/m²)	Abundance (%)	Biomass (gC)	Biomass (%)
Filter feeders	16.0	5.6	0.034	2.1
Detritus feeders	114.4	39.9	0.481	28.9
Predators	48.8	17.0	0.734	44.1
Scrapers	16.8	5.9	0.036	2.2
Shredders	8.8	3.1	0.338	20.3
Other/unknown	81.6	28.5	0.040	2.4
Sum	286.4	100.0	1.663	100.0

Table 3-51. Abundance and biomass of different functional groups of benthic fauna in the Littoral type III of Lake Frisksjön (mean values, N = 5) /Ericsson and Engdahl, 2004c/.

Functional groups	Abundance (number/m²)	Abundance (%)	Biomass (gC)	Biomass (%)
Filter feeders	27.9	1.5	179.9	97.3
Detritus feeders	1,534.9	83.3	1.4	0.7
Predators	260.5	14.1	3.6	2.0
Scrapers	0.0	0.0	0.0	0.0
Shredders	0.0	0.0	0.0	0.0
Other/unknown	18.6	1.0	0.0019	0.0010
Sum	1,841.9	100.0	184.9	100.0

Table 3-52. Abundance and biomass of different functional groups of benthic fauna in the profundal zone of Lake Frisksjön (mean values, N = 5) /Ericsson and Engdahl, 2004c/.

Functional groups	Abundance (number/m²)	Abundance (%)	Biomass (gC)	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	18.6	0.6	0.38	5.4
Predators	2,455.8	99.4	6.67	94.6
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	0	0	0	0
Sum	2,474.4	100	7.05	100

The catch from the fish survey was dominated by perch in numbers, as well as in biomass, followed by roach and bream /Engdahl and Ericsson, 2004/. Data from the fish survey, divided into functional groups, is presented in Table 3-53.

Table 3-53. Compiled results of fish data from Lake Frisksjön (8 gillnets), August 2004 /Engdahl and Ericsson, 2004/.

Functional group	Species	Weight per Unit Effort (WPUE, kg)	Biomass per hectare (kg/ha)	Total biomass (kg)	Total biomass (kg C)
Planktivorous fish	Perch	0.044			
	Planktivorous fish total	0.044	1.5	15.6	1.5
Benthivorous fish	Bream	0.272			
	Ruffe	0.008			
	Perch	0.267			
	Roach	0.312			
	Rudd	0.032			
	Benthivorous fish total	0.891	29.4	314.4	30.9
Piscivorous fish	Perch	0.112			
	Pike	0.723			
	Piscivorous fish total	0.835	27.6	294.8	29.0
Total		1.70	58.4	624.9	61.5

3.9 Marine biota

3.9.1 Introduction

In this chapter a description of the marine ecosystems of Simpevarp is presented, based on site specific results with emphasis on biological components. The overview section contains a brief description of the ecosystems, including abiotic characteristics, followed by presentation of data on producers and consumers in which basin specific data is presented. The basins are assumed to be parts of the marine environment that are more or less physically or bathymetrically separated from each other. The basins are treated like separate units, as would lakes, based on the assumption that relevant flow of matter will be possible to quantify either with estimations of abiotic carbon flow (runoff and oceanographic flows) or biotic (migration of organisms).

3.9.2 Overview

The Simpevarp marine ecosystem has been divided in three basins. These basins are described below (Figure 3-79) and in Chapter 4.

The marine system in Simpevarp encompasses three major habitats; enclosed bay areas to a varying degree affected by the fresh water effluence, coastal archipelago with sheltered areas and a Baltic Sea coastal habitat exposed to sea currents and wave action. The bays have a variable geometry, large shallow areas (< 1 m) are found as well as depth down to 18 m. The basins described here have mean depths of 0.8, 3.4 and 4.5 m The bay areas have an average surface salinity of 3.5–4.5 ‰ whereas the bottom water (16 m) has a salinity close to the surrounding coastal area of 6 ‰. The bay areas are characterized of humic, low transparency conditions, averaging a light penetration of 2–3 m in enclosed bays, 4–7 m in the archipelago and 12 m in the open sea. The bay areas have a nutrient content of 600–700µg tot–N/l, decreasing to roughly 300µg tot–N/l in the coastal areas and 20–30µg tot–P/l /Ericsson and Engdahl, 2004a/. In Figure 3-79, a bathymetrical map over the Simpevarp area is presented with cross sections, Figure 3-80 and 3-81, showing water depths in relation to different photic depths in the two basins Borholmsfjärden and Granholmsfjärden. This bathymetrical data /Brydsten, 2004a/ have been updated and the data used in this report in calculations of depth and volumes have been reported in /Ingvarsson et al. 2004/.

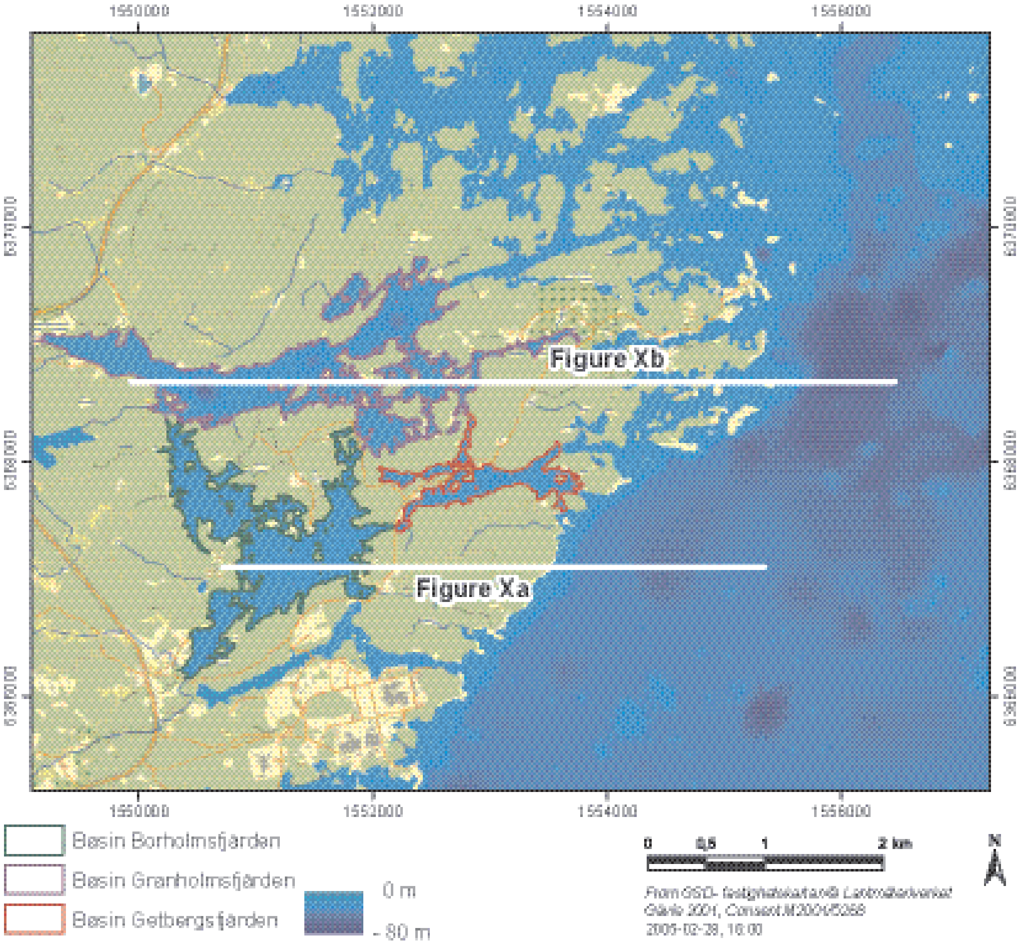


Figure 3-79. *Bathymetric map over the Simpevarp area with the three basins and two profiles crossing basin Borholmsfjärden (green) and Granholmsfjärden (brown), see figures below. Grey indicates Basin Getbergsfjärden. Depth indicated with increasingly dark blue colour. Figure Xb refers to Figure 3-81 and figure Xa to Figure 3-80.*

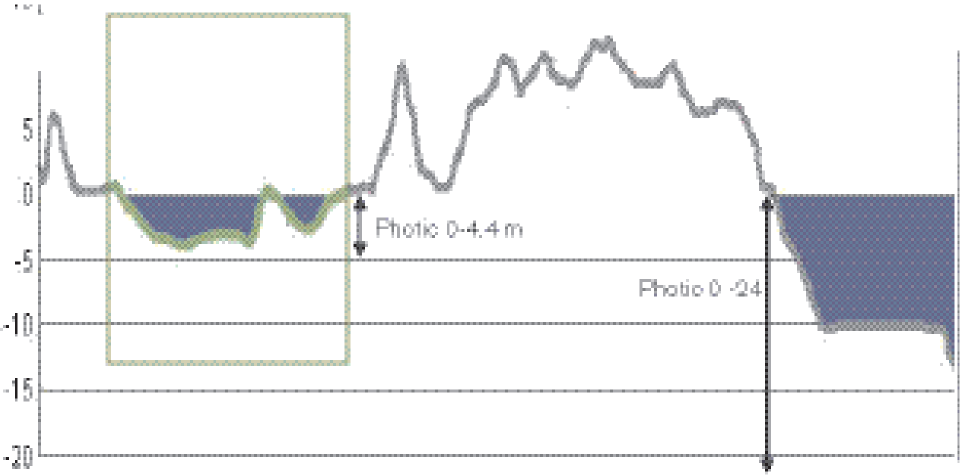


Figure 3-80. *Sketch of depths for basin Borholmsfjärden and the coastal zone with photic zone for both areas. Depth (m) on Y axis.*

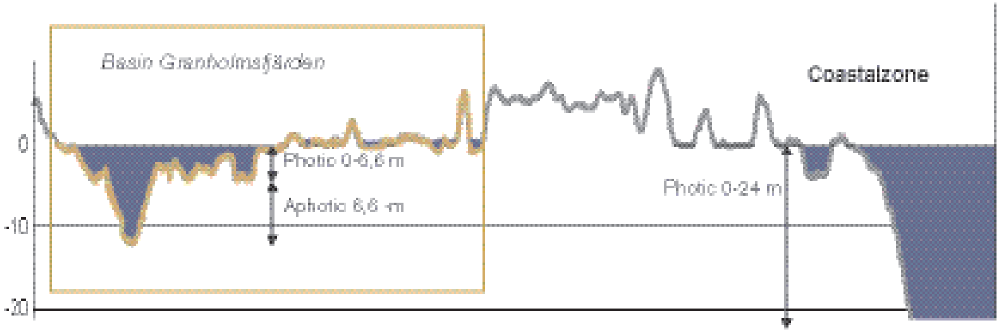


Figure 3-81. Sketch of depths for basin Granholmsfjärden and the coastal zone with photic and aphotic zone for basin Granholmsfjärden. Depth (m) on Y axis.

The inner soft bottom parts of the archipelago north of Simpevarp (around Äspö) are dominated by *Chara sp.* (Figure 3-82). West of Ävrö a large area is covered by the *Xanthophyceae Vaucheria sp*. On corresponding bottoms in the southern area the vegetation is dominated by vascular plant communities, dominated by *Potamogeton pectinatus* and *Zostera marina*. The sheltered inner coastal waters, particularly south of Simpevarp, are dominated by *P. pectinatus* (Figure 3-82). Further out towards more exposed areas *P. pectinatus* and *Z. marina* occurs together in a patchy appearance. On hard substrates, in shallow areas, the vegetation is dominated by *Fucus vesiculosus* and in deeper areas red algae covers the hard substrata, with a common cover degree of 25% /Fredriksson and Tobiasson, 2003/. *Fucus sp.* in low abundance is recorded to approxemately 10 m depth and red algae down to approximately 30 m /Tobiasson, 2003/. The benthic fauna is in all basins dominated by detritivores. Detritivores, often *Macoma baltica* or *Hydrobia sp*., constitutes for 50–80% in the basins presented below. Totally 45 species associated to the vegetation occurred in the area around Simpevarp and 41 in the sediment. The *Fucus sp.* communities is the most diverse concerning associated fauna and harbour 31 species or higher taxa, while the soft bottom soft bottom without vegetation have 14 species.

Primary producers in the pelagic habitat, which accounts for a relatively small part of the carbon flow of the ecosystem (see Chapter 4), seems to be dominated by the diatoms. Copepods are the dominating zooplankton, and zooplankton as a group is more abundant in the inner bays than in the coastal areas.

3.9.3 Producers

Input data and method

Three sources of site specific data have been used, all a part of the site investigation programme, Table 3-54.

Table 3-54. Data sources concerning primary producers in the marine systems of Simpevarp.

Parameter	Basin	Data	Year	Reference
Light penetration depth	Basin Borholmsfjärden	4.4 m	2002–2004	/Ericsson and Engdahl, 2004a and field measurements in SICADA/
	Basin Granholmsfjärden	6.6 m	2002–2004	
	Basin Getbergsfjärden	5.5 m	2002–2004	
Bathymetrical measurements	Basin Borholmsfjärden-3	See Chapter 4	2004	/Ingvarsson et al. 2004/
Phytoplankton – Biomass	Basin Borholmsfjärden and 2, Offshore	See below	2003–2004	/Sundberg et al. 2004/
Macrophytes – Biomass, distribution	All basins	See below	2002	/Fredriksson and Tobiasson, 2003/
Reed (*Phragmites australis*) – Biomass	Basin Borholmsfjärden, 2 and 3	See below	2004	/Alling et al. 2004/

The vegetation map presented in /Fredriksson and Tobiasson, 2003/ is based on three different data sets; the general survey of 1,280 discrete sites with recordings on dominant macrophytes and coverage, twenty diving transects, 40 video recordings and bathymetrical data from the Swedish sea charts. The map was drawn by hand and the accuracy is dependent on the density of observations – generally higher in the inner bays and coastal areas and lower in the offshore area. The site observations and diving transects present data in cover degree i.e. the percentage of the sea bottom that is covered by macrophytes. The biomass in the basins is calculated by using the average cover degree of the vegetation type and a biomass related to percentage cover. The quantitative sample size for each vegetation type ranges between two and twelve. Data is presented per vegetation type in dry weight per square metre and cover degree. As a complement biomass has been recalculated into gC using species specific conversion factors presented in /Kautsky, 1995/.

From the general survey different vegetation communities were defined on basis of dominating species or higher taxa. For the area around Simpevarp nine vegetation communities were defined (Figure 3-82). It also presents the area covered by the different vegetation communities. Red algae community covered the largest area with almost 6 million square meters. Second highest coverage had the *Potamogeton pectinatus*-community with area coverage of almost 2 million square meters. Regarding coverage, the *P. pectinatus* community were followed by the *Chara sp.*

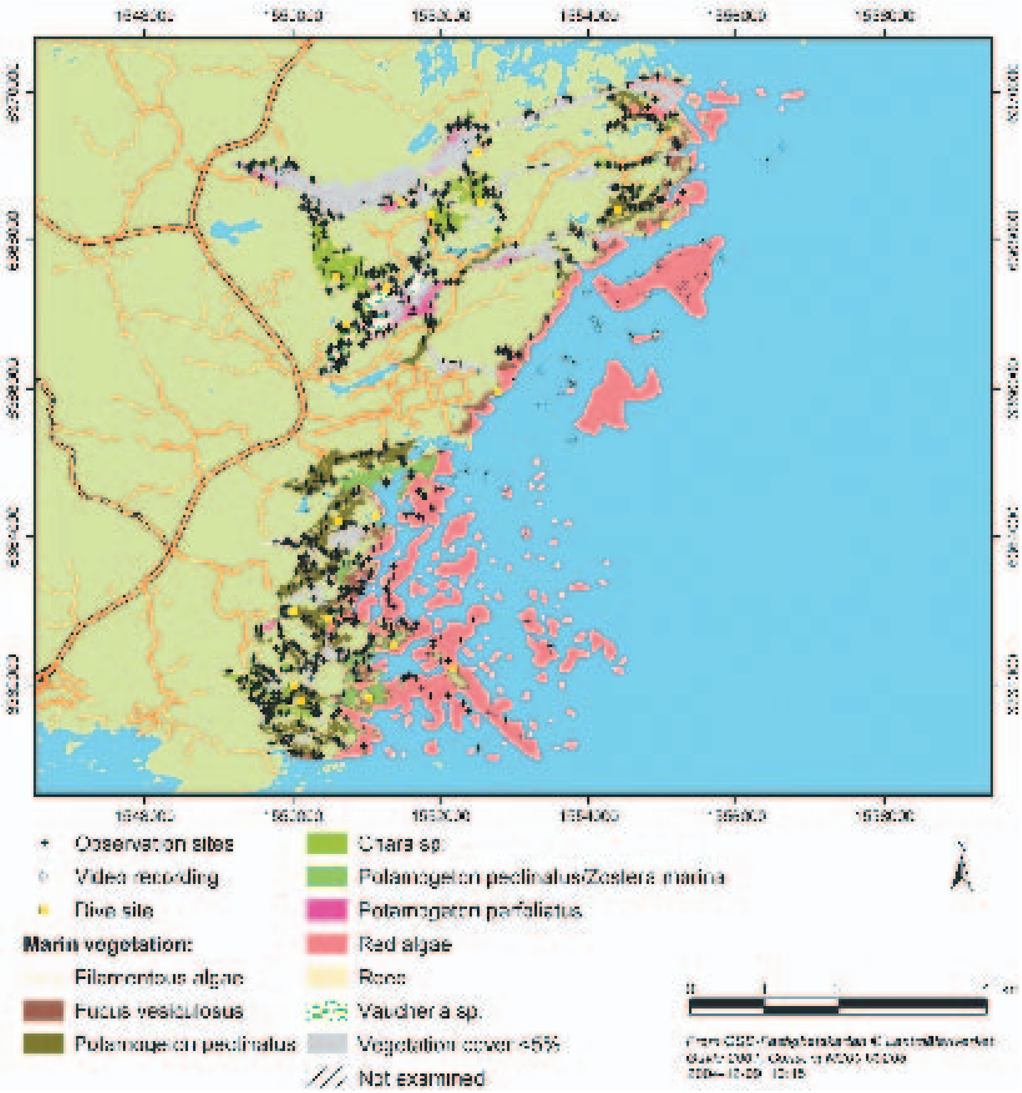


Figure 3-82. The marine vegetation map and data sources.

and *Fucus vesiculosus*[1] communities with an coverage of 1.3 and 1 million square meters respectively. The vegetation communities consist of subareas of different composition of species and coverage degree. Occurring species in the vegetation communities are presented in Table 3-55. The vegetation community with the highest number of species was the Filamentous-community with 23 found species or higher taxa (Table 3-55). The community with the second highest number of species was the *F. vesiculosus* community which included 19 taxa. The lowest number of species was recorded in the *P. perfoliatus* and *Vaucheria sp.* communities (Table 3-55) with only one and three species respectively.

Table 3-55. Macrophyte species present in vegetation communities. O = occurrence.

	Cyanophyceae			Charophyceae						Zygnematophyceae	Chlorophyceae									Xanthophyceae	Phaeophyceae					Rhodophyceae							Magnoliophyta								
Vegetation type	RIVULARIA sp.	Calothrix scopulorum	Lyngbya aestuarii	CHARA sp.	Chara aspera	Chara baltica	Chara tomentosa	Chara horrida	Chara baltica var. liljebladii	MOUGEOTIA sp.	ULOTHRIX sp.	Monostroma grevillei	ENTEROMORPHA sp.	CHAETOMORPHA sp.	CLADOPHORA sp.	Cladophora glomerata	Cladophora rupestris	UROSPORA sp.	unknown Chlorophyceae	VAUCHERIA sp.	Pylaiella littoralis	[illegible]	Dictyosiphon foeniculaceus	Fucus vesiculosus	unknown Phaeophyceae	Furcellaria lumbricalis	PHYLLOPHORA sp.	Aglaothamnion byssoides	Ceramium nodulosum	Ceramium gobii	Polysiphonia fucoides	Polysiphonia fibrillosa	Ceratophyllum demersum	Myriophyllum spicatum	Potamogeton pectinatus	Potamogeton perfoliatus	Ruppia cirrhosa	Zannichellia sp.	Najas marina	Zostera marina	Σ
Filamentous	O	O		O						O	O	O	O	O	O	O	O		O	O	O		O	O	O					O	O	O		O			O	O			23
Chara sp.				O	O		O	O	O						O				O	O															O			O	O		11
P. pectinatus			O	O		O				O					O							O					O			O		O	O	O	O		O	O			14
P. perfoliatus																																				O					1
Vaucheria sp.																				O														O			O				3
F. vesiculosus	O									O			O		O	O					O	O	O	O		O				O	O	O	O	O							15
Undergrowth	O												O		O	O	O	O			O			O		O	O		O	O	O	O									14
Z. marina																								O		O				O	O			O	O		O			O	8
Red algae											O		O		O						O					O	O	O		O	O	O					O				11
Occurrence	3	1	1	3	1	1	1	1	1	3	2	1	4	1	6	3	2	1	2	3	4	2	2	4	1	4	3	1	1	6	5	5	2	5	3	1	5	3	1	1	

From GSD-fastighetskartan © Lantmäteriverket
Gävle 2001, Consent M2001/5288
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Figure 3-83. Reed sampling sites 2004.

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[1] In the text, Fucus vesiculosus community include its undergrowth, presented separately in table X.

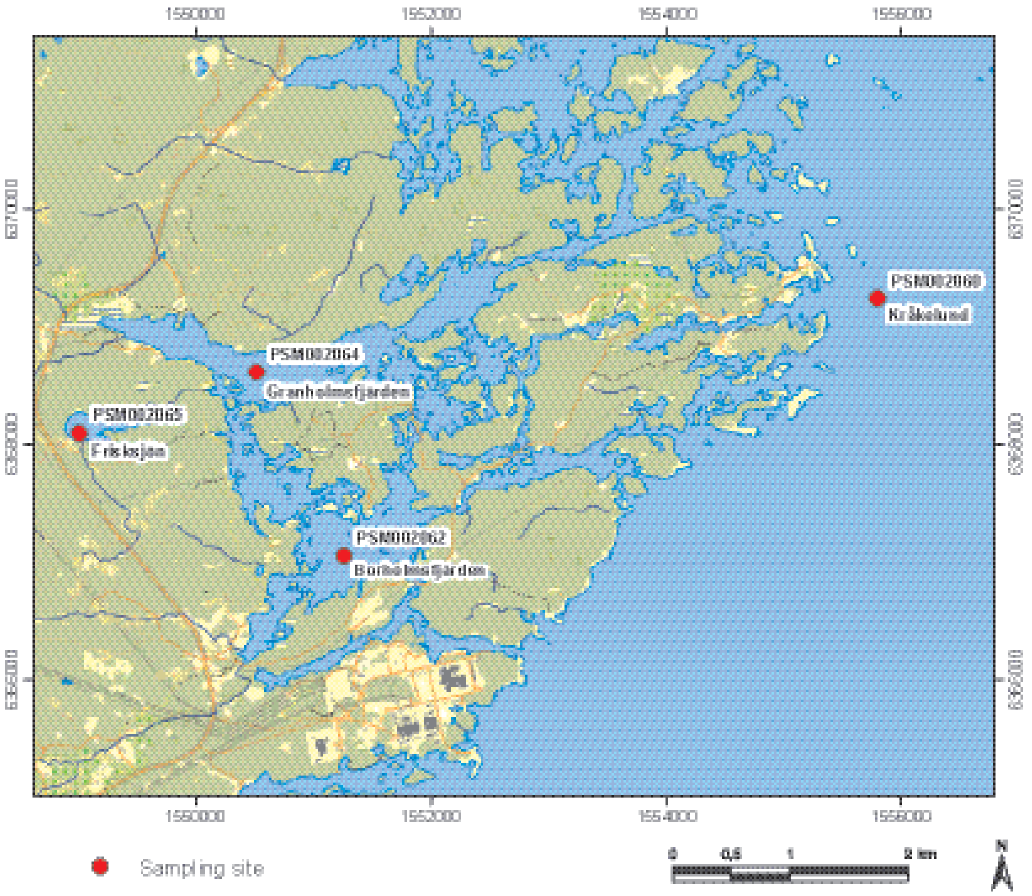

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Figure 3-84. *Plankton and water chemistry sampling sites during 2003–2004 and 2002–2004, respectively.*

The most common species in the samples were *Cladophora sp.* and *Ceramium gobii* which occurred in 6 of the 9 vegetation communities (Table 3-55). Other common species were the red algae *Polysiphonia fucoides* and *Polysiphonia fibrillosa* which along with the phanerogams *Myriophyllum spicatum* and *Ruppia sp.* was found in the samples from five different vegetation communities.

Reed, *Phragmites australis*, was sampled in six sites in the three basins in 2004. The mean biomass for reed biomass in the Oskarshamn area is 1.3×10^3 gDW/m^2. Mean value for reed rhizome biomass in the same area is 3.7×10^3 gDW/m^2. The result from the standing crop biomass measurement corresponds with earlier studies of reed biomass, but the mean biomass value for the rhizome was almost the double, which could depend on that this study included both dead and living roots.

Data on phytoplankton are presented in /Sundberg et al. 2004/ and originate from three sampling occasions (December, April and June) in four areas, se Figure 3-87 during 2003–2004. Data is presented per taxa or species and in dry weight per litre. The sampling sites are the same as site as for water chemistry samples.

Basin Borholmsfjärden

The benthic macro vegetation is to a large part composed of *Chara sp.*-community, in the shallower parts and *Vaucheria*-community in the deeper parts, approximately at depths of 4–6 m, see Figure 3-85. *Chara* covers a two times larger area than *Vaucheria* and dominates somewhat in biomass (gDW) but recalculated into carbon (gC) *Vaucheria* dominates in biomass in the basin due to a denser constitution (Figure 3-86). The *Chara sp.*-community consists of sub areas with different composition in cover of *Chara* and also different amount of associated species as *P. pectinatus,* *Myriophyllum sp. and Najas marina*. About one fifth of the *Chara sp.*- community is not dominated by *Chara sp.* but by *Najas marina*. The *P. perfoliatus*-, *Vaucheria sp.*-communities are much more homogenous. All associated macrophyte species are presented in Table 4-61 in previous chapter. Reed covers a small area but contributes with a large biomass. Area cover and biomass is presented in Table 3-56 and in Figure 3-85.

Table 3-56. Area cover (m^2) and biomass (gDW, gC) of benthic vegetation in basin Borholmsfjärden.

Vegetation type	Area (m^2)	Macrophytes (gDW)	Macrophytes (gC)
Vegetation cover less than 5%	2.76×10^5	0	0
Chara sp.	6.46×10^5	1.64×10^8	2.26×10^7
Potamogeton pectinatus	6.54×10^3	4.62×10^5	1.49×10^5
Potamogeton perfoliatus	1.39×10^5	1.18×10^6	3.81×10^5
Vaucheria sp.	3.02×10^5	7.90×10^7	3.09×10^7
Reed, Phragmites australis	9.23×10^3	1.16×10^7	4.57×10^6
Not examined	1.78×10^3	0	0

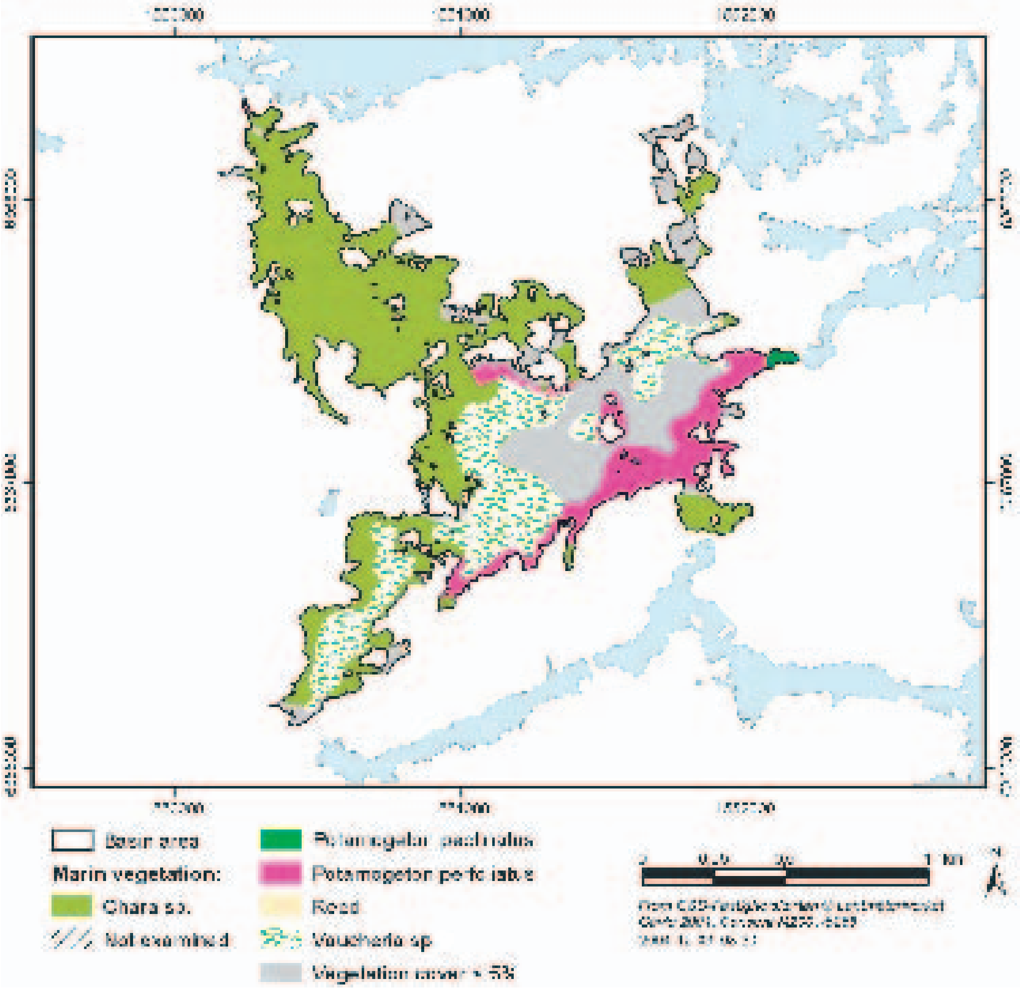


Figure 3-85. *Distribution of different vegetation communities in Basin Borholmsfjärden.*

Chryptophytes and diatoms dominated the biomass of the phytoplankton community in July and December 2003. In April 2004 there was no predominant group (Figure 3-87) *Diatoma tenuis* and *Cryptomonas spp.* were most common in July and December 2003. *Pseudopedinella elastica* together with other small monadoids were dominating in April 2004. The highest algal biomass was recorded in July 2003 (1.2 mg WW/l). In December 2003 the biomass was 0.4 mg WW/l and in April 2004, 0.3 mg WW/l. Several species of bluegreen algae (cyanophyceae) were recorded in July but in a very low biomass (< 0.001 mg WW/l). /Sundberg et al. 2004/.

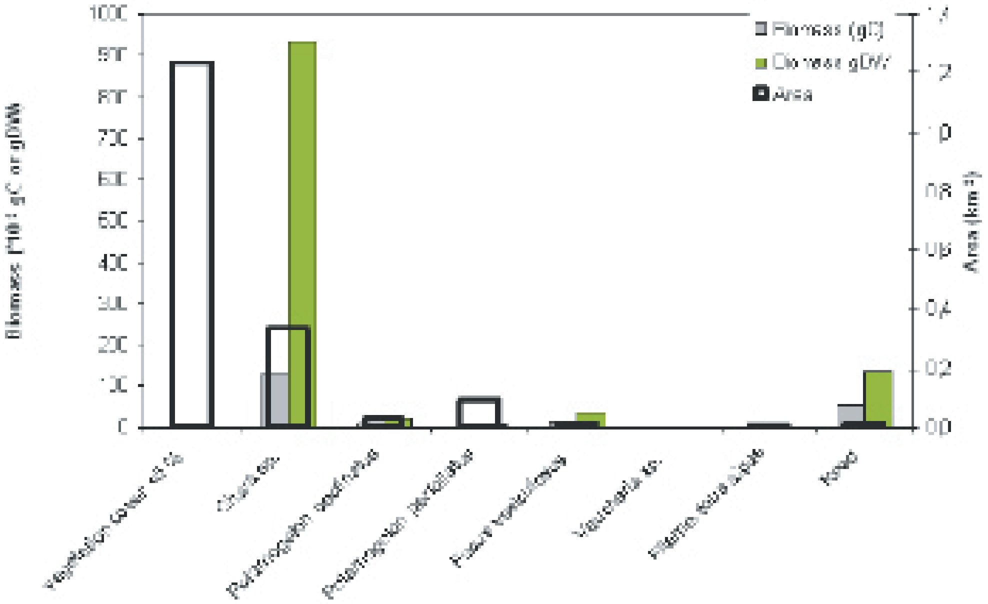


Figure 3-86. Area cover (km²) and biomass in gDW and gC for different vegetation communities in Basin Borholmsfjärden. Vegetation cover < 5% is assumed to have no biomass.

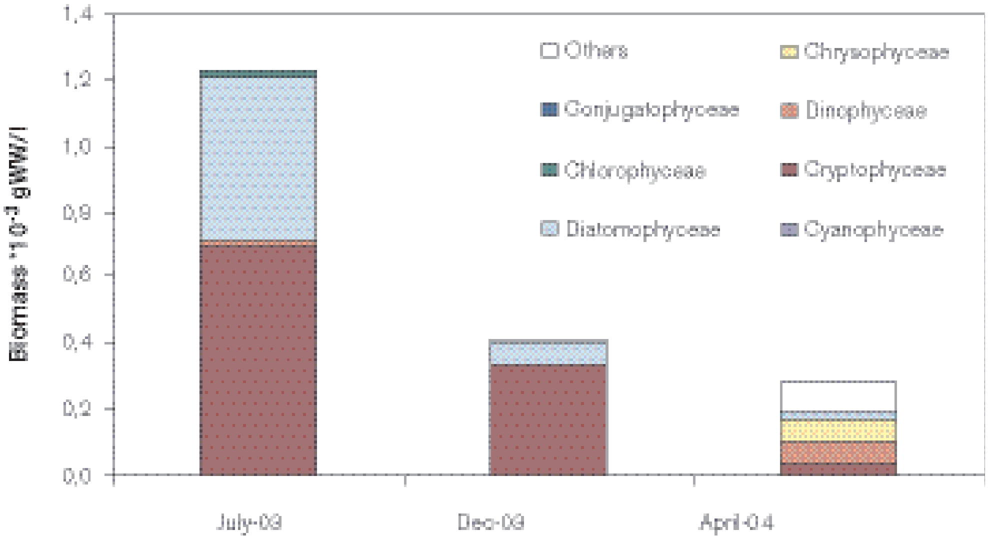


Figure 3-87. Biomass of phytoplankton separated into different classes from the sampling site in Basin Borholmsfjärden (0–2 m). From /Sundberg et al. 2004/.

Basin Granholmsfjärden

The largest part, approximately 70%, of this basin is too deep for macrophytes (Figure 3-88 and 3-89). The photic benthic vegetation is clearly dominated of *Chara sp*.-community (about 20% of the area) and they dominate in the sheltered bays in the south east of the basin. On soft bottoms in the large part of the basin, *P. pectinatus* occur and there are also areas with *F. vesiculosus*-communities. The *Chara sp*.-community consists of sub areas with different cover degree and biomass. The communities are denser than in basin Borholmsfjärden and have about double the biomass per square metre compared to basin Borholmsfjärden. All associated macrophyte species are presented in Table 3-55 in Input data-chapter. Reed covers a small area but contributes with a large biomass. Area cover and biomass is presented in Table 3-57 and in Figure 3-88.

Table 3-57. Area cover (m^2) and biomass (gDW) of benthic vegetation in basin Granholmsfjärden.

Vegetation type	Area (m^2)	Macrophytes (gDW)	Macrophytes (gC)
Vegetation cover < 5%	1.23×10^6	0	
Chara sp.	3.39×10^5	9.33×10^7	1.29×10^7
Weed	3.67×10^4	2.37×10^6	7.64×10^5
Potamogeton perfoliatus	9.53×10^4	4.95×10^5	1.60×10^5
Fucus vesiculosus	1.39×10^4	3.56×10^6	1.16×10^6
Vaucheria sp.	4.28×10^2	1.17×10^5	4.57×10^4
Filamentous algae	6.55×10^3	4.62×10^4	1.20×10^4
Reed	1.08×10^4	1.36×10^7	5.37×10^6

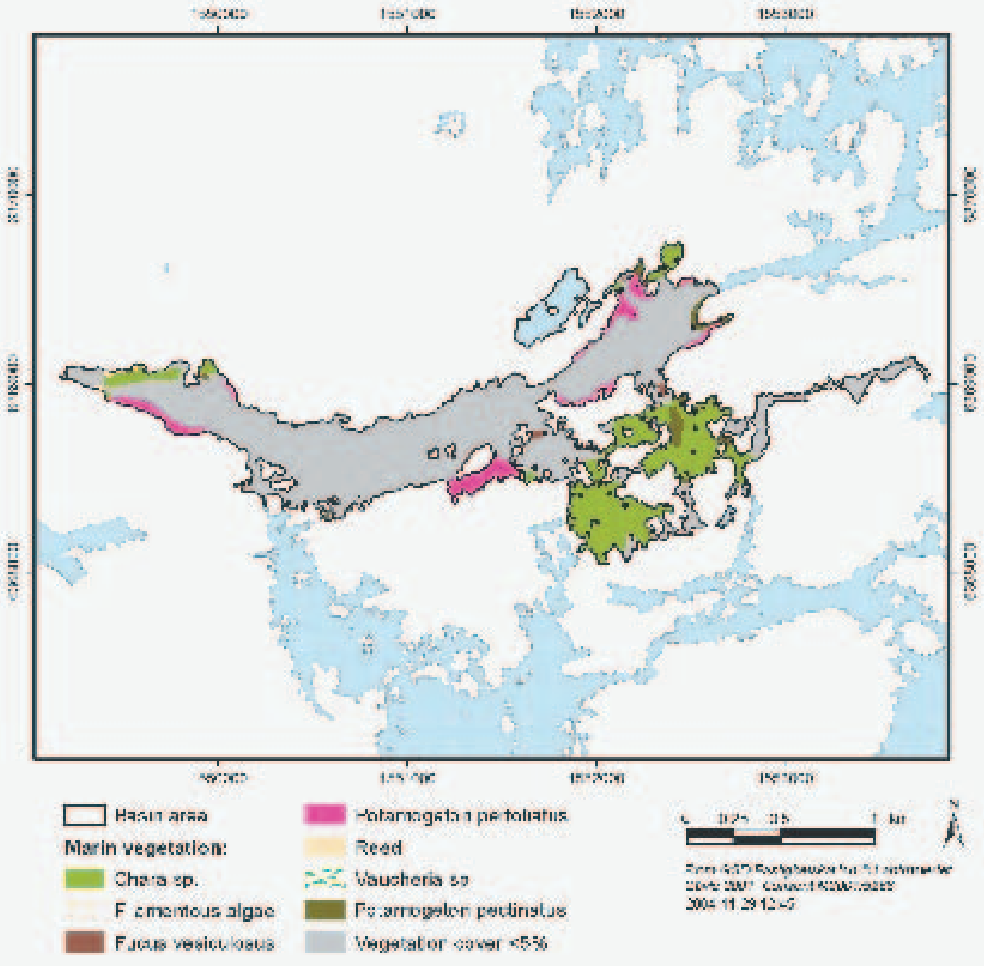


Figure 3-88. Distribution of different vegetation communities in Basin Granholmsfjärden.

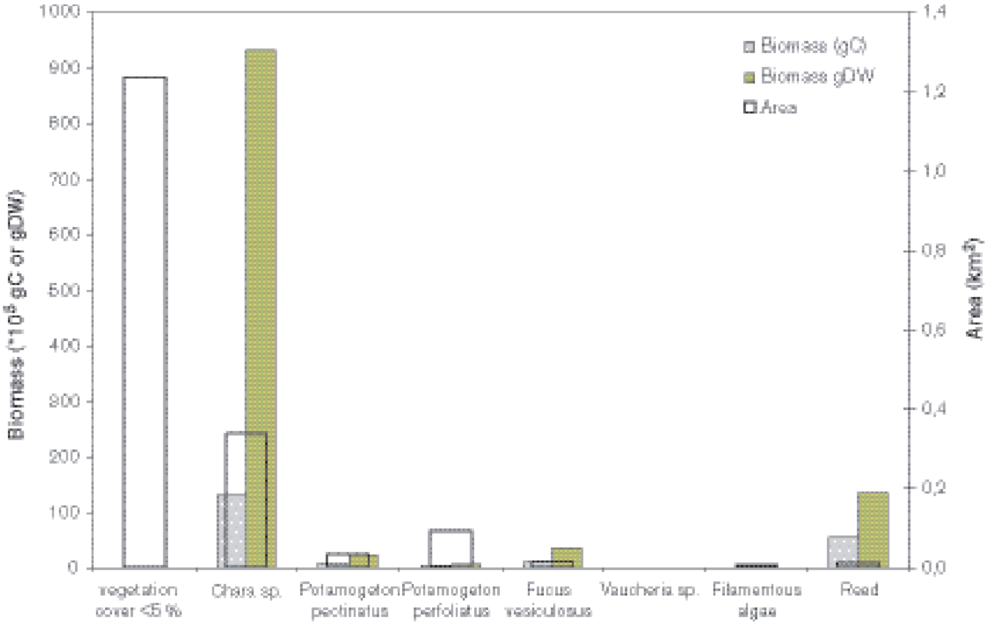


Figure 3-89. *Area cover (km²) and biomass in gDW and gC for different vegetation communities in Basin Granholmsfjärden. Vegetation cover < 5% is assumed to have no biomass.*

Cryptophytes dominated the biomass of the phytoplankton community in July 2003 whereas dinophytes were dominant in December 2003. In April 2004 were diatoms the most dominant algae group (Figure 3-90). Different species of *Cryptomonas* were common in both July and December 2003. In December also species of dinophyceae were frequent. In April 2004 was however the genera *Chaetoceros* the most common taxa. The highest algal biomass was recorded in April 2004 (0.9 mg WW/l). In July 2003 the biomass was 0.1 mg WW/l and in December 2003, 0.2 mg WW/l. /Sundberg et al. 2004/.

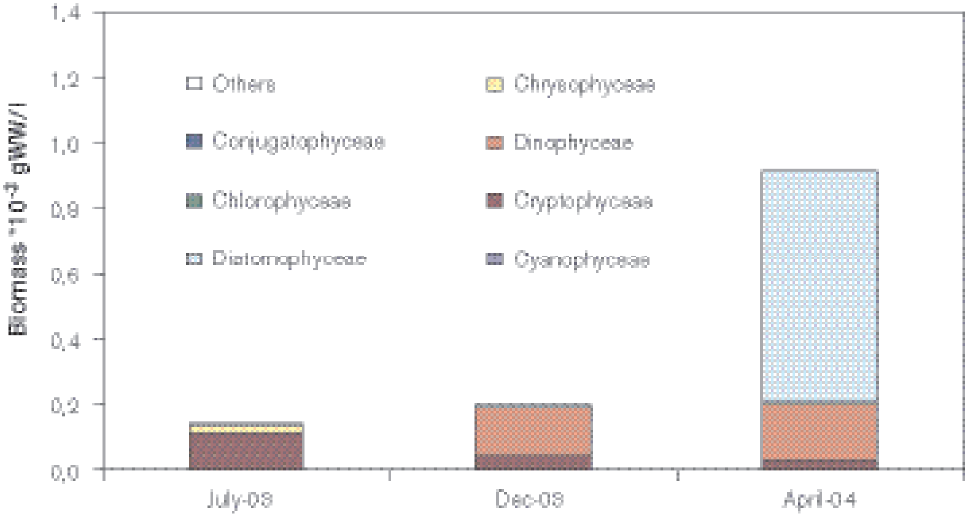


Figure 3-90. *Biomass of phytoplankton separated into different classes from the sampling site in Basin Granholmsfjärden (0–16 m). From /Sundberg et al. 2004/.*

Basin Getbergsfjärden

Large parts of basin three do not contain macrophytes to a large extent due to its depth but this is also the case in some shallow bays. *P.pectinatus*, *P.perfoliatus* and *Chara sp.*- communities dominates the photic soft bottom substrate, and *F. vesiculosus* the hard substrate, see Figure 3-91. The largest biomass contributor, *P. pectinatus* consist of sub areas where Myriophyllum spicatum as well as algae eg. F*ucus vesiculosus* and *Chorda filum* are present. All associated macrophyte species are presented in Table 3-55 in the Input data section. Reed covers a small area but contributes with a large biomass. Area cover and biomass is presented in Table 3-58 and in Figure 3-91.

Table 3-58. Area cover (m²) and biomass (gDW) of benthic vegetation in basin Getbergsfjärden.

Vegetation	Area (m²)	Macrophytes (gDW)	Macrophytes (gC)
Vegetation cover less than 5%	1.89×10^5	0	
Chara sp.	1.67×10^4	1.52×10^6	2.09×10^5
Weed, Potamogeton pectinatus	7.12×10^4	7.48×10^6	2.41×10^6
Potamogeton perfoliatus	2.11×10^4	1.90×10^5	6.16×10^4
Fucus vesiculosus	1.17×10^4	2.20×10^6	7.15×10^5
Potamogeton pectinatus/Zostera marina	1.42×10^3	1.17×10^5	3.79×10^4
Reed	1.26×10^3	1.58×10^6	6.25×10^5
Not examined	4.98×10^4	4.87×10^6	7.84×10^5

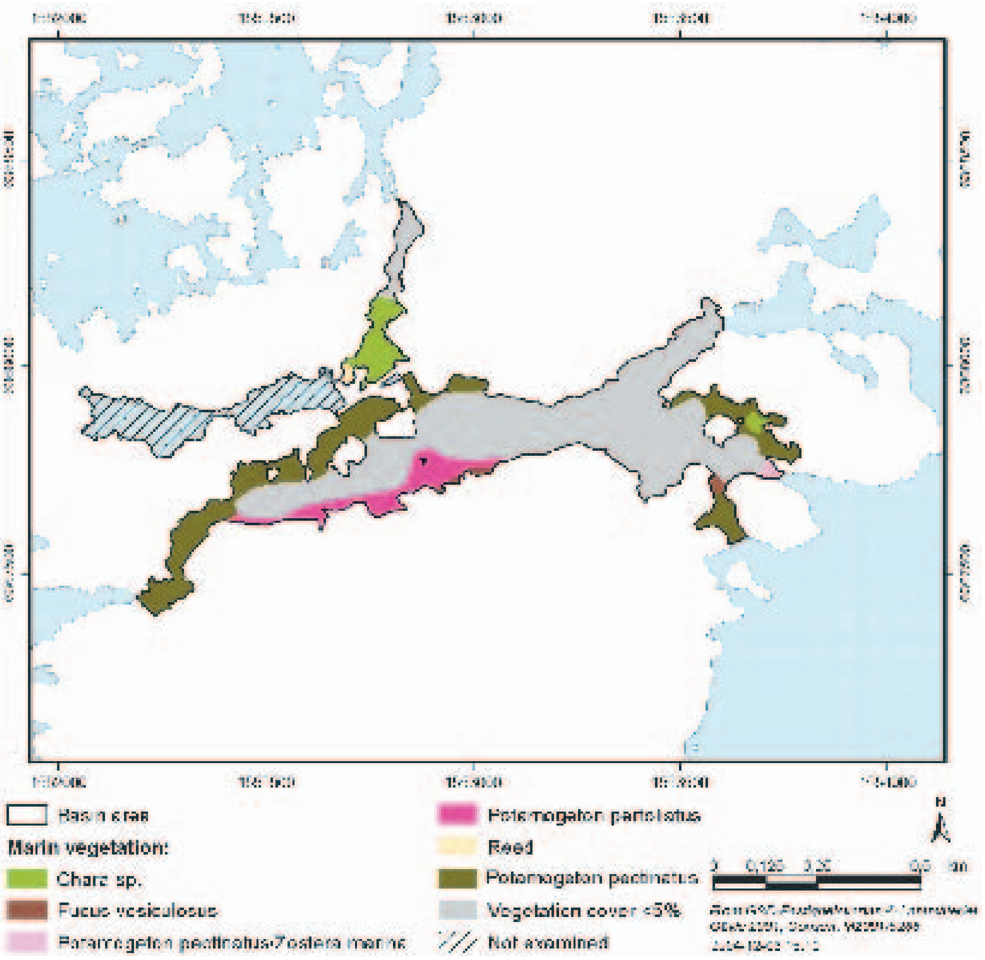


Figure 3-91. Distribution of different vegetation communities in Basin Getbergsfjärden.

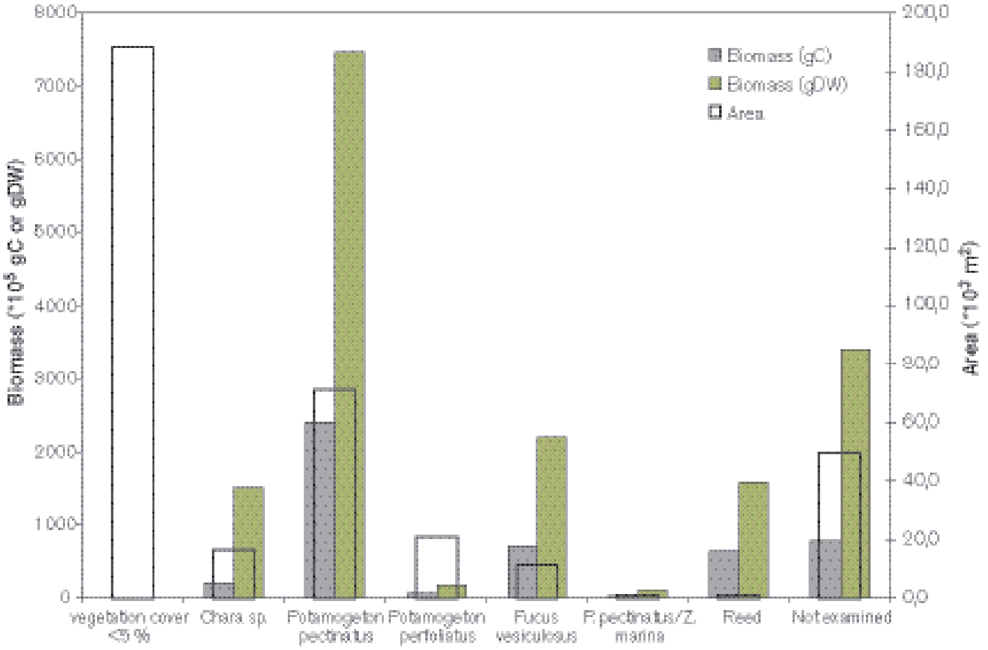


Figure 3-92. *Area cover (*$^x10^3$ m^2*) and biomass in gDW and gC for different vegetation communities in Basin Getbergsfjärden. Vegetation cover < 5% is assumed to have no biomass.*

There is no specific data from Basin Getbergsfjärden regarding plankton. An average between the results from Basin Borholmsfjärden and Granholmsfjärden is used in the modelling.

3.9.4 Consumers

Input data and method

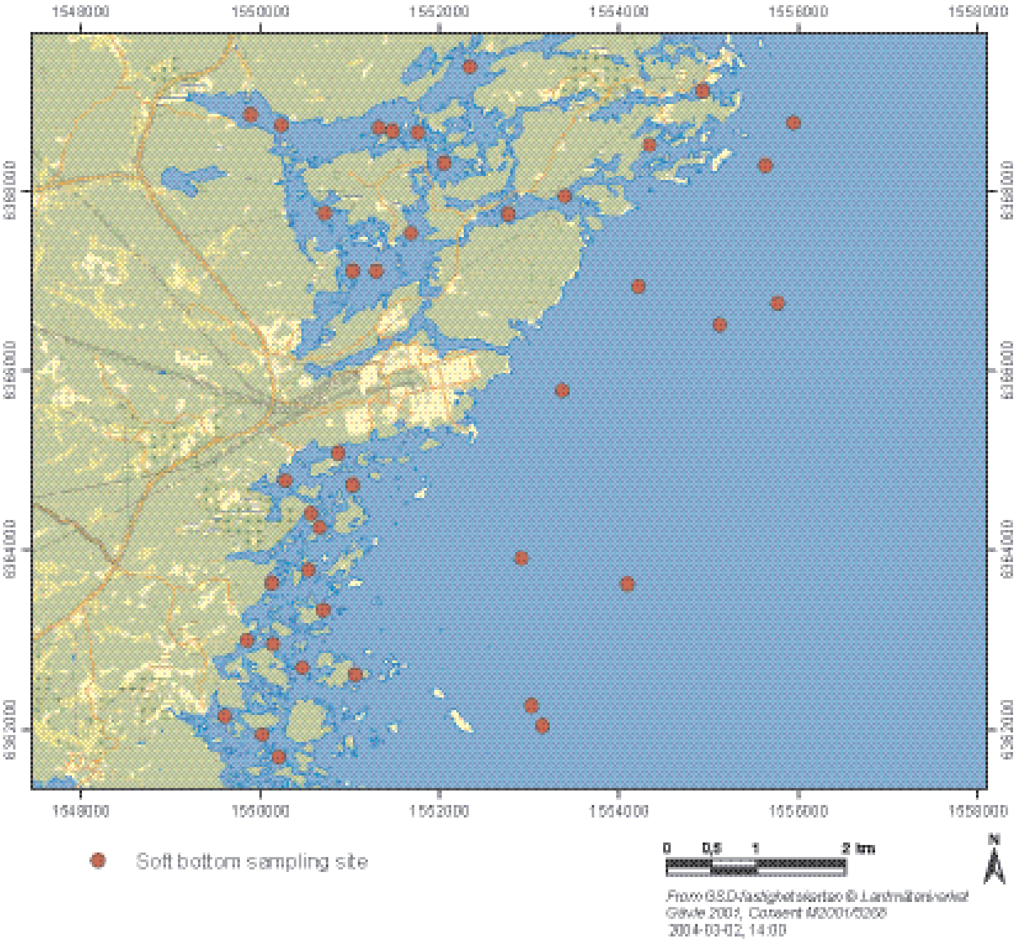
Four sources of site specific data have been used, all a part of the site investigation programme, Table 3-59.

Table 3-59. Data sources concerning consumers in the marine systems of Simpevarp. Data is presented under each basin description.

Parameter	Basin	Year	Reference
Batymetrical measurements	All basin.	2004	/Ingvarsson et al. 2004/
Zooplankton – Biomass	Basin Borholmsfjärden and Granholmsfjärden.	2003–2004	/Sundberg et al. 2004/
Epifauna in macrophytes communities – Biomass	All basins.	2002	/Fredriksson and Tobiasson, 2003/
Soft bottom infauna – Biomass	All basins.	2003	/Fredriksson, 2004a/
Bird – number of individuals	Basin Borholmsfjärden	2003	/Green, 2004/

Two main sources of biomass data have been used; the vegetation mapping study /Fredriksson and Tobiasson, 2003/ where also associated epifauna was sampled, and a study on soft bottom fauna /Fredriksson, 2004a/. The quantitative data presented in these reports; biomass per biomass vegetation community (gDW/100 gDW) and biomass per area (gDW/m^2) respectively, have been used to calculate the total biomass per basin and functional group. The species have been grouped into functional groups according to the classification given by /Kautsky, 1995/. The soft bottom fauna was sampled in 40 locations (see Figure 3-93) were sampled and the result was presented per habitat, either vegetation community or bare sediment in archipelago (inshore) or offshore.

The average biomass of the epifauna associated to the vegetation was about 107 grams dry weight per 100 grams dry weight vegetation. Highest epifaunal biomass was found in the Red algae and *F. vesiculosus2* communities (Figure 3-94). Approximately 390 and 310 grams epifauna per 100 grams vegetation were found in these communities respectively. The dominating species was the bivalve *Mytilus edulis* which alone contributed with nearly 275 of totally 390 grams in the Red algae community and 230 of totally 300 grams in the *F. vesiculosus* community. This corresponds to approximately 71 and 77% of the total epifauna biomass in the Red algae and undergrowth community respectively.



From GSD-fastighetskartan © Lantmäteriverket Gävle 2001, Consent M2001/5268
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Figure 3-93. *Sampling sites in the soft bottom fauna study.*

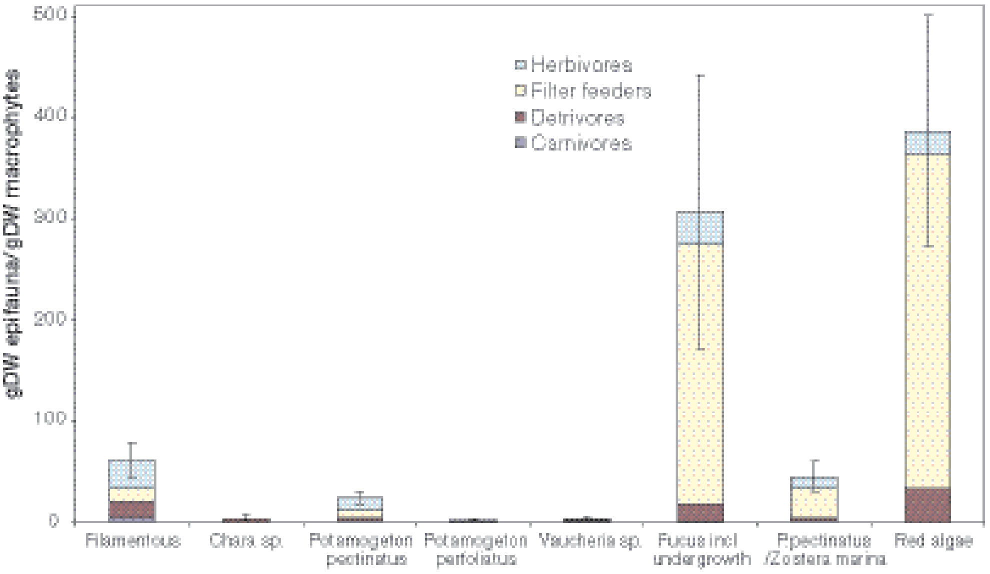
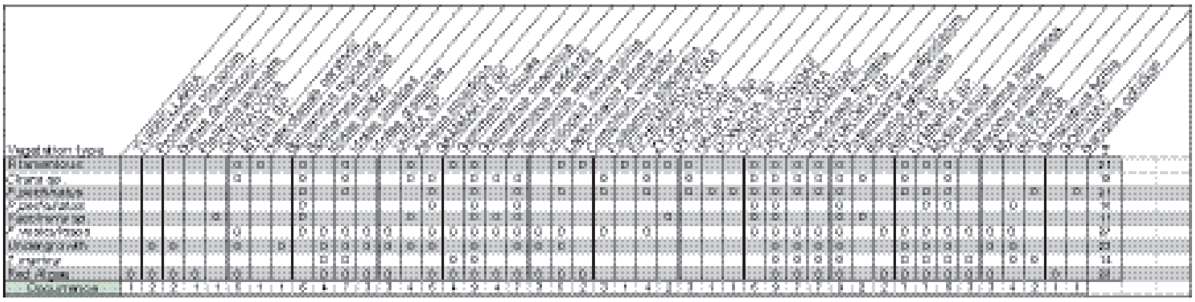


Figure 3-94. *Biomass of epifauna on vegetation communities (gDW/100gDW, error bars show SE).*

Table 3-60. Epifauna species present in vegetation communities. O = occurrence.



In bare sediment in the inshore area the functional group of detrivores accounted for most of the biomass of the infauna (Table 3-60). As much as 95% of the detritivore biomass and 84% of the sum of infauna consisted of *M. baltica*. The dominating functional group regarding infauna biomass in the samples from the *Vaucheria sp*. and *Chara sp*. communities was the omnivores (Figure 3-95) represented by Chironomidae, in the *Vaucheria sp.* community 84% of the biomass consisted of omnivores. In the *Chara sp.* community Chironomidae accounted for approximately 95% of the omnivore and 55% of the total biomass. The major part of the other infauna was detritivores, the gastropod *Hydrobia sp.* In the samples from the Weed (*P. pectinatus* and *Z. marina*) community the biomass was more evenly distributed among the different functional groups. Highest biomass share (58%) had the functional group detrivores (Figure 3-95), and here *M. baltica* dominated (76% of the detrivore biomass). 26% of the infauna biomass in this community consisted of filter feeders most of which were the bivalves *Mytilus edulis*, *Cerastoderma glaucum* and *Cerastoderma hauniense*. Totally 41 species or higher taxa were found in the samples from the area around Simpevarp**.** All occurring species of the infauna are presented in Table 3-61.

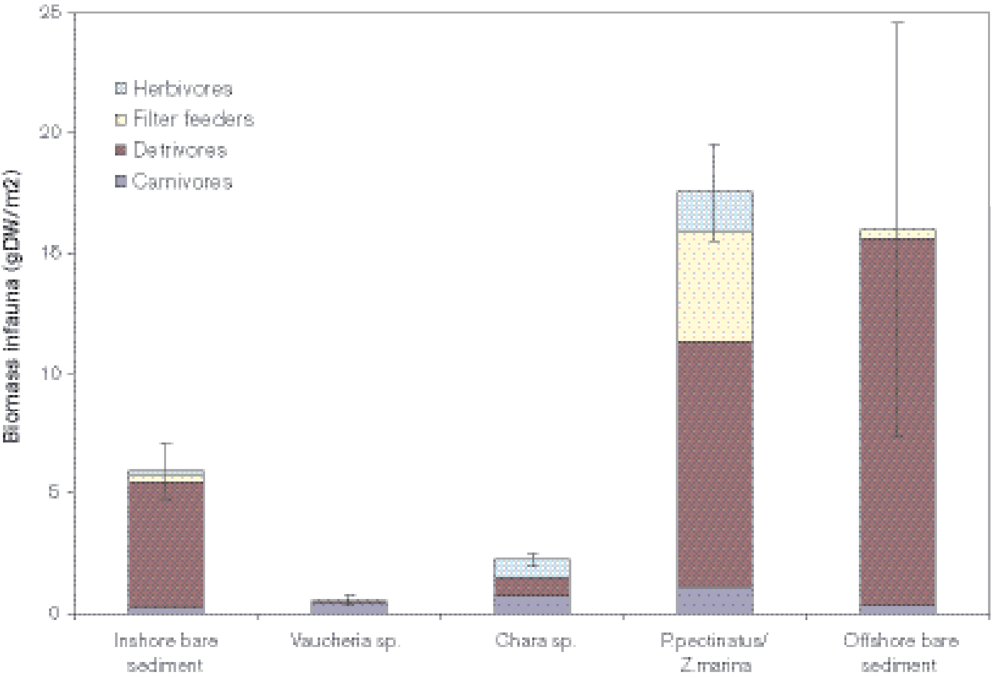
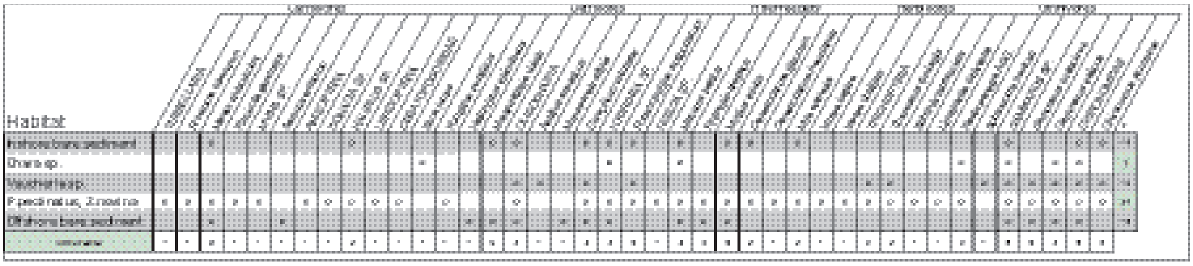


***Figure 3-95.** Biomass of infauna in different habitats (vegetation communities and bare sediment)in (gDW/m^2, error bars show SE) in functional groups.*

Table 3-61. Infauna species present in soft bottom habitats. O = occurrence.


Habitat
Inshore bare sediment
Chara sp.
Vaucheria sp.
P.pectinatus, Z.marina
Offshore bare sediment

Basin Borholmsfjärden

The domination of the *Chara sp*. community is reflected by the domination of associated benthic fauna in the basin, see Figure 3-96. Detritivores are the largest contributor to the benthic fauna biomass and most of it is found in associated to the *Chara sp*. vegetation most of it being the snail *Potamopyrgus antipodarum*. In the infauna, *Macoma baltica* is dominating in all communities except *Chara sp.* Herbivores and carnivores respectively are found in approximately same quantity (half of that of detritivores), but whereas carnivore are evenly spread among the different communities, most of the herbivores are found in the *Chara sp*. and *Vaucheria* communities. *Lymnea sp* is the most common herbivore. Carnivores are represented by *Donacia sp.* (a beatle larva) and the fish *Syngnathus typhle* in *Potamogeton* communities and by *Sphaeroma hookeri*3 and the shrimp *Palaemon adspersus* in the Chara community.

The differences between *Potamogeton* communities in amount of infauna and epifauna respectively depends the difference in density of macrophytes *P. perfoliatus* covers a large area but is much more sparse than *P. pectinatus*.

In Borholmsfjärden the zooplankton community (total biomass was 0.074 mg DW/l) was dominated by rotifers in July 2003 (Figure 3-97). The most important species was *Keratella cochlearis*. In December 2003 (0.061 mg DW l^{-1}) calanoid copepods were most important (adults and juveniles of *Acartia sp.* and *Eurytemora sp.*) and in April 2004 (0.352 mg DW l^{-1}) large cyclopoid copepods, i.e. *Cyclops sp.* dominated strongly. Tintinnids and macro-invertebrate larvae were absent or very scarce at all sampling dates. /Sundberg et al. 2004)/.

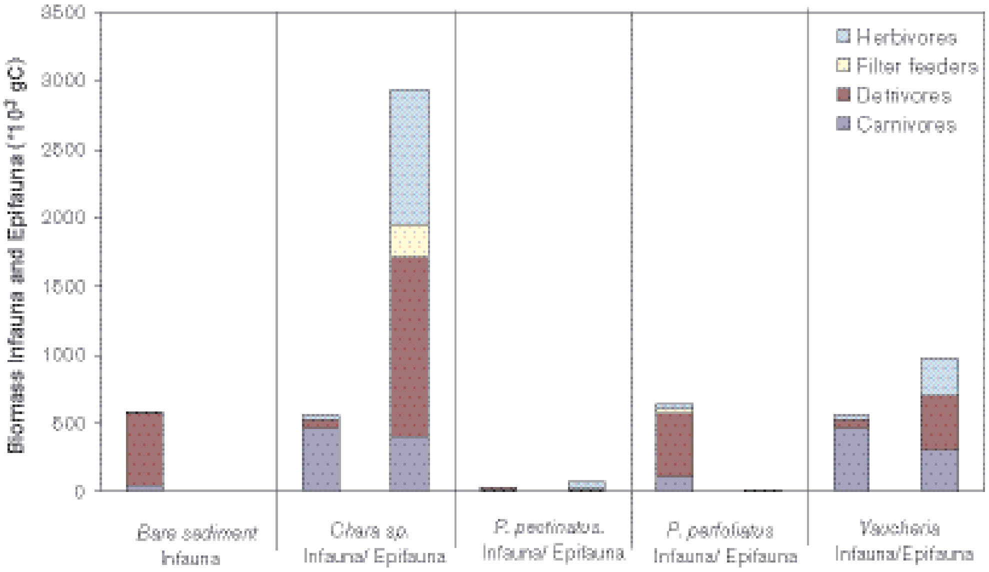


***Figure 3-96.** Biomass (gC) of benthic functional groups of infauna and epifauna in different habitates; Bare sediment (vegetation cover < 5%), Chara sp., P. pectinatus, P. perfoliatus, Vaucheria in basin Borholmsfjärden.*

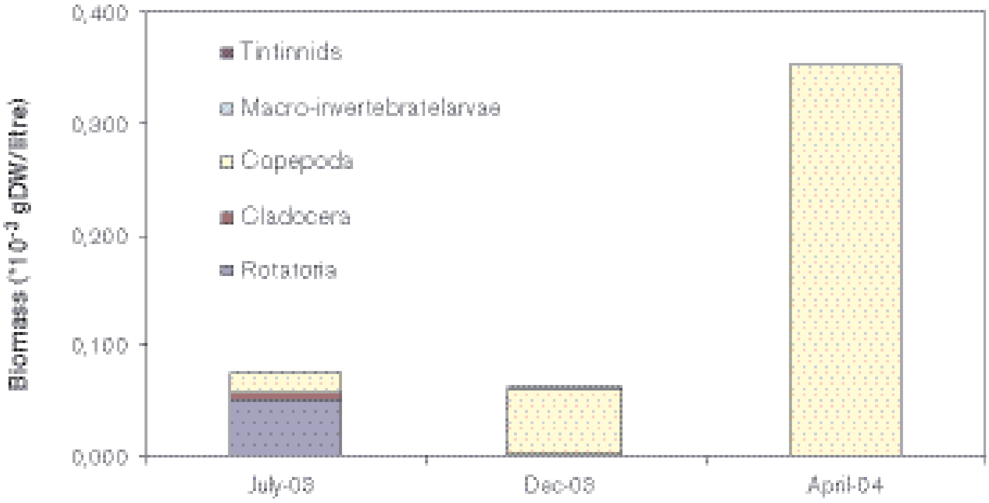


***Figure 3-97.** Biomass of different zooplankton groups in the whole water column in basin Borholmsfjärden (0–3 m). From /Sundberg et al. 2004/.*

Basin Granholmsfjärden

Approximately 70% of basin Granholmsfjärden is bare sediment or have less vegetation coverage than 5%. The fauna composition of his area therefore determines a large part of the benthic fauna composition. Detritivores completely dominate the benthic fauna. The detritivores constitutes in the bare sediment of *Macoma baltica* (88%) and *Potamopyrgus antipodarum* of the total fauna. Carnivores, in the sediment and in the *Chara sp.* community, are dominated by the Oligochaetae *Nereis diversicolor* and species of Diptera larvae Chironomidae. The herbivores found in *Chara sp.* and *Fucus vesiculosus* communities are mainly the Gastropods *Theodoxus fluviatilis* or *Lymnea sp.* and the Crustaceans *Idothea sp.*

In basin Granholmsfjärden zooplankton biomass is low (eg compared to Basin Borholmsfjärden) at all sampled times and all depths (Figure 3-98). In July 2003 copepods and cladocerans dominates the total biomass of 0.048 mg DW l^{-1} (calculated mean for the whole water column). *Bosmina longispina* was the most common cladoceran while *Eurytemora* spp contributed most to the copepod biomass. Copepods dominated in December 2003, when total zooplankton biomass was 0.045 mg DW l^{-1}, and in April 2004, when total biomass was 0.025 mg DW l^{-1}. /Sundberg et al. 2004/.

Basin Getbergsfjärden

Similar to basin Granholmsfjärden the benthic fauna is dominated by the large amount of sediment lacking vegetation. Detritivores are dominating both in the sediment and associated to the vegetation (Figure 3-100), and again *Macoma baltica* is the most dominating. Among carnivores *Neries diversicolor* have the highest biomass. The part of the area not examined was assumed to consist of 30% bare sediment, 35% P. pectinatus and 35% *Chara sp.* as a similar a bay have a composition like this.

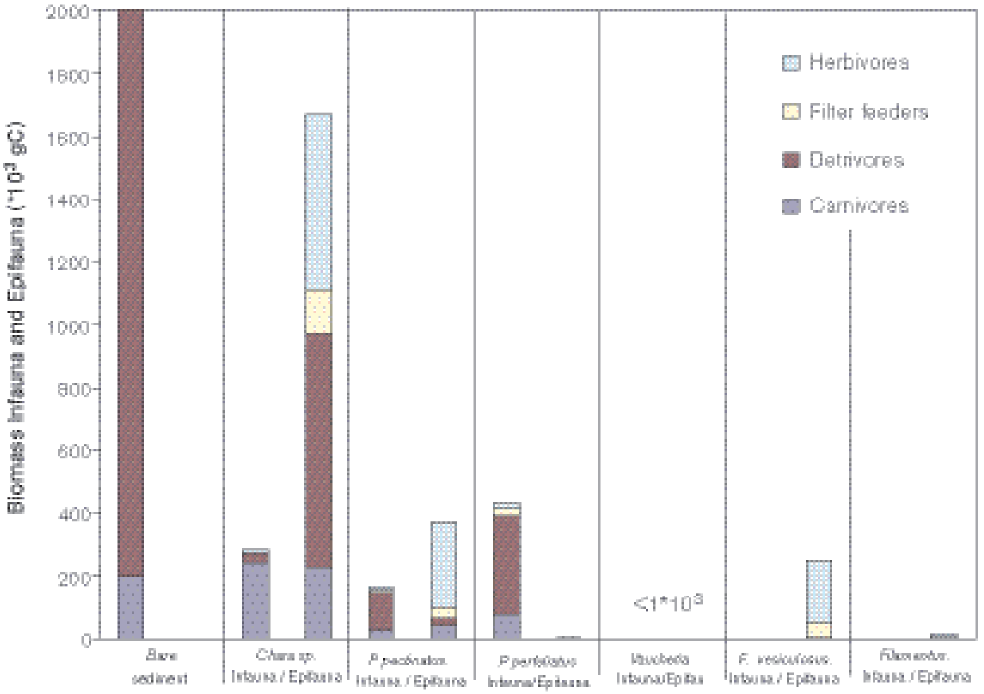


Figure 3-98. *Biomass (gC) of benthic functional groups of infauna and epifauna in different habitates; Bare sediment (vegetation cover < 5%), Chara sp., P. pectinatus, P. perfoliatus, Vaucheria, Fucus vesiculosus and filamentous algae in basin Granholmsfjärden.*

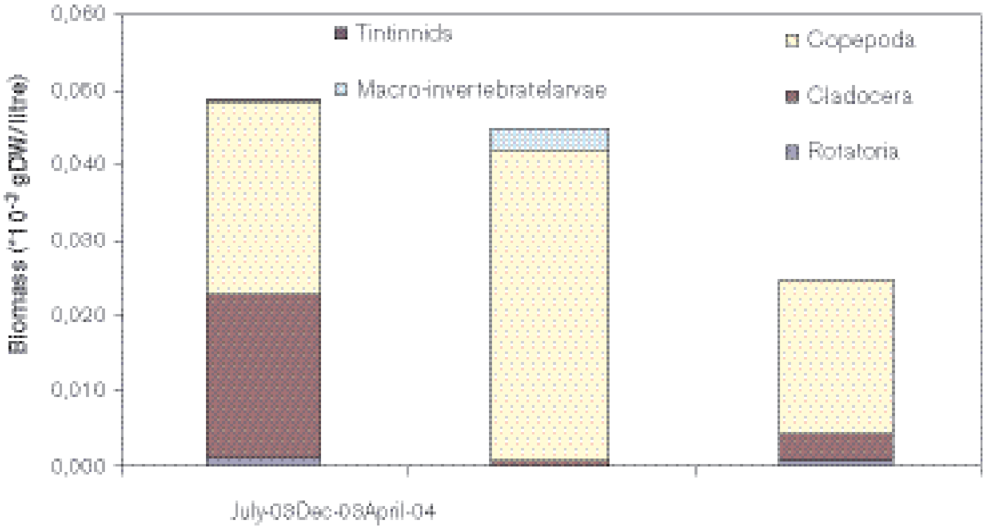


Figure 3-99. Biomass of different zooplankton groups in the whole water column in basin Granholmsfjärden (0-3 m). From Sundberg et al. (2004).

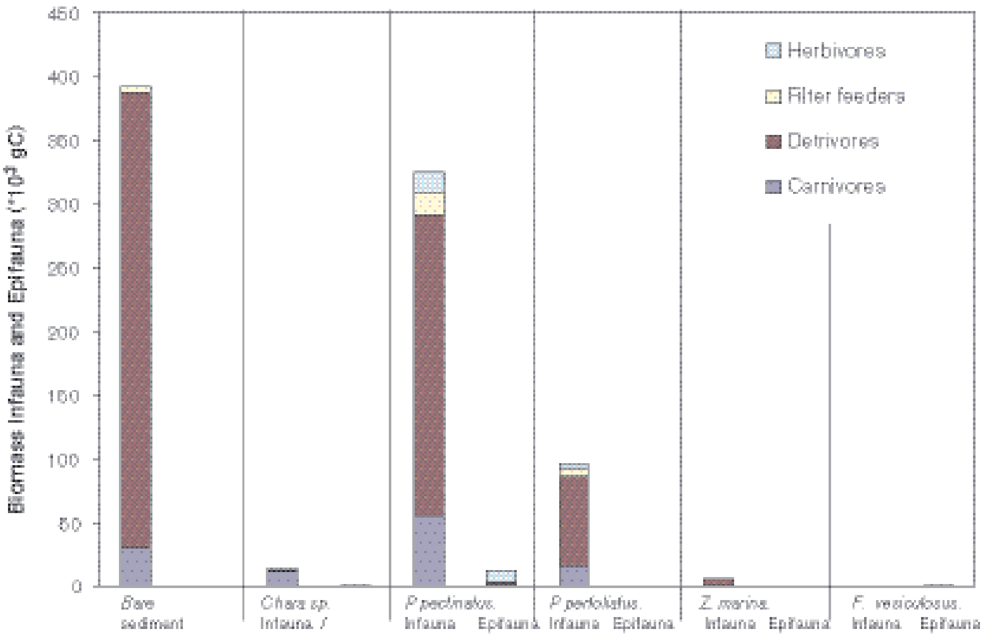


Figure 3-100. Biomass (gC) of benthic functional groups of infauna and epifauna in different habitates; Bare sediment (vegetation cover < 5%), Chara sp., P. pectinatus, P. perfoliatus, Vaucheria, Fucus vesiculosus and filamentus algae in basin Getbergsfjärden.

Confidence and uncertainties

High quality site specific bathymetric measurements have been used for the calculation of areas and volumes.

Photic zone and aphotic zone estimations are based on the assumption thet photic depth equals double light penetration depth.

Phytoplankton

Estimations of biomass (gDW/m^3) are made from three samples each for basin Borholmsfjärden and Granholmsfjärden. The sampled values range between low and very high in comparison with national data. However, phytoplankton plays a minor role in the carbon flows in the basins presented in Chapter 4.

Macrophytes

Field measurements of biomass and distribution are assumed to be of high quality due to the large number of sampling sites.

As is presented below the biomass is changing within the year as opposed to the assumption made here (constant biomass during the year). An approach to compensate for this will be tested in a later version of this document.

Since year 2000 a study regarding macrophytes, associated epifauna and infauna has been executed in two shallow bays (Kuggviken and Utrikeviken) in the archipelago of Västervik approximately 50 km north of Oskarshamn in a monitoring programme /eg. Tobiasson and Andersson, 2004/. Below comparisons are made between these two and the Simpevarp area. All sampling in the Västervik archipelago, except for the year-round study has been performed in late august. Mean values from this study are based on five replicates. Comparisons with these studies for *Chara sp.*, *P. pectinatus* and *F. vesiculosus* communities are presented below.

Chara sp. community

In Figure 3-101 the mean macrophyte biomass in a *Chara sp.* dominated community is presented.

The result from the Simpevarp area are in the same order of magnitude (1–5×10^2 g DW/m^2) as in Västervik, but the result from Västervik suggests possible large changes in benthic vegetation between years.

The time of year, when sampling was performed in the Simpevarp area (during late October and early November) the biomass in the *Chara sp.* community in Kuggviken was declining. This indicates that the calculated biomass for the *Chara sp.* community in the Simpevarp area might be low on a year-round basis, Figure 3-102, so possibly underestimating the yearly average biomass estimation in Simpevarp.

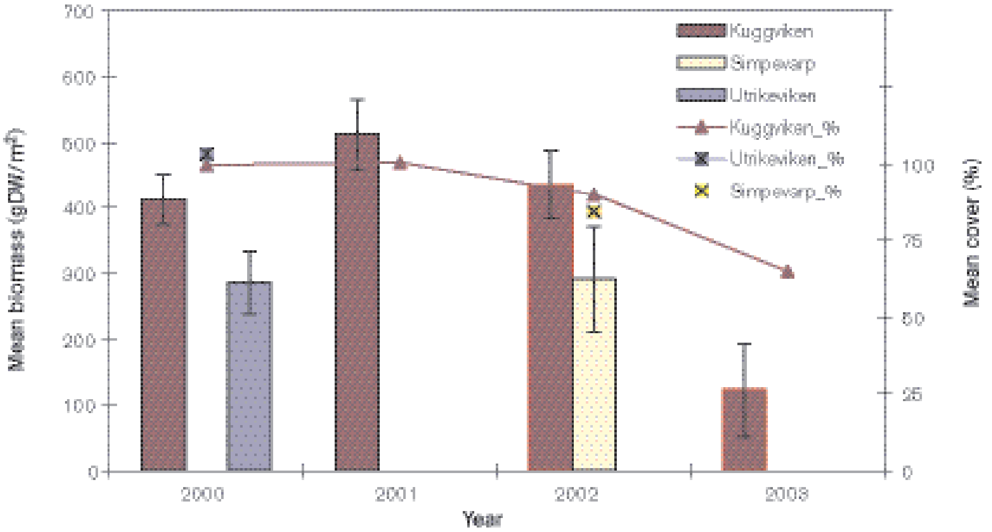


Figure 3-101. *Mean biomass (g DW/m^2, error bars display SE) and cover degree (%) for quantitative vegetation samples from Chara sp. dominated communities in Kuggviken, Utrikeviken and the Simpevarp area.*

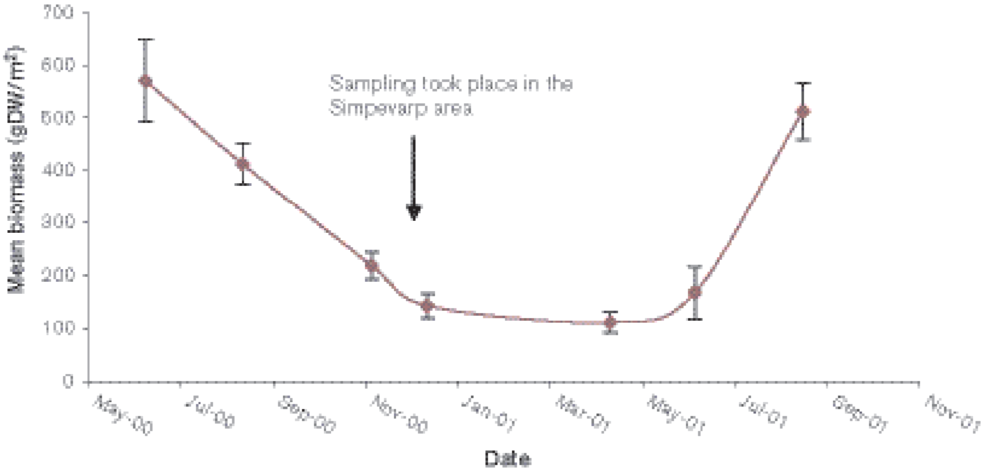


***Figure 3-102.** Mean biomass (g DW/m², error bars display SE) for quantitative vegetation samples from the year-round study in Chara sp. dominated communities in Kuggviken from june-00 to june-01. Data is only presented for Kuggviken due to the disappearance of the Chara sp. from the sampling sites in Utrikeviken and Örserumsviken after two sampling occasions.*

Potamogeton pectinatus

In the *Potamogeton pectinatus* dominated community the biomass per square meter in Simpevarp was almost equal to the one in Utrikeviken, 2002, Figure 3-103.

Figure 3-104 presents the results from a year-round study in *P. pectinatus* dominated sampling sites in Kuggviken and Örserumsviken. From the study in Västervik it seems like the biomass in a *P. pectinatus* dominated community peaks somewhere between September and November, when the sampling in Simpevarp was performed (during late October and early November). The grand mean for Öreserumsviken is 90 gDW/m² for all sampling occasions, the November value 156 gDW/m². For Örserumsviken the grand mean is 62 gDW/m² and the September and October figures 104 gDW/m² and 89 gDW/m² respectively. This implies that the calculated biomass for the *P. pectinatus* community in the Simpevarp area might be overestimating the yearly average biomass in Simpevarp.

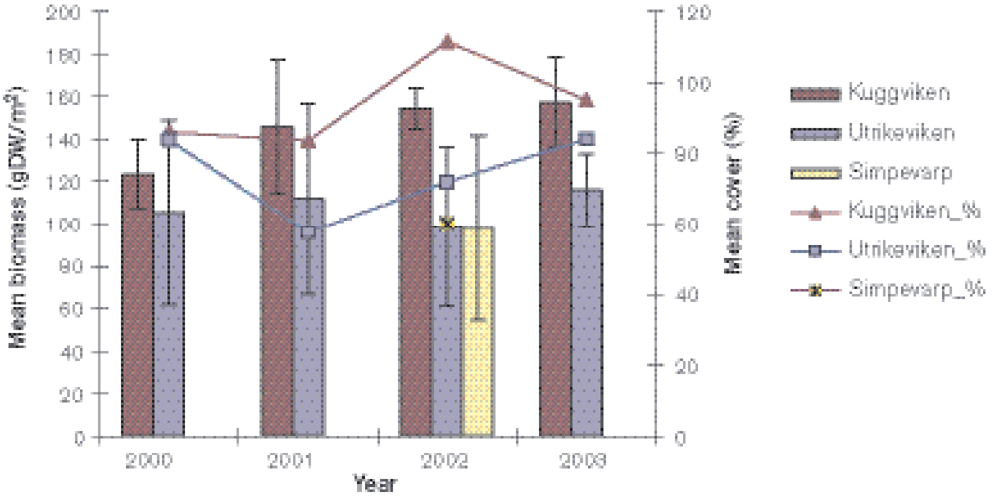


***Figure 3-103.** Mean biomass (g DW/m², error bars display SE) and cover degree for quantitative vegetation samples from P. pectinatus dominated communities in Kuggviken, Utrikeviken and the Simpevarp area.*

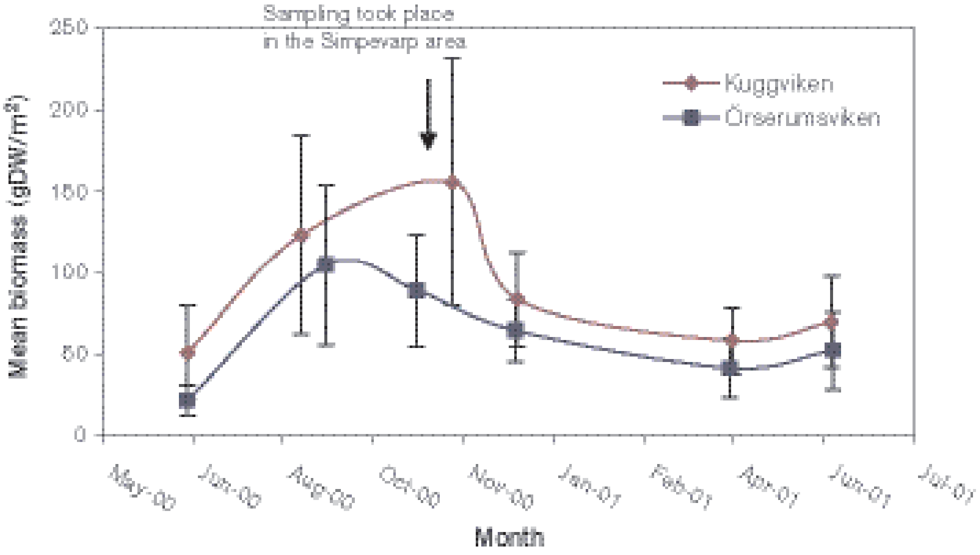


***Figure 3-104.** Mean biomass (g DW/m², error bars display SE) for quantitative vegetation samples from the year-round study in P. pectinatus dominated communities in Kuggviken and Örserumsviken from june-00 to june-01.*

Fucus vesiculosus

During the years 1990–1996 three diving transects were investigated in the Simpevarp area, the same stations that were investigated 2002 in /Fredriksson and Tobiasson, 2003/. Temporal variation between years is presented in Figure 3-105 together with data from the investigation performed in 2002 for *Fucus vesiculosus* community. Station OKG3H (LSM000015) displays a very large variation between years and the two other stations have comparably low biomasses 2002 compared with all previous years.

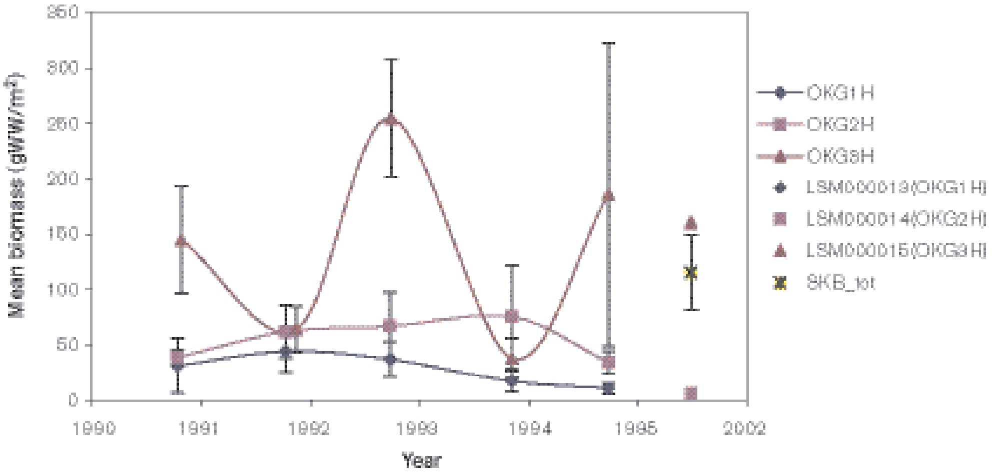


***Figure 3-105.** Mean macrophyte biomass (g DW/m², error bars display SE) in the F. vesiculosus community from diving transects in the Simpevarp area OKG1-3H, 1989 till 1995 and 2002. SKB_tot = mean of all samples from in the site investigation. (In station 13 and 14 the same figure results in overlapping markers).*

Zooplankton

Estimations of biomass (gDW/m^3) are made from three samples per basin or an average of two basins.

Benthic fauna

Since year 2000 a study regarding macrophytes, associated epifauna and infauna has been executed in two shallow bays (Kuggviken and Utrikeviken) in the archipelago of Västervik approximately 50 km north of Oskarshamn in a monitoring programme /e.g. Tobiasson and Andersson, 2004/. Below comparisons are made between these two and the Simpevarp area. All sampling in the Västervik archipelago, except for the year-round study has been performed in late august. Mean values from this study are based on five replicates. Comparisons with these studies regarding epifauna and infauna in; *Chara sp. P. pectinatus* - communities and infauna in bare sediment are presented below.

Chara sp.

The epifaunal biomass in the Simpevarp area was on level with corresponding samples in Kuggviken before Chara disappeared (Figure 3-106).

The year-round study in the *Chara* sp dominated vegetation indicates that the time for sampling in the Simpevarp area should result in an overestimation of biomass of epifaunal (Figure 3-107).

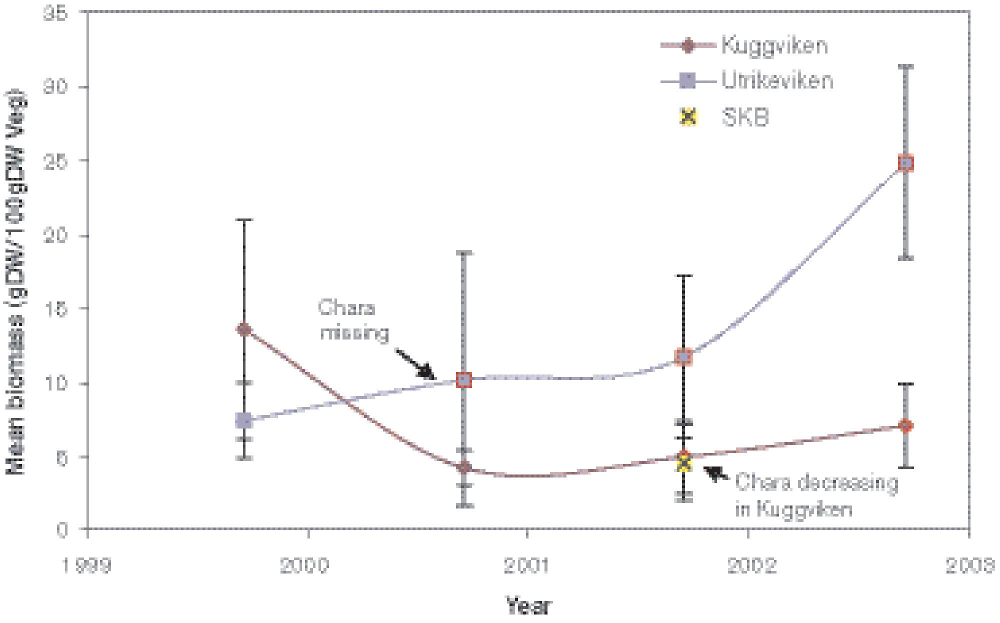


Figure 3-106. *Mean epifaunal biomass (g DW/100 g DW Veg) in Chara sp. dominated vegetation. Red border in Utrikeviken = Chara missing. Mean biomass in Kuggviken, year 2002 and 2003 based on three replicates.*

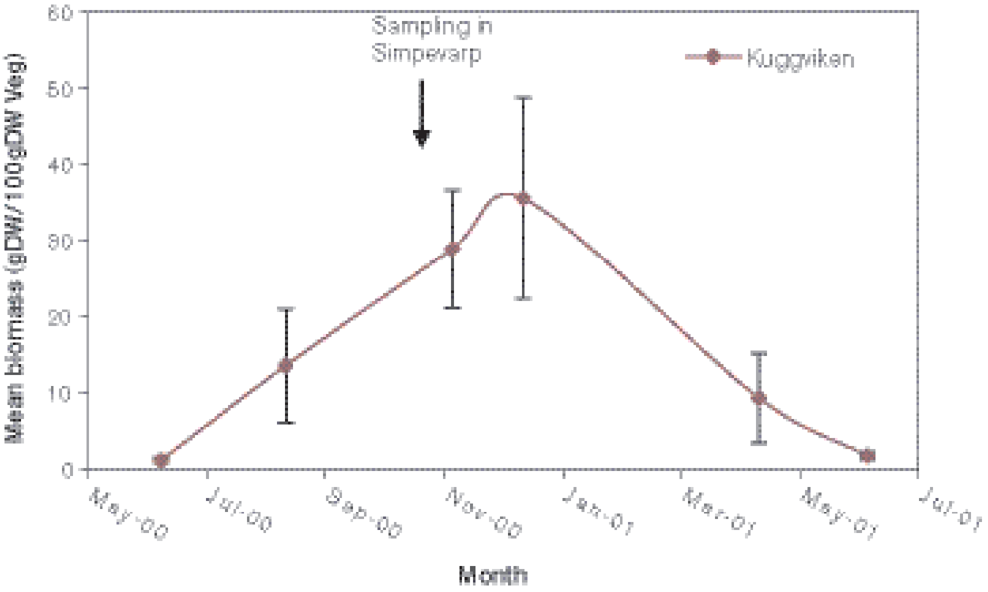


Figure 3-107. Mean epifaunal biomass (g DW/100 g DW Veg) in Chara sp. dominated vegetation in Kuggviken. Year-round study from june-00 until june-01.

Potamogeton pectinatus

The epifaunal biomass in the *P. pectinatus* dominated vegetation in the Simpevarp area was somewhere between the one in Kuggviken and Utrikeviken in the archipelago of Västervik (Figure 3-108).

Except for Kuggviken 2000 the epifaunal biomass in the *P. pectinatus* community are relatively stable between years.

The year-round study in the *P. pectinatus* dominated vegetation indicates that the time for sampling in the Simpevarp area should represent agood estimate of the annual avarege or a small overestimation. (Figure 3-109).

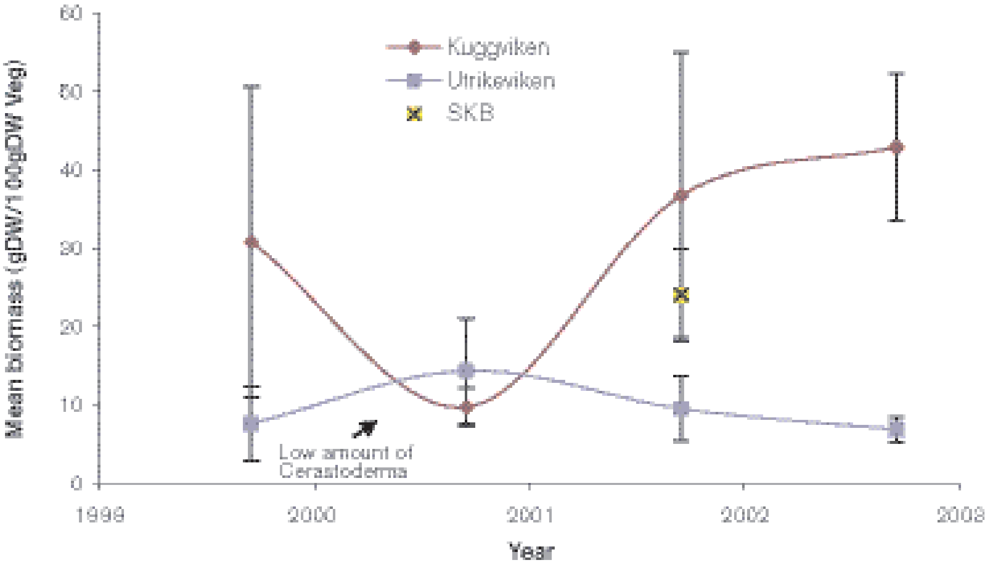


Figure 3-108. Mean epifaunal biomass (g DW/100 g DW Veg) in P. pectinatus dominated vegetation from Kuggviken, Utrikeviken and the Simpevarp area.

In the Potamogeton pectinatus community, the biomass of infauna in the Simpevarp area seems to be lower than in Kuggviken and Utrikeviken (Figure 3-110).

The study from Västervik indicates that year-round sampling may result in a good estimate of annual average (Figure 3-111).

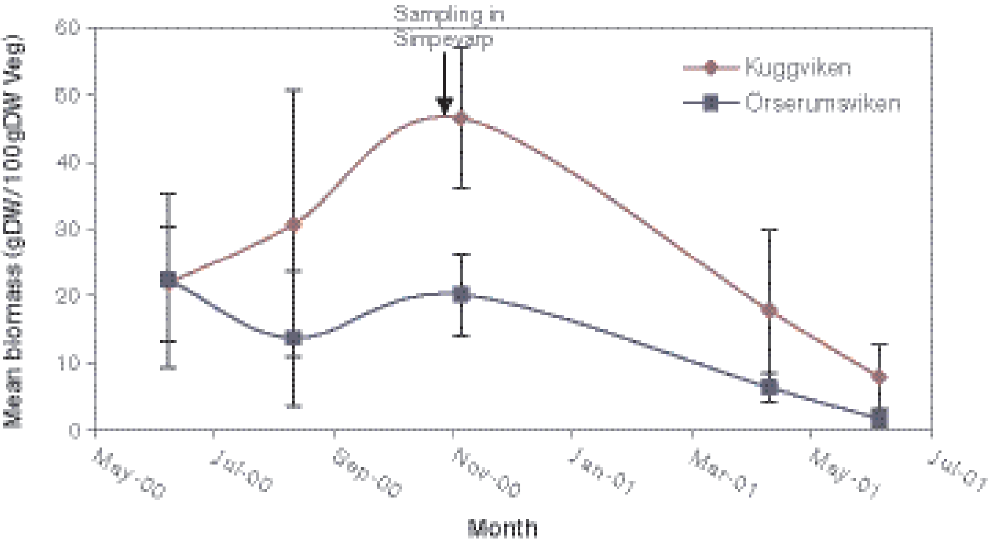


***Figure 3-109.** Mean epifaunal biomass (g DW/100 g DW Veg) in samples from the year-round study in P. pectinatus dominated communities in Kuggviken and Örserumsviken from june-00 to june-01.*

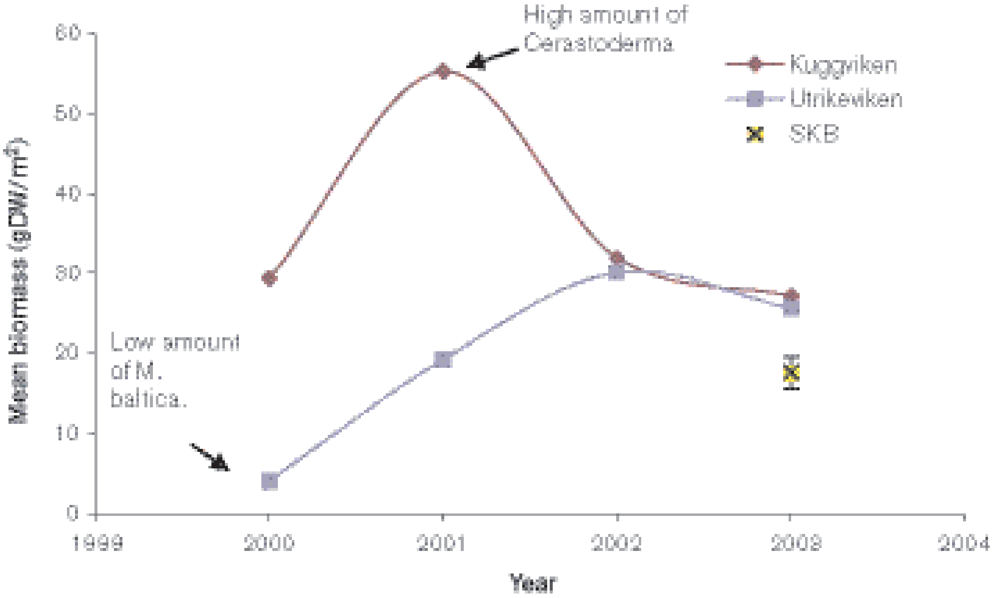


***Figure 3-110.** Mean infauna biomass (gDW/m^2) in P. pectinatus dominated vegetation in Kuggviken, Utrikeviken and the Simpevarp area.*

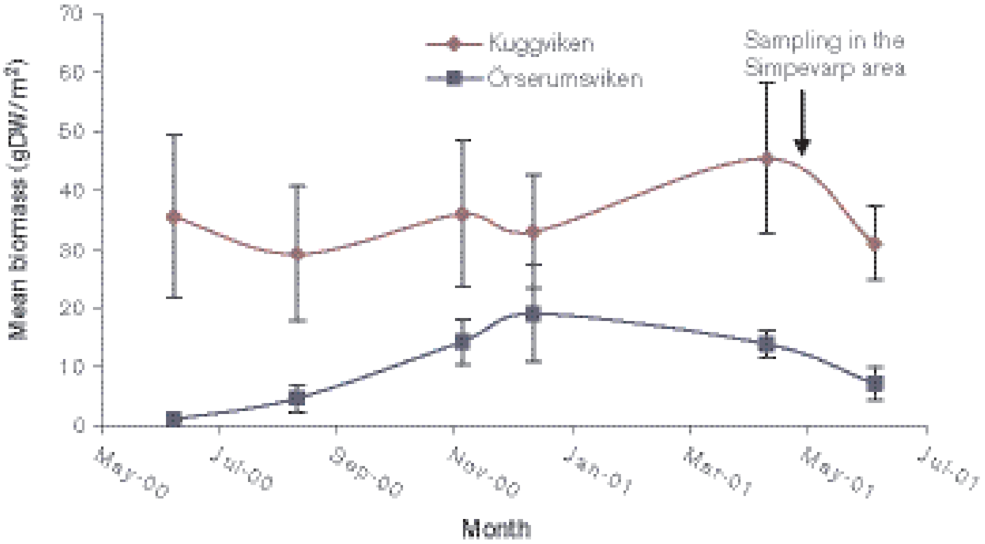


Figure 3-111. Mean infauna biomass in P. pectinatus dominated vegetation. Year-round study in Kuggviken and Örserumsviken from june-00 until june-01.

Bare sediments

The mean infauna biomass for samples taken on bare sediment in the Simpevarp area were similar with corresponding samples from the bay Kuggviken (Figure 3-112), but much lower than the samples found in Utrikeviken.

The year round study indicates that the infauna biomass in Kuggviken was fairly stable over the year (Figure 3-113). Considering the resemblance with Örserumsviken the sampling time is likely to be a good estimate of the annual average biomass.

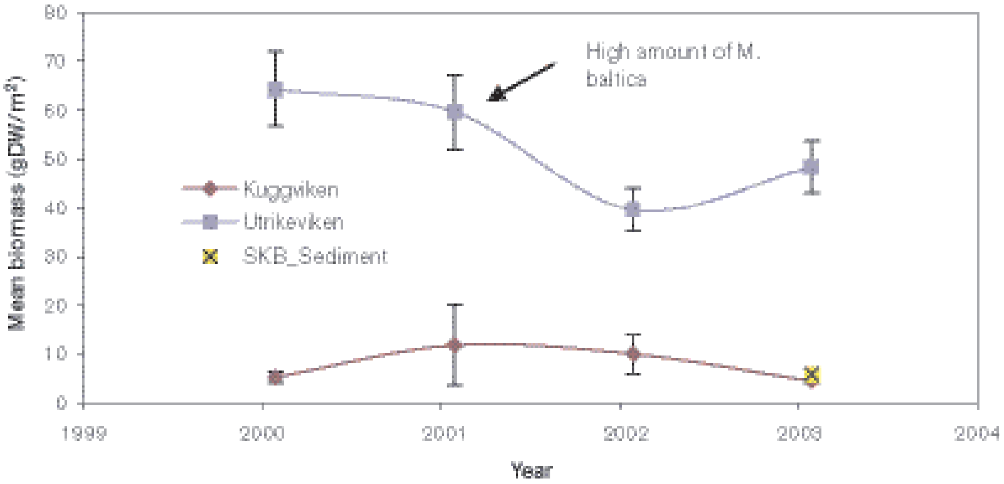


Figure 3-112. Mean macrozoobenthos biomass (g DW/m^2) in samples taken on bare sediment in Kuggviken, Utrikeviken and the Simpevarp area.

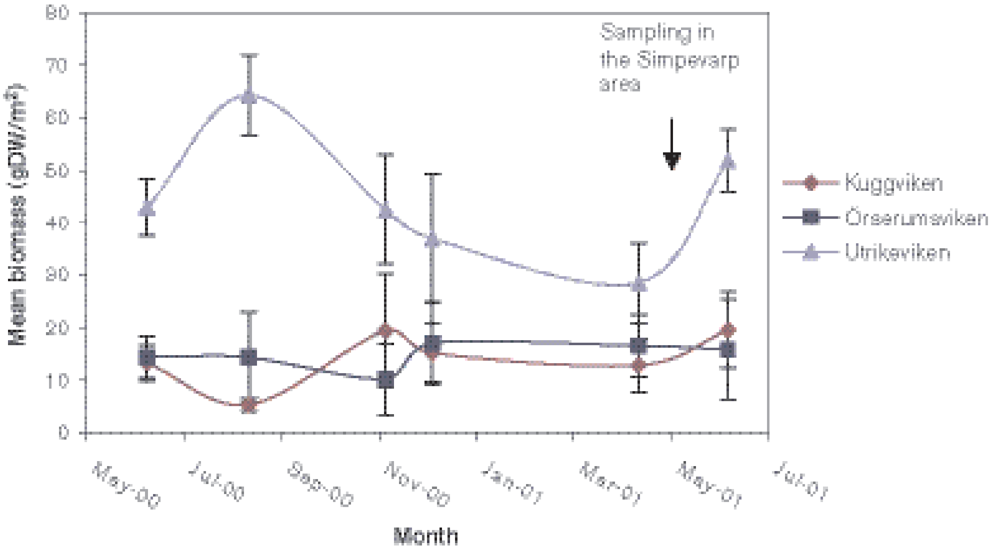


Figure 3-113. Mean infauna biomass (g DW/m^2) in samples taken on bare sediment in Kuggviken, Utrikeviken and Örserumsviken. Year-round study from june-00 to june-01.

3.10 Human description

3.10.1 Input data and methodology

The human description is based on the results presented in the report Human population and activities in Simpevarp (Miliander et al. 2004) and describes the situation in Misterhult parish, since much of the data was only available at the parish level. For the modelling area, Simpevarp 7 (the drainage area of Lake Frisksjön), the numbers have been calculated based on data at the parish level. Most of the data were obtained from *Statistiska Centralbyrån* (SCB). Other sources such as *Fiskeriverket*, *Länsstyrelsen* in Kalmar County and The National Association of Huntsmen (*Sw: Svenska Jägareförbundet)* have also been used.

Wherever possible, the data has been collected for a time series of ten years. However, data for a time period of ten years has not been available for all variables, so shorter time series occur as well. The advantage of using data from longer time series is that mean values can be calculated and trends could be more sufficient analysed.

The variables in /Miliander et al. 2004/ are most often shown as an actual value from the latest year for which data were available (normally 2002), a mean value with a standard deviation, a minimum value, a maximum value and a value per unit area (e.g. kg/km^2 or 10^6 m^2). For more detailed information, see /Miliander et al. 2004/.

3.10.2 Human population

In total, 2,709 people lived in Misterhult parish in 2002. The population is slowly decreasing, with a maximum over the last ten years in 1993, with 2,987 inhabitants. The density has on average been 7.1 inhabitants per square kilometre. In 2002 the population density in Misterhult parish was approximately three times lower than in Kalmar County. 55.5% of the inhabitants were over 45 years compared to 47.2% in Kalmar County.

The inhabitants live in one- or two- family houses (45.1% of the properties) or in farm houses (17.3%). Only 1.7% of the properties in the parish are multi-dwelling houses. In 2002 there were 707 holiday houses in the parish and they are the second most dominating type of property (31.5%). There are in total 5.5 buildings per square kilometre in the parish, compared to 10.4 in Kalmar County. Fewer dwellings per square kilometre are built in the parish compared to the municipality and county. In the municipality and county the construction is continuous with some new dwellings annually. In the parish on the other hand, the construction is more occasional.

The ill-health (number of days with sickness benefit or early retirement pension per year and person between 16 and 64) has increased in the parish from 36.2 in 1998 to 49.1 in 2002. The ill-health has increased with the same proportion in Kalmar County and is only somewhat lower than in the parish (44.7 days in 2002). The ill-health in women is higher than the ill-health in men.

The dominant employment sector within Misterhult parish is electricity-, gas- and water supply, sewage and refuse disposal and it relates to 60% of the employed day-time population (working in the area). Within the employed night-time population (living in the area) on the other hand, only 11.7% is working in that sector. Thus, there is a major ingoing commuting due to Oskarshamn nuclear power plant. The net commuting is positive in Misterhult parish, meaning the ingoing commuting is larger than the outgoing. The net commuting is, on the other hand, negative in Kalmar County as a whole. Mining and manufacturing is the second largest type of business within the day population and the largest within the night population. There were in total 263 work places within the parish in 2002. The majority, 105 places, is within agriculture, forestry, hunting and fishing, but only 45 persons do work within that sector.

In Misterhult parish, 11.1% of the total population was non-employed in 2001, which is somewhat lower than in Kalmar County, where it is 12.7%. The early retired and the non-employed of other reason are proportionately more numerous in the parish than in Kalmar County. The students and the unemployed, on the other hand, are proportionately less in the parish. The proportion of non-employed inhabitants was lower in 2001 than in 1997.

Human activities in terms of land use

The land use in Misterhult parish is assumed to be similar to the land use in Simpevarp area. The land use within Simpevarp area differs evidently from the average land use in Kalmar County. The forest area is far more dominating in Simpevarp area than in Kalmar County. The proportion of arable land is considerably lower in Simpevarp area, 4.4% compared to 11.6% in Kalmar County. The same holds for wetlands.

Forestry

The forests are influenced by forestry; approximately one third of the forest within the regional model area is younger than 30 years. The average age of the productive forest is approximately 53 years. About 1/4 of the logging products are used for pulp production, and the rest are used as timber.

Agriculture

The agricultural activities are limited in Misterhult parish compared to Kalmar County. The farm density in Misterhult parish is on average only 0.2 farm/km^2, which is half of the density in Kalmar County as a whole (0.4 farms/km^2). There were in average 70 farms (> 2 ha) in Misterhult parish between 1990 and 1999 /Miliander et al. 2004/.

Only a few percent of the total land area in Misterhult parish is classified as arable land, compared to almost 12% in the county. The amount of arable land is almost five times larger than the amount of grassland in Misterhult parish. In Kalmar County the difference is smaller, the amount of arable land is only three times larger than grassland. The area of grassland has increased though between 1990 and 1999, in Kalmar County as well as in Misterhult parish. In contrast, the arable land area has decreased with 10% in the parish, but only 2% in Kalmar County. This corresponds with the fact that the number of farms has decreased more significant in Misterhult parish, a reduction of 31% between 1990 and 1999 compared to 17% in Kalmar County.

The main part of the arable land (64%) is used for fodder production. Barley is the far most dominating crop in Misterhult parish according to data from 1999. The standard yield of spring barley in harvest area nr. 0814, in which the Misterhult parish is located, is slightly below the county average (90%) and clearly below the national average (79%).

The number of cattle, sheep and fowls (*Sw: höns*) has decreased between 1990 and 1999. In 1999 the number of cattle was 1,207. For cattle the breeding cows has increased, whereas the dairy cows and heifers, bulls and bullocks are decreasing in numbers. The number of pigs has increased with 50%, from 292 (the average between 1990 and 1999) to 422 in year1999.

Horticulture, aquaculture, mineral extraction

There is no horticulture within Misterhult parish. There is one aquaculture for recreational crayfishing approximately 12 km north of Oskarshamn, near Virkvarns airport in Misterhult parish. There are three active leases for mineral extraction in the parish, all for extraction of decoration stones none within Simpevarp area /Axheden, 2003, pers. comm./.

Water supply

The water use within Misterhult parish in the year 2000 has been roughly calculated based on the water use within Oskarshamns municipality the same year as well as the number of inhabitants, work places, farms and holiday houses in Misterhult parish. Some assumptions have been made in order to calculate the water use and the water withdrawal. These assumptions are described in /Miliander et al. 2004/.

The freshwater use at Oskarshamns nuclear power plant represents approximately 1/3 of the total water use within Misterhult parish. As the power plant uses water from the lake Götemar, the main part of the withdrawal in the parish is surface water.

The number of work places in the parish is low, only 12% of the work places in Oskarshamns municipality. The water use within the industry sector, excluding the nuclear industry, is therefore estimated to be low, only 10%. In Sweden, the industry stands for approximately 65% of the water use. The total withdrawal of water in the parish is calculated to 630,700 m^3 per year.

Coastal fishing

Kalmar County is the fifth largest fishing county in Sweden and it answers for more commercial fishing than the rest of the east coast altogether. Fishery is not a very common employment in Oskarshamn municipality though. Fishermen in Borgholm and Västervik municipality catch the main part of the fish. The number of commercial fishermen living in the parish is not known. The statistics indicate that there might be one logbook- or journal-keeping fisherman in the parish.

In the off-shore grid (EU-grid) outside the coast of Kalmar, the catch is predominantly from square 44G7, which begins approximately 10 km northeast of Simpevarp. The average catch has been 4,479 kg/km^2, between 1995 and 2002. Among the EU-squares adjacent to the coastline, the catch per unit area is largest in square 43G6, in which Simpevarp area is located (1,728 kg/km^2).

There are eight commercial receivers within Kalmar County that buy fish from small as well as large vessels fishing off the Coast of Kalmar County. Fishermen living in Kalmar County caught 4,560 tonnes of fish in 2002, according to *Fiskeriverket*. The same year the commercial receivers in Kalmar County received 18,645 tonnes of fish. This indicates that the receivers obtain fish from vessels coming from other counties. Robin Lundgren at *Fiskeriverket* considers the commercial fishing outside Kalmar County as relatively intense. Even vessels from the west coast operate in this region. 4% of the received catch is used for animal fodder (fish-meal) and the rest for human consumption.

Outdoor life

Wildlife hunting

According to the figures from *Länsstyrelsen* in Kalmar County, moose hunting is more extensive in Misterhult parish than in the municipality and county as a whole (0.35 individuals/km^2 compared to 0.30 respectively 0.19, in 2003). The harvest has been larger in Misterhult parish than in Oskarshamn municipality and Kalmar County along the entire dataset (1997–2003). No obvious trend can be seen in the data between 1999 and 2003. The number of harvested moose per km^2 reached a peak in 2000. During the last two seasons the number per km^2 has decreased.

The estimated harvest of roe deer and hares in Misterhult parish are based on the values for the hunting zone of *Oskarshamns Norra jaktvårdskrets*, obtained from The National Association of Huntsmen.

According to these figures, the harvest of roe deer has on average been 2.15 individuals/km^2 in the parish during the period 1997–2001. In 2001 the harvest was 1.3 individuals/km^2. The harvest of European/common hare (*Sw: fälthare*) has on average been 0.29 individuals per square kilometre in the parish during the period 1997–2001. In 2001 the harvest was 0.31 individuals/km^2. The harvest of mountain/alpine hare (*Sw: skogshare*) has on average been 0.10 individuals per square kilometre in the parish during the period 1997–2001. In 2001 the harvest was 0.04 individuals/km^2

According to the survey based on pellet sampling conducted /Cederlund et al. 2004/ the population density was estimated to be 5 individuals/km^2 of roe deer, 3.5 individuals/km^2 of European/common hare and 0.5 individuals/km^2 of mountain/alpine hare in the Simpevarp area in the spring of 2003. For more information about wild game, see Consumers 3.8.2.

Picking of wild berries and mushrooms

According to /Berggren and Kyläkorpi, 2002/, 23.0 million litres of berries and 15.3 million litres of mushrooms were picked for own-consumption in Sweden in 1997. The main part of the berries (83%) was lingon berries and blue berries. The total area of forest and mires in Sweden gives an average amount of 81 litres/km^2 of wild berries and 54 litres/km^2 of mushrooms in the forests and mires. The total amount of picked berries has been calculated for Simpevarp area, Oskarshamns municipality and Kalmar County based on the forest area. There are no available data for the forest in Misterhult parish, but the picking is assumed to be similar to the amount picked in Simpevarp area. The picked amount per unit area is higher in Simpevarp area (and Misterhult parish) than in Oskarshamns municipality and Kalmar County, as the forest area is more dominating in Simpevarp area.

Fishing

The recreational fishing is a common activity in Misterhult parish, both in lakes and in coastal areas. The fishing tourism is well expanded and still growing. There is only one attractive fishing-water within Misterhult parish and that is Marströmmen. One fishery administration area in Marströmmen sells fishing licenses (Miliander et al. 2004.

The annual catch has been calculated based on the data from /Fiskeriverket, 2000/ presuming that the recreational fishers (55% of the population between 16 and 64 y) are sport fishermen that catch 18 kg per year.

Other

Other out-doors activities that are practiced in Misterhult parish are bird watching, golf playing, boat life and hiking/jogging. There are two attractive spots for bird watching, Simpevarp och Kråkelund, within the parish /Miliander et al. 2004/.

Four nature reserves are situated in Misterhult parish: Talldungen, Misterhults archipelago, Stenhagen at Figeholm and Virbo with Ekö, and they are often used for hiking. Two different hiking trails, the Äspö hiking trail and Simpevarvet, are located completely within Misterhult parish. More than half of Ostkustleden is located within Misterhult parish. Four jogging tracks are within Misterhult parish: Fårbo, Figeholm, Misterhult and Simpevarp /Miliander et al. 2004/.

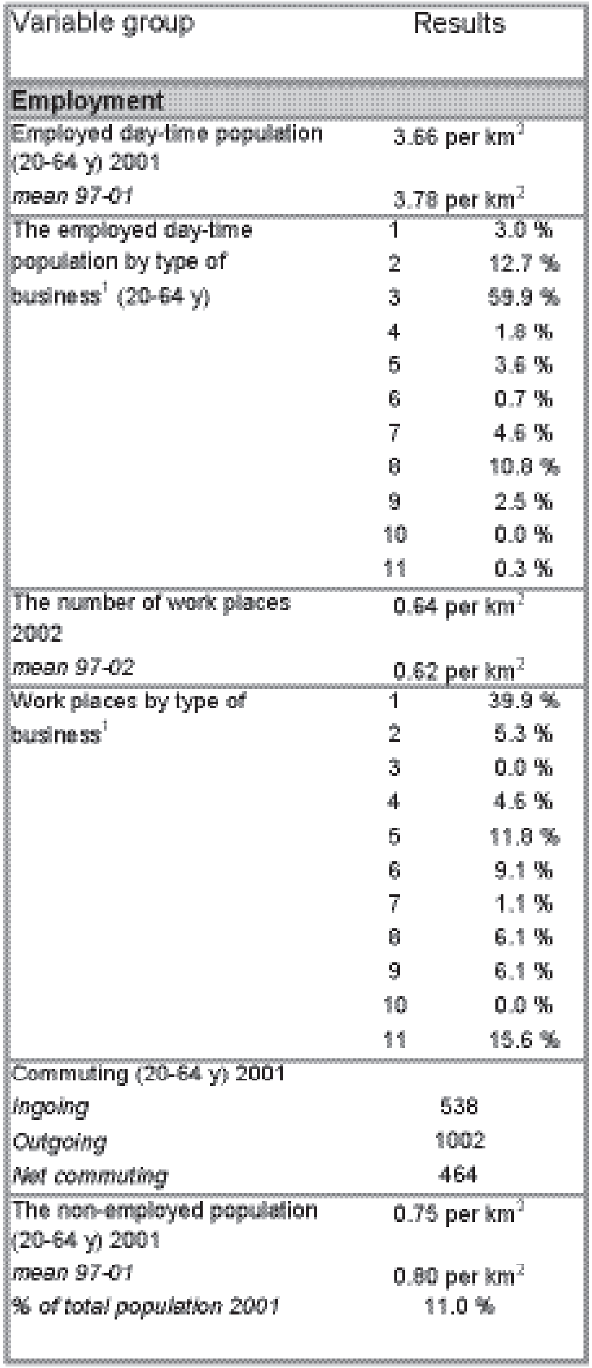
There are two open-air baths along the coastline at Misterhult parish (Laxemar and Figeholm) and four bathing places nearby lakes within the parish: Fårbo, Krokstorp and Mörtfors, Figeholm and Götemar. Figeholm Fritid och Konferens is the only camping area within Misterhult parish, while Figeholm Golf & Country Club is the only golf course. There are two guest harbours in Misterhult parish (Klintemåla and Figeholm) and five marinas. There are also nice paddle opportunities in Misterhults archipelago (Miliander et al. 2004).

Table 3-62. A compilation of data from Misterhult parish – an overview.

A

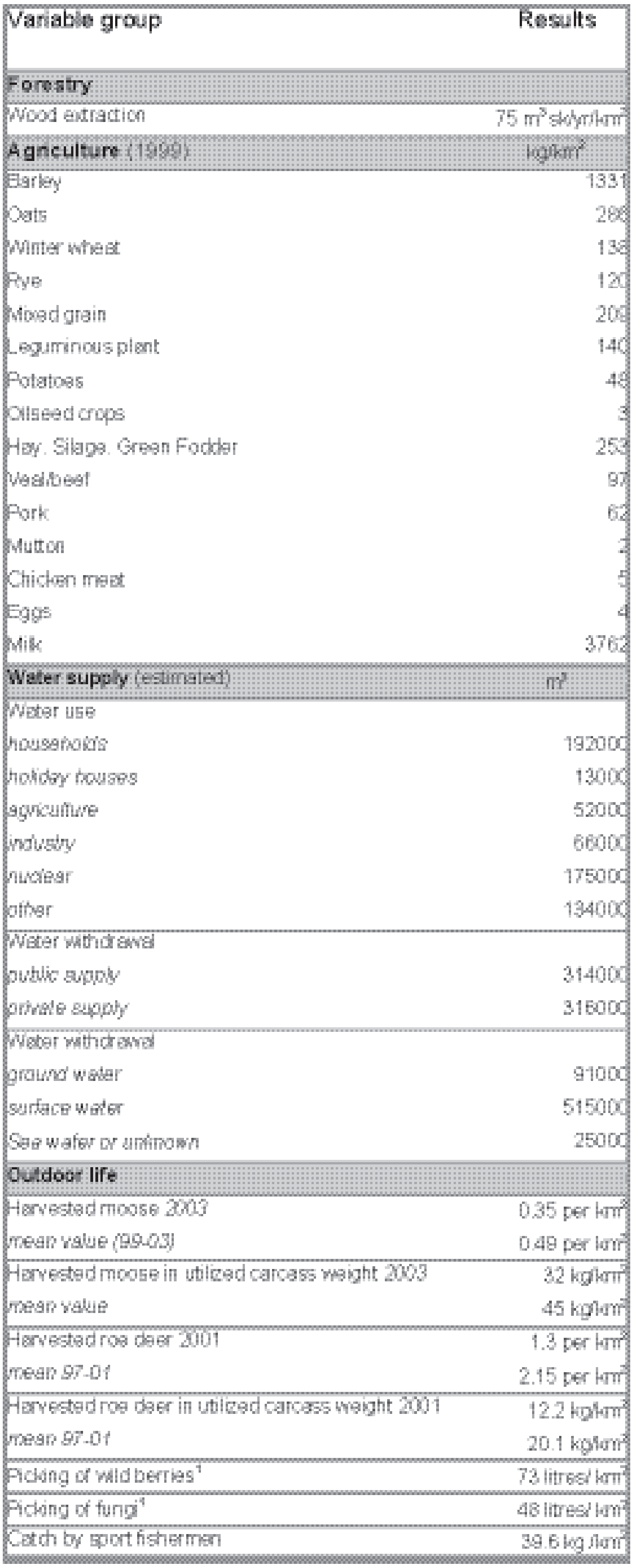
Variable group	Results	
Demography		
Population 2002	6.6 per km^2	
mean 93-02	7.1 per km^2	
Age structure 2002	0-15 y	17.0 %
	16-24 y	8.1 %
	25-44 y	19.4 %
	45– 64 y	32.8 %
	$\geq$ 65 y	22.7 %
Properties and buildings		
Type of properties 2002		
farms	0.95 per km^2	
one-or two dwellings	2.46 per km^2	
holiday houses	1.73 per km^2	
multi dwellings	0.09 per km^2	
other	0.25 per km^2	
Building permits		
dwellings 2002	3	
mean 96-02	4	
business premises 2002	5	
mean 96-02	7	
Completed dwellings 2002	0	
mean 93-02	4.9	
Employment		
Employed night-time population (20-64 y) 2001	2.98 per km^2	
mean 97-01	2.99 per km^2	
The employed night-time population by type of business[1] (20-64 y)	1	4.3 %
	2	24.2 %
	3	11.7 %
	4	7.3 %
	5	12.8 %
	6	7.7 %
	7	5.6 %
	8	18.8 %
	9	4.2 %
	10	2.5 %
	11	0.9 %

B



Variable group	Results	
Employment		
Employed day-time population (20-64 y) 2001	3.66 per km^2	
mean 97-01	3.78 per km^2	
The employed day-time population by type of business[1] (20-64 y)	1	3.0 %
	2	12.7 %
	3	59.9 %
	4	1.8 %
	5	3.6 %
	6	0.7 %
	7	4.6 %
	8	10.8 %
	9	2.5 %
	10	0.0 %
	11	0.3 %
The number of work places 2002	0.64 per km^2	
mean 97-02	0.62 per km^2	
Work places by type of business[1]	1	39.9 %
	2	5.3 %
	3	0.0 %
	4	4.6 %
	5	11.8 %
	6	9.1 %
	7	1.1 %
	8	6.1 %
	9	6.1 %
	10	0.0 %
	11	15.6 %
Commuting (20-64 y) 2001		
Ingoing	538	
Outgoing	1002	
Net commuting	464	
The non-employed population (20-64 y) 2001	0.75 per km^2	
mean 97-01	0.80 per km^2	
% of total population 2001	11.0 %	

C



Variable group	Results
Forestry	
Wood extraction	75 m^{3}sk/yr/km^2
Agriculture (1999)	kg/km^2
Barley	1331
Oats	288
Winter wheat	138
Rye	120
Mixed grain	209
Leguminous plant	140
Potatoes	48
Oilseed crops	3
Hay, Silage, Green Fodder	253
Veal/beef	97
Pork	62
Mutton	2
Chicken meat	5
Eggs	4
Milk	3762
Water supply (estimated)	m^3
Water use	
households	192000
holiday houses	13000
agriculture	52000
industry	66000
nuclear	175000
other	134000
Water withdrawal	
public supply	314000
private supply	316000
Water withdrawal	
ground water	91000
surface water	515000
Sea water or unknown	25000
Outdoor life	
Harvested moose *2003*	0.35 per km^2
mean value (99-03)	0.49 per km^2
Harvested moose in utilized carcass weight *2003*	32 kg/km^2
mean value	45 kg/km^2
Harvested roe deer 2001	1.3 per km^2
mean 97-01	2.15 per km^2
Harvested roe deer in utilized carcass weight 2001	12.2 kg/km^2
mean 97-01	20.1 kg/km^2
Picking of wild berries[1]	73 litres/ km^2
Picking of fungi[1]	48 litres/ km^2
Catch by sport fishermen	39.6 kg /km^2

[1] Values for Simpevarp area

Quantitative model – Simpevarp 7

The carbon flow related to the humans in Simpevarp 7 has been calculated, and the results are listed in Table 3-63. The calculations are described below. A flow chart with total carbon flow to man from herbivorous and vegetation, respectively, within Simpevarp 7 is shown in Figure 3-77 (under consumers).

Humans

There were seven inhabitants within Simpevarp 7 (Lake Frisksjön) in 2002. No employed day-time population exists within the area, and therefore no commuting into the area. The holiday population is expected to be low due to lack of holiday houses in the area (Miliander et al. 2004).

Agriculture

There are 10.6 ha arable land and 3.6 ha grassland (142,735 m^2) in Simpevarp 7 according to /Boresjö Bronge and Wester, 2003/, but there is no agricultural production within Simpevarp 7 today, according to data from SCB. According to /LivsmedelsSverige, 2004, website/ each person needs 3,000 m^2 (0.3 hectare) to be self-sufficient. Approximately half of that is needed for fodder production. Based on this value, Simpevarp 7 would be able to feed 47 persons. Thus, the seven persons actually living in Simpevarp 7, would need approximately 1,500 m^2 each for crop production, in total 10,500 m^2. The production in Simpevarp area is dominated by barley /Miliander et al. 2004/. Thus, the crop production in Simpevarp 7 is assumed to be barley. The production is based on the standard yield in SKO-area 0814 in 2003, in where Simpevarp 7 is located. The amount of carbon in milk is 2% and the amount of carbon in crop is estimated as 45.3% of the dry weight. The dry weight is 85% of the fresh weight according to /Jordbruksverket, 2003/.

The remaining area of arable land and grassland in Simpevarp 7 is assumed to be used for production of fodder and grazing, in total 13.22 ha. Based on the fact that a cow need 1.8–3.0 (mean 2.4) hectares for fodder production and grazing /Arnesson, 2001/, we can estimate that the remaining arable- and grassland in Simpevarp 7 can feed 5 cows. One dairy cow produces in average 7,735 kg of milk per year (2002). An average dairy cow is slaughtered at the age of five years after she has given birth to three calves /Miliander et al. 2004/. Five cows, 1–5 years old, can together produce three calves per year. One calf per year would have to be kept for breeding, which leaves two for slaughter. The average weight of slaughtered cattle is 290 kg, of which 165.3 kg (57%) can be utilized and the carcass weight for a calf is 110 kg, of which 62.7 kg (57%) can be utilized /Miliander et al. 2004/. The amount of carbon has been estimated as 10% in slaughtered cattle.

The total meat consumption is in average 38 kg per person and year (meat delicatessen not included) and the milk consumption is 194 litres (including cream, cheese and butter) /Miliander et al. 2004/. The export from Simpevarp 7 is calculated based on these values.

Hunting

The species that are mainly hunted for consumption are moose, roe deer and hare. The average harvest of moose in Misterhults parish and the average harvest of roe deer and hare in *Oskarshamns norra jaktvårdskrets* that are demonstrated in /Miliander et al. 2004/ are applied to Simpevarp 7. The utilized carcass weights are calculated according to /Miliander et al. 2004/, and the amount of carbon is assumed to be 10% of the carcass weight.

The total consumption of game meat is in average 2 kg per person and year. The hunters eat of course larger amounts. If the inhabitants in Simpevarp 7 are assumed to eat 2 kg moose per person and year, there will be a considerable export of game meat from Simpevarp 7. The total amount of the harvested hares, roe deer, red deer and birds (carcass weights) are assumed to go for export, as the inhabitants meat consumption is covered through beef meat and some moose meat.

The birds that are hunted for consumption are demonstrated in Table 3-63. The figures have been collected from *Oskarshamns norra jaktvårdskrets*. The live weights for a few species have been applied to the other species. According to /Jägarnas Riksförbund, 2004, website/ the carcass weight of a Mallard *(Sw: gräsand*) is approximately 67% of the fresh weight.

Fishing

A theoretical value of the annual recreational catch of fish can be calculated based on the data in /Fiskeriverket, 2000/, presuming that the recreational fishers (55% of the population between 16 and 64 y) are sport fishermen that catch 18 kg per year. As there are seven people within Simpevarp 7, a theoretical caught would be approximately 54 kg (18×3). 1 kg carbon (CPU) is equal to 30 kg fish biomass, i.e. 3.3% carbon, according to expert judgement /P. Nyberg, Fiskeriverket, pers. comm./. Assuming that the fish comes from the lakes in the area and not from the coast, the amount per unit area can be calculated. The mean catch (1995–2002) within EU-square 43G6, in which Simpevarp 7 is situated, is demonstrated in the Table 3-63.

Picking of berries and mushrooms

An average amount of 81 litres of wild berries per square kilometre forests and mires, are picked for own-consumption in Sweden /Miliander et al. 2004/. The land area of forest and mire (17% of the wetland) is 1,782,046.7 m^2 in Simpevarp 7. The weight of 1 litre berries is assumed to be equal to 500 gram. The total available amount of wild berries can be calculated based on the fact that 5–7% of the available amount was picked in 1977, which was 75.3 millions litres /Berggren and Kyläkorpi, 2002/. That gives a total amount of 1,255 million litres. The total area of forest and mires in Sweden is 284,000 km^2 /SCB, 1998/. This, the total available amount per unit area is 4,419 litres/km^2.

An average amount of 54 litres of mushrooms per square kilometre forests and mires, are picked for own-consumption in Sweden /Miliander et al. 2004/. The land area of forest and mire (17% of the wetland) is 1,782,047 m^2 in Simpevarp 7. The weight of 1 litre berries is assumed to be equal to 200 gram. The total available amount of fungus that can be consumed is 40 kg/ha according to /Berggren and Kyläkorpi, 2002/. The carbon content is assumed to be 1.2% in fungi and 10% in berries.

Table 3-63. The calculated carbon flow, related to the humans in Simpevarp 7.

Species		Amount		Biomass						Export
		Number per km^2	Total number in Simpevarp 7	kg/ind or kg/litre (utilized carcass weight)	Biomass utilized carcass weight g/m 2/y	Biomass C utilized carcass weight gC/m2/y	Biomass C Tot utilized carcass weight Simpevarp 7 or EU-square 43G6	Biomass C living weight gC/m2/y	Biomass C Tot living weight Simpevarp 7 or EU-square 43G6 gC/y	Export C Tot from Simpevarp 7 gC/y
Humans	Humans	3,3	7,0							
Agriculture[2]	Cropproduction-barley				335,0			129,0	**1354413,4**	0
	Milkproduction			1,00	234,0			4,68	618800,0	591640,0
	Meatproduction-calves+cow		3,0	96,90	0,151	0,02	29070,0	0,034	66068,2	2470,0
Hunting[4]	moose	0,49	1,0	93,68	0,0493	0,00493	9464,3	0,01120	21509,8	8064,3
	roe deer	2,15	4,4	9,38	0,0216	0,00216	4158,4	0,00492	9450,9	4158,4
	European (common) hare (field)	0,29	0,6	2,20	0,0007	0,00007	131,5	0,00016	299,0	131,5
	Alpine (mountaine) hare (forest)	0,10	0,2	1,76	0,0002	0,00002	36,3	0,00004	82,5	36,3
	Birds				0,0014	0,00014	269,5	0,00020	385,0	269,5
	Sum intake of meat						**43130,0**		**97795,3**	
Fishing[3]	EU-square 43G6				1,7279			0,05702	74240951,4	
Recreational fishing[5]					0,4557			0,01504	1782,0	0
Picking of fungus[6 (litres)]		54	96	0,2	0,011			0,0001	231	?
Picking of berries[6 (litres)]		81	144	0,5	0,041			0,0041	7217	?
Sum berries and mushrooms									**7448**	
Available amount of consumable fungus (litres)		200	356	0,2	0,040			0,00048	855	?
Available amount of berries (litres)		4419	7875	0,5	2,210			0,2210	393743	?
Sum berries and mushrooms (available)									**394599**	
	sum intake of vegetation								1361861,6	
	max theoretical intake of vegetation (available)								1749012,0	

[2] The biomass per unit area is expressed as gram per estimated arable land respectively grazing land.

[3] The commercial fishing refers to EU-square 43G6 in which Simpevarp 7 is situated. The biomass per unit area is expressed as gram fresh weight per water area

[4] The figures for Misterhults församling and Oskarshamns Norra jaktvårdskrets has been applied on Simpevarp 7. The biomass figures are based on utilized carcass weight.

[5] A theoretical value. The biomass per unit area is expressed as gram fresh weight per water area

[6] The total amount in Simpevarp 7 is calculated based on the landarea of forest and other (including mire)

3.10.3 Confidence and uncertainties

Most of the data in /Miliander et al. 2004/ were obtained from SCB. When only a single object is found within a geographic area, SCB adjusts this single object to a “false” zero for reasons of secrecy. If two objects are found, the count is adjusted to three (SCB, 2003). This can result in incoherence between the sum of values for different categories and the total number (as an example the total number of inhabitants and the sum of inhabitants per age class). Also for sparsely populated areas the data becomes more statistically unreliable, irrespective of this deliberate reporting bias.

Furthermore, there are some uncertainties concerning the data from *Fiskeriverket*. The catch statistics within the offshore grid (EU-grid) only comprise the catch from the logbook-keeping vessels, as they report the tackle position. The catch is registered in the square where the tackle is placed, but that does not necessarily mean that the fish has been caught in that particular square. Fishing boats can trawl a long distance and therefore catch the main part of the fish in a neighbouring square. The catch data at each EU-square therefore varies considerably between years.

4 Ecosystem models

4.1 The terrestrial ecosystem

The ecosystem concept integrates various fields of abiotic and biotic parameters with the aim of describing the organisms, the physical environment and the interactions between these in a given area. The ecosystem approach is here used with the purpose for describing accumulation and flow of matter in a temporal and a spatial context. A budget of organic matter is described by quantification of the different pools of matter and the fluxes between these pools. The foundation in such a ground-based estimate of stocks makes this method close to direct, but is limited by the accuracy with which the stocks, the stock change, and the decomposition rates are known. Another approach is to use a comprehensive ecosystem model to explore balances between energy, water and matter. This approach may simulate all the pools and fluxes in the ecosystem or it may also use site-specific input data setting starting conditions. The approach also requires running the model to equilibrium and adapting parameters accordingly. Using this method it will be possible to estimate factors that are difficult to measure under field conditions. In brief this chapter is devoted to;

- the building of a conceptual model describing the terrestrial ecosystem,
- quantification of the different carbon pools and fluxes in the conceptual model for a number of habitats,
- the construction of a carbon budget for a discharge area,
- presentation of a comprehensive numerical ecosystem model, the COUP model, used to estimate different parameters.

4.1.1 A definition of the terrestrial ecosystem

The terrestrial ecosystem is defined as land above the sea that is not part of a lake. The terrestrial ecosystem extends one meter below the surface (the upper regolith), which is the part of the regolith layer that is most affected by climate, hydrology, vegetation and soil fauna etc (see Section 3.3). The terrestrial system also includes wetlands, such as wetland forests and mires. However, wetlands in connection to a lake are today treated within the limnic ecosystem.

4.1.2 The conceptual model of the terrestrial ecosystem

The conceptual model of carbon pools and net fluxes in the terrestrial ecosystem is put together using information from mainly three chapters in this report; biota, soil and hydrology (Figure 4-1). Information is also used from Section 3.10 to estimate input to humans from biota. Some pools have been joined and some fluxes have been left out due to their small impact on the system as a whole e.g. dissolved organic carbon (DOC) washed out from the vegetation during rainfall. The premises behind these simplifications have been elaborated within the chapter covering the specific field. Below follows a description of the principal functioning of some of the main components within the conceptual model (Figure 4-1).

Abiotics

Soil

The soil is an important factor setting the abiotic conditions both in regard of nutrients but also for important hydrological parameters, such as hydraulic conductivity and field capacity. Most of the organic carbon in the ecosystem is entering this pool where it is decomposed leaving the system as carbon dioxide. In most terrestrial ecosystems is the soil carbon pool the largest carbon pool /e.g. Chapin et al. 2002/. There are two more or less easily identified layers; the humus layer that consists of more or less decomposed organic matter; and the mineral soil. A measure of the carbon content in the humus layer or the thickness of the humus layer gives a good indication of how fast the decomposition is. High carbon contents in the mineral soil layer are often an indication of

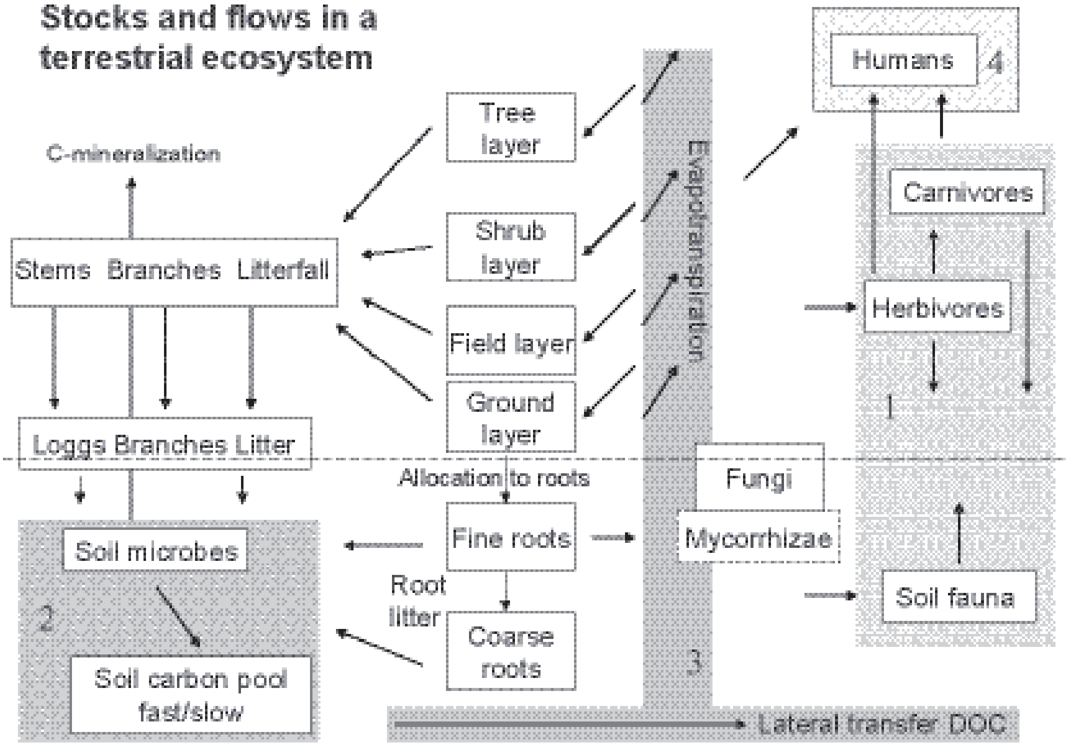


Figure 4-1. *The conceptual terrestrial ecosystem model. The numbers indicate the chapter where the different subsystems are further treated. The boxes/fluxes that are not a member of the boxes 1–4 are treated within the chapter Producers. Boxes indicate carbon pools while arrows indicate fluxes of carbon. Respiratory fluxes have been omitted in the figure. Arrows within subsystem 3 indicate water flow.*

well-drained nutrient rich soils. These soil types often have a less obvious border between humus and mineral soil layers, partly because of the bioturbation that may be significant. Bioturbation is the movement of matter in the soil caused by soil fauna, e.g. earthworms. Typically, bioturbation goes deep in well drained and well buffered soils, making the horizon between humus layer and mineral soil layer difficult or impossible to identify. Most of the carbon mineralization is occurring close to the surface while some carbon is transported further down in the soil, either by bioturbation or by water movement. This carbon is often referred to as the slow decomposing carbon pool, and constitutes of humins and humic acids /Schlesinger, 1997, see also below/.

Peat is the most extreme soil type, where little of the carbon has been mineralised due to the anaerobic environment induced by the near surface water table. Peat forming wetlands are carbon sinks where a thick layer might be accumulated over time. Data of the accumulation rate in peat, using some sort of dating technique, gives information about decomposition if the carbon input to soil is known.

Hydrology

Water movements control transport of matter in the plant, on the ground and in the soil. There are three main flows of water (see 3.4.3); 1) the downward flow (infiltration and percolation), 2) the upward flow (evapotranspiration) and 3) the lateral flow (surface runoff).

The largest water flow (1) results in leaching of organic matter and a transport of humic acids downward in the soil profile. This transport consists mainly of silicon, aluminum and iron ions that are tied up as hydroxides and oxides in lower soil horizons. Dissolved organic carbon (DOC) is also transported downwards, but the major part is decomposed within a short time period /e.g. Cleveland et al. 2004/. Some of the DOC may travel down where non-humic hydrophilic substances, that are considered more easily biodegradable, are dominating the soil organic matter (SOM) while humic substances are tied up in soil sorption processes /Neff and Ashner, 2001/.

The upward transport (2) of water is driven by a combination of evaporation from the leaf/needle surface and transpiration from the vegetation. This is a passive process linking the water around roots with the water in the plants and the water in the atmosphere /Larcher, 1995/. This transport is of importance for the upward transport of substances in the soil due to hydralic lift /Caldwell et al. 1998/ and to the actual plant uptake of substances dissolved in water, but is of minor importance for transport of DOC.

The lateral flow of water (3) may be significant during periods when precipitation intensity exceeds the infiltration capacity. This flow is of major importance in regard of transport of substances, mainly DOC but also particulate organic carbon /Canhem et al. 2004; unpubl. data from Forsmark/, from terrestrial to limnic and marine ecosystems. The transport between terrestrial ecosystems, not classified as wetlands, is regarded as of minor importance compared to the actual carbon fluxes within an ecosystem. However, the transport to and from wetlands may be important for accumulation of allochtonous matter.

Functional groups

Producers

The vegetation is the main producer binding carbon dioxide during the photosynthesis, except for fungi that also is treated in this group. The producers are divided into the functional layers, tree, shrub, field and ground layer. These are further divided, if possible, into woody and green parts above ground, and coarse and fine roots below ground. Producers are presented more exhaustively in 3.8.1.

Consumers

Although terrestrial animals consume a relatively small proportion of net primary production (NPP), they may strongly affect energy flow and nutrient cycling. Moreover, the flow of carbon through individuals may be considerable, making potential accumulation of substances similar to carbon large. Soil microbes are left out of the following calculations. Because of the lack of site specific data, the total carbon content in the soil includes the carbon from the microbial biomass. Consumers are presented more exhaustively in 3.8.2.

Decomposers

Decomposers are one of the most important functional groups because of the importance of the carbon mineralization process in the carbon cycle. There is no data from the site describing this group or the process of decomposition and is therefore left out in the quantitative descriptive model described below.

Dead organic matter

This is a pool that has an important function for biodiversity in the landscapes today. This pool is quantified and we also have figures describing the flux of dead matter (except for logs) but we have so far no data describing the actual turnover of dead organic material.

Habitats

The terrestrial ecosystem is subdivided into a number of vegetation types, based on their quantified properties (see 3.8.1). However, most terrestrial habitats behave in a similar way, in regard of accumulation and flows, making the conceptual model easy to apply to the different vegetation types at the site. However, wetlands having periodically inundated soils creating anaerobic conditions do accumulate organic matter in a high rate compared to the other terrestrial habitats found at the site. Therefore these habitats are of particular interest when describing accumulation and transport of organic matter in the descriptive ecosystem model.

Wetlands

There are two main types of wetlands found at the site, the poor mire – bog type with sphagnum dominated ground layer on peat dominated soil and the forested wetland with a more herb rich field layer on mineral soils. The mire-bog type are peat forming while the later type have a thick humus layer on mineral soil and does therefore contain less carbon in the organic soil pool (which is also confirmed from site specific measurements in Forsmark, /Lundin et al. 2004a,b/). The anaerobic conditions created in the inundated soil lead to emission of methane gas in lack of oxygen during decomposition. This emission is low compared to the carbon dioxide emitted during heterotrophic respiration (e.g. a boreal bog, between 1–2 gCm^{-2} /Alm et al. 1999/ and 4 gCm^{-2} /Waddington and Roulet, 2000/).

Studies of DOC loading to lakes, as a function of vegetation types, in a drainage area have shown that wetlands export more DOC than other vegetation types /e.g. Canhem et al. 2004, Humborg et al. 2004/. /Canhem et al. 2004/ calculated the export from conifer wetlands, "emergent marches" and forests to 17.5 $gCm^{-2}y^{-1}$, 12.5 $gCm^{-2}y^{-1}$ and 3.5 $gCm^{-2}y^{-1}$ respectively, using a predictive model based on 2,750 lakes and their drainage areas in Canada. /Waddington and Roulet, 2000/ found the lateral transport from a boreal bog in Sweden to be 4.2 gCm^{-2} and 6.7 gCm^{-2} in two consecutive years. These figures are small in comparison to the local carbon budgets (see Table 4-7 to 4-9 for the forest and the mire), but their impact on the recipient may be large depending on the size of the drainage area.

4.1.3 Ecosystem properties

A number of different emergent properties exist at the ecosystem level. Some of these are of particular interest for understanding the accumulation and flow of matter in a patchily distributed landscape. Moreover, there is also a temporal aspect of the different pools and fluxes that in some cases may be insignificant but in some cases crucial to handle.

Production and accumulation

Net primary production

Net primary production (NPP) is here the sum of all materials that have been produced and are retained by live plants at the end of a given interval and the amount of organic matter that was both produced and lost by the plants during the same interval (Clark et al. 2001). Some of the input data to the model is in the form of net annual biomass increment (from Chapter 3.8.1) and a number of fluxes, such as litterfall and root litter have to be added to get an estimate of NPP.

Net ecosystem production

Net ecosystem production (NEP) is the net annual biomass accumulation in the ecosystem by plants (B_{plant}), animals (B_{animal}) and the soil (Soil Organic Matter), plus or minus lateral transport ($F_{lateral}$) among ecosystems.

$$NEP = \frac{(\Delta B_{plant} + \Delta B_{animal} + \Delta SOM)}{\Delta t} \pm F_{lateral}$$

ΔB_{plant} is the net gain of biomass in plants, and is a function of the net primary production (NPP) and the different losses. This is described by

$$\frac{\Delta B_{plant}}{\Delta t} = NPP - (F_{pl-soil} + F_{herbiv} + F_{emiss} + F_{pl-fire} + F_{harv})$$

where the flux from plants to the soil ($F_{pl–soil}$) is the largest loss, while the flux to herbivores (F_{herbiv}) usually is considered to be small (see Section 3.7). Losses from emission of volatile compounds to the atmosphere is described by F_{ei} and losses by fire and harvest by $F_{pl–fire}$ and F_{hrv}.

ΔB_{animal} is the net gain of biomass in animals and the process is described by

$$\frac{\Delta B_{animal}}{\Delta t} = F_{herbiv} + F_{microb-anim} - (R_{anim} + F_{anim-soil})$$

Net heterotrophic gain of biomass is equal to plant biomass eaten (F_{herbiv}), the soil animals eating microbial biomass ($F_{microb–anim}$) minus losses to animal respiration (R_{anim}) and fluxes from animals to the soil due to excretion and mortality ($F_{anim–soil}$). Transfers of carbon within the animal box are often subsumed in the overall carbon budget equations /Chapin et al. 2002/.

The second largest avenue of carbon loss from plants, after respiration, is the carbon flux to the soil through litter fall, secretion of soluble organic compounds by roots into the soil, and carbon fluxes to microbes that are symbiotically associated with roots e.g. nitrogen fixers and mycorrhizae /Chapin et al. 2002/. These are also the largest inputs to soil organic matter. ΔSOM is the net gain of biomass in the soil organic matter pool and described by

$$\frac{\Delta SOM}{\Delta t} = F_{pl-soil} + F_{anim-soil} - (R_{microb} + F_{microb-anim} + F_{CH_4} + F_{leach} + F_{soil-fire})$$

The flux of plant material and the input of organic matter from animals ($F_{anim–soil}$) are the fluxes to the soil. Respiration (R_{microb}), consumption of microbes by animals ($F_{microb–anim}$), methane emission (F_{CH4}) and leaching of organic and inorganic carbon to groundwater (F_{leach}) and fire ($F_{soil–fire}$) are the carbon losses in the soil. The dead organic materials in the uppermost soil layers are after decomposition again available for the vegetation if not emitted or leached. The accumulation and decomposition rate is affected by factors such as hydrology, soil type, soil chemistry, soil fauna and vegetation.

Temporal variation in the ecosystem

The temporal variation have few implications for the overall carbon budget, but may be of importance when collecting data or studying specific transport events, such as a short term release of radionuclides and their potential accumulation during their transport through the landscape.

Growing season

The pools and fluxes are very much dependent on the growing season that is a function of the diurnal mean temperature. This means that the accumulated change during the year, which is used here, only illustrates the total outcome of the year e.g. decomposition has a positive exponential relationship to soil temperature, which means that the decomposition is much lower in the winter then in the summer /Widén, 2002/. This is also detected in the total amount of DOC in running water at the Forsmark site, which is much higher during the winter months. This relationship also means that the variation between years may be large due to variation in climatic factors such as precipitation and temperature. Consequently, NEP may vary between years. Such variations were found in a boreal bog in northern Sweden /Waddington and Roulet, 2000/. They also concluded that because of the low difference in mean annual air temperature and total precipitation between these years the variation within the growing season is important for the season carbon balance.

Water flow

Water flow is an important factor, with a large variation within the year that control lateral transport of DOC in the ecosystems. The largest flows are during spring and autumn. Thus, available matter is more prune to be transported during these periods, which is also illustrated by the example above. The transport of water within the plants is also highly dependent on the growing season.

4.1.4 Quantitative descriptive model

This section describes how estimate of carbon pools and fluxes are introduced into the conceptual model. Firstly, a description of the data and how the data was used is presented. Secondly, the results are discussed that were extracted from three habitats and compared with other studies. There after, the stocks and flows of carbon for a whole drainage area in Oskarshamn are presented.

Methodology and modelling assumptions

The GIS model

The data that was used to turn the conceptual descriptive model into a quantitative descriptive model was taken from sources in accordance with Table 4-1 and from tables presented in this section.

Table 4-1. Presentation of the properties that was used to characterise the entities in the quantitative descriptive ecosystem model and where in the report they are more thoroughly treated.

Entity	Chapter	Table nr.	Property
Producers	3.7.1	3-28–3-30	Biomass, NPP and turnover
Consumers	3.7.2	3.50	Biomass, consumption and faeces
Humans	3.10	–	Hunting, utilized berries and fungi
Hydrology	3.4	–	Evaporation, transpiration, specific runoff

Carbon content and turnover in the soil

The carbon content in the soil is separated into humus layer and mineral soil layer (Table 4-2). The soil microbial biomass is included in this carbon pool, and there is no site specific data describing the microbial biomass separately.

Today we have no data describing the decomposition rates at the site and we therefore assume that the yearly flux of carbon from the standing stock is in a steady–state with decomposition. This is of course a rough simplification especially as most forests are carbon sinks /Chapin et al. 2002/.

For wetlands there is data describing the accumulation of carbon using the age of the site and the thickness of the peat layer (Table 4-3). By comparing this rate of accumulation with the input of carbon to the soil, it will be possible to evaluate how they correspond to each other.

Table 4-2. Soil carbon content in different vegetation types. All values are originating from field studies in Forsmark /Lundin et al. 2004a,b/. These classes correspond to the other vegetation types used in 3.7.1.

Description of the class	Class in /Lundin et al. 2004a,b/	Humus layer gCm^{-2}	Below humus layer gCm^{-2}
Shore line (bedrock excluded)	AR/GL	863	3,194
Forested wetlands	GL	2,594	7,171
Herb dominated moist soils on fine texture parent material	GL/CM	0	14,536
Mires	HI	43,282	0
Thin soils with lichen rich heath vegetation	LP	3,322	56,55
Woodland, coniferous forest	RG/GL	2,921	6,256

Table 4-3. A rough estimate of accumulation rate of carbon in four wetlands in the Forsmark area. These values are calculated using information of the depth of the peat soil and the approximate age since the wetland emerged from the sea.

Locality in Forsmark	g C/m^2 year	Reference
Stenrösmossen	43.2	/Fredriksson, 2004b/
Lersättermyran	66.3	/Fredriksson, 2004b/
T1	58.3	/Lundin et al. 2004b/
T2	73.8	/Lundin et al. 2004b/
Mean	60.4	

Transport of DOC

The downward flow of carbon is not treated in this version, because of the comparatively lower mobility of DOC in lower soil horizons /Neff and Ashner, 2001, Berggren et al. 2003/, (see also 4.1.1).

The upward water movement due to evapotranspiration from plants is regarded as unimportant in affecting transport of carbon. However, this flow of water is considerable and may be important for transport of other substances and is therefore presented but not further treated in this section. This upward flow is estimated using the Mike She model (see 3.4.4).

Lateral transport is dependent on the specific runoff that is set to 5.7 $ls^{-1}m^{-2}$ for the whole site (see 3.4.3). The lateral transport between neighbouring terrestrial ecosystems is, however, in lack of data assumed to be of minor importance (3.5 $gCm^{-2}y^{-1}$ is transported from conifer forests, see 4.1.1 Wetlands). Nevertheless, it is calculated for the drainage area, thereby making comparisons with DOC transport data from the limnic ecosystem possible. Transport to and from wetlands may be larger due to a discharge area that concentrates water flow to a smaller area. A number of properties describing parameters related to water transport to and from a wetland is presented for each wetland within the discharge area (Table 4-4).

According to /Brydsten, 2004b/ data from six investigated lakes in the Forsmark area suggested that the lake sediments have a high degree of material of autochtonous origin. This is also supported by several other factors supported that, such as small topographic variation (small watersheds), low current velocities and low abundance of fine-grained sediments. Nevertheless was an example calculated to illustrate how much the carbon dynamics within the wetland could be influenced. This was based on literature data where /Canhem et al. 2004/ estimated leaching of DOC from conifer forests to 3.5 $gCm^{-2}y^{-1}$. The size of the drainage area was multiplied with this figure to get a measure of the DOC loading to the specific wetland. Output from emergent marshes was estimated by /Canhem et al. 2004/ to 12.5 $gCm^{-2}y^{-1}$. This figure was multiplied with the wetland size to get a measure of the transport DOC from the wetland (Table 4-5). These results were compared with the input to SOC, the SOC pool and the calculated yearly accumulation of carbon in the peat layer (Table 4-3).

The results suggest that the accumulation of external DOC to the wetland is 4% of the total internal to the SOC as litter (field layer and roots) in both the wetlands. The external input of DOC is low in relation to the local flux of carbon to the SOC. In lack of better data it is therefore assumed that the major part of the carbon deposited in wetlands originates from production within the wetland.

Few figures have been published presenting the carbon mineralization in wetlands. /Moore et al. 2002/ presented the figure 245 $gCm^{-2}y^{-1}$ from a boreal bog in Canada. The peat accumulation for the two wetlands in the area was calculated by subtracting that C-mineralization rate from the flux of litter and incoming DOC (Table 4-5). This calculated rate was very high compared to estimated rates from Forsmark and in literature /e.g. Ohlson and Okland, 1998/. Further investigations have to elucidate this large minus.

Table 4-4. Properties describing the wetlands within the catchment area of Frisksjön. First column shows the id of the wetland. North and south is related to the spatial location of the wetlands in the drainage area (Figure 4-2). The specific runoff that has been used to calculate the incoming water flow to the wetland is 5.7 $lm^{-2}s^{-1}$ (3.4.3). The parameters were calculated using the hydrology extension in ArcGIS 8.3 (See 3.4.4).

Wetland id.	Area (m^2)	Discharge area (m^2)	Inflow (m^3s^{-1})	Inflow (m^3y^{-1})
North	10,513	106,063	0.00060	19,065
South	4,929	53,159	0.00030	9,556

Table 4-5. Total input, output and accumulation of DOC in the two wetlands within the drainage area. All figures are in $1x10^6\,gCy^{-1}$. The flux of litter is produced within the wetland. Calculation of peat accumulation was done in two ways; (1) by generic data of decomposition and adding column 4 and 5, and subtracting column 6, and (2) from estimated peat accumulation from Table 4-2.

Wetland id.	Input DOC	Output DOC	Accumulation of external DOC	Flux litter	C–mineralization	Peat accumulation (1)	Peat accumulation (2)
North	0.37	0.13	0.24	6.36	2.6	4	0.63
South	0.19	0.06	0.12	2.98	1.2	1.9	0.30

Carbon budget within some vegetation types

The large amount of information describing pools and fluxes and the different spatial resolution of this information called for an implementation of the conceptual model on a number of vegetation types before a carbon budget is presented for a complete catchment area. Three vegetation types were therefore chosen by using a vegetation map, to represent a forest, a mire and an agriculture land (see Table 4-6). Biomass production and flow data were extracted for these vegetation types (Table 4-7 to 4-10) and compared with available data from other studies, in order to assess the validity of the resulting descriptive ecosystem model and control for inconsistencies. Moreover, data describing some of the water fluxes was extracted for these habitats (Table 4-11). However, some of the data was not available for the three vegetation types.

Table 4-6. The three vegetation types and their location chosen for the typification of the conceptual model in Oskarshamn. The grid codes follows the vegetation map by /Boresjö Bronge and Wester, 2002/.

Vegetation type	Grid code (veg. map)	X	Y
Old spruce forest, mesic – moist	Old spruce-dominated forest, mesic-wet types, 11	1547170	6369194
Open wetland, poor carpet mire, Sphagnum-dominated	Open wetland, reed-dominated, poorer or wetter, 79	1540912	6363396
Arable land	81	1548807	6368031

Table 4-7. The different pools of carbon presented for the three different vegetation types in the Simpevarp area. The number after the sum represents the net annual increase of biomass. Those without such a number are supposed to be in a steady state between loss and accumulation during one year. Soil Organic Carbon (SOC) is presented for the humus layer and the mineral soil separately.

Properties	Carbon pools in (gC m^{-2})		
	Forest	Mire	Agriculture land
Carnivores	0.57×10^{-3}	0.57×10^{-3}	0.57×10^{-3}
Herbivores	0.14 0.14 0.14		
Soil fauna	Is a part of the soil organic carbon pool below		
Tree layer above ground	5,688+164	–	–
Tree layer below ground	1,307+110	–	–
Field and ground layer AG	401	264	225
Field and ground layer BG	0	1,261	97
Fungi	117	–	–
Dead wood	103	9	–
Litter layer	154	322	–
SOC humus layer	2,921	43,282	
SOC Below humus layer	6,256	–	14,062
Overall sum	16,947	45,137	14,384

Table 4-8. Carbon fluxes affecting the Soil Organic Carbon pool (SOC) during one year and the total SOC pool for three vegetation types in the Simpevarp area. In this version are the mire and the agriculture land lacking fungi. All above ground vegetation is harvested in the agriculture land.

Properties	Carbon fluxes in (gC $m^{-2}y^{-1}$)		
	Forest	Mire	Agriculture land
Litter fall	253	202	0
Root litter	455	403	97
Mycel litter	137	0	0
Sum Input to soil	845	605	97
SOC humus layer	2,921	43,282	–
SOC below humus layer	6,256	–	14,062

Table 4-9. Carbon fluxes affecting the plant biomass during one year. The accumulation in biomass is the difference between NPP and the removal of carbon from the vegetation as litter and harvest.

Properties	Carbon fluxes in (gC $m^{-2}y^{-1}$)		
	Forest	Mire	Agriculture land
NPP trees	982	–	–
NPP plants	34	667	322
Production mycel	137	–	–
Sum production	1,153	667	322
Litterfall	253	202	0
Root litter	455	403	97
Mycel litter	137	0	0
Harvest	–	–	225
Sum removal	845	605	322
Accumulation in biomass	308	62	0

Table 4-10. Fluxes related to humans and animals during one year. The carbon flux from hunting to humans is the actual utilized meat after the slaughter. Herbivory is considered as the input of carbon to animals from the vegetation. These fluxes are more thoroughly presented in Section 3.7.2.

Properties	Carbon fluxes in (gC $m^{-2}y^{-1}$)		
	Forest	Mire	Agriculture land
Human from vegetation	0.004	0.004	129
Human from animals (hunting)	0.022	0.022	–
Sum input to humans	0.026	0.026	129
Carnivory	0.100	0.100	0.1
Herbivory (sum input to animals)	7.600	7.600	7.6
Faces and mortality carnivores	0.020	0.020	0.02
Faces and mortality herbivores	3.800	3.800	3.8
Sum input to SOC	3.800	3.800	3.8

Table 4-11. Estimates of different water flows in the three exemplified vegetation types in the Simpevarp area. See 3.4 for a description of how the estimates were obtained.

Properties	Water fluxes in ($m^{-3}y^{-1}$)		
	Forest	Mire	Agriculture land
Transpiration	141 mm	–	–
Evaporation (intercept.)	183 mm	–	–
Lateral flow	5.7 $lm^{-2}s^{-1}$	–	–

Forest

The carbon pool of productive forests in Sweden, including soil carbon down to 1 m depth, has been calculated to have approximately 80 metric tonnes C/ha (8,000 gCm^{-2}) /Olsson, 2000/. The corresponding values for Oskarshamn are 9,177 gCm^{-2} in the soil. This is also in agreement with the figures from Skogaby /Persson et al. 2001/ where they had a carbon content in the humus layer of 2,200 gCm^{-2} and 10,000 in 0.5 m of the mineral soil. The later value is higher than the value from Oskarshamn, but the difference may be explained by the rather young soils in Oskarshamn where the carbon has had much less time to accumulate in the deeper soils (see 3.3, this data is from Forsmark in lack of better data for Oskarshamn).

If it is assumed that the carbon pool in the soil is in a steady state with incoming organic matter, the C-mineralisation would be 845 $gCm^{-2}y^{-1}$. This can be compared with estimations from the Skogaby plots /Persson and Nilsson, 2001/ of 266 $gCm^{-2}y^{-1}$.

Wetland

Peatlands in Sweden are assumed to have a general carbon content of 260 kg /m^{-2} /Olsson, 2000/. This figure does not fit the figure 43 $kgCm^2$ from Oskarshamn well. This may be partly an effect of the comparatively young soils in Oskarshamn (or Forsmark, which is from where the estimation is taken). The figure does also only cover the first metre of the regolith, which therefore is an underestimation if the peat layer is deeper.

Agriculture land

The agriculture land has most of the biomass above ground, and this biomass is regularly harvested leaving some amount of root litter. Typically, this land is ploughed one or two times each year, creating a more or less homogenous soil where no humus layer horizon is found. Here it is assumed that everything above ground is removed, which is a simplified assumption because a small part of the straw is left after harvest. The difference between what is harvest (in Table 4-9) and what is utilized by humans (in Table 4-10) is the threshing loss and straw.

A carbon budget for a drainage area

The descriptive ecosystem model is applied at the landscape level covering a discharge area. Pools and fluxes for all vegetation types are summed using the GIS (earlier described). The resulting budget is reduced with regard to pools (boxes) and fluxes (arrows) compared to the conceptual model.

The Drainage area

The modelled drainage area is situated in the Simpevarp area (Figure 4-2) and has a total area of 2.061 km^2. The dominating vegetation types are forests, primarily pine on acid rocks and pine forest of mesic-moist type. Some agriculture land is also present.

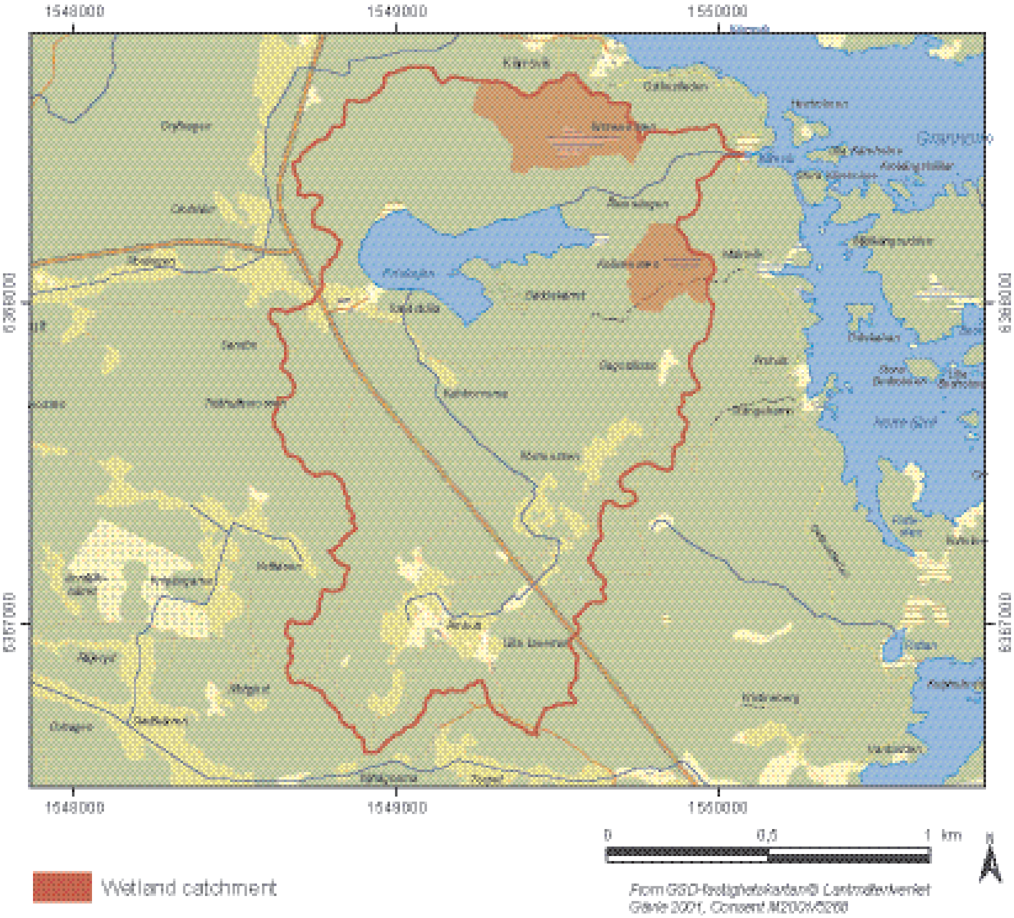


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***Figure 4-2.** The drainage area in Oskarshamn on which the descriptive ecosystem model was applied in order to construct a large scale carbon budget. The two wetlands "North" and "South" with their sub-cathment areas shown.*

The descriptive model

The descriptive model has been reduced in number of boxes and fluxes, and is presented in Figure 4-3. The carnivore box is the sum of all carnivores presented in Section 3.7.2. Where measure of biomass and faeces and mortality were missing, the simple assumption was made that it was on average the same as for those animals whose figures were known. The arrow from vegetation to humans represents crops from the agriculture land in the discharge area, and berries and fungi that are utilized (see 4.11 for more information behind these figures). The arrow from herbivores to humans is the actual utilized meat after the slaughter. If a steady state between carbon input to SOC and C-mineralization is assumed, the C-mineralization should approximate 1.24×10^9 gCy^{-1}.

Flow of matter

The total lateral transport of DOC was calculated using a figure from /Canhem et al. 2004/ that estimated leaching of DOC from conifer forests into lakes to 3.5 $gCm^{-2}y^{-1}$. This figure was multiplied with the total discharge area (lake area 0.13 km^2 subtracted). This resulted in an amount of 0.94×10^6 gCy^{-1} that was transported as DOC from the terrestrial land types in the discharge area.

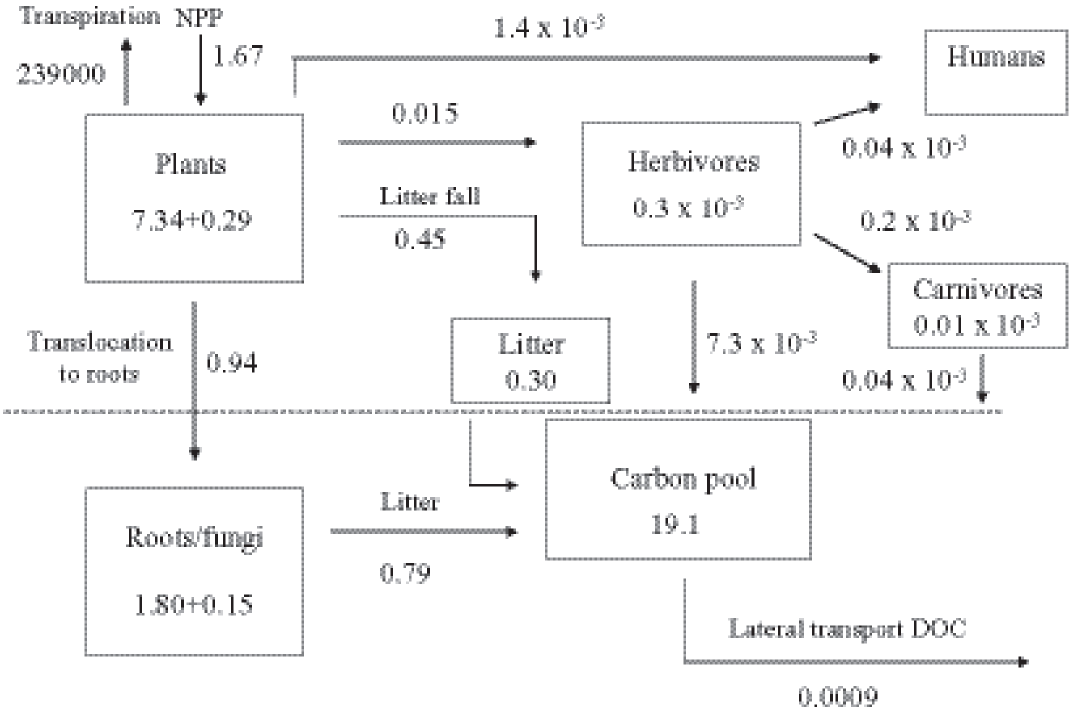

Figure 4-3. *Major pools and net fluxes of carbon for the overall drainage area Frisksjön. Transpiration is in* m^3y^{-1}*, figures in boxes are in* $1x10^9gC$ *and figures describing fluxes in* $1x10^9gCy^{-1}$*. Net change in a pool is shown within the box.*

Confidence and uncertainties

The importance of the different pools and fluxes is for the overall carbon budget is of course is set by their relative size. Thus, large variation or uncertainties in relative large pools/fluxes overshadow the influence of relative smaller pools/fluxes. This has in this report been an argument to why some smaller pools or fluxes have been left out. There is a large spatial variation within a regional area as an effect of different abiotic conditions and of disturbances, such as logging and thinning in the forestry industry. The biomass of trees is probably the data that have the best estimations in this carbon budget since that is sampled from a fairly large regional area covering a large number of age classes and abiotic conditions. This means that local deviance from the general spruce forest ecosystem may be large, but that these deviances should even out when a sufficient large area is used for the calculations. Therefore should calculations of the carbon budget get less sensitive to spatial variation when the area of interest gets larger. The carbon budget for the discharge area should therefore be more robust (relative deviance from the actual pools and fluxes) than the carbon budgets for the local forest, mire and agriculture land presented earlier.

4.1.5 The Coup Model

Water and carbon budgets were calculated for the forest area of the Simpevarp site investigation with the terrestrial ecosystem model CoupModel /Jansson and Karlberg, 2004/. An updated analysis and more detailed description of the applications to Simpevarp and Forsmark will be given by /Gustafsson et al. 2005/.

Model description

The CoupModel is a one-dimensional model for simulations of fluxes of water, heat, carbon and nitrogen in a soil-plant-atmosphere system. It is an integration of the SOIL /Jansson and Halldin, 1979/ and SOILN /Eckersten et al. 1998/ models, corresponding to the water and heat part and the nitrogen and carbon part of the model, respectively. It has been developed to account for interactions between climate, vegetation and conditions in the soil, and applied mainly for Nordic conditions. A detailed description of the model is given by /Jansson and Karlberg, 2004/.

The carbon and nitrogen part is based on three conceptual models: 1) carbon input is governed by solar radiation, 2) carbon flows govern nitrogen flows, and 3) nitrogen in plants determines growth. Plants are represented by one pool of carbon and one of nitrogen for three compartments, stem, leafs (needles), and roots. The stem compartment represents all woody material: stems, branches and roots except fine roots.

The organic material in the soil is represented in different ways depending on the purpose of the simulation. Soil organisms, such as microorganisms, decompose the organic matter, and their activity, therefore, accounts for the fluxes between different organic pools in the soil. To account for differences in substrate, the model has a minimum representation of two organic pools independent of soil horizon. One of these is *Litter* and has a high turnover rate. The other one is *Humus* and represents a low turnover rate.

Simulations of soil temperature, soil moisture conditions and the soil water flows are based on physical equations. The most important interaction between the carbon turnover and the physical conditions is governed by the leaf area index and the ratio between actual and potential transpiration. Both will in turn influence the input of carbon to the system and both are strongly related to the temperature and the moisture.

Input data

Meteorological data, vegetation characteristics governing evapotranspiration, soil hydraulic properties, and boundary conditions for runoff are the most important input data for the water part of the model.

A one-year dataset with hourly values of air temperature, wind speed, relative humidity, precipitation, and global radiation was created based on the available data from Ölands norra udde 1981 /Larsson-McCann et al. 2002/. Wind speed values were corrected with a factor of 0.4. The correction factor was derived by comparison of average and maximum wind speeds at Ölands norra udde and the available measurements at Äspö since 2003. Precipitaion was corrected with 6% and 10% at air temperatures above and below +1°C, respectively.

Water and heat processes (i.e. transpiration, interception, snow melt, soil heat and water flows) were parameterised according to /Gustafsson et al. 2004/, who calibrated the CoupModel using measurements of evaporation, transpiration, soil temperatures, and soil water contents from the Norunda forest, Uppland, Sweden. The important vegetation properties leaf area index, canopy height, and root depth were simulated by the carbon and nitrogen model.

Input parameters for carbon and nitrogen processes were based on previous applications of SOILN and CoupModel to several Swedish forest sites, Skogaby, Halland /Eckersten and Beier, 1998; Gärdenäs et al. 2003/, Asa, Småland /Svensson, 2004/, and Jädraås /Gärdenäs et al. 2003/ and Knottåsen /Svensson, 2004/ in Hälsingland. All these applications rely on site-specific calibrations of critical parameters governing carbon and nitrogen flows related to plant growth. These parameters were re-calibrated using data on stem biomass development estimated from /Marklund, 1988/ and Swedish forestry statistical yearbook 2003 /Skogsdata, 2003/ for the Kalmar region. Parameters for carbon and nitrogen turnover rates in the soil were assumed to be more site-independent and were taken directly from Skogaby (mineral N processes) and Asa (organic processes).

Site model

The CoupModel was set up to simulate the water, carbon, and nitrogen budgets for a forest soil with a single tree layer. A multiple vegetation layer simulation is possible in the model, however discarded in this version. The simulation was made for a 30-year development starting at 30 years stand age up to 60 years /Gustafsson et al. 2005/ will present simulations for a whole rotation period of 80 years.

Initial values for carbon content in the vegetation were selected according to /Marklund, 1988/ and /Skogsdata, 2003/ for the Kalmar region. Initial content of carbon and nitrogen in the soil were set according to Lustra site Asa /Svensson, 2004/.

The climate series from 1981 was repeated for every year of the simulation. As indicated above, allocation of nitrogen and carbon to different parts of the plant and direct uptake of organic nitrogen from the soil was used as calibration parameters. The simulated stand development was compared to /Marklund, 1988/ and /Skogsdata, 2003/ (Figure 4-4). The simulation reached the present estimated carbon content in the tree layer (above and below ground) in Simpevarp (7.1 kg C m–2) at a stand age of 47 years. Water and carbon budgets were calculated based on the simulations for this particular year.

Water budget

Accumulated annual precipitation in the simulation was 495 mm, partitioned on 376 mm evapotranspiration and 122 mm runoff. The correction of measured precipitation (6% for rain and 10% for snow) may be somewhat lower on average than the monthly correction factors derived by Larsson-McCann et al. 2002. However, the distribution on 75% evapotranspiration and 25% runoff corresponds well to the estimates with MIKE SHE model for the area.

The relation between evapotranspiration components (Table 4-12) was similar to the results of /Gustafsson et al. 2004/. Interception evaporation was about one third of the total evapotranspiration. Verification of the partitioning between soil evaporation and transpiration is difficult without measurements of either one of these components or soil water content in the root zone.

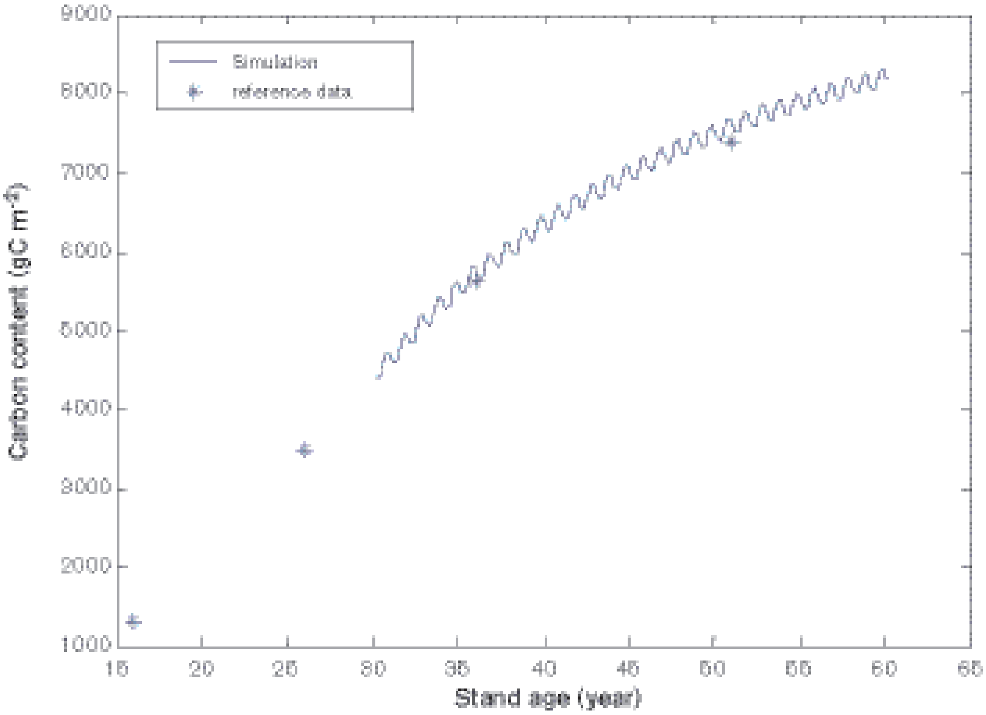

Figure 4-4. Simulated carbon content in the forest tree layer compared with estimated stand development based on /Marklund, 1988/ and /Skogsdata, 2003/.

Table 4-12. Annual evaporation components.

	(mm)	% of evapotranspiration
Transpiration	167	44
Interception evaporation	106	28
Soil evaporation	98	26
Snow evaporation	5	1

Carbon budget

Simulated carbon storages in plants and soil were compared with the estimations from Simpevarp (Table 4-13). The simulated net growth was about 50% of the estimated. There are at least two possible reasons for the discrepancy: first, the data used for calibration represents the entire Kalmar region and not the coastal zone specifically, second, the simulation was run with a constant climate of the selected year 1981 based on data from north of Ölands.

Simulated and observed carbon fluxes give a similar picture (Table 4-14). Simulated net carbon assimilation is approximately 50% of the observed, and the total litter fall is even less (about one third).

Table 4-13. Simulated annual average carbon pools for the forest site at a stand age of 47 years (gC m^{-2}), compared with the corresponding observations derived from Table 4-7 Net annual increases are given after the sum signs.

	Simulation (gC m^{-2})	Observed (gC m^{-2})
Tree layer (stem+needles+roots)	7,158+99	6,995+274
Soil organic carbon (litter+humus)	7,259+80	9,177+0

Table 4-14. Simulated annual fluxes of carbon in the forest compared with observed values derived from Table 4-9 (gC m^{-2} year^{-1}).

	Simulated	Observed
Carbon assimilation (net photosynthesis)	507	982
Litter fall (stem+needle+roots)	288	363
Plant respiration (maintainance)	120	–
Soil respiration	204	–

Conclusion

The results indicate that the present parameterisation of the nitrogen and carbon part of the model represents a system with a too low turnover rate in general. A re-calibration of the model is needed, taking the available observations into account.

4.2 The limnic ecosystem

The limnic system includes both lakes and running waters. Lakes may be regarded as sedimentation traps, where accumulation of particles, nutrients and trace elements occur, and where biological processes, such as primary production, consumption and respiration may have considerable impact on accumulation and transport of matter. Streams, on the other hand, may principally be regarded as transport routes, where deposition and accumulation of matter is of minor importance, and where biological processes of importance for accumulation of matter is insignificant. This simplified view of the limnic ecosystem is used in version 1.2 of the Site Descriptive Model. In later versions of the report, the importance of stream processes for the transport of matter will be evaluated.

Only 5 lakes are situated completely within the Simpevarp regional model area. In addition, a couple of lakes are situated partly within the area, and there are also some minor, but permanent, pools. Chemical, physical and biological properties of some of these lakes have been described in previous chapters. Most lakes and streams in the area are affected by human activities. The naming of some wetlands and minor fields in the area indicate that a number of previous lakes have disappeared during the last centuries due to human activities, probably with the intention to increase farming areas. There are also indications on that the water level of several of the remaining lakes have been lowered by man. Moreover, most of the streams in the area are affected by straightening and ditching.

4.2.1 Conceptual model of the lake ecosystem

Habitats and functional groups

Habitats

The lake ecosystem is usually divided into three major habitats or zones; the littoral, the pelagial and the profundal (Figure 4-5), which are described in detail in Section 3.8. In short, the bottom of the lake basin is separated from the free open water, *the pelagial*. *The littoral zone* covers the bottom area of the photic zone, while the remainder of the bottom, which consists of exposed fine sediments free of vegetation, is referred to as *the profundal zone* /Wetzel, 2001/. The littoral zone can be further divided into a number of subhabitats. /Brunberg et al. 2004/ distinguished three different littoral types; the Littoral Type I with emergent and floating-leaved vegetation, Type II with hard bottom substrate, and Type III with submerged vegetation (cf. Section 3.8). In the budget calculations for Lake Frisksjön, the Littoral Type III and the profundal has been combined to the *benthic habitat*. The combination is motivated both by a need to reduce model complexity, and by large similarities between the two habitats with regard to dominating organisms and processes in this type of lake.

Most lakes in the Oskarhamn area are relatively shallow, with brown water due to high input of organic matter from the surrounding catchment. Because of the brownish water, light penetration is poor and the depth of the photic zone is generally small. This means that the profundal zone covers extended areas in most lakes, despite their relative shallowness.

Functional groups – Primary producers

The major groups among primary producers in lakes in the Oskarshamn area are macrophytes, phytoplankton, and epiphytic algae. This grouping of primary producers has been used also in the quantitative model of the lake ecosystem.

In the littoral with emergent and floating-leaved vegetation (Littoral I), both biomass and primary production is dominated by macrophytes. No information about dominating taxa or biomass from the lakes in the area was available when writing this report.

Lake Frisksjön is a humic lake, and based on observations from diving in the lake it can be concluded that the underwater vegetation in open water areas is very scarce. Because of that it was assumed that the the Littoral type III contains no bottom vegetation. It may be reasoned that since there are no submerged macrophytes, this zone should instead be classified as profundal.

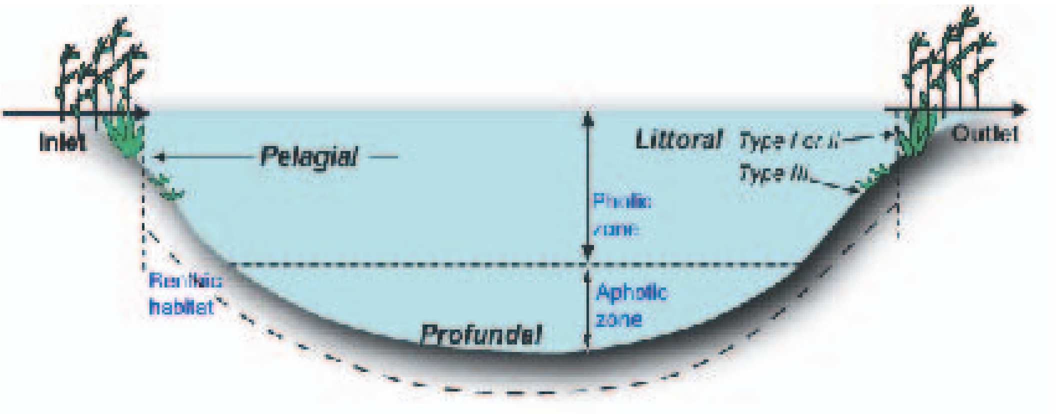

Figure 4-5. *Conceptual illustration of a lake ecosystem with the conventional division into littoral, pelagial and profundal habitats. In the budget calculations, the bottom areas of the Littoral type III and the profundal zone has been combined to the benthic habitat.*

However, the classification into Littoral III and profundal which is described in /Brunberg et al. 2004/ has been used also in this report, and since the two habitats are combined in budget calculations it has no practical implication.

The major taxonomic groups of phytoplankton in Lake Frisksjön in July were dinophytes, whereas diatoms dominated in December and April /Sundberg et al. 2004/. Generally, both biomass and taxonomic composition of phytoplankton varies greatly during the year. In budget calculations, the total biomass of all taxonomic groups was used. Regardless of seasonal variations in taxonomic composition, it was assumed that half of the phytoplankton community consists of potentially mixotrophic species, as is the case in Lake Eckarfjärden in northern Uppland /Blomqvist et al. 2002/.

The third group of primary producers consists of epiphytic algae, which are attached to the surfaces of macrophytes. At present, we have no site-specific data describing the taxonomic composition of this plant group.

In lakes with clear water, periphyton (i.e. microflora growing upon substrata), may play an important role in the benthic habitat, in terms of both biomass and primary production. However, due to the poor light conditions in lakes in the area, the role of periphyton in the benthic habitat can be neglected in an ecosystem model.

Functional groups – Consumers

Consumers include all heterotrophic organisms, i.e. herbivores, carnivores and detrivores. For the limnic system, these are divided into 4 major taxonomic groups; bacteria, zooplankton, benthic fauna and fish.

Bacteria as an organism group is highly variable, in that they occur on different substrates, they may assimilate carbon from different carbon pools and they are assumed to be eaten at different rates. The bacteria have been divided into three groups; bacterioplankton, benthic bacteria and epiphytic bacteria. No site-specific data concerning bacteria in Lake Frisksjön is available. Literature values from lakes as similar to Lake Frisksjön as possible have been used.

Each of the groups of zooplankton, benthic fauna and epiphytic fauna are very heterogeneous concerning organism size, life cycle and food choice. However, a higher level of detail was not assumed to be of importance for the carbon budget calculations, and therefore no further division has been used for these groups. Data concerning zooplankton and benthic fauna has been collected in Lake Frisksjön, whereas generic data was used for epiphytic fauna.

Fish are also very heterogeneous, especially concerning food choice, and fish data was therefore divided into the functional groups zooplanktivorous fish (Z-fish), benthivorous fish (M-fish) and piscivorous fish (F-fish), according to /Holmgren and Appelberg, 2000/ (cf. Section 3.8).

Food web relationships

The food web relationships between different functional groups in the lake ecosystem, which are assessed to be potentially important, are shown in Table 4-15.

All primary producers; macrophytes, phytoplankton and epiphytic algae, utilize 100% of their carbon need as dissolved inorganic carbon (DIC). However, as the macrophytes are mainly made up of emergent species, they utilize DIC from the air and do not influence the DIC pool in the water. The group phytoplankton also includes mixotrophic plankton. These plankton can migrate vertically /Smayda, 1997/, and are thus capable to utilize both bacterioplankton and, at least to some extent, benthic bacteria.

Table 4-15. Potentially important food web relationships between major functional groups in lakes in the Simpevarp regional model area.

	Phytoplankton	Macrophytes	Epiphytic algae	Epiphytic bacteria	Epiphytic fauna	Bacterioplankton	Zooplankton	Z-fish	M-fish	F-fish	Benthic bacteria	Benthic fauna	DOC	POC	DIC
Phytoplankton						X					X				X
Macrophytes															X
Epiphytic algae															X
Epiphytic bacteria													X	X	
Epiphytic fauna			X	X											
Bacterioplankton													X	X	
Zooplankton	X					X	X								
Planktivorous fish							X								
Benthivorous fish			X	X	X							X			
Carnivoruos fish								X	X	X					
Benthic bacteria														X	
Benthic fauna	X					X	X				X	X		X	

Bacteria can assimilate both DOC (Dissolved Organic Carbon) and POC (Particulate Organic Carbon) and therefore bacterioplankton and epiphytic bacteria are assumed to consume DOC and POC in proportion to the occurrence of the two fractions in the water. Benthic bacteria on the other hand, have access to a large POC pool and are assumed to consume only POC.

Zooplankton can consume bacterioplankton, phytoplankton and zooplankton. All bacterioplankton and phytoplankton are assumed to be available as a food source for zooplankton, whereas only 50% of the zooplankton are assumed to be available.

Benthic fauna is composed of functionally different groups, such as benthic filter feeders, detritus feeders, predators, scrapers and shredders, but these were in the budget calculations treated as one group. Benthic fauna is assumed to consume benthic bacteria, benthic fauna, bacterioplankton, phytoplankton, zooplankton and POC in proportion to the occurrence.

Fish feeding on zooplankton (Z-fish) are assumed to consume zooplankton, whereas POC and phytoplankton is assumed to be too small to be ingested by fish.

Fish feeding on benthic fauna (M-fish) are most probably feeding selectively. However, we have no data on food preferences, and therefore M-fish are assumed to eat in proportion to the availability of benthic fauna, epiphytic bacteria, epiphytic algae and epiphytic fauna, respectively.

Piscivorous fish/Carnivoruos fish (F-fish) are assumed to consume only fish. Most likely the shift from other food sources to fish will not be complete, but it is assumed so in this budget/model. Moreover, it is assumed that there is no preference for specific prey species or sizes, and the consumption is assumed to be in proportion to what is available in biomass of Z-, M- and F-fish.

4.2.2 Quantitative site specific model

In this section the quantitative ecosystem model for Lake Frisksjön is described. The section starts with an account of the assumptions made in the development of the model, then the model is presented, and it ends with a section discussing confidence and uncertainties.

Modelling assumptions

Distribution of organism groups

Bacterioplankton and plankton are assumed to be evenly present within the pelagial. Benthic bacteria and benthic fauna are assumed to be present over the whole lake area, except for in the reed belt (Littoral I). Macrophytes (in Lake Frisksjön mainly represented by reed) are assumed to occur in the whole area of Littoral I. Epiphytic algae, epiphytic bacteria and epiphytic fauna are assumed to be present in the reed belt on straws of *P. australiensis* and *Typha sp.* It is therefore assumed that these groups are present in the whole area of Littoral I. The biomass values used here are related to m^2, using the same substrate area as in Lake Eckarfjärden /Andersson and Kumblad, submitted/. Fish are assumed to be distributed in the pelagial.

Biomass

Biomass of phytoplankton was calculated by using measured values of Chlorophyll *a* from the lake. Biomass of zooplankton was estimated using the measured value from July for the period May–August, and an average value of the measured values from December and April for the period September–April. Biomasses of benthic fauna and fish have been measured in Lake Frisksjön and these have been used for the budget calculations. In one sample of benthic macroinvertebrates in the sublittoral, a mussel was present which made up almost the entire biomass. This biomass was subtracted before calculating a mean biomass value to be used in budget calculations. Literature values were used for biomasses of epiphytic algae /Meulemanns, 1988, oligotrophic lake/, and epiphytic fauna /Ahlkrona et al. 1998, mesotrophic lake/. The biomass of epiphytic bacteria was assumed to be the same as the biomass of epiphytic algae. Biomass data for macrophytes has been taken from a lake in the Forsmark area, Lake Eckarfjärden /Andersson et al. 2003a/. Bacterioplankton biomass has been taken from the coloured Lake Tvigölingen in Uppland /Lindström, 1998/ and biomass of benthic bacteria has been taken from Lake Erken in Uppland /Goedkop and Törnblom, 1996/.

Primary production

No measurements of primary production have been performed in Lake Frisksjön. Instead, the mean production value from several humic lakes is used /Nürnberg and Shaw, 1999/. There are large variations in the amount of fixed carbon that is released as DOC from phytoplankton (5-80%, /Kato and Stabel, 1984; Chranowski and Hubbard, 1989; Camarero et al. 1999/). In this budget it was assumed that 40% of the primary production (by phytoplankton and epiphytic algae) is released into the lake water as DOC.

Respiration

Bacterial respiration was assumed to be 3 times bacterial production (measured as thymidine incorporations). For bacterioplankton, mean bacterial production for several coloured lakes was used. For benthic bacteria, bacterial production from Lake Erken has been used, and for epiphytic bacteria, bacterial production on reed from /Haines et al. 1987/ was used. The respiration for the remaining consumers was calculated from site specific data on biomass, using conversion factors in /Kautsky, 1995/ and measured temperature in Lake Frisksjön.

Consumption

For bacteria, consumption was assumed to be the sum of respiration and bacterial production (thymidine incorporations). The consumption of the remaining consumers was assumed to be 3 times the respiration, except for fish where the consumption was assumed to be 1.73 times the respiration.

Zooplankton, benthic fauna and F-fish consume to some extent organisms belonging to their own taxonomic group, and this has been accounted for in the budget calculations; half of the biomass of zooplankton was assumed to be available for consumption by other zooplankton, the total biomass of benthic fauna was assumed to be available for consumption by other benthic fauna, and the total biomass of F-fish was assumed to be available for consumption by F-fish.

Conversion factors

Data available in other units than gC were converted with the aid of conversion factors from /Kautsky, 1995/ (see Table 4-16).

Table 4-16. Conversion factors used to calculate biomass and respiration rates for various organism groups (compiled from /Kautsky, 1995/). The respiration conversion factors are valid for a temperature of 20°C. They were used together with temperature measurements in the lake (performed at samplings for chemical analyses, 20 times per year) to calculate the respiration, assuming a direct linear relationship between respiration and temperature.

Functional group	Biomass gdw gww^{-1}	Biomass gC gdw^{-1}	Respiration gC gC^{-1} day^{-1}
Pelagic habitat			
Zooplankton	–	–	0.115
Fish	0.200	0.492	0.033
Benthic habitat			
Benthic bacteria	–	–	0.069
Benthic filter feeders	0.222	0.196	0.028
Benthic detrivores	0.204	0.300	0.032
Benthic herbivores	0.154	0.251	0.029
Benthic carnivores	0.197	0.430	0.033
Littoral habitat			
Macrophytes	–	0.395	–
Epiphytic fauna	–	0.400	0.030

Carbon transport to and from the lake

The net inflow and outflow of organic carbon (DOC and POC) to and from the lake has not been included in the carbon budget.

Ecosystem model for Lake Frisksjön

The ecosystem model for Lake Frisksjön is as far as possible based on the site specific data presented in Chapter 3. Production and respiration have been calculated from biomass and temperature data with the aid of conversion factors, as described above. Where site specific biomass data is missing, generic data available in the literature has been used. The data sources for the different parameters in the model are compiled in Table 4-17.

Table 4-17. Data sources used in the carbon budget calculations for Lake Frisksjön.

Budget parameter/parameter group	Site specific data	Generic data	References
Biomass per functional group			
Pelagic habitat			
Phytoplankton	X		/Sundberg et al. 2004/
Bacterioplankton		X	/Lindström, 1998/
Zooplankton	X		/Sundberg et al. 2004/
Z-fish (zooplanktivore)	X		/Engdahl and Ericsson, 2004/
M-fish (benthivore)	X		/Engdahl and Ericsson, 2004/
C-fish (carnivore)	X		/Engdahl and Ericsson, 2004/
Benthic habitat			
Benthic bacteria		X	/Goedkoop and Törnblom, 1996/
Benthic fauna	X		/Ericsson and Engdahl, 2004/
Littoral habitat			
Macrophytes		X	/Andersson et al. 2003/
Epiphytic algae		X	/Meulemanns, 1998/
Epiphytic bacteria		X	Assumed to have the same biomass as epiphytic algae
Epiphytic fauna		X	/Ahlkrona et al. 1998/
Lake carbon pools	X		/SICADA/
Surface and volume info	X		/Brunberg et al. 2004/

Food web matrix for Lake Frisksjön

The consumption of different food sources for each functional group was obtained by first identifying the food web relationships between all groups in the system. Consumers were assumed to eat in proportion to what is available of their food item/prey (in biomass), and the food web relationships, together with food availability, was used to calculate the estimated proportions of different food sources for the functional groups in Lake Frisksjön (Table 4-18).

Table 4-18. Food web matrix, including estimated food proportions (based on the availability of different food sources), for Lake Frisksjön.

	Phytoplankton	Macrophytes	Epiphytic algae	Epiphytic bacteria	Epiphytic fauna	Bacterioplankton	Zooplankton	Z-fish	M-fish	F-fish	Benthic bacteria	Benthic fauna	DOC	POC	DIC
Phytoplankton						0.22					0.28				0.50
Macrophytes															1.00
Epiphytic algae															1.00
Epiphytic bacteria													0.96	0.04	
Epiphytic fauna			0.50	0.50											
Bacterioplankton													0.96	0.04	
Zooplankton	0.44					0.15	0.41								
Planktivorous fish							1.00								
Benthivorous fish			0.06	0.06	0.00							0.88			
Carnivorous fish								0.03	0.50	0.47					
Benthic bacteria														1.00	
Benthic fauna	0.02					0.01	0.03				0.81	0.05		0.08	

Ecosystem model – Carbon budget for Lake Frisksjön

Both production and biomass of primary producers in Lake Frisksjön is dominated by macrophytes (reed), followed by phytoplankton and epiphytic algae (Table 4-19, Figure 4-6). Reed utilises DIC from the air and not from the water, and does accordingly not influence the DIC compartment in the water. On the other hand, when decomposing, a relatively large part of the reed could be released to the pelagic as POC /Gessner et al. 1996/, contributing to the bacterial production and thereby influencing the carbon budget.

Lake respiration was strongly dominated by bacteria, both benthic and pelagic, which together made up 92% of the total respiration in the lake (Table 4-19, Figure 4-6). Accordingly, bacteria also made up the main part of the consumption in the lake (84%).

On an annual basis, almost all organism groups show a carbon excess when subtracting respiration and grazing from production/consumption. Since there is no increase in biomass over time, this excess carbon is assumed to contribute to the POC pool. However, with the feeding assumptions made, phytoplankton and fishes are not able to sustain the grazing/predation on an annual basis. These deficits may, however, be adjusted by only small changes in the assumed feeding preferences. The deficit in fish is small, only 30 kgC year^{-1}, and if F-fish in addition to zooplankton consume some of the excess 900 kgC year^{-1} benthic fauna, there is enough fish production each year. Likewise, if zooplankton has a slightly higher preference for bacterioplankton than for phytoplankton, there will be an excess of both phytoplankton and bacterioplankton.

Carbon is transported to the top predator (F-fish) through two main pathways. One is through benthic bacteria to benthic fauna, to M-fish, and further to F-fish. The other pathway is through bacterioplankton to zooplankton (or through mixotrophic phytoplankton to zooplankton), to Z-fish and further to F-fish. Although the magnitude of carbon assimilation at the base of the two food webs is roughly the same, the main part of carbon reaching F-fish goes through the first, benthic pathway (Figure 4-6).

Table 4-19. Total average biomass (gC) and annual metabolic rates (gC year^{-1}) of functional organism groups in Lake Frisksjön. Note that phytoplankton includes both autotrophic and mixotrophic species and hence has primary production as well as respiration and consumption.

Functional group	Biomass		Prim. prod.		Respiration		Consumption	
	gC	%	gC/year	%	gC/year	%	gC/year	%
Pelagic habitat	1.8E+5	6.8	1.8E+6	27.2	2.6E+7	48.9	3.9E+7	51.5
Phytoplankton	3.8E+4	1.4	1.8E+6	27.2	9.1E+5	1.7	1.8E+6	2.4
Bacterioplankton	1.3E+4	0.5			2.2E+7	41.6	2.9E+7	38.4
Zooplankton	7.0E+4	2.6			2.5E+6	4.8	7.6E+6	9.9
Planktivorous fish	2.0E+3	0.06			9.0E+3	0.02	1.5E+4	0.02
Bentivorous fish	3.1E+4	1.2			1.8E+5	0.3	3.1E+5	0.4
Carnivorous fish	2.9E+4	1.1			1.7E+5	0.3	2.9E+5	0.4
Benthic habitat	1.8E+6	66.3	0	0	2.7E+7	50.9	3.7E+7	48.2
Benthic bacteria	1.7E+6	62.1			2.6E+7	49.7	3.6E+7	45.8
Benthic fauna	1.1E+5	4.2			6.3E+5	1.2	1.9E+6	2.5
Littoral habitat	7.2E+5	26.9	4.9E+6	72.8	1.7E+5	0.3	2.3E+5	0.3
Macrophytes	7.1E+5	26.3	4.5E+6	67.8				
Epiphytic algae	7.0E+3	0.3	3.4E+5	5.1				
Epiphytic bacteria	7.0E+3	0.3			1.7E+5	0.3	2.3E+5	0.3
Epiphytic fauna	1.4E+2	0.0			6.0E+2	0.0	1.8E+3	0.0
Lake total	2.7E+6		6.7E+6		5.3E+7		7.6E+7	
Lake carbon pools (kgC)								
DIC	4.8E+5							
DOC	3.6E+6							
POC	1.6E+5							

The carbon budget indicates that the respiration in Lake Frisksjön is about 10 times higher than the primary production. Thus, the lake must be sustained with carbon from allochtonous sources, e.g. inflow of humic substances from the surroundings. This agrees well with the brown water colour of the lake and the high concentrations of dissolved organic substances.

The net inflow and outflow of organic carbon (DOC and POC) to and from the lake has not been included in the calculations. A rough estimate of carbon transport out of the lake, based on measured TOC in lake surface water and modelled discharge, indicates that the transport of organic carbon from the lake is approximately 4.7×10^6 gCy^{-1}. Thus, annual carbon outflow seems to be in the same order of magnitude as both the annual primary production and the average carbon pool in lake water, while it is about 10 times lower than the total annual respiration (Table 4-19).

There is no measured data to estimate the inflow of carbon into the lake, nor the accumulation rate of organic matter in sediments. In the terrestrial ecosystem model described in this report, the transport of carbon from the terrestrial system in the catchment area of Lake Frisksjön (including on additional area of about 10% downstream the lake) to the sea is calculated, based on literature data. The calculated transport, 0.9×10^6 gCy^{-1}, is at least a magnitude lower than total lake respiration in the limnic model. Since the lake ecosystem most probably is sustained with carbon from allochtonous sources, the calculated transport from the terrestrial system may be an underestimation. In future model versions, efforts will be made to develop and integrate the terrestrial and limnic models to calculate a balanced carbon budget for the whole catchment area.

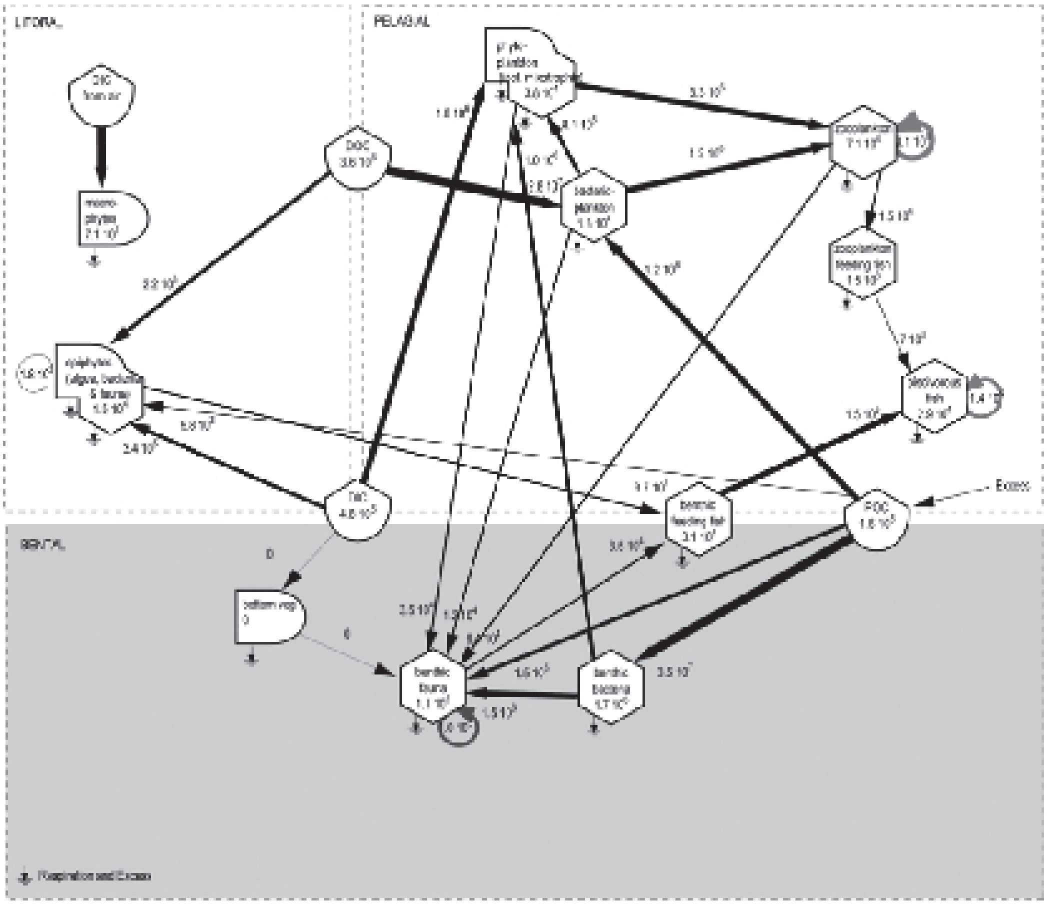

Figure 4-6. Carbon budget for Lake Frisksjön. Arrow size indicates the magnitude of carbon flow between different functional groups. Since the biomasses of all epiphytic groups (algae, bacteria and fauna) are so small, they have been treated as a single epiphyte group in the picture.

Confidence and uncertainties

This is the first attempt to develop an ecosystem model for a lake in the Oskarshamn area. Since site specific data on biomass and distribution is lacking for several functional groups, and since we have no site specific data on important ecosystem processes (i.e. consumption and respiration), the model is of course associated with uncertainties. However, the conclusion that Lake Frisksjön is dominated by respiration can be considered highly realistic. Humic lakes with high water colour favour heterotrophic bacteria, whereas phytoplankton and primary production tend to be limited by poor light conditions.

Biomass, production and respiration of bacteria have not been measured in Lake Frisksjön and therefore the magnitude of these parameters may be over- or underestimated. Literature values have been taken from lakes as similar to Lake Frisksjön as possible, although studies of epiphytic and benthic bacteria are not as common as for bacterioplankton and thus these values may be treated with some caution.

Phytoplankton primary production is based on the mean from several coloured lakes and could be assumed to be in the right order of magnitude, if not in exact size of actual production. Phytoplankton biomass was calculated from chlorophyll *a* measurements in the lake. The ratio of chl *a*:gC may vary with status of the algal community and therefore biomass may be over- or underestimated. The estimated biomass of phytoplankton was relatively high and probably somewhat overestimated. This agrees well with the result that there is not enough of phytoplankton production, but an excess of bacterioplankton consumption (assimilation) in our budget. As grazing is related to biomasses of the prey, smaller biomass would also lead to smaller grazing pressure and the phytoplankton production would be enough to sustain the standing stock.

Generally, zooplankton biomass show high seasonal variation. However, biomass has only been measured at three occasions. Moreover, at one sampling occasion the biomass was extremely high, whereas it was low at the other two occasions. This makes it difficult to elucidate the biomass, as well as respiration and consumption, of this group of consumers. Zooplankton biomass is high in the resulting budget, and this seems reasonable since there is a large pool of bacteria and phytoplankton for the zooplankton to utilize as food, and a low predation pressure from Z-fish which in turn is most probably suppressed by F-fish.

Fish data is collected by standardized and generally accepted methods; however, the generated data is only semi-quantitative. The conversion of catch per unit effort (CPUE) data to an absolute estimate of biomass per area unit is associated with large uncertainties. To our knowledge, no study exists to validate any conversion factor, and the proposed conversion factor which was used in this report may be regarded as an “expert guess”.

In conclusion, despite that there are many parameters that are not measured in the lake, this carbon budget may be assumed to be close to reality. When site specific data was lacking, generic data has been achieved from lakes as similar to Lake Frisksjön as possible. The main pattern seen in other humic lakes, with a dominance of respiration from bacteria, was seen also here when using these literature values.

4.3 The marine ecosystem

The coastal ecosystems are the most productive regions in the marine environment, and have often been regarded as an important filter and transition zone of organic matter and nutrients discharged from land. The marine ecosystem in Oskarshamn has a varied bathymetry, with enclosed bays clearly affected by fresh water effluence, a thin archipelago and open sea areas heavily exposed to currents and wave action. As a result, elements discharged into the marine environment from the adjacent terrestrial and limnic environments will have a different fate depending on where they enter the marine system.

The Simpevarp marine ecosystem has been divided into eight basins, of which three is shown in Figure 4-7. These three basins, i.e. Borholmsfjärden, Granholmsfjärden and Getholmsfjärden, are described below as they are the basins that mainly receive the discharge from Frisksjön catchment

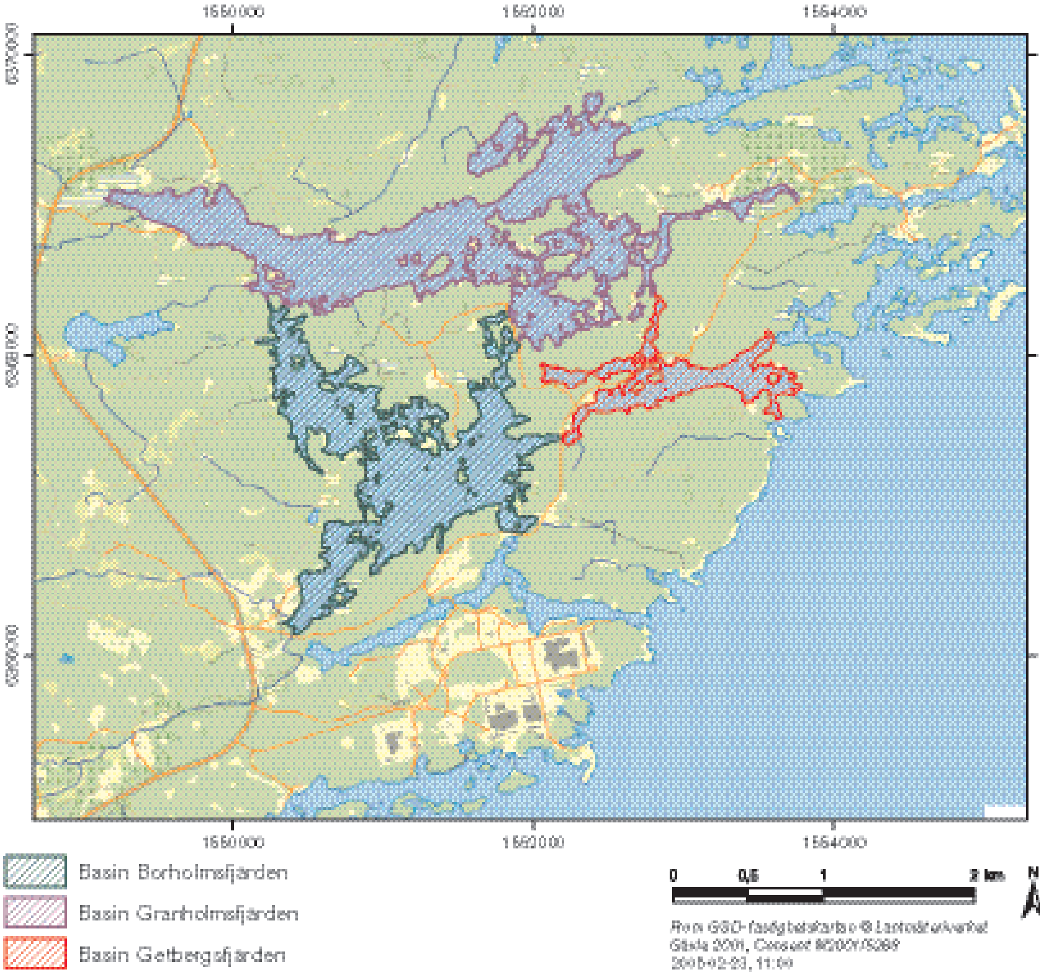

Figure 4-7. Three basins in the Simpevarp area; Borholmsfjärden (green), Granholmsfjärden (violet) and Getbergsfjärden (red).

area. Remaining basins will be described in a later version of this document. The basins are parts of the marine environment but are more or less physically or bathymetrically separated from each other. The basins have in the descriptions been treated as separate units, based on the assumption that relevant flow of carbon will greater within the basins than between the basins. The flows of carbon between the basins are assumed to be possible to quantify either with estimations of abiotic carbon flows (runoff and oceanographic flows) or biotic flows (i.e. migration of organisms).

4.3.1 Conceptual model of the marine ecosystem

Habitats and functional groups

Habitats

In Figure 4-8 the habitats of the marine ecosystem is illustrated. The phytobenthic habitat was defined to be the benthic habitat in the photic zone, the soft bottom habitat the benthic habitat in the aphotic zone and the pelagic habitat the open water habitat, both photic and aphotic.

Two of the basins in the Simpevarp area encompass all habitat presented above. Basin Borholmsfjärden, however, does not have any aphotic environment as the assumed photic zone depth (4.4 m) exceeds the maximum depth (4.2 m). All basins differ from each other in total area, surface areas for each habitat and volumes as a result of different light penetration depths and bathymetry.

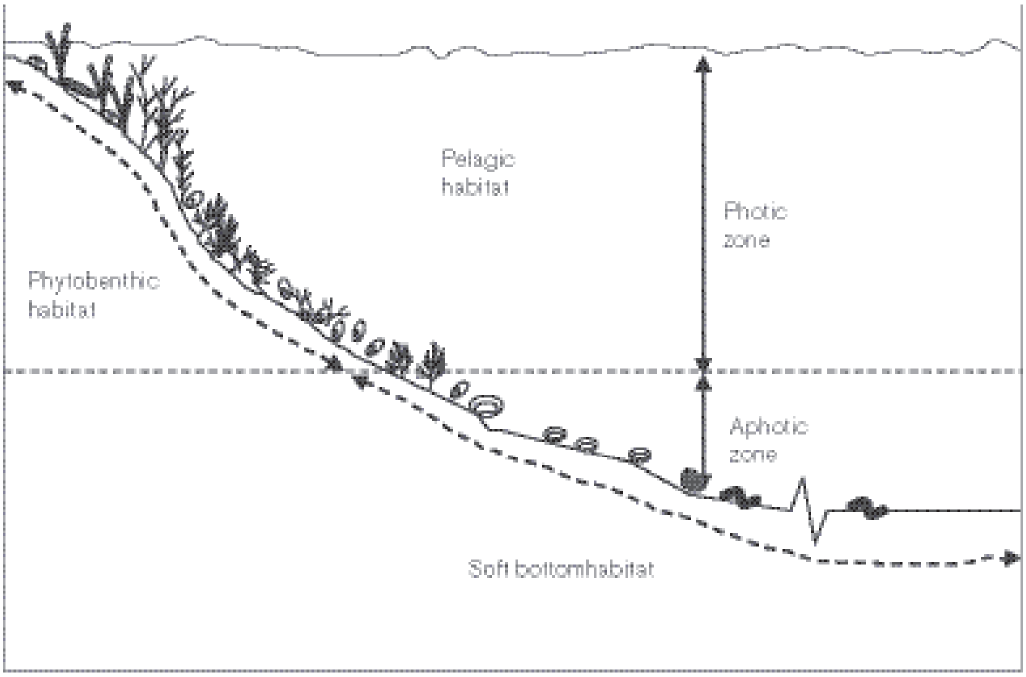

Figure 4-8. *Conceptual illustration of the marine coastal ecosystem in the Simpevarp area including illustrations of the habitats (phytobenthic, soft bottom and pelagic).*

Functional groups – Primary producers

The primary producers in basins in the Oskarshamn area are macrophytes (including macroalgae), microphytobenthos and phytoplankton (cf. Section 3.9). This grouping of primary producers has also been used in the quantitative model of the marine ecosystem.

In the phytobenthic habitat, both biomass and primary production is dominated by macrophytes. The macrophytes that contribute most to the biomass in the benthic community in Oskarshamn in total are the brown algae *Fucus vesiculosus,* the soft bottom dwelling *Chara sp*. and red algae (e.g. *Ceramium sp.*). However, the dominating species varies greatly between the basins. This is described in detail in Section 3.9. Epiphytic primary producers, i.e. algae that are attached to the surfaces of macrophytes, have been assumed to be already included in the macroalgae data (both in terms of biomass and primary production).

In the same habitat also microphytobenthos are present. This organism group is in coastal Baltic systems often important both in terms of biomass and primary production. In the Oskarshamn area no site-specific data is available. In the quantitative descriptions of the basins the microphytobenthos has been assumed to resemble the Forsmark region both in quantity and character.

Phytoplankton is the only primary producing organism group in the pelagic habitat and are in Oskarshamn are dominated by diatoms, Cryptophytes and dinoflagellates. However, the biomass varies greatly during the year.

Functional groups – Consumers

The functional group consumers include all heterotrophic organisms, i.e. herbivores, carnivores and detrivores, and these are in the quantitative model divided into the major groups; bacterioplankton, zooplankton, fish (zooplankton feeding, benthic feeding and carnivorous), benthic herbivores, benthic filter feeders, benthic detrivores (including meiofauna), benthic carnivores, benthic bacteria, birds (fish feeding and benthic feeding) and humans.

Bacteria have an important role in the mineralization process of dead organic material and the recirculation of nutrients. The species composition of the bacteria is not known and is assumed to not be of importance for the budget calculations. Because bacteria on different substrate are assumed to assimilate carbon from different pools and be eaten at different rates, bacteria were divided into two groups, bacterioplankton and benthic bacteria. None of these organism groups have been studied in the Oskarshamn area and therefore data from other region have been used. For the pelagic bacteria, data from /Kuparinen, 1987/ were used and for the benthic bacteria, data from a study by /Mohammadi et al. 1993/ were used.

The group zooplankton is a very heterogeneous group with respect to organism size, life cycle and food choice. However, in this budget the zooplankton has been treated as one homogenous group and a higher level of detail was assumed to not be of importance for the carbon budget calculations.

Fish, on the other hand, was divided into the functional groups zooplanktivore fish (zooplankton feeding fish), bentivore fish (benthic fauna feeding fish) and piscivore fish (carnivorous fish) based on the assumption that 75% of the total fish biomass was Zooplankton feeding fish, 20% was benthic feeding fish and 5% was carnivorous fish. This assumption was based on former modelling analyses performed in the Forsmark region concluded that this distribution was feasible with regard to the available resources /Kumblad and Kautsky, 2004/.

The benthic fauna was classified into four groups; (i) benthic filter feeders with a clear dominance of *Mytilus edulis* in the *Fucus* and red algae communities, and *Cerastoderma hauniense* in other areas; (ii) benthic detrivores dominated by *Macoma baltica* in the soft bottom community and *Hydrobia sp.* in the phytobenthic habitat; (iii) benthic herbivores which were dominated by *Theodoxus fluviatilis*, and (iv) benthic carnivores represented by *Nereis diversicolor* and a few fish species such as *Syngnathus typhle,* gobides and juvenile pike. The functional group benthic omnivores (represented by crustaceans such as *Gammarus sp.* and *Idothea* sp) were included in benthic carnivores and benthic herbivores (50% in each). Benthic detritivores also include meiofauna, an organism groups that not has been studied in the area and therefore data from studies in the Askö area, south east of Stockholm, were used in the calculations /Ankar, 1977/.

Birds were classified into benthic feeding birds (feeding on benthic macrophytes and fauna) and fish feeding birds after their food preferences. The used data source only comprises nesting birds which clearly implies an underestimation.

Food web relationships

The distribution of the consumption pattern from various food sources are shown in Table 4-20. The consumption of different food sources were obtained by identifying the food web relationships between the functional groups in the system and calculating the demand of food (total consumption) by each consumer. For the consumers it was assumed that they eat in proportion to what is available of their food item/prey (in biomass).

All primary producers, i.e. macrophytes, microphytobenthos and phytoplankton, were assumed to assimilate 100% of their carbon from the dissolved inorganic carbon pool (DIC). Bacteria can assimilate both DOC and POC. However, in the model the bacteria were assumed to only consume POC since the availability of POC is much larger than DOC in marine waters. Zooplankton was assumed to consume bacterioplankton and phytoplankton in proportion to their availability.

Benthic herbivores were assumed to consume macrophytes and microphytobenthos, and the benthic filter feeders POC, phytoplankton, bacterioplankton and zooplankton. The benthic detrivores were assumed to consume POC and benthic bacteria, and the benthic carnivores the other benthic fauna groups, i.e. benthic herbivores, filter feeders and detrivores.

Table 4-20. Food web matrix (food web relationships) used in the ecosystem model of the Oskarshamn area.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Phytoplankton																		x	
2. Microphytes																		x	
3. Macrophytes																		x	
4. Bacterioplankton																			x
5. Zooplankton	x			x															
6. Zooplankton feeding fish					x														
7. Benthic fauna feeding fish									x	x	x	x							
8. Carnivorous fish						x	x	x											
9. Benthic herbivores		x	x																
10. Benthic filter feeders	x			x	x														x
11. Benthic detrivores													x						x
12. Benthic carnivores									x	x	x								
13. Benthic bacteria																			x
14. Fish feeding birds						x	x	x											
15. Benthic feeding birds			x						x	x	x	x							
16. Seals						x	x	x											
17. Humans						x	x	x											
18. DIC																			
19. POC																			

Fish feeding on zooplankton (zooplankton feeding fish) were assumed to consume zooplankton whereas POC, phytoplankton and bacterioplankton were assumed to be too small to be ingested by fish. Fish feeding on benthic fauna (benthic fauna feeding fish) are most probably feeding selectively. Of this we have no detailed information, therefore the benthic feeding fish were assumed to consume in proportion to what's available of the benthic fauna (benthic herbivores, filter feeders, detrivores and carnivores). Carnivore fish were assumed to eat only fish. Most likely the shift from other food sources to fish will not be complete but was assumed so in this budget.

Benthic feeding birds were assumed to feed on benthic macrophytes and fauna in proportion to their abundance, whereas fish feeding birds consume fish in proportion to their abundance.

4.3.2 Quantitative site specific model

In this section the quantitative models of Basin Borholmsfjärden, Granholmsfjärden and Getbergsfjärden in the Oskarshamn area are described. First general modelling assumptions and for each organism group are described, then a quantitative carbon flow for each of the basins are presented.

Modelling assumptions

General

Surface areas for the basins were calculated using GIS by using the shoreline from the map data from Metria. The two dimensional area was assumed to be approximately the same as the actual bottom area. For basin Granholmsfjärden and Getbergsfjärden both the area above and below the photic zone have been presented.

The water volume of the basins (photic and aphotic) was calculated as the average water depth multiplied by the surface area. The photic volume was calculated as the total volume minus the volume in the aphotic zone. The depth grid used is reported by /Ingvarson et al. 2004/.

The primary production was generally estimated by calculations from the biomass data and species-specific conversion factors /Wallentinus, 1978; Gutenstam, 1979; Kautsky, 1995/ related to the insolation during the year. The epiphyte primary production was assumed to be included in the macrophyte production.

The respiration was for the major part of the functional fauna groups (zooplankton, fish, benthic herbivores, filter feeders, detrivores carnivores and benthic bacteria) calculated from the biomass with the aid of species-specific conversion factors /Jansson et al. 1982; Ankar and Elmgren, 1978; Schneider, 1990; Kautsky, 1995/ and the temperature during the year /SKB, HMS database/. The bacterioplankton respiration was obtained from field measurements performed by /Kuparinen, 1987/. The plant respiration was assumed to be zero since both the measured and calculated primary production was the net primary production, i.e. the gross primary production subtracted by the respiration.

If no other assumption is described, the respiration to consumption was assumed have the relationship 1:3 /Elmgren, 1984/ except for bacteria where the relationship 1:2 was assumed as suggested by /Kumblad et al. 2003/. In some cases, actual figures on respiration are given and in some cases figures on consumption, se below. Respiration was calculated as yearly respiration multiplied by normalized degree days (2,550/20) /Kautsky, 1995/.

Carbon transport to and from the basins were based on modelled oceanographic water movement (retention time) see Section 3.5, and fresh water discharge, multiplied with the carbon content in the water from measurements in field during 2002–2003 /Ericsson and Engdahl, 2004a/.

Except for the conversion factors described for the calculations of primary production and respiration from biomass data, conversion factors compiled by /Kautsky, 1995/ have been used to convert data presented in other units than gC into gC.

Phytoplankton

Estimations of biomass (g dry weight m^{-3}) were obtained from three samples and analyses during 2003–2004 /Sundberg et al. 2004/ and the photic volume of the basin. Average biomass for one year is an average of values for each month, made by extrapolations from measurements. For instance, measured values from December have been used as a winter value for January and February, and the March value was calculated as an average between April and February, etc. For Basin Borholmsfjärden and Granholmsfjärden data sampled within the basins were used, and for Basin Getbergsfjärden the average of these two stations was used.

The specific net primary production for phytoplankton (gC gC^{-1} yr^{-1}) was calculated from the primary production and biomass measured by /Lindahl and Wallström, 1980/ for the Forsmark region. The specific net primary production, i.e. primary production per biomass, was then used to estimate the primary production from the biomass estimated in the Oskarshamn region /Sundberg et al. 2004/ and the production estimate was compensated for the difference in annual insolation between the Forsmark and Oskarshamn region. Phytoplankton was assumed to be evenly distributed in the photic zone of the pelagial.

Microphytes

Data on biomass and primary production for microphytobenthos from Forsmark were used /Snoeijs, 1985,1986/. Primary production was compensated for the difference in annual insolation in the same manner as Phytoplankton. Microphytes were assumed to be evenly distributed on the seabed in the phytobenthic zone.

Macrophytes

The biomass of macrophytes was calculated from areas of vegetation communities (presented in GIS-projects) multiplied with average coverage and biomass per vegetation community and coverage /Fredriksson and Tobiasson, 2003/. Recalculations from dry weight (g dry weight) to carbon (gC) for the vegetation types was made using species-specific (or higher taxa-specific) conversion factors (see above) which were weighted for relative abundance in each vegetation community.

Net primary production was calculated by multiplying biomass calculations with figures of species specific production per biomass (gC gC^{-1}) presented by /Kautsky, 1995/, related to the annual insolation and weighted for the relative abundance in each vegetation type. The biomass was assumed to be constant during the year.

Bacterioplankton

Biomass (gC m^{-3}) of bacterioplankton was calculated from estimates made for the pelagic habitat in Tvärminne, Finland /Kuparinen, 1987/. Data from this study was also used to estimate the respiration, and from respiration consumption was calculated, by multiplying the respiration by a factor two. Bacterioplankton were assumed to be evenly distributed in the pelagial.

Zooplankton

Estimations of zooplankton biomass were made from three samples during 2003–2004 /Sundberg et al. 2004/. For Basin Borholmsfjärden and Granholmsfjärden data from sample stations within the basins were used, whereas for Basin Getbergsfjärden the average of these two stations was used. The assumption used by /Andersson et al. 2003b/ that 48% of the dry weight was carbon, was used in the calculations.

Specific respiration (gC gC^{-1} yr^{-1}) was calculated from respiration and biomass figures from the Forsmark region presented in /Eriksson et al. 1977/. The specific respiration was multiplied by the site-specific biomass. In the respiration calculations the difference in temperature between Forsmark and Oskarshamn were compensated for. Zooplankton was assumed to be evenly distributed in the whole pelagial.

Fish

Biomass data on fish and proportions between the three functional groups of fish used was obtained from /Jansson et al. 1985/. The proportions of occurring fish groups where assumed to be: 75% zooplankton feeding fish, 20% benthic feeding fish and 5% carnivorous fish. The respiration was estimated with conversion factors (compiled by /Kautsky, 1995/) from the biomass and the consumption was assumed to be 1.73 times the respiration and proportional to the occurring prey (for benthic and fish feeding fish). Fish were assumed to be evenly distributed in the whole water column.

Benthic fauna

The following functional groups where assumed/identified: benthic herbivore, benthic filter feeders, benthic detrivores including meiofauna, benthic carnivores.

Two main sources of biomass data have been used; the vegetation mapping study /Fredriksson and Tobiasson, 2003/ where also associated fauna was sampled, and a study on soft bottom fauna /Fredriksson, 2004a. The quantitative data presented in these reports; biomass per biomass vegetation (g dry weight g dry $weight^{-1}$) and biomass per area (g dry weight m^{-2}) respectively have been recalculated into carbon (gC) using the species specific (or highter taxa specific) conversion factors presented by /Kautsky, 1995/. In areas with macrophytes, quantitative data from the both studies have been combined.

Data on biomass of meiofauna found in the northern Baltic proper (Askö) presented in /Ankar, 1977/ was used for the Oskarshamn area as thre were site specif data available. The meiofauna was assumed to be present in/on the seabed in the entire basin.

The respiration and consumption of the benthic fauna was calculated using species specific (or higher taxa specific) data presented by /Kautsky, 1995/ and weighted for relative abundance in each habitat type (vegetation type or bare sediment).

Benthic bacteria

Data on biomass of benthic bacteria found in the Bothnian Sea presented in /Mohammadi et al. 1993/ was used in the budget calculations. The benthic bacteria were assumed to be present in the sea bed in the entire basin area. The respiration was calculated with conversion factor per day respiration (gC $gC^{-1}day^{-1}$) /Kautsky, 1995/ multiplied by normalized temperature days (2,550 divided by 20). The consumption was estimated to be twice the respiration. Benthic bacteria were assumed to be evenly distributed in the benthic whole basin area.

Birds

A study on nesting pairs of birds in the inner archipelago of Simpevarp region has been used as data source for birds in Basin Borholmsfjärden and 2 /Green, 2004/. Data on biomass data and data on consumption was given by /Solbreck C pers. comm./. For bird species were biomass and consumption information were lacking, averages from birds similar in size or behaviour was used.

Humans

Data on human fisheries (consumption) presented by /Milliander et al. 2004/ was used. Dissolved inorganic carbon (DIC) and particulate organic carbon (POC)

The abiotic carbon pools were calculated using average concentrations described elsewhere in this report (Section 3.6) and basin volumes. The inflows of abiotic carbon from runoff were calculated by using average concentrations of the dominating water course (Laxemarsån for Basin Borholmsfjärden and Kärrsviksån for Basin Granholmsfjärden) /Ericsson and Engdahl, 2004a/ and modelled runoff (see Section 3.4). The inflow of abiotic carbon from water exchange with other sea basins were calculated using average basin concentrations of carbon and yearly water exchange. Water exchange was calculated using the Average Transit Residence (ATR) time presented in Section 3.5 according to:

Water exchange = (basin volume×(365/ATR)) – runoff

Ecosystem model for Basin Borholmsfjärden

Basin Borholmsfjärden in the Simpevarp area (Figure 4-7) is located west and south of the Äspö laboratory and has a total surface area of 1.37 km^2 and water volume of 0.0024 km^3. The maximum depth in this basin is about 4.2 metres, the average depth 1.7 metres and light penetration depth about 2.2 metres (field measurements). As the photic zone is assumed to be double the light penetration depth, the whole basin is assumed to be photic. The average annual retention time for the water in this basin is about 9 days, see further Section 3.5.

Food web matrix for Borholmsfjärden

When assuming that the functional groups identified to be present in Basin Borholmsfjärden consume in proportion to the available biomass of their respective food source, the resulting food web matrix for the basin turns into as in Table 4-21.

Ecosystem model – Carbon budget for Borholmsfjärden

The biomass and primary production is clearly dominated by macrophytes and microphytes (e.g. Figure 4-9, 4-10 and 4-11, Table 4-22). Phytoplankton plays a minor role in terms of carbon flow in the system. The same pattern, benthic organisms dominates over the pelagic, is found among consumers. In terms of biomass, benthic organisms (especially detritivores) are the largest group.

Table 4-21. Food web matrix including food proportions (estimated from the food web matrix and the identified available biomass of their respective food source) for Basin Borholmsfjärden in Oskarshamn.

	1	2	3	4	5	6	7	8	9	10	11	12	13	18	19
1. Phytoplankton														1.00	
2. Microphytes														1.00	
3. Macrophytes														1.00	
4. Bacterioplankton															1.00
5. Zooplankton	0.53			0.47											
6. Zooplankton feeding fish					1.00										
7. Benthic fauna feeding fish									0.20	0.04	0.53	0.22			
8. Carnivorous fish						0.75	0.20	0.05							
9. Benthic herbivores		0.11	0.89												
10. Benthic filter feeders	0.04			0.04	0.12										0.81
11. Benthic detrivores													0.53		0.47
12. Benthic carnivores									0.26	0.06	0.68				
13. Benthic bacteria															1.00
14. Fish feeding birds						0.75	0.20	0.05							
15. Benthic feeding birds			0.90						0.02	0.00	0.05	0.02			
16. Seals						0.75	0.20	0.05							
17. Humans						0.75	0.15	0.10							
18. DIC															
19. POC															

All compartments except zooplankton and benthic bacteria and are in excess on a yearly scale (Figure 4-9), i.e. the supply of biomass from the compartment was higher than the demand from their predators. The possible explanation for benthic bacteria being extinct is that there has been an overestimation of the predation by the large group benthic detritivores. It might also be due to an underestimation of the importance of POC as food source for benthic detrivores. Figure 4-11 and Table 4-22 also present an deficit of POC (negative excess) which probably is due to that the influx of POC from terrestrial runoff and water exchange with other basins of the sea not have been included in the calculations. Taking the POC inflow from these sources into account would probably lead to a positive excess of POC in the budget which also would lead to a higher proportion of the consumption of POC by benthic detrivores and consequently would the predation pressure on benthic bacteria decrease. However, the data on bacteria are not site-specific which might contribute to and underestimated standing stock in the area. The reason for the estimated “negative excess” for the zooplankton compartment is possibly due to an overestimation of the fish feeding biomass and/or their consumption rate. The fish biomass data are not site-specific and the estimations of the metabolic rates of fish do not have particularly high confidence.

A summary of the biomass, annual primary production or consumption, respiration, supply (available for consumption), consumption and excess in the ecosystem by each functional group are summarized in Table 4-22. In Figure 4-9 the carbon budget have been illustrated graphically as a food web, where all resources, flows and recirculation pathways are shown.

In the calculations presented in this section the net inflow of DIC and POC from runoff and exchange with other sea basins has not been included. For basin Borholmsfjärden the annual terrestrial runoff contributes to approximately 1.6×10^{7} gPOC. The basin has a modelled Average Transit Residence (ATR) time of 9 days which possibly generates an exchange of 4.8×10^{7} gPOC. Together runoff and water exchange could provide about 6.3×10^{7} gPOC to the basin which correlate quite well the calculated depletion of POC of -5.69×10^{7} gPOC (Table 4-22). However, the total excess of biota, i.e. supply – grazing or predation, also contributes to the POC pool and thus, the total annual contribution of POC is almost 9×10^{8} gC, which also indicate that there is a net sedimentation of carbon in the area.

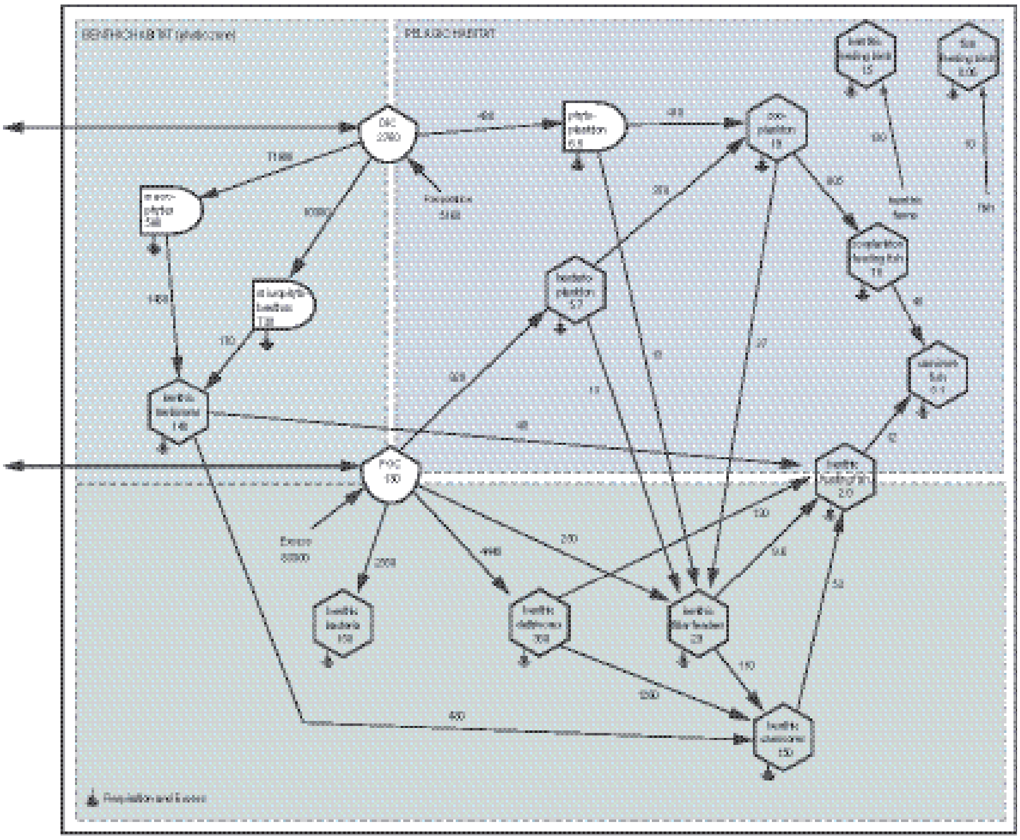

Figure 4-9. Carbon flow model for Basin Borholmsfjärden in the Simpevarp area. Biomasses (10^4 gC) and flow of carbon between the functional groups, i.e. consumption (10^4 gC yr^{-1}).

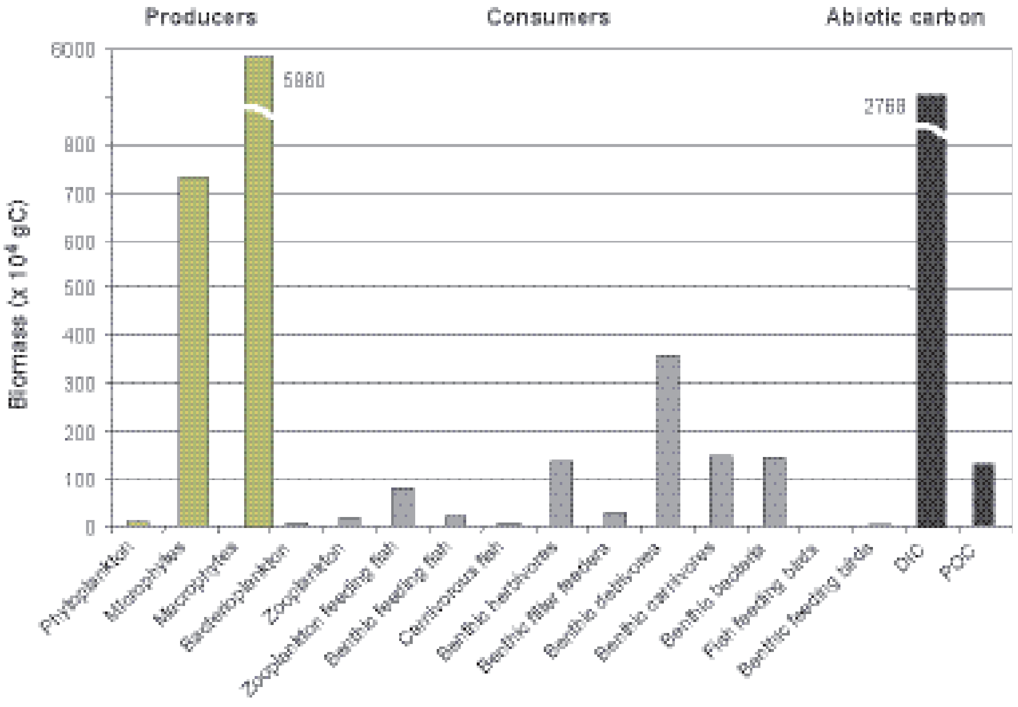

Figure 4-10. Biomass in Basin Borholmsfjärden (10^4 gC) for all functional groups and abiotic carbon pools. Primary producers in green, consumers in grey, and DIC and POC in black.

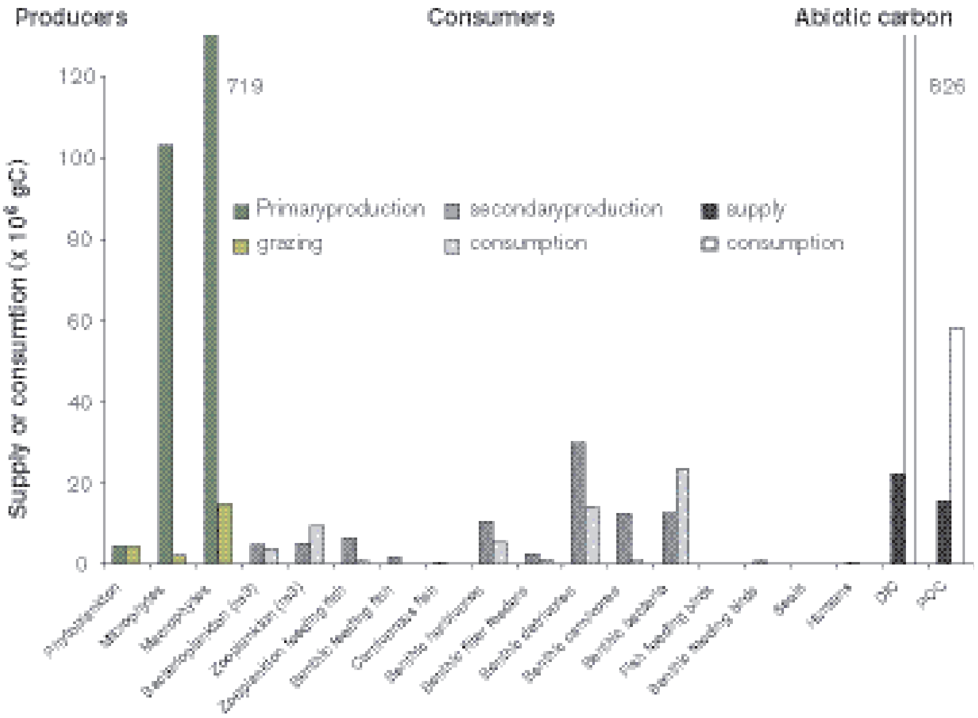

Figure 4-11. *Supply (dark) and demand (light) from/of primary producers (green), consumers (grey) and DIC and POC (black) in Basin Borholmsfjärden (10^6 gC yr^{-1}).*

Table 4-22. Biomass (gC basin^{-1}), annual primary production or consumption of carbon by each functional group (gC basin^{-1} yr^{-1}), respiration (gC basin^{-1} yr^{-1}), supply (available for grazing or predation) (gC basin^{-1} yr^{-1}), grazing or predation on the functional groups (gC basin^{-1} yr^{-1}) and excess (gC basin^{-1} yr^{-1}) in the ecosystem in Basin Borholmsfjärden. (Seals have been excluded due to lack of data.)

Borholmsfjärden	Biomass gC	Prod. or cons. gC yr^{-1}	Respiration gC yr^{-1}	Supply[1] gC yr^{-1}	Graz. or pred.[2] gC yr^{-1}	Excess[3] gC yr^{-1}
Phytoplankton	6.45E+04	4.27E+06	–	4.27E+06	4.26E+06	1.13E+04
Microphytes	7.31E+06	1.03E+08	–	1.03E+08	1.69E+06	1.01E+08
Macrophytes	5.86E+07	7.19E+08	–	7.19E+08	1.48E+07	7.04E+08
Bacterioplankton	5.69E+04	9.20E+06	4.60E+06	4.60E+06	3.76E+06	8.40E+05
Zooplankton	1.89E+05	7.79E+06	2.60E+06	5.19E+06	9.42E+06	–4.22E+06
Zooplankton feeding fish	7.62E+05	9.05E+06	3.02E+06	6.04E+06	6.74E+05	5.36E+06
Benthic feeding fish	2.03E+05	2.41E+06	8.05E+05	12.61E+06	1.70E+05	1.44E+06
Carnivorous fish	5.08E+04	6.04E+05	2.01E+05	4.02E+05	5.46E+04	3.48E+05
Benthic herbivores	1.37E+06	1.53E+07	5.08E+06	1.02E+07	5.38E+06	4.79E+06
Benthic filter feeders	2.89E+05	3.09E+06	1.03E+06	2.06E+06	1.13E+06	9.25E+05
Benthic detrivores	3.58E+06	4.44E+07	1.48E+07	2.96E+07	1.41E+07	1.55E+07
Benthic carnivores	1.47E+06	1.86E+07	6.20E+06	1.24E+07	5.59E+05	1.18E+07
Benthic bacteria	1.45E+06	2.55E+07	1.28E+07	1.28E+07	2.34E+07	–1.07E+07
Fish feeding birds	5.80E+02	1.01E+05	3.38E+04	6.76E+04	–	6.76E+04
Benthic feeding birds	1.52E+04	1.33E+06	4.43E+05	8.87E+05	–	8.87E+05
Humans	–	1.94E+05	–	1.94E+05	–	1.94E+05
DIC	2.76E+07	–	–	2.76E+07	8.26E+08	–8.04E+08
POC	1.30E+06	–	–	1.30E+06	5.82E+07	–5.69E+07
Total (only biota)	7.54E+07	(prod.) 8.26E+08	5.16E+07	9.12E+08	7.94E+07	8.33 E+8
	–	(cons.) 1.38E+08	–	–	–	–

[1] Supply = consumption – respiration.

[2] Grazing or consumption upon the respective functional group.

[3] Excess = supply – grazing or predation.

Ecosystem model for Basin Granholmsfjärden

Basin Granholmsfjärden in the Simpevarp area (Figure 4-7) is located west and south of the Äspö laboratory and has a total surface area of 1.82 km^2 and water volume of 0.0082 km^3. The maximum depth in this basin is about 20 metres, the average depth 4.4 metres and light penetration depth about 3.3 metres (field measurements). As the photic zone is assumed to be double the light penetration depth, the photic zone extends to about 6.6 meters. The average annual retention time for the water in this basin is about 26 days, see further in Section 3.5.

Food web matrix for Granholmsfjärden

When assuming that the functional groups identified to be present in Basin Granholmsfjärden consume in proportion to the available biomass of their respective food source, the resulting food web matrix for the basin turns into as in Table 4-23.

Ecosystem model – Carbon budget for Granholmsfjärden

The biomass and primary production is clearly dominated by macrophytes and microphytes in Granholmsfjärden (e.g. Figure 4-12, 4-13 and 4-14, Table 4-24) whereas phytoplankton plays a minor role in terms of both biomass and carbon flows in the system. The same pattern, benthic organisms dominates over the pelagic, is found among consumers. In terms of biomass, benthic organisms (especially detritivores) are the largest group.

Table 4-23. Food web matrix including food proportions (estimated from the food web matrix and the identified available biomass of their respective food source) for Basin Granholmsfjärden in Oskarshamn.

	1	2	3	4	5	6	7	8	9	10	11	12	13	18	19
1. Phytoplankton														1.00	
2. Microphytes														1.00	
3. Macrophytes														1.00	
4. Bacterioplankton															1.00
5. Zooplankton	0.53			0.47											
6. Zooplankton feeding fish					1.00										
7. Benthic feeding fish									0.16	0.04	0.68	0.12			
8. Carnivorous fish						0.75	0.15	0.10							
9. Benthic herbivores		0.26	0.74												
10. Benthic filter feeders	0.05			0.05	0.04										0.87
11. Benthic detrivores													0.34		0.66
12. Benthic carnivores									0.18	0.05	0.77				
13. Benthic bacteria															1.00
14. Fish feeding birds															
15. Benthic feeding birds															
16. Seals						0.75	0.15	0.10							
17. Humans						0.75	0.15	0.10							
18. DIC															
19. POC															

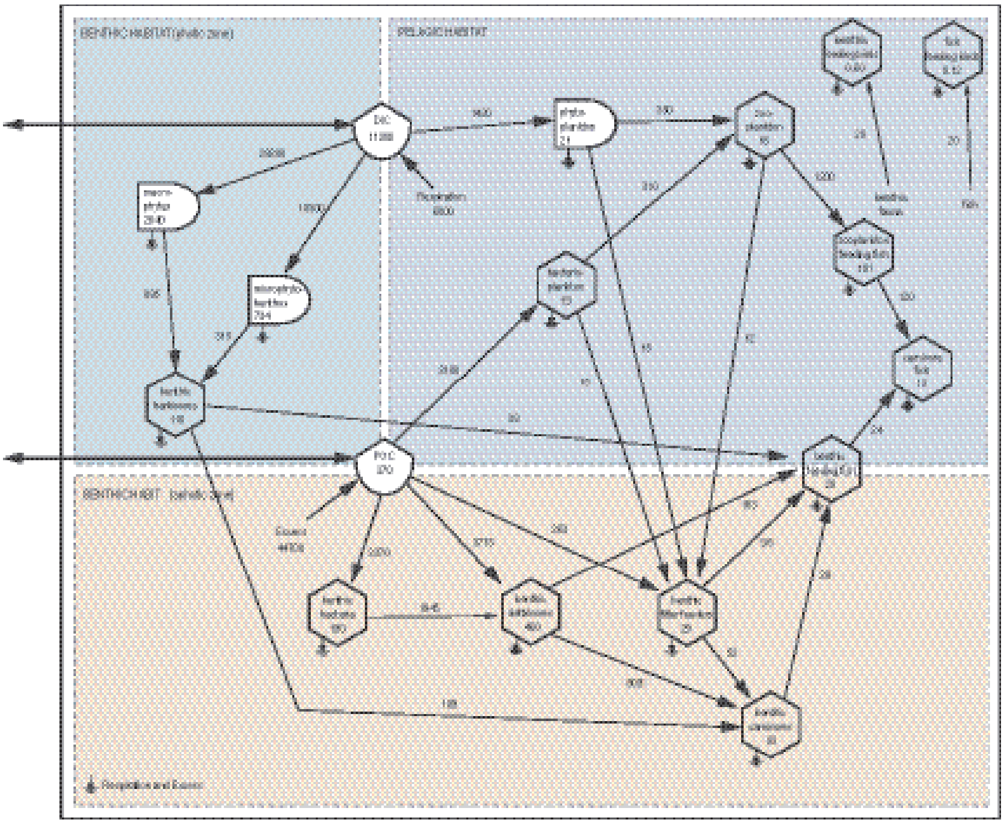

__Figure 4-12.__ Carbon flow model for Basin Granholmsfjärden in the Simpevarp area. Biomasses (10^4 gC) and flow of carbon between the functional groups, i.e. consumption (10^4 gC yr^{-1}).

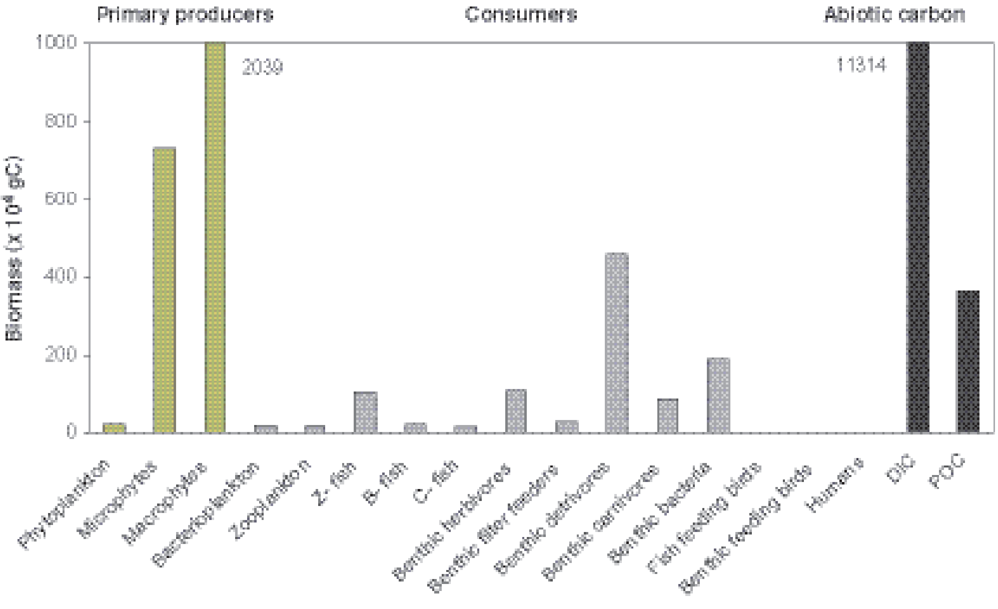

__Figure 4-13.__ Biomass in Basin Granholmsfjärden (10^4 gC) for all functional groups and abiotic carbon pools. Primary producers in green, consumers in grey, and DIC and POC in black.

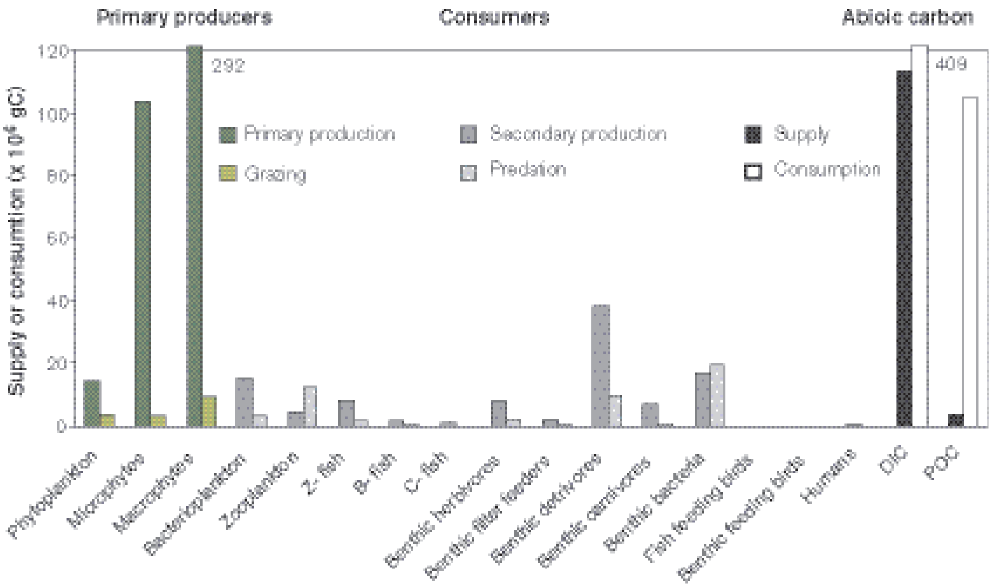

Figure 4-14. *Supply (dark) and demand (light) from/of primary producers (green), consumers (grey) and DIC and POC (black) in Basin Granholmsfjärden (10^6 gC yr^{-1}).*

Table 4-24. Biomass (gC basin^{-1}), annual primary production or consumption of carbon by each functional group (gC basin^{-1} yr^{-1}), respiration (gC basin^{-1} yr^{-1}), supply (available for grazing or predation) (gC basin^{-1} yr^{-1}), grazing or predation on the functional groups (gC basin^{-1} yr^{-1}) and excess (gC basin^{-1} yr^{-1}) in the ecosystem in Basin Granholmsfjärden. (Seals have been excluded due to lack of data.)

Granholmsfjärden	Biomass gC	Prod. or cons. gC yr^{-1}	Respiration gC yr^{-1}	Supply[1] gC yr^{-1}	Graz. or pred.[2] gC yr^{-1}	Excess[3] gC yr^{-1}
Phytoplankton	2.14E+05	1.42E+07	–	1.42E+07	3.63E+06	1.06E+07
Microphytes	7.34E+06	1.03E+08	–	1.03E+08	3.21E+06	1.00E+08
Macrophytes	2.04E+07	2.92E+08	–	2.92E+08	8.91E+06	2.83E+08
Bacterioplankton	1.92E+05	3.11E+07	1.56E+07	1.56E+07	3.26E+06	1.23E+07
Zooplankton	1.60E+05	6.60E+06	2.20E+06	4.40E+06	1.21E+07	–7.68E+06
Zooplankton feeding fish	1.01E+06	1.20E+07	3.99E+06	7.98E+06	1.60E+06	6.37E+06
Benthic feeding fish	2.01E+05	2.39E+06	7.98E+05	1.60E+06	3.20E+05	1.27E+06
Carnivorous fish	1.34E+05	1.60E+06	5.32E+05	1.06E+06	2.14E+05	8.50E+05
Benthic herbivores	1.09E+06	1.21E+07	4.04E+06	8.08E+06	2.28E+06	5.80E+06
Benthic filter feeders	2.85E+05	3.05E+06	1.02E+06	2.03E+06	5.98E+05	1.43E+06
Benthic detrivores	4.62E+06	5.72E+07	1.91E+07	3.82E+07	9.70E+06	2.85E+07
Benthic carnivores	8.29E+05	1.05E+07	3.49E+06	6.98E+06	2.91E+05	6.69E+06
Benthic bacteria	1.92E+06	3.37E+07	1.69E+07	1.69E+07	1.96E+07	–2.75E+06
Fish feeding birds	1.18E+03	2.04E+05	6.79E+04	1.36E+05	–	1.36E+05
Benthic feeding birds	6.02E+03	2.04E+05	3.46E+05	–1.42E+05	–	–1.42E+05
Seals	–	–	–	–	–	–
Humans	–	5.40E+05	–	5.40E+05	–	5.40E+05
DIC	1.13E+08	–	–	1.13E+08	4.09E+08	–2.96E+08
POC	3.68E+06	–	–	3.68E+06	1.05E+08	–1.01E+08
Total (only biota)	3.84E+07	(prod.) 4.09E+08 (cons.) 1.71E+08	6.80E+07	5.13E+08	6.57E+07	4.47E+08

[1] Supply = consumption – respiration.
[2] Grazing or predation upon the respective functional group.
[3] Excess = supply – grazing or predation.

All compartments except zooplankton and benthic bacteria and are in excess on a yearly scale (Figure 4-14), i.e. the supply of biomass from the compartment was higher than the demand from their predators. The deficit of benthic bacteria is though fairly small. A possible explanation for the benthic bacteria being excessively predated on is an overestimation of the consumption rate by the large group benthic detritivores. It might also be due to an underestimation of the importance of POC as food source for benthic detrivores. Figure 4-14 and Table 4-24 also present an deficit of POC (negative excess) which probably is due to that the influx of POC from terrestrial runoff and water exchange with other basins of the sea not have been included in the calculations. Taking the POC inflow from these sources into account would probably lead to a positive excess of POC in the budget which also would lead to a higher proportion of the consumption of POC by benthic detrivores and consequently would the predation pressure on benthic bacteria decrease. However, the data on benthic bacteria are not site-specific which might contribute to and underestimated standing stock in the area. The reason for the estimated "negative excess" for the zooplankton compartment is possibly due to an overestimation of the fish feeding biomass and/or their consumption rate. The fish biomass data are not site-specific and the estimations of the metabolic rates of fish do not have particularly high confidence.

A summary of the biomass, annual primary production or consumption, respiration, supply (available for consumption), consumption and excess in the ecosystem by each functional group are summarized in Table 4-24. In Figure 4-12 the carbon budget have been illustrated graphically as a food web, where all resources, flows and recirculation pathways are shown.

In the calculations presented in this section the net inflow of DIC and POC from runoff and exchange with other sea basins has not been included. For basin Granholmsfjärden the annual terrestrial runoff contributes to approximately 2.9×10^6 gPOC. The basin has a modelled Average Transit Residence (ATR) time of 26.4 days which possibly generates an exchange of 4.8×10^7 gPOC. Together runoff and water exchange could provide about 5.1×10^7 gPOC to the basin which is less than the calculated depletion of POC of -1.01×10^8 gPOC. However, the total excess of biota, i.e. supply – grazing or predation, also contributes to the POC pool and thus, the total annual contribution of POC is almost 5×10^8 gC, which also indicate that there is a net sedimentation of carbon in the area.

Ecosystem model for Basin Getbergsfjärden

Basin Granholmsfjärden in the Simpevarp area (Figure 4-7) is located west and south of the Äspö laboratory and has a total surface area of 0.36 km^2 and water volume of 0.0012 km^3. The maximum depth in this basin is about 11.4 metres, the average depth 3.3 metres. The light penetration depth has not been measured in this basin so an average value of the light penetration depths for basin Borholmsfjärden and Granholmsfjärden have been assumed, which is about 2.8 metres. As the photic zone is assumed to be double the light penetration depth, the photic zone extends to about 5.5 meters. The average annual retention time for the water in this basin is about 5.5 days, see further in Section 3.5.

Food web matrix for Getbergsfjärden

When assuming that the functional groups identified to be present in Basin Getbergsfjärden consume in proportion to the available biomass of their respective food source, the resulting food web matrix for the basin turns into as in Table 4-25.

The biomass and primary production is clearly dominated by macrophytes and microphytes in Getholmsfjärden (e.g. Figure 4-15, 4-16 and 4-17, Table 4-26) whereas phytoplankton plays a minor role in terms of both biomass and carbon flows in the system. The same pattern, benthic organisms dominates over the pelagic, is found among consumers. In terms of biomass, benthic organisms (especially detritivores and benthic bacteria) are the largest group.

Table 4-25. Food web matrix including food proportions (estimated from the food web matrix and the identified available biomass of their respective food source) for Basin Getbergsfjärden in Oskarshamn.

	1	2	3	4	5	6	7	8	9	10	11	12	13	18	19
1. Phytoplankton														1.00	
2. Microphytes														1.00	
3. Macrophytes														1.00	
4. Bacterioplankton															1.00
5. Zooplankton	0.53			0.47											
6. Zooplankton feeding fish					1.00										
7. Benthic fauna feeding fish									0.16	0.04	0.68	0.12			
8. Carnivorous fish						0.75	0.15	0.10							
9. Benthic herbivores		0.26	0.74												
10. Benthic filter feeders	0.05			0.05	0.04										0.87
11. Benthic detrivores													0.34		0.66
12. Benthic carnivores									0.18	0.05	0.77				
13. Benthic bacteria															1.00
14. Fish feeding birds															
15. Benthic feeding birds															
16. Seals						0.75	0.15	0.10							
17. Humans						0.75	0.15	0.10							
18. DIC															
19. POC															

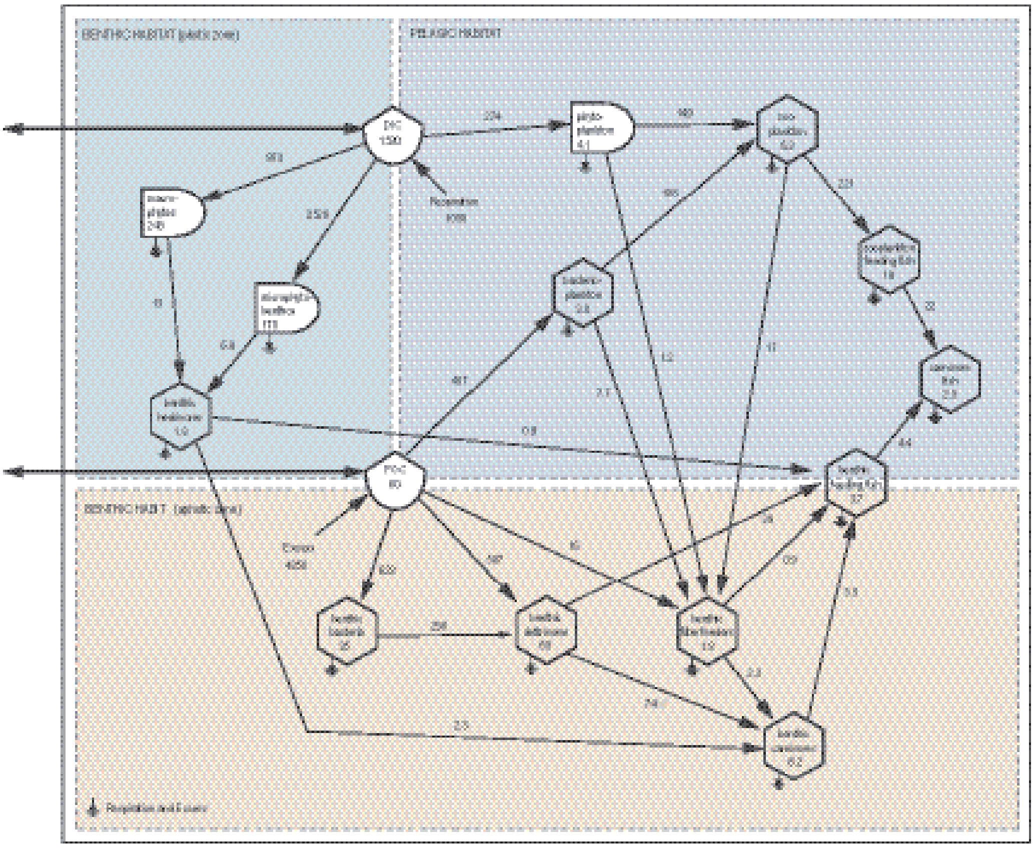

Figure 4-15. Carbon flow model for Basin Getbergsfjärden in the Simpevarp area. Biomasses (10^4 gC) and flow of carbon between the functional groups, i.e. consumption (10^4 gC yr^{-1}).

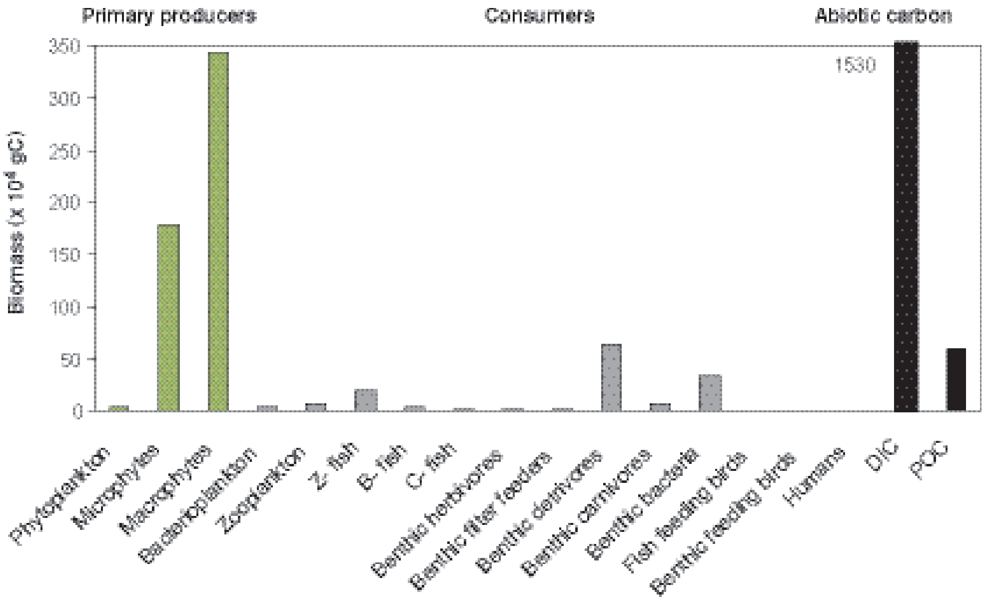

__Figure 4-16.__ Biomass in Basin Getbergsfjärden (10^4 gC) for all functional groups and abiotic carbon pools. Primary producers in green, consumers in grey, and DIC and POC in black.

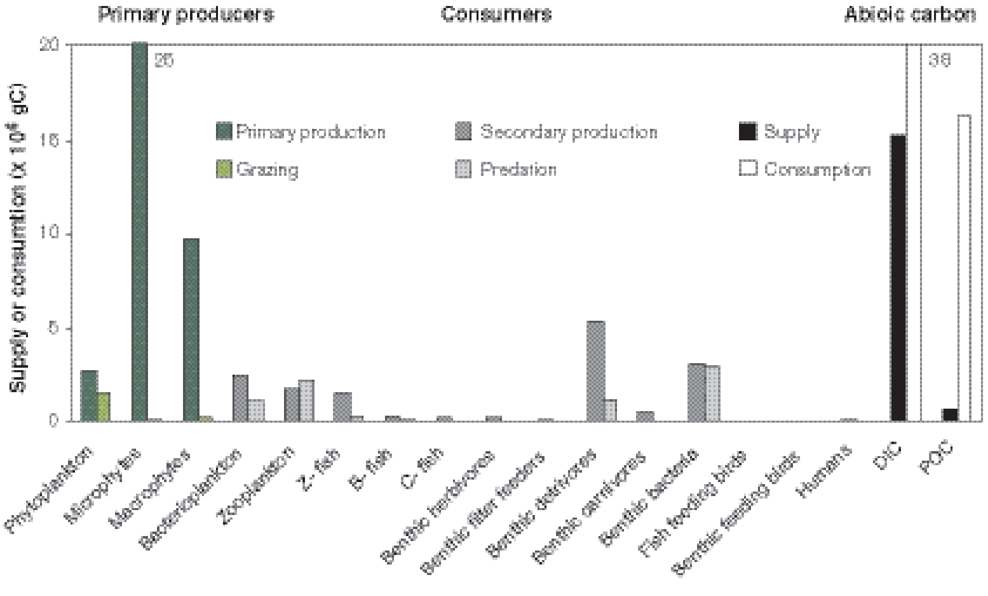

__Figure 4-17.__ Supply (dark) and demand (light) from/of primary producers (green), consumers (grey) and DIC and POC (black) in Basin Getbergsfjärden (10^6 gC yr^{-1}).

In the calculations presented in this section the net inflow of DIC and POC from runoff and exchange with other sea basins has not been included. For basin Getbergsfjärden the annual terrestrial runoff was assumed to be of insignificant importance. The basin has a modelled Average Transit Residence (ATR) time of 5.5 days which possibly generates an exchange of 4.0×10^7 gPOC. The total excess of biota, i.e. supply – grazing or predation, also contributes to the POC pool and thus, the total annual contribution of POC is about 8×10^7 gC, which also indicate that there is a net sedimentation of carbon in the area.

A summary of the biomass, annual primary production or consumption, respiration, supply (available for consumption), consumption and excess in the ecosystem by each functional group are summarized in Table 4-26. In Figure 4-15 the carbon budget have been illustrated graphically as a food web, where all resources, flows and recirculation pathways are shown.

In the calculations presented in this section the net inflow of DIC and POC from runoff and exchange with other sea basins has not been included. For basin Getbergsfjärden the annual terrestrial runoff was assumed to be of insignificant importance. The basin has a modelled Average Transit Residence (ATR) time of 5.5 days which possibly generates an exchange of 4.0×10^7 gPOC. The total excess of biota, i.e. supply – grazing or predation, also contributes to the POC pool and thus, the total annual contribution of POC is about 8×10^7 gC, which also indicate that there is a net sedimentation of carbon in the area.

Table 4-26. Biomass (gC basin^{-1}), annual primary production or consumption of carbon by each functional group (gC basin^{-1} yr^{-1}), respiration (gC basin^{-1} yr^{-1}), supply (available for grazing or predation) (gC basin^{-1} yr^{-1}), grazing or predation on the functional groups (gC basin^{-1} yr^{-1}) and excess (gC basin^{-1} yr^{-1}) in the ecosystem in Basin Getbersgsfjärden. (Seals have been excluded due to lack of data.)

Getbergsfjärden	Biomass gC	Prod. or cons. gC yr^{-1}	Respiration gC yr^{-1}	Supply[1] gC yr^{-1}	Graz. or pred.[2] gC yr^{-1}	Excess[3] gC yr^{-1}
Phytoplankton	4.14E+04	2.74E+06	0.00E+00	2.74E+06	1.50E+06	1.24E+06
Microphytes	1.78E+06	2.52E+07	0.00E+00	2.52E+07	6.94E+04	2.51E+07
Macrophytes	3.43E+06	9.73E+06	0.00E+00	9.73E+06	1.34E+05	9.59E+06
Bacterioplankton	3.01E+04	4.87E+06	2.44E+06	2.44E+06	1.09E+06	1.34E+06
Zooplankton	6.25E+04	2.58E+06	8.60E+05	1.72E+06	2.23E+06	–5.07E+05
Zooplankton feeding fish	1.86E+05	2.21E+06	7.37E+05	1.47E+06	2.56E+05	1.22E+06
Benthic feeding fish	3.72E+04	4.42E+05	1.47E+05	2.95E+05	5.13E+04	2.43E+05
Carnivorous fish	2.48E+04	2.95E+05	9.82E+04	1.96E+05	3.42E+04	1.62E+05
Benthic herbivores	1.82E+04	2.03E+05	6.77E+04	1.35E+05	3.16E+04	1.04E+05
Benthic filter feeders	1.80E+04	1.93E+05	6.42E+04	1.28E+05	3.12E+04	9.72E+04
Benthic detrivores	6.50E+05	8.05E+06	2.68E+06	5.37E+06	1.13E+06	4.24E+06
Benthic carnivores	6.20E+04	7.83E+05	2.61E+05	5.22E+05	3.66E+04	4.86E+05
Benthic bacteria	3.54E+05	6.23E+06	3.12E+06	3.12E+06	3.00E+06	1.17E+05
Fish feeding birds	–	–	–	–	–	–
Benthic feeding birds	–	–	–	–	–	–
Seals	–	–	–	–	–	–
Humans	–	4.73E+04	–	4.73E+04	–	4.73E+04
DIC	1.53E+07	–	–	1.53E+07	3.76E+07	–2.23E+07
POC	5.96E+05	–	–	5.96E+05	1.63E+07	2.78E+07
Total (only biota)	6.70E+06	(prod.) 3.76E+07 (cons.) 2.59E+07	1.05E+07	5.31E+07	9.59E+06	4.35E+07

[1] Supply = consumption – respiration
[2] Grazing or consumption upon the respective functional group
[3] Excess = supply – grazing or predation

Confidence and uncertainties

The quality and representativity of the used data have been summarised in Table 4-27 and are discussed more in detail below.

Table 4-27. Estimations of the quality of input data and how representative the data is for the basins in Oskarshamn. Higher figures indicate higher quality or better representativity,

Functional group	Quality of data (1–4)	Representativity of data (1–4)
Areas and volumes	4	4
Photic zone	3	4
Carbon transport	2	2
DIC	2	4
POC	2	4
Phytoplankton	2	4
Macrophytes	3	4
Bacterioplankton	3	2
Zooplankton	2	4
Zooplankton feeding fish	2	1
Benthic fauna feeding fish	2	1
Carnivorous fish	2	1
Benthic herbivores	3	3
Benthic filter feeders	3	4
Benthic detrivores	3	4
Benthic carnivores	3	3
Benthic bacteria	3	2
Fish feeding birds	1	4
Benthic feeding birds	1	4
Humans	2	2

General

The bathymetric data that were used to estimate the areas and volumes of the basins originate from a combination of recent site-specific measurements and existing digital sea charts are considered to be of very high quality (cf. Section 3.2)

The estimations of the extensions of the photic and aphotic zone were based on a rough assumption that the photic zone is twice the light penetration depth (which has been measured on the sites). An assumption that is probably fairly correct. However, it would have been good to correlate the estimates of the photic zone to the actual depth where plants are present in some of the basins to validate the assumption. The extension of the photic zone can also differ within a basin, which not has been taken into account. The estimates of the extension of the photic zone have a large influence of the final results of the carbon budgets and are thus very important. The influence of ice-cover on the extension zone has not been taken into account. However, this has probably only a very small effect on the results since the primary production during months with ice cover is very small.

The primary production was generally estimated from the biomass, conversion factors, and the insolation during the year. Optimal would have been to measure the primary production at the sites during the year. However, the calculated primary production probably has a sufficient good quality since the used conversion factors were species-specific and mostly obtained from the Baltic Sea and the insolation measurements used in the calculations were site-specific. The assumption that the epiphyte biomass and primary production was included in the macrophyte estimates probably contributes to a small underestimation in biomass and primary production.

The reasoning applicable for the estimates of the primary production also applies to the estimates of the respiration, i.e. that real measurements would have given a better estimate than the calculations used in this study. For the primary production, species-specific conversion factors contributed to that the calculations are fairly correct. The assumption that the respiration to consumption ratio is approximately 1:3 is a fairly accepted relationship, as is also that it is less for bacteria (1:2), since their metabolism has a higher rate.

Carbon transport to and from the basins were based on modelled oceanographic water movement (turnover time), which is described in detail in Section 3.5. Evaluations of the modelled runoff from land are described in Section 3.4. Concentrations of DIC and POC were based on a 2.5 year monitoring sampling programme with samples every third week. The estimation of total carbon flow is probably of low quality since the variation of concentration of carbon and runoff is great and these two parameters normally covariates and only averages for each parameter is used here.

Phytoplankton

Estimations of biomass were made from three samples per basin for Borholmsfjärden and Granholmsfjärden. The sampled values range between low and very high in comparison with national data, so the accuracy must be regarded as fairly low. Quality of the calculated specific net primary production and respiration is considered to be good but neither species nor site specific, which may affect the quality of the estimates in this budget. However, overall phytoplankton plays a minor role in the carbon flows in the basins presented here and thus is the specific net primary production used here good enough.

Microphytes

The microphytes biomass or primary production has not been measured at the site. The used microphyte data originate from studies performed around the biotest basin off Forsmark nuclear power plant during 1985 and 1986 /Snoeijs 1985,1986/. The quality of the data is considered to be high but as only a few data points have been used in this study (because the majority of the data points were located in the biotest basin and therefore were considered to be unrepresentative) the confidence is reduced. There was no information on the annual variation. The representatively of the data is probably medium good.

Macrophytes

Field measurements of biomass and distribution are of high quality due to the large number of sampling sites, but the quality of the extrapolations made (from point and line data to area data) has not been quantified. As demonstrated in Section 3.9 the biomass is changing over the year as opposed to the assumption made here.

Bacterioplankton

The bacterioplankton biomass or respiration has not been measured at the site. The used data was obtained from a study performed in Tvärminne, Finland /Kuparinen, 1987/. Data from this study was also used to estimate the respiration and consumption. The Tvärminne data has a high quality but the representatively for this area have not been evaluated.

Zooplankton

Estimations of biomass were made from three samples per basin in Borholmsfjärden and Granholmsfjärden. The accuracy of these measurements has not yet been verified with data from similar regions. The respiration and consumption has been calculated with the aid of conversion factors, which is considered to give fairly good estimates of quality

Fish

Data on fish biomass, species distribution of fish, consumption and respiration are not available from the area. Instead biomass data from a SCUBA diving survey performed in the Trosa archipelago has been used. This study has very low representatively for the basins focused on in this study. The proportions between fish having different feeding habits, i.e. zooplanktivorous, bethivorous and carnivorous fish have just been assumed without any justification from this area.

Benthic fauna

The benthic fauna was sampled at the site in a fairly thorough investigation and thus can the biomass data for these functional groups be considered to have high quality and be very representative. However, there is a risk that the amount of benthic fauna in the phytobenthic community have been overestimated as some organisms probably have been found both when collecting vegetation by SCUBA diving and taking grab samples with an Ekman-sampler. And this was not compensated for.

The meiofauna have not been studied in this area and data used originate from Askö /Ankar, 1977/. The representatively of this study for the Simevarp area is not known but could probably be considered to be low.

All bottom substrate were assumed to be soft bottoms, except when the presence of benthic algae suggested differently. No data on hard bottom fauna was available (except associated to the macrophytes). However, for the three basins presented here the vast majority of bottom substrate is soft bottom. This conclusion can be drawn from the large areas covered by vascular plants and data in /Ingvarsson et al. 2004/.

Benthic bacteria

The benthic bacteria biomass or respiration has not been measured at the site. The used data was obtained from a study performed in the Bothnian Sea /Mohammadi et al. 1993/. Data from this study was also used to estimate the respiration and consumption. The data has a high quality but the representatively for this area have not been evaluated.

Birds

The estimated number of birds is probably underestimated as only nesting birds are included.

Humans

Data on human fisheries are generic (figures from European studies) and the accuracy and representatively is not known.

4.4 Integrated ecosystem model

In this section, the stocks and flows of water and carbon in the three ecosystems are connected, using information from the discharge area 7 (Frisksjön), the Lake Frisksjön itself and the connected marine basins, described in previous sections. The main aims of integrating the separate ecosystem models are; to 1) quantitatively follow the path of carbon from the binding into primary producers on land to the last hold, in this scenario, the Baltic sea, 2) quantitatively illustrate the turnover of different pools in the landscape, and 3) provide the safety assessment with input to landscape modelling and identification of important properties of biosphere objects.

Because water is the principal media for transport and accumulation of elements and matter in the landscape, the work is in the first step focused on establishing an integrated model describing the hydrology. The next step is to combine the knowledge from the ecosystem specific carbon budgets with landscape hydrology. Below follows a description of the conceptual model. Thereafter follows a description of the major pools and fluxes within the three ecosystems that are used to build the integrated model. The last section concludes on the carbon budget for the integrated ecosystem model.

4.4.1 Conceptual description of an integrated ecosystem model

The integrated model combines the previously described ecosystem models covering the terrestrial, limnic and marine environments. The processes in focus are:

- Transport
- Accumulation
- Carbon turnover

Transport

The transport processes are mediated by water flow and at the landscape scale is the focus on the horizontal flow between the ecosystems. These flows are driven by hydrological factors that are described using the following parameters:

- Precipitation
- Evapotranspiration
- Water residence time
- Flow into the system
- Flow out from the system

The water fluxes are presented in Figure 4-18 and the carbon fluxes is presented in Figure 4-19 for the different ecosystems and subsystems constituting the landscape.

Accumulation

Carbon may be accumulated both in living biomass, necromass and as organic carbon in soil or sediments.

Carbon turnover

The turnover of carbon in different pools is an estimate of how long time the carbon may be stuck into a certain pool before it leaves the pool again (residence time). This estimation is of course based on a number of premises that in this version of the model are more or less realistic e.g. some parts of the pool may be more easily retained while others have a higher turnover. Here we put the carbon pool mass in relation to processes that either add or remove carbon from the pool, e.g. litter input to the ground carbon pool/sediment pool in relation to respiration (mineralization).

4.4.2 Quantitative descriptive model

The ecosystem is described using a number of hydrological parameters (which, in turn, describe transport processes) and a number of carbon pools that are described below, separately for each subsystem. The carbon pools are described along with those fluxes that are considered to be the most important in adding and/or removing carbon, i.e. influencing the turnover of the pool.

Hydrology

Below are a number of basic hydrological parameters presented that have been used for the calculations of water exchange

- Precipitation is set to 576 mm y^{-1} (Werner et al. 2005).
- Runoff is estimated to 5.7 l $s^{-1}km^{-2}$ using regional data (Section 3.4).
- Evapotranspiration is estimated to 426 mm y^{-1} (Section 3.4).
- Transpiration from the terrestrial system in the discharge area Frisksjön is set to 2.4×10^5 $m^3\,y^{-1}$ (see Figure 4-2).

A number of derived properties were calculated as follows,

- Evaporation was calculated as the difference between evapotranspiration and transpiration.
- The total runoff from the land surface was calculated using the land area and the specific runoff.
- Water residence time of the mobile groundwater store for the discharge area was calculated using the following assumptions. The mobile groundwater storage was calculated as a function of the land area, the estimated mean soil depth (2 m) and an assumed proportion of mobile groundwater in soil (10% of the soil volume as a first estimate). The storage was then divided with the runoff.

The terrestrial ecosystem

The parameterisation is done using information from the detailed descriptions in previous chapters in this report (mainly Sections 3.7 and 4.1.3).

Primary producers

This is the main biomass pool in the terrestrial environment. Here is a merged value used (from Figure 4-3), that describes the overall biomass including trees, shrubs, field and ground layer above and below ground. Similarly is the flux of carbon into the primary producers an aggregated value. A theoretical value of the residence time for the carbon in this pool was calculated as the biomass divided by the annual net input (respiration excluded) from the photosynthesis (Table 4-29).

Consumers

The total biomass of herbivores and carnivores in the discharge area is 3.1×10^5 gC. In relation to the other carbon pools, this pool is small, but may, however, be important due the relative high carbon flow (in relation to weight) via herbivores. This pool does also contain several species that are regularly hunted by humans. Carbon residence time of this pool has not been estimated in this version and neither is the pool included in Figure 4-19.

Necromass and soil organic carbon

The soil carbon pool is the largest carbon pool in the terrestrial environment (see Section 4.1). To this pool is the much smaller pool of necromass added (from Figure 4-2). The residence time of this combined pool is calculated using the assumption that the decomposition equals the annual input of litter in Figure 4-3. This is most certainly an overestimation (see discussion in Section 4.1.3), but may in this version serve as a base for further discussions.

Transport from the ecosystem

The transport of dissolved organic carbon (DOC) from the terrestrial discharge area was calculated in Section 4.1.3, using generic data from the literature.

Carbon turnover

The hypothetical overall carbon residence time in the terrestrial system is a function of the total carbon pool (dead+living) and the yearly leakage of carbon in runoff to the lake and the closest basin.

The limnic ecosystem

The parameterisation for limnic ecosystem model is done using information from the detailed descriptions in previous chapters in this report (mainly Sections 3.8 and 4.2.2).

Primary producers

According to the carbon budget presented in Section 4.2.2, primary producers (i.e. macrophytes, phytoplankton and epiphytic algae), constitute together about one third of the total biomass in the limnic system (however, this estimate is probably too low; see discussion concerning benthic bacteria below). Both the estimated biomass and production of primary producers are strongly dominated by macrophytes. The theoretical residence time for the carbon in primary producers, calculated as the mean biomass divided by the annual net input from the photosynthesis (respiration excluded), is 0.1 year.

Consumers

The estimated total biomass of consumers (i.e. both predators and decomposers) is strongly dominated by benthic bacteria (Table 4-19). According to the carbon budget, consumer biomass is about twice the biomass of primary producers, and consumer respiration is almost 10 times higher than total primary production. Although the brownish water colour of Lake Frisksjön indicates an important contribution of carbon from terrestrial origin to the lake ecosystem, the estimates of both biomass and respiration of benthic bacteria are unrealistic high, and the accuracy of these estimates will be reconsidered in future model versions. The theoretical residence time for the carbon in limnic consumers, calculated as total consumer biomass divided by annual respiration (see Table 4-29), is 0.04 year.

Necromass and soil organic carbon

The carbon pool in the sediment of Lake Frisksjön was calculated from data given in /Nilsson, 2004/. Mean sediment depth was assumed to be half of the average maximum sediment depth observed in the three sediment cores. Percentage carbon per sediment dry weight, as well as sediment water content, was calculated as the overall mean values from all sampling points and sediment depths, and the specific weight of the sediment was assumed to be on average 2 times that of water. The resulting pool carbon in the sediment is by far the largest carbon pool in the limnic system.

The accumulation rate of carbon into the sediments of Lake Frisksjön was calculated, using an estimated total sedimentation rate of 1.3 mm per year /Nilsson, 2004/. The ratio of the sediment carbon pool and the annual accumulation rate of carbon into the sediments, gives a theoretical residence time for carbon in the sediment of almost 2,000 years (Table 4-29).

Transport to the ecosystem

The transport of carbon to the limnic system is assumed to correspond to the transport of DOC from the terrestrial discharge area (as described above).

Transport from the ecosystem

The transport of carbon from the limnic system was calculated from monthly mean values of measured total organic carbon (TOC) concentrations in lake surface water and modelled monthly discharge from the lake.

Carbon turnover

A hypothetical total carbon residence time was calculated as the ratio between the total carbon pool in the lake (dead+living) and the annual transport of carbon from the lake, as calculated above.

The marine ecosystem

The large-scale flows of carbon within the marine ecosystem, and the flows to and from adjacent ecosystems, are described in terms of runoff from the surrounding terrestrial environments to the three different sub-basins, water exchange to/from/between the basins, and the primary production, respiration and sedimentation of carbon within the basins.

The carbon pools are described along with those fluxes that are considered to be the most important for adding and/or removing carbon, i.e. influencing the turnover of the total carbon pool in the system. The parameterisation is done using information from the detailed descriptions in Chapter 3 in this report.

Primary producers

The total biomass and production of primary producers (i.e. macrophytes including macroalgae, microphytes and phytoplankton) in the three different sub-basins are presented in Section 4.3. The theoretical carbon residence time (year) for marine primary producers, which was calculated as the ratio of the biomass (gC) and the primary production rate (gC $year^{-1}$), amounted to c. 0.1 year for all three basins.

Consumers

The biomass and respiration of the autotrophic organisms (including bacterioplankton, zooplankton, fish, benthic herbivores, benthic filter feeders, benthic detrivores, benthic carnivores, benthic bacteria, and birds) in the three sub-basins are presented in Section 4.3. The values are merged values that describe the overall biomass and respiration. The theoretical residence time for carbon in marine consumers (year), calculated as the ratio of the biomass (gC) and the respiration rate (gC $year^{-1}$), amounted to 0.1–0.2 year in the three basins.

Sediment and sedimentation

The total carbon content in the sediment (gC) was calculated as the density of carbon in the sediment (gC m^{-3}) multiplied with the basin area (m^2). The density of carbon in the sediment was estimated as the product of the density of dry substance (gds/m^3) in the sediment and the relative amount dry substance in the sediment (%). The density of dry substance was 400 gds/m^3 for Borholmsfjärden /Nilsson, 2004/ and was assumed to be the same for the two other basins. The relative amount of dry substance was assumed to be 12.6%, which was an average of all sampling sites and all sampling depths /Nilsson, 2004/. It was also assumed that the particulate fraction of the sediment had twice the weight compared to the dissolved fraction.

The sedimentation rate for the whole basin (gC $year^{-1}$), was calculated from the sedimentation rate per square meter (gC m^{-2} $year^{-1}$) and the basin area (m^2). The sedimentation rate per square meter was calculated from the sediment density (gCm^{-3}) and the accumulation rate (m $year^{-1}$), which was derived from data stating that 3.5 meters sediment have been accumulated in Borholmsfjärden during the last 3,000 years /Risberg, 2002/. The same accumulation rate was assumed for the two other basins.

The theoretical residence time for carbon in the sediment (year), estimated by the ratio of carbon content in the sediment (gC) and the sedimentation rate (gC $year^{-1}$), was c. 2,000 years (Table 4-29).

Transport to the marine basins from terrestrial runoff

The total transport of water and carbon to the three sub-basins from terrestrial runoff was estimated by using the hydrological model described in Chapter 3 and mean values of TOC, measured in representative stream sites in the drainage areas.

Transport to and from the marine basins from other basins and the Baltic Sea

The main flows of water and carbon to and from the marine basins are via water exchange with the other basins and with the open Baltic Sea. These flows were estimated in the oceanographic model, described in Chapter 3. A simplified illustration of the net water flow to and from the three basins is shown in Figure 4-18 and the resulting carbon transport to and from the basins with the water exchange is shown in Figure 4-19.

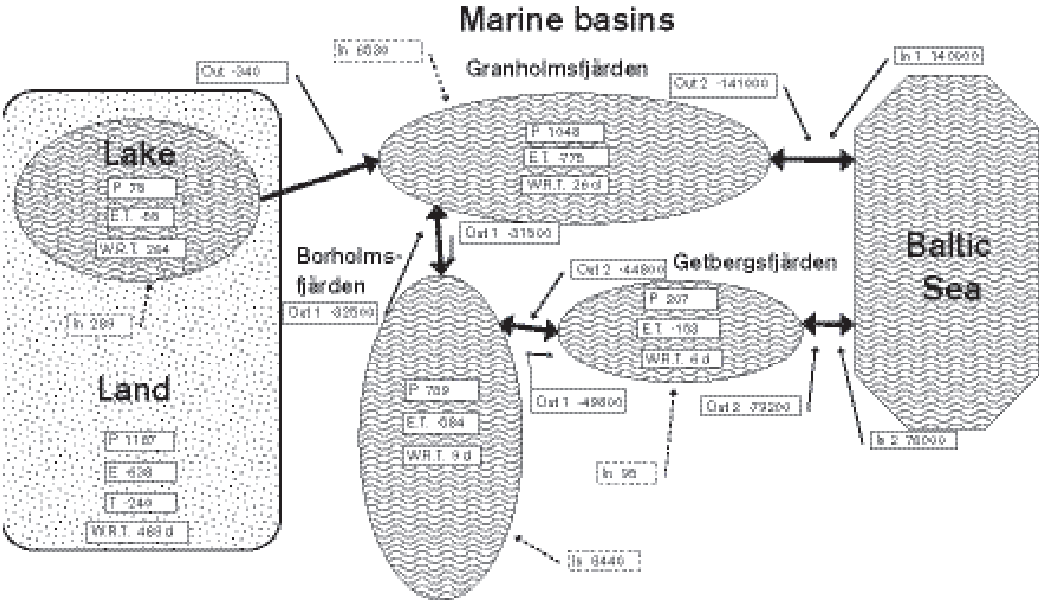

Figure 4-18. *An annual water budget for the discharge area Frisksjön, where land, the lake and the coastal basins have been interconnected. Negative sign indicates a flux that is leaving the specific subsystem, e.g. evapotranspiration or water transport from the lake or a specific basin. Diffuse inflow of water is shown in boxes with broken lines. P = Precipitation, E.T. = EvapoTranspiration, W.R.T. = Water Residence Time in days for the specific subsystem. All numbers are on the base 1×10^3 and have the unit m^3, except for the W.R.T.*

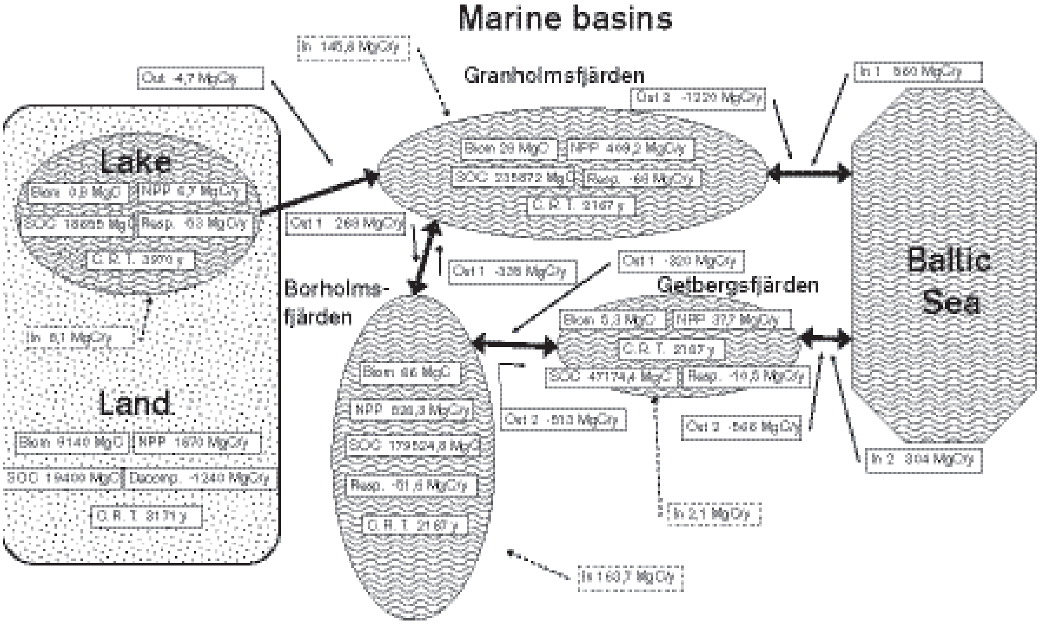

Figure 4-19. *An annual carbon budget for the discharge area Frisksjön, where land, the lake and the coastal basins have been interconnected (MgC in units denotes 10^6 gC). Negative sign indicates a flux that is leaving the specific subsystem, e.g. respiration. NPP = Net Primary Production, Biom. = Biomass, SOC = Soil/Sediment Organic Carbon, Resp. = Respiration, Decomp. = Decomposition and C.R.T. = Carbon Residence Time (theoretical) in years for all organic carbon in the specific subsystem (see also Table 4-29). Diffuse inflow of carbon is shown in boxes with broken lines.*

Overall carbon transport to and from the basins

In Figure 4-19, the major inflows and outflows of carbon in Granholmsfjärden, Borholmsfjärden and Getbergsfjärden are illustrated. The processes contributing with most carbon to the basins are primary production and runoff from the terrestrial environment, while respiration and sedimentation remove carbon from the system. Water exchange can be both a contributing and a removing process, depending on net flow direction of water. The net flow of all these processes was expected to be zero. However, on an annual basis there is a positive net contribution of carbon of 6.0×10^8 in Borholmsfjärden and a net deficit in Granholmsfjärden and Getbergsfjärden of -2.2×10^8 and -6.2×10^7 respectively. The reason for the net contribution/deficit to the basins is further discussed in Section 4.4.3.

Table 4-29. A description of the hypothetical carbon residence times for the different carbon pools in the different geometrically delimited ecosystems in the discharge area of Lake Frisksjön and in three marine basins. Residence time for carbon in the biomass is set by the primary production. Residence time for organic carbon in soil/sediment is set by decomposition or respiration. The column "Total" is a theoretical measure of overall carbon residence time in the system, estimated as the ratio between total amount of organic carbon in the system and the annual flow of organic carbon from the system, assuming that all carbon transport is mediated by runoff (for land and lake systems) or water currents (for marine systems).

System	Residence time of carbon pools (year)		
	Biomass	Soil/sediment	Total
Land	5	16	3,171
Lake Frisksjön	0.1	1,923	3,970
Basin Granholmsfjärden	0.1–0.2	2,167	396
Basin Borholmsfjärden	0.1–0.2	2,167	692
Basin Getfjärden	0.1–0.2	2,167	180

4.4.3 Conclusions on the landscape carbon budget

When the separate ecosystem models are connected to each other it is apparent that the magnitude of estimated fluxes of water and carbon over system borders are roughly consistent, even though they have been estimated independently with different models or with measured fluxes or concentrations.

The largest fluxes of both water and carbon in the Simpevarp area are driven by the exchange of water between the marine basins and between the basins and the open Baltic Sea. Another large flux is the terrestrial runoff to Granholmsfjärden and Borholmsfjärden, where the relatively large watersheds of the two streams Laxemarsån and Kärrviksån contribute with substantial flows of water and carbon. The estimated carbon fluxes from terrestrial areas to the marine basins, based on the measured concentration of TOC in the streams, are proportional to the water fluxes.

However, the major pathways for water and carbon flux differ. High carbon fluxes are generated from the net primary production (NPP). The fixation of atmospheric carbon (and thus also uptake of essential nutrients) is partly balanced by high relative fluxes due to respiration (release to the atmosphere and mineralization), especially on land and in lakes. Another large fraction is the storage of organic carbon in soil and sediments.

For water it is assumed that there is no annual storage. The highest fluxes are found in the coastal area. The runoff from the larger watersheds provides a substantial part of the water turnover. However, the discharge area of Friskjön, studied in this case, adds less than 5% to the total water flow in basin Granholmsfjärden. Thus, any inflows of matter from the geosphere to the coastal area will have a high dilution due to the large flows and fast water turnover in the coastal area.

The theoretical residence time for water (water volume divided by flow) shows that the shortest residence time is in the coastal area, ranging from a few days to a month, whereas the Lake Frisksjön has a residence time close to one year and the entire discharge area has a residence time for water of almost 1.5 years.

The theoretical residence time for carbon (biomass or organic carbon pool dived by the outflow) is considerably longer, ranging from 200–700 years for marine bays to 3,000–4,000 years for the lake and terrestrial ecosystems. This is mainly due to the large amount of carbon stored in the sediments and soils.

As a result of the difference in residence time between water and carbon, elements easily dissolved in water and with a low affinity to carbon will quickly be transported out of the area, while elements sorbing to or incorporated in organic matter will accumulate in the area for a longer time periods. The estimated residence times for carbon roughly set limits for possible time periods for the accumulation of e.g. radionuclides or other pollutants in the area. In bioavailable matter (organic matter and water), the accumulation can be at most in the order of 4,000 years in this area.

The overall ecosystem budget performed in this study is a unique attempt to obtain a holistic view of the landscape, which both provides the safety assessment with values for parameters used in the dose models, e.g. landscape information on fluxes, but also with possible limits for residence times and fluxes.

Although the fluxes between the studied ecosystems match quite well, there are some obvious misalignments. For example, in the budget for the Lake Frisksjön, the respiration seems to be overestimated since there is no measured or modelled flow that can match the sink of carbon. Moreover, the budgets for the marine basins seem to overestimate the net primary production or underestimate the export of carbon.

Some of the discrepancies are due to the estimation of net flows from the differences between large numbers. Small errors in the originate estimates will therefore contribute to large errors in the net flow estimates. This is probably mainly the case for the marine basins. These errors can be estimated and in some cases minimised by further use of collected data of e.g. other elements than carbon.

Other discrepancies are due to lack of spatial resolution in the measurements of e.g. TOC contents in other marine basins, or that the metabolic rate constants for organisms are generic or guessed. This can be improved and refined by *in situ* process measurements in the area as planned for the next stage of the site investigations (KPLU).

The amount of resources in the area that humans can utilise is described in Section 3.10. In the next version, this information will be distributed over the different ecosystems in order to estimate how much food that can be obtained from each ecosystem for a sustainable population of humans. This will also enable estimations of the maximum sustainable population at the site.

In summary, this first attempt to obtain an overall carbon budget for the different connected ecosystems has given a platform to build dose models, to obtain data for biosphere objects and to build a landscape model (see Appendix 2). Still there are issues which need to be resolved by reinterpretation of available data, by collection of new data (especially process measurements), as well as a thorough review of the many assumptions and calculations. The major benefit is that already at this stage of the site-investigation, a large set of quantitative data from the site can be utilised.

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Model definitions used in this report

To make it easier for the reader, a number of important model concepts used in this report have been listed together with how they are defined in SurfaceNet. Each definition has a heading with its English name followed by the Swedish name within parenthesis.

Site description (Sv. Platsbeskrivning)

A total description of a site in text, equations and data. See e.g. report *Preliminary site description Forsmark area – version 1.1* SKB-R-04-15. Specifically, a site description refers to an entire site, never a part of it.

Biosphere object (Sv. Biosfärsobjekt)

A biosphere object is a component in a landscape model representing a specific sub area. It is normally a simplification of the available information for a studied ecosystem aiming at a mathematical representation suitable for dynamic simulation of radioactive matter. A biosphere object is of a specific class e.g. lake, coast, mire etc. depending on the originating ecosystem type that is modelled. It is described in text and equations. It also has a set of data specifying its properties like area, density, volume etc. A biosphere object can typically be an exposure model, but when it has been fitted into a landscape model it is referred to as a biosphere object.

Landscape model (Sv. Landskapsmodell)

A description of how biosphere objects are distributed (position and extension) and interconnected in a given area, in this context referred to as a landscape. A landscape model is normally intended to calculate concentration and transport of radionuclides in and between different parts of a landscape.

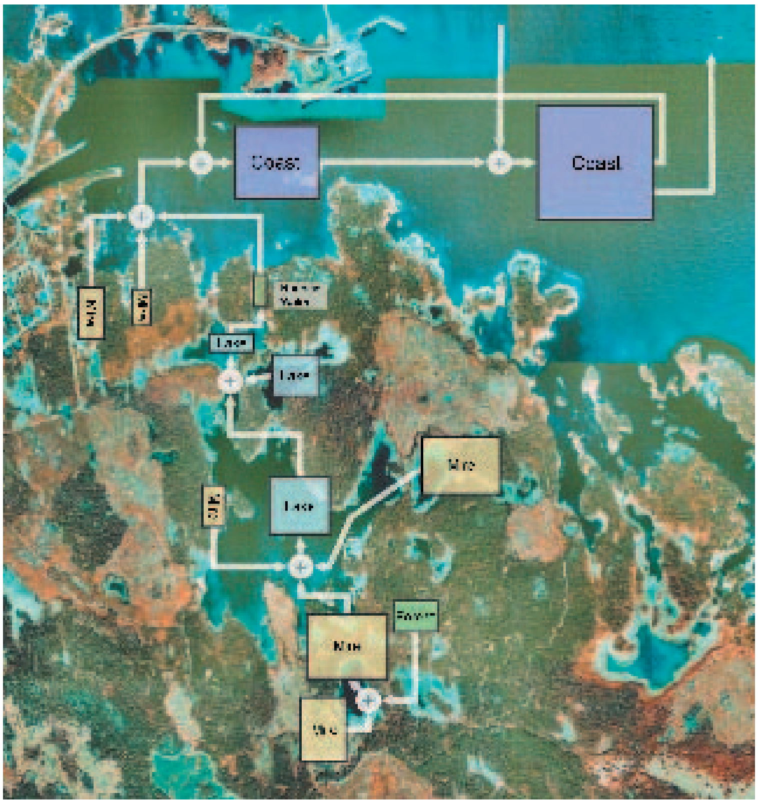

Figure A1-1. *This is a schematic image of a landscape model in the Forsmark area. The boxes represent biosphere objects and the arrows connections.*

Descriptive model (Sv. Beskrivande modell)

A record of any type of properties e.g. spatially distributed biosphere properties stored in a GIS database, parameters in a table and properties described in words.

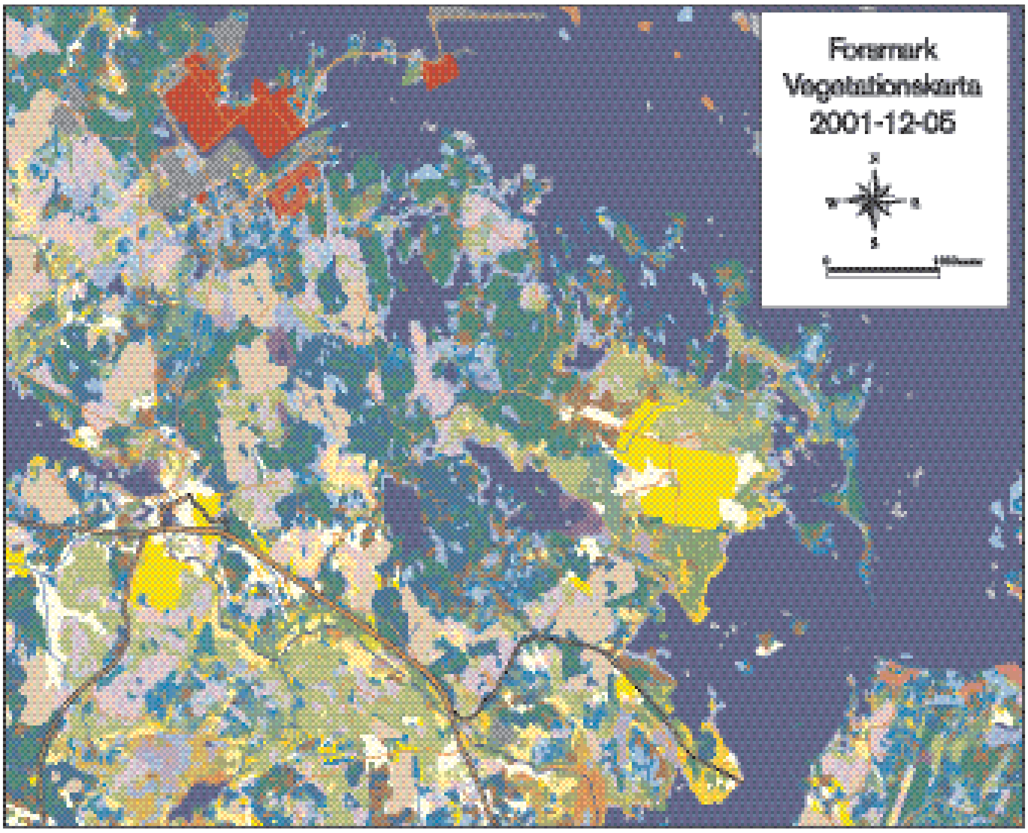

Figure A1-2. *This image shows a vegetation map from the Forsmark area extracted from a GIS database, it is an example of a descriptive model.*

Budget

A quantitative estimate of distribution and flow of elements in a system during a certain period of time, e.g. the flow of carbon in an ecological system described with the help of year based flows between different pools.

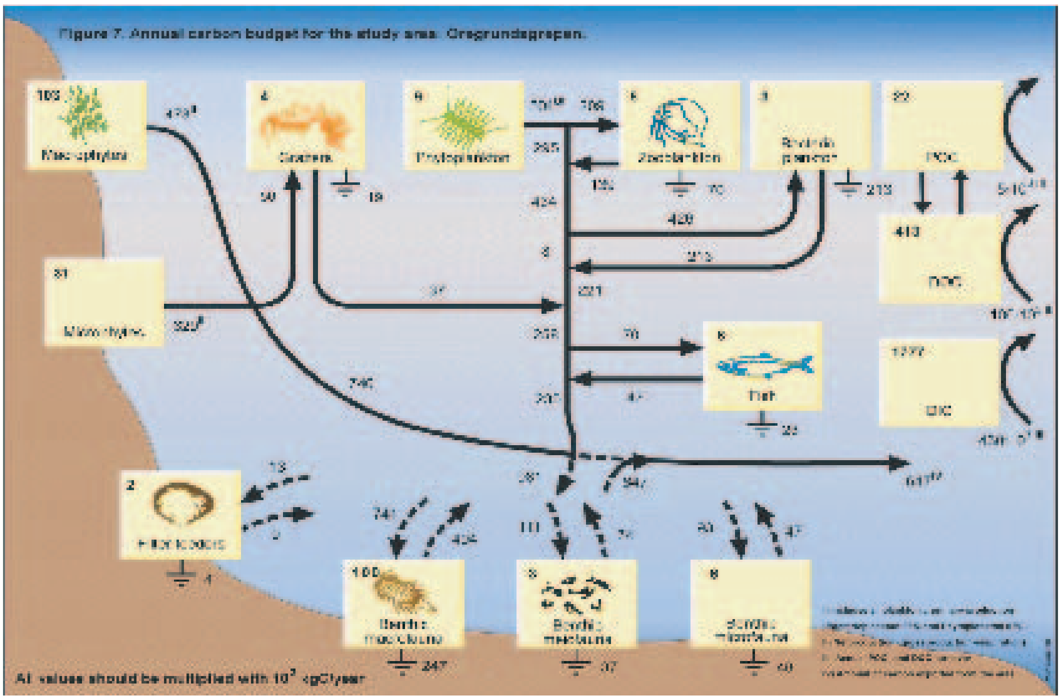

Figure A1-3. *Carbon budget for Öregrundsgrepen, an example of a budget.*

DEM Digital Elevation Model (Sv. DEM Digital höjdmodell)

A digital representation of a continuous variable over a two-dimensional surface by a regular array of z-values referenced to a common datum. Digital elevation models are typically used to represent terrain relief. It is also referred to as digital terrain model (DTM).

Quantitative model (Sv. Kvantitativ modell)

A quantitative model is in SurfaceNet defined as a model having quantitative output. In the case of a budget (a static model) results of transport and standing stock will be of interest. For other models time dependent output of e.g. transport and states are usually of interest. Budgets are one type of quantitative models.

Appendix 2

Application for safety assessment

The biosphere is an essential part of the system that has to be understood and analysed in a safety assessment of a nuclear waste repository, since the consequences of a potential release occur in the biosphere. For the time scales of relevance to the safety assessment, the biosphere will undergo considerable development, in particular due to expected future climate changes involving periods of permafrost and glacial conditions. A realistic, site specific handling of the biosphere is likely to yield very low doses during most of the assessment period /cf. SKB, 2004/.

Releases from the repository are expected to be negligible for thousands of years into the future when today's biosphere has undergone considerable development. Nevertheless, it is essential to obtain a thorough understanding of the current biosphere, e.g. from site data, since this is the best available basis for a description of future biospheres during temperate conditions. Also, an important factor affecting the biosphere structure in an interglacial period is the position of the shore line which is fairly predictable, partly since it is strongly related to the local topography, i.e. the DEM (Section 3.2) Furthermore, much of the knowledge required to describe the functioning of the biosphere is generic in nature meaning that results regarding the current biosphere from the site investigation are applicable also for altered future biosphere conditions. Studying and analysing the biosphere is therefore an essential part of the ongoing site investigations and the results of these studies are of direct relevance for the safety assessment.

In this section an overview is given how site data will be used in the safety assessment together with some examples. The data used in the following examples are from earlier versions of site data. Thus data presented elsewhere have not been incorporated yet, but that will be in the work for SRcan. Further information regarding the safety analysis is provided in the SRcan interim report, and later in dedicated reports regarding the safety analysis and the biosphere.

Integrated landscape model

The novel approach for the biosphere is to assign different biosphere objects which can be interconnected in an integrated landscape model (cf. Figure A2-2). The landscape models are created for different representations of critical time periods.

The biosphere will be defined as a combination of specific biosphere objects. The objects have different spatial extension and properties. Each such object can be regarded as an ecosystem with an intrinsic turnover of matter.

The two main categories of ecosystems, aquatic and terrestrial, are further subdivided into a number of ecosystem types. Aquatic ecosystems include marine systems, lakes and running water and terrestrial systems include agricultural land, mire and forest. For each of these, there are in general several possible model types that can be applied.

In order to assess doses to humans, given the calculated distribution of radionuclides in the landscape, a number of assumptions have to be made concerning living habits, exploitation of the landscape etc. Many of these must be generic, but the characteristics of the site and its potential future states do also provide a number of constraints on such assumptions. It is e.g. possible to estimate the number of individuals that can live off the natural resources at a site.

The interconnection of the biosphere objects is facilitated from the understanding of the surface hydrology and the locations of the discharge points.

After identification of the positions of the discharges and the associated ecosystem type, the accumulation of the discharged radionuclides downstream in the catchment will be modelled.

The discharge points of radionuclides from the geosphere to biosphere, obtained from the geosphere modelling, in SRcan interim report /SKB, 2004/, were selected as an illustration of how the biosphere objects will be connected and positioned in relation to the discharge points. From the discharge points, the major biosphere types were identified (Figure A2-1). If there are several stream-tubes entering the same catchment basin, but in different biosphere objects, these will be combined by connecting the different biosphere objects together based on site-specific maps. The maps not only describe how the biosphere objects are interconnected with each other, but also provide estimates of important parameters such as water turnover, accumulated runoff and information on how the biosphere can be utilised by humans.

The result from this preliminary analysis shows that more than half of the exit points are located at the coastal seafloor (Sea 17). Approximately 200 (5% of the total) have also advective travel times less than 1,000 years, i.e. still a coastal situation. Another large fraction (27%) of exit points are in lake Bolundsfjärden (area 9) and fringing mires (areas 4 and 8). For the majority of these points the advective travel time is less than 1,000 years. That is within the projected persistence of Bolundsfjärden.

Notable from this exercise is that very few points (0.5%) are in terrestrial environments other than mire.

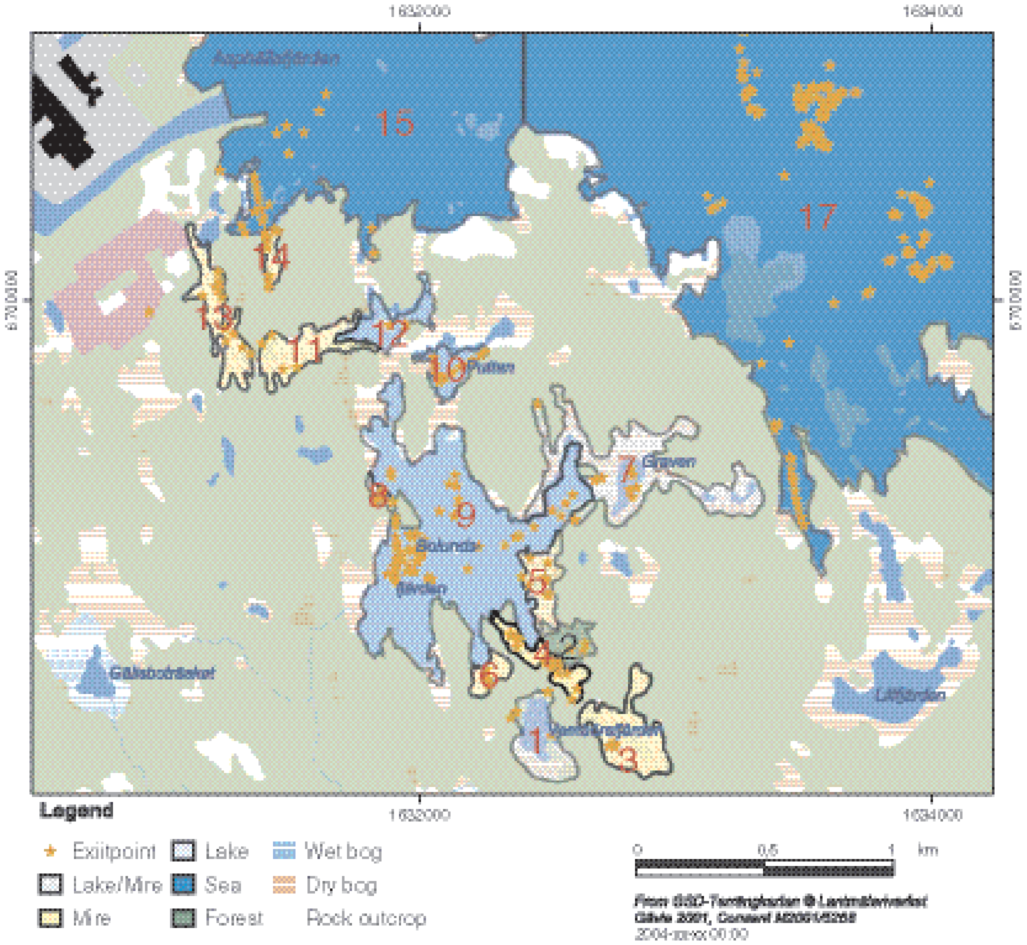

Figure A2-1. Map with biosphere objects classified according to the exit points of radionuclides to the biosphere, cf. legend. The objects are numbered. Sea object 16, 18 and 19 are outside the of the map area.

These findings from the preliminary data indicate that it is likely that the coast, lakes and fringing mires are the primary receivers of discharge from the geosphere. This confirms earlier analysis.

The identified biosphere objects were represented with corresponding dose models, which are interconnected, see Figure A2-2. The dose models are listed in Table A2-1 and described in relevant sections later. As far as possible site-specific data have been used in the different models (listed in Table A2-1). Some data are from the SAFE study /Karlsson et al. 2001/ and data used are listed in a data report /cf. SKB, 2004/.

A constant unit release of 1 Bq/year was applied to the most upstream object Varmbörsfjärden (Mire1). Four hypothetical radionuclides with near infinite half life and with K_d values in the range 1–1,000 (m^3/kg) were simulated in the model over 10,000 years.

The results show that radionuclides with lower K_d (1 m^3/kg) flowed through the network of connected ecosystems out into the sea. On the other hand nuclides with higher K_d (1,000 m^3/kg), remained almost exclusively in the first three ecosystems nearest the simulated discharge from the geosphere. The radionuclides with intermediate K_d values (10 and 100 m^3/kg) were found in the middle of the chain, in lake Bolundsfjärden. A considerable fraction of these radionuclides also left the system.

The preliminary results from this exercise indicate that the coastal ecosystems, lakes and some type of mires are all major receivers of discharges and that the highest concentrations and the highest doses will arrive closest to the discharge points.

In SrCan this method will be used and applied for the biosphere at the different periods dependent on availability of spatial data.

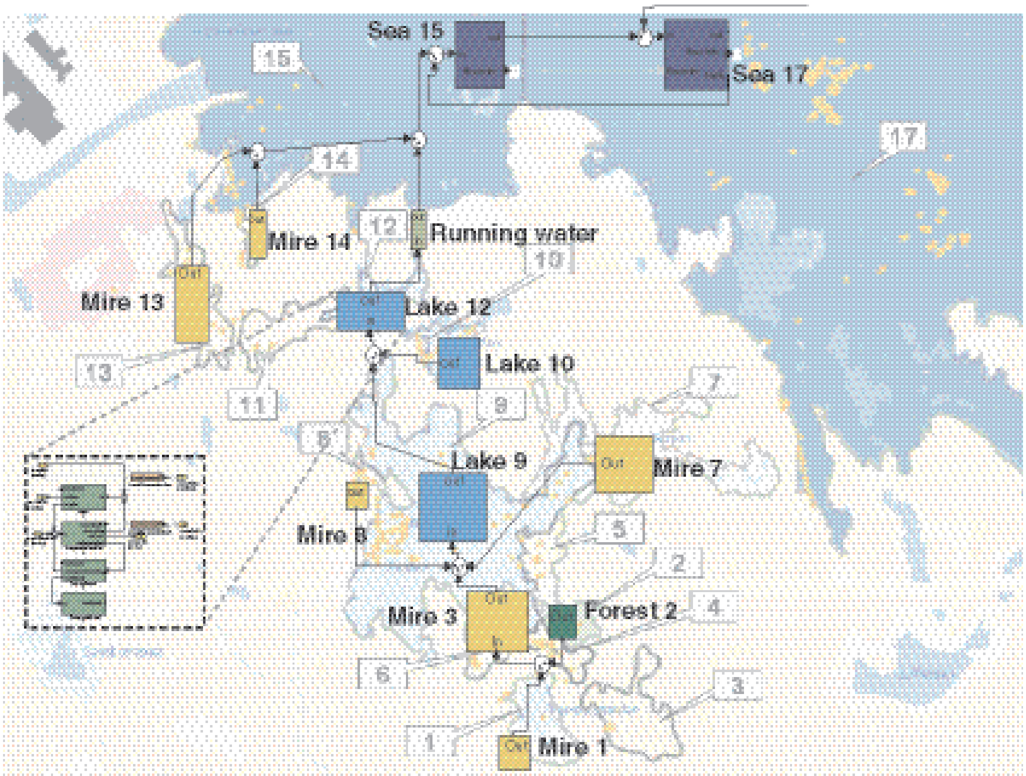

Figure A2-2. Integrated landscape model consisting of a number of connected biosphere objects. Each biosphere object is a representation of underlying biosphere model, cf. Lake 12 and the hatched panel at the left.

Table A2-1. Classification and properties of ecosystem objects including statistics of discharge points to the biosphere and associated advective transport times. Data for the object are an example from an earlier version used in the Sr–Can interim report /SKB, 2004/.

Name	Id	Ecosystem	Number of points		Adv. transp. time		Model	Object area	Drainage			
			(n)	(%)	median (years)	max (years)		(10^3 m^2)	area (10^3 m^2)	mean depth (m)	volume (10^3 m^2)	turn over time (years)
Vambörsfjärden	1	Mire/Lake	76	1.7	35	178	Mire1	56	484	0.4	21	0.19
	2	Forest	22	0.5	37	510	Forest2	22	702			
Djupsundsdel.	3	Mire	32	0.7	35	281	Mire3	70	695			
	4	Mire	367	8.2	35	12,670	Mire3	32	1,280			
	5	Mire	77	1.7	24	922	Mire3	36	1,267			
	6	Mire	59	1.3	14	80	Mire3	16	63			
						tot	Mire3	154	2,610			
Graven	7	Mire/Lake	53	1.2	32	184	Mire7	50	615	0.1	6	0.07
	8	Mire/Lake	419	9.3	26	3,605	Mire8	7	26			
Bolundsfjärden	9	Lake	406	9.0	60	2,440	Lake9	610	8,003	0.6	374	0.21
Puttan	10	Lake	120	2.7	29	4,361	Lake10	80	236	0.4	30	0.02
	11	Mire	7	0.2	4	18	Lake12	52	271			
N. Bassängen	12	Lake	2	0.0	3,217	4,321	Lake12	80	13,440	0.3	24	0.01
	13	Mire	61	1.4	7	1,187	Mire13	54	709			
	14	Mire	92	2.0	28	97,830	Mire14	13	61			
Asphällsfjärden	15	Sea	207	4.6	26	2,072	Sea15	1,026		1.8	1,856	0.002
	16	Sea	36	0.8	4,327	10,670	Sea16	1,557		2.3	3,550	0.002
	17	Sea	2,343	52.1	3,613	84,410	Sea17	4,465		3.8	17,012	
	18	Sea	12	0.3	7,932	30,370	Sea17	4,398		4.2	18,340	
						tot	Sea17	8,863		4.0	35,351	0.002
	19	Sea	103	2.3	10,250	57,320	Sea19	11,490		10.7	122,943	0.002
Öregrunds-grepen		Sea	0	0	0	0	Sea	456,000		11.2	5,107,000	0.033

Biosphere objects

The biosphere objects available are the mire, lake, sea, forest, running water, agricultural land and well. Each of them has site specific properties as geometry (position, length, area, volume etc.) and local hydrology (effective precipitation, discharge etc.). Other site data are important for some of the objects, depending on the model type.

The biosphere objects can be used in the landscape model described above or alternatively as site-generic average representative objects, not positioned in the landscape.

The biosphere objects are described elsewhere /Bergström et al. 1999; Karlsson et al. 2001; SKB, 2004/, here only the well and the mire are shortly mentioned.

Wells constitute an important pathway for human exposure of potential releases from the repository. The approach to modelling of wells in SR-Can is based partly on site specific information (e.g. well capacity, density, depth, position) and considers constraints on the size of a population that can utilise a local well /SKB, 2004/. Other data are universal, e.g. water consumption by humans or cattle, irrigation practises etc.

The mire model

In many areas around the sites, mires are the common pre-stage before they are drained by ditching and used as agricultural land. The model of the mire object is, in principle, the same as was used in the safety assessments SR97 and SAFE /Bergström et al.1999; Karlsson et al. 2001/ except that the water turnover in this version is estimated from the total amount of water coming from the drainage area according to the equation:

$TC = \frac{R}{\varepsilon \cdot D} \frac{A_d}{A_m}$ where R = Effective precipitation., ε = Porosity, D = Depth, A_d = Drainage area, A_m = Mire area

In the previous model, only the surface area of the mire was receiving the effective precipitation, not the drainage area. The geometry of the mires and their position is based on the statistiscs from site-specific data (Table A2-2), collected from about 200 mires in the area (Figure A2-3). In Table A2-1 the mires used in the landscape model are listed.

Effective precipitation from /Larsson-McCann et al. 2002/ Wetlands statistic from SICADA database and areas from GIS.

Data from SICADA based on smallest cultivation depth, best estimate depth is from database while max depth is taken from /Karlsson et al. 2001/.

The ecosystem specific dose conversion factors (EDF) were calculated using probabilistic simulations with the *Tensit* tool /cf. Jones et al. 2004/ integrated over a 10,000 years period. An example of the EDF distributions for some radionuclides is shown in SR-Can interim report

For most radionuclides the EDFs in SR-Can are one to two orders of magnitude lower than in SR97 for the mire model. This decrease is mainly because the drainage area is larger than the mire. However, there are also other site-specific parameters contributing to the differences, i.e. the depth and surface area of the mire.

This relatively simple mire model shows that the use of site-specific information improves understanding for the actual site and thus the model formulation, which results in considerable changes in estimated doses. Still this type of EDF model is a very coarse estimate which is probably pessimistic. For example the accumulation time in a mire affects the dose considerable and thus the assumptions of how long time a mire can be used for agriculture before the transition from mire to agricultural land is important. Many mires can be utilised before 10,000 years of accumulation, which gives lower doses. The growth of the mire is omitted which gives higher concentrations in the peat etc. Most of these parameters can be obtained from the site data and a careful analysis of historical development of the site /Bergström, 2001; Brydsten, 2004a/ and this will be developed.

Table A2-2. Data used in the mire model. Min and max are truncations of normal (N) and log-normal (LN) distributions and minimum and maximum values for triangular (T) or log-triangular (LT) distributions.

Parameter	Units	Dist	Best est.	Std	Min– max	Type
Runoff[1]	m/year	N	0.23	0.078	0.071–0.451	Site-specific
Density[2]	kg/m^3	T	100		80–120	Site-specific
Porosity[2]	–	T	0.9		0.8–0.95	Site-specific
Area[3]	m^2	LN	10,931	3.82	900–1.1 10^{6}	Site-specific
Depth[4]	m	T	0.33		0.2–2.1	Site-specific
Drainagearea[3]	m^2	LN	550,935	2.61	9 10^{3}–1.7 10^{7}	Site-specific
Tk[2]	year	LT	10^{-3}		10^{-5}–10^{-1}	Universal

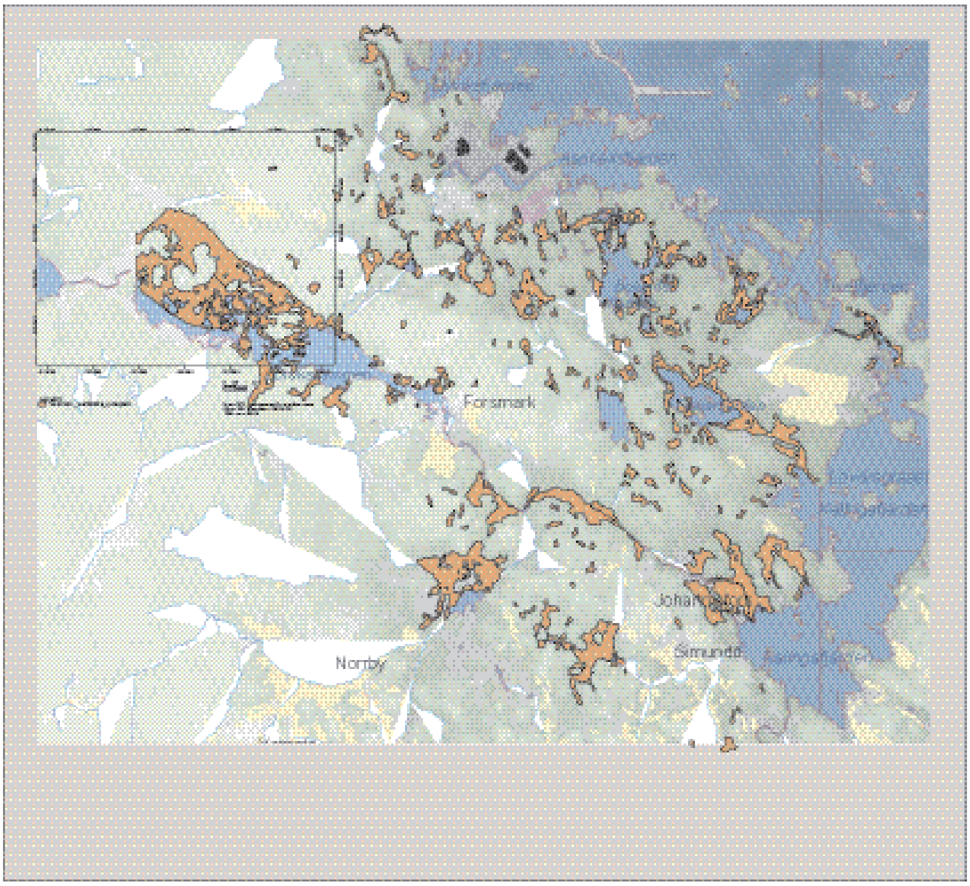

Figure A2-3. *Mires identified from an early version of site data from Forsmark.*

Understanding of future conditions/Ecosystem and landscape succession

Apart from providing descriptions of the geosphere and the biosphere, the site descriptive model gives an understanding of past and ongoing processes at the site. This information will be useful for the description and modelling of the future development in the safety assessment. The results should be compatible with the understanding of the site history.

The characteristics of the ecosystems will vary over time which is outlined in the following section. The most important long -term external factors are shore-line displacement and the glacial cycle. These factors affect the selection of models, e.g. terrestrial, marine or when a well can be drilled. For most contexts this is handled by selecting an appropriate configuration of ecosystem objects to provide a snapshot representation of the overall environment for each time period. A critical parameter is how long time the ecosystem persists. This affects the total amount of radionuclides accumulated in the system. For the marine ecosystem, which persists throughout the major part of the interglacial period, shore-line displacement has a significant effect on model parameters which affects calculated radionuclide concentration. The shore-line displacement is inferred from site data.

Long term internal development can also affect the persistence of the ecosystems. This is obvious for lakes, which transforms to mires, but this can also be applied to wells, agricultural land and mires which also have constraints in life length and thus also a maximum time for radionuclide accumulation. This information is obtained partly from the site. Finally, locations of discharge points from the geosphere is likely to vary with time.

In Figure A2-4 a hypothetical example is provided how the pattern of ecosystems may develop with time.

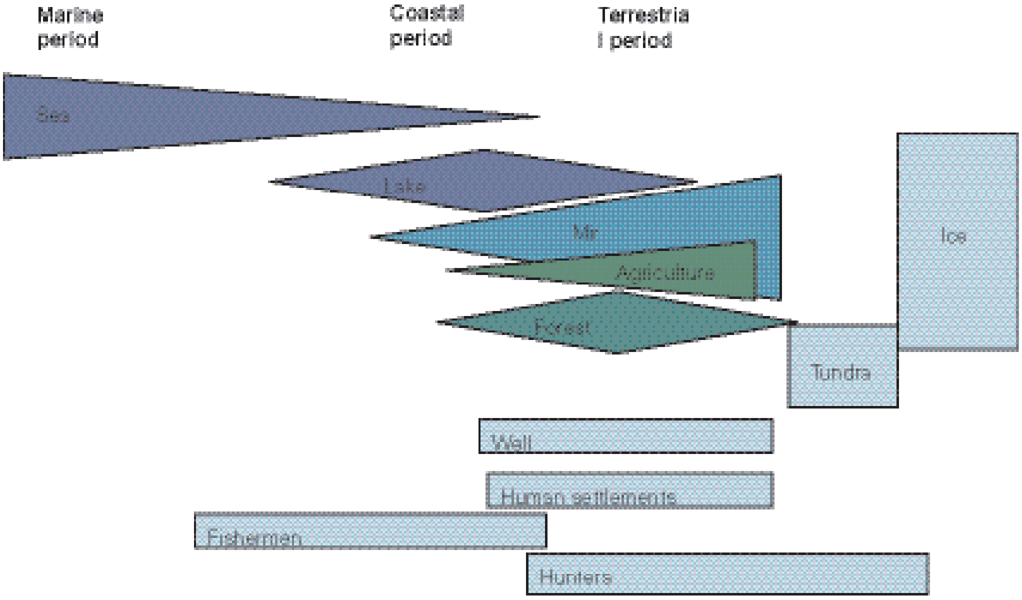

Figure A2-4. Hypothetical extension of different ecosystems and human settlement during an interglacial period at a site.

Handling of the temporal development of the biosphere

For the present temperate period, the overall development of the biosphere at the site will be outlined in a 1,000 year perspective and beyond, essentially based on the ongoing land-uplift and the understanding of the impact this has on the biosphere. The information will be summarised as a succession of simulated biosphere maps of the site, each representing a certain part of the temperate period, Figure A2-5. The maps will be the basis for the further modelling of the biosphere.

Next 1,000 years

The development of the shore-line will induce changes of the internal biosphere conditions such as biosphere succession (mire and forest development) and sediment redistribution (sedimentation and resuspension/erosion). The future shore-line displacement and sedimentation processes are in the assessment inferred from the historical development e.g. information about the sediment stratigraphy and shore line displacement (Section 3.1 and Section 3.3).

For the future ecosystem, vegetation and associated fauna are gradually following the shore-line displacement. Some processes will interact, e.g. peat development and forest succession, which can also be inferred from site data (see Section 3.7).

The expected effects of the shore-line displacement on the landscape the next 1,000 years are exemplified in 6.6, based on an early version of the bathymetry. In the area above the repository the shore-line is displaced some 100 meters from the present. That means that some of the bays, e.g. Äsphällsfjärden, are transformed to land and some larger islands appear. However, the main part of the regional modelling area is still a marine environment, with shallower bays.

The infilling of lakes and transformation to mires will be further analysed based on the rates estimated in the site description (Section 3.8). The properties of future lakes are inferred from information of lakes today at the site.

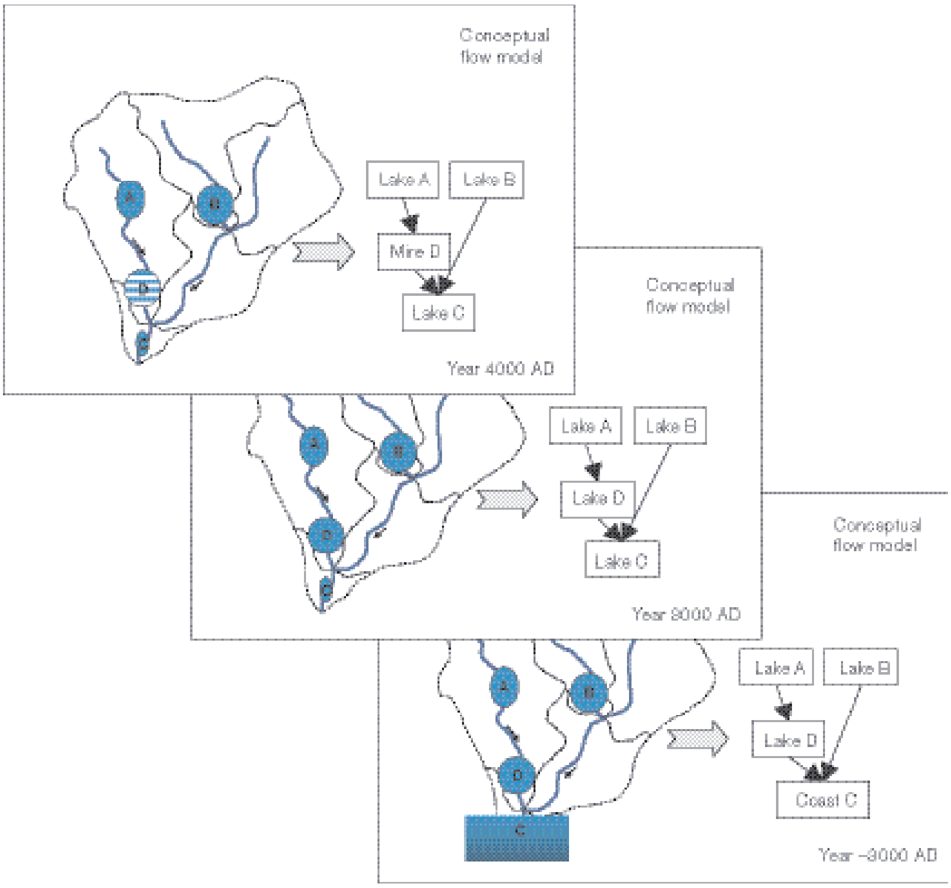

Figure A2-5. *Example of a succession of biosphere maps for temperate conditions. The maps represent different time periods with different biosphere objects and data. A new map is compiled for a new state when a relevant change from the previous state has occurred.*

Other expected changes of importance during the coming 1,000 years are human exploitation of the sites and climate change. Predicting human behaviour is always uncertain but the detailed description of the current conditions of the biosphere at the site, the historic land use and the catchments development during the coming 1,000 years indicates constraints for human settlement, food and water supply etc. Future human exploitation of the environment at the sites in terms of e.g. farming, fishing, hunting, collecting berries and mushrooms, is thus estimated by the prediction of availability of suitable soils and water and their productivity, which is based on the DEM (Section 3.2) and the marine geological maps (Section 3.3). Moreover, old cadastral maps gives input information of previous land use of the site (Section 3.1), which can be extrapolated for the future. The maps developed for the coming 1,000 years will contribute to estimating the constraints of possibilities to use the area for different purposes, e.g. agriculture. The use of the wetlands will be constrained based on the further analysis of the site data on quaternary deposits (Section 3.3) which indicates that areas with e.g. large boulders are unsuitable for farming.

Climate change or variability due to the greenhouse effect the coming 1,000 years is also expected to influence important parameters in the biosphere such as the hydrological cycle, sea level, and salinity of the Baltic Sea e.g. /Gustafsson, 2004/. However, climatic alterations are more difficult to put into the context of a continuously changing environment, because the rate of change and variability cannot be defined. The expected magnitude and trends are mainly based on large scale simulations, where site data have little contribution. However, the variability of site data can be used to study extreme situations which are maybe future averages.

In summary, the biosphere at the site during the next 1,000 years is assumed to be quite similar to the present situation. The most important changes are the natural infilling of lakes and slight withdrawal of the sea with its effects on the coastal basins.

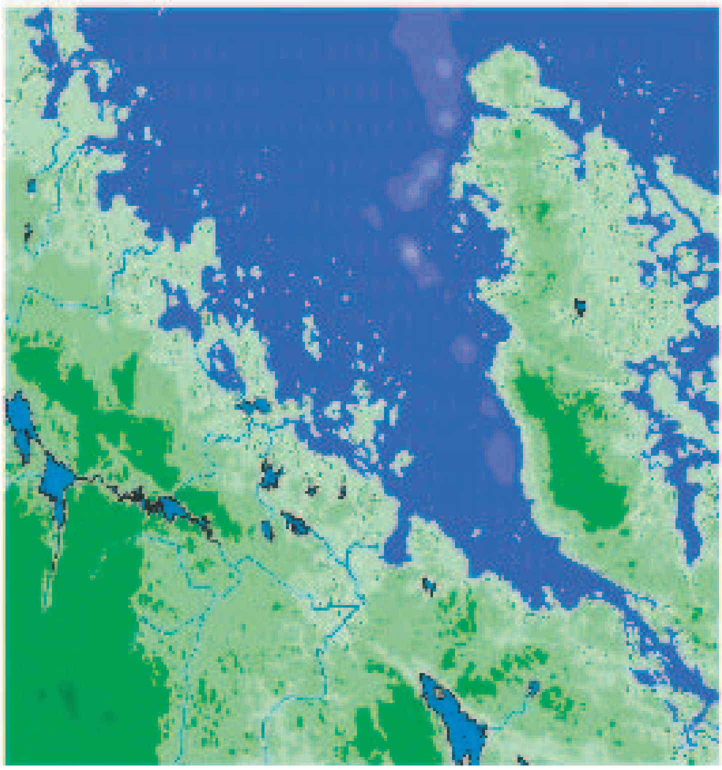

__Figure A2-6.__ The Formark region in 1,000 years. Today's shoreline is marked as a grey dotted line based on the version 1.1 of the DEM.

Until next glaciation

The continued shore-line displacement will influence the local biosphere and eventually result in a situation where the site is located in the inland rather than at the coast (Figure A2-7). This will in turn influence the positions of the potential discharge points of radionuclides. The shore-line displacement and subsequent ecosystem development will also change the possible exploitation of the ecosystems. Previous lakes will e.g. have become agricultural areas. Moreover, erosion processes of the regolith can change the topography and consequently the potential discharge points for radionuclides.

During the series of transitions dependent on shore-line displacement and succession, several important stages can be identified. The aim is to systematically look at the transitions of the coast to lakes, rivers and possibly other critical development phases.

The major data input is from the DEM of the site and rates of ecosystem processes as infilling and mire growth. Moreover, the current ecosystems will be scaled to the future map. The properties of e.g. lakes are inferred from lakes today in the region.

Complete glacial cycle

Permafrost conditions

The permafrost and tundra situation will be described and discussed in SR-Can. The sources of data on parameters and processes of importance for potential transport of radionuclides are based on knowledge from other places than the site. However, the DEM of the site and the knowledge about the soils will determine how the general data should be applied.

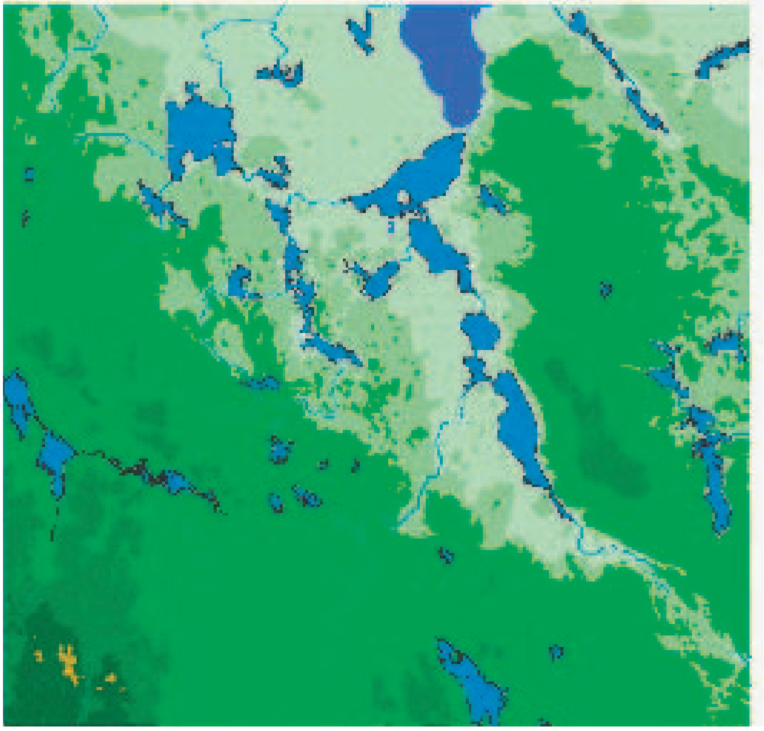

Figure A2-7. The expected Forsmark region at 7,000 AD. The entire area is terrestrial and some large deep lakes are situated along the former island Gräsö.

Glacial conditions

During glacial conditions the surface ecosystems are expected to contain few species and food chains and human population is likely absent or sparse. Therefore, the doses from potentially discharged radionuclides are expected to become very low. A description of the glaciated and ice-margin surface ecosystems and its human exploitation will be compiled for SR-Can. Data for this will be derived from generic data and not from the site.

Next interglacial period

The Forsmark area has earlier been submerged by the sea or very large freshwater lakes. The sea has likely experienced periods with higher salinity than today /Westman et al. 1999/, and, immediately after deglaciation, also freshwater periods. After a future glaciation the shore-line displacement is expected to gradually make the Forsmark area less submerged and eventually the first land in the area will appear, maybe 10,000 years after the ice retreat. The sediments are expected to be eroded by strong, wave driven resuspension forces /Brydsten, 1999/ during this period, before transformation to a terrestrial environment will occur. Only some limited areas along Gräsö are expected to have continuous accumulation bottoms during the next 10,000 years (Figure A2-8). Thereafter, similar to the present situation, a period dominated by a coastal environment is expected to take over, followed by a terrestrial period when lakes, rivers and mires will be formed.

In general the ecosystem processes during the next interglacial period are expected to be similar to those occurring during the present interglacial. There will be a Baltic Sea basin, with a lower salinity than ocean water. Rock outcrops and depressions with till, bays, lakes and bogs will probably be located at approximately at the same places as today, since their locations are essentially controlled by the underlying geological structures which have persisted the last millions of years. However, eskers cannot be generalised in this way. Humans will probably be able to exploit the sea, the lakes and the land in similar ways as today, and their needs are assumed to be the same. Thus, the description of the coming 10,000 years and the historic description of the biosphere can serve as a general "model" for all coming interglacial periods. That means that the knowledge about the site today and its history as well as the DEM from the site will be important site information.

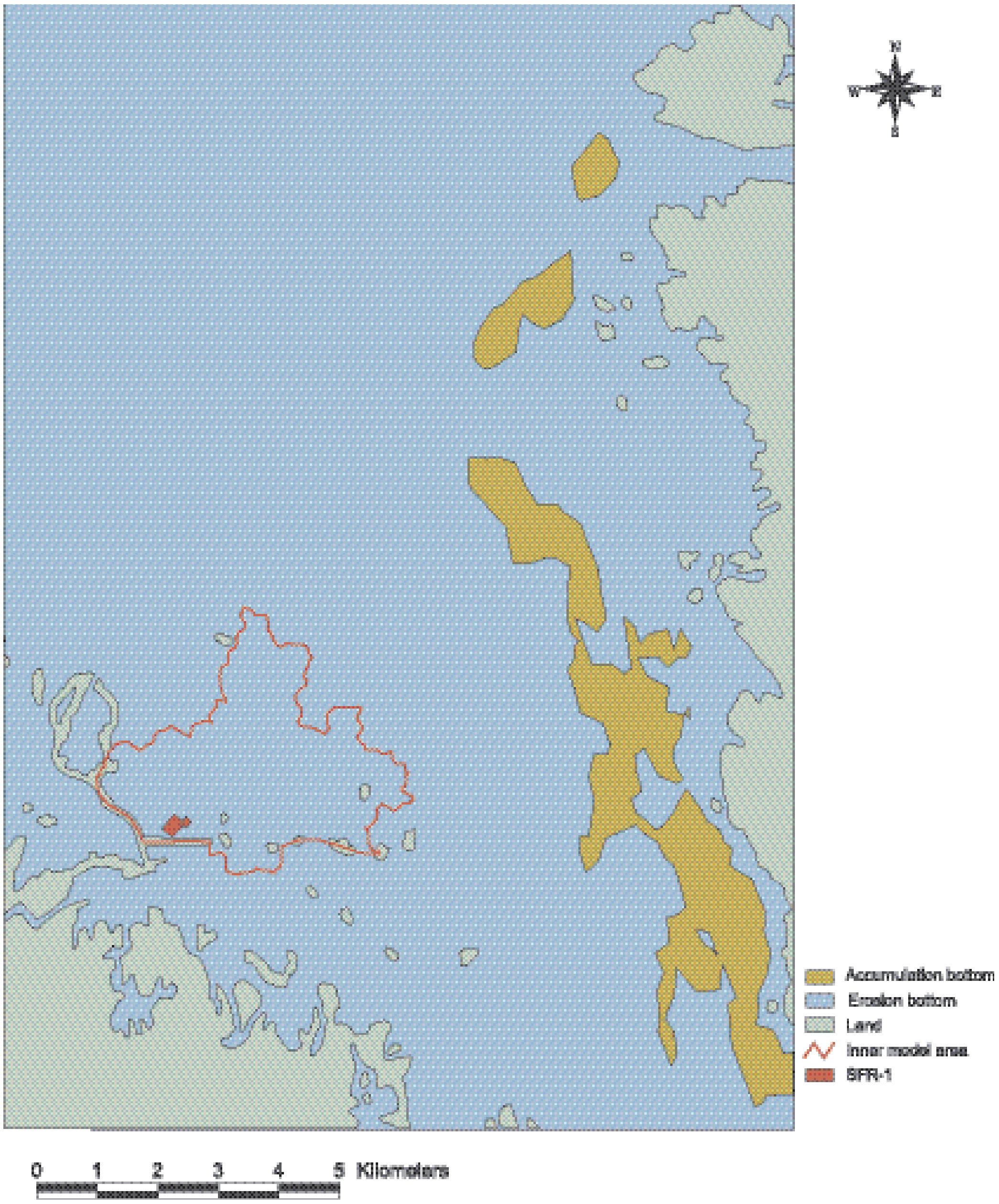

Figure A2-8. *Areas along the Gräsö island that are expected to have continuous accumulation bottoms during the next 10,000 year /Brydsten, 1999/.*

Appendix 3

Map over Simpevarp area

Map over Simpevarp area