R-06-11

Description of surface systems

Preliminary site description Laxemar subarea – version 1.2

Tobias Lindborg (editor)
Svensk Kärnbränslehantering AB

March 2006

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ISSN 1402-3091
SKB Rapport R-06-11

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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 Laxemar site and the various models developed to support the ecosystem description (e.g. hydrology, regolith, chemistry, vegetation, animals and the human land use). The ecosystem description is an integration 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 development. Improving the descriptions is important during both the initial and the complete site investigation phase. Before the start of the initial site investigation phase in Laxemar, a version 0 site descriptive model was developed. The results of the initial site investigation phase is compiled into a preliminary site description of Laxemar (version 1.2) in February 2006. This report provides the major input, and background to the integrated biosphere description, in the 1.2 version of the Laxemar site description.

The basis for this interim version is quality-assured field data from the Laxemar subarea and regional area, available in the SKB SICADA, and GIS data bases (data freeze November 1, 2004), as well as version 1.2 of the Simpevarp surface system model /Lindborg 2005b/.

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 flows and stocks of matter among and within functional units in the biosphere. Methodologies for developing descriptive- and ecosystem models are only described briefly in this report; 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 (listed in order of appearance) contributed to the project and/or to the report:

Tobias Lindborg (SKB) – project leader, ecosystems and editor,

Gustav Sohlenius, Anna Hedenström, (Geological Survey of Sweden, SGU) – distribution, properties and history of the quaternary deposits, soils and sediments,

Ulf Jansson, (Dept. of human geography, Stockholm univ.) – historical description, land use and human population, SKB R-06-37,

Lars Brydsten, Mårten Strömgren (Dept. of ecology and environmental science, Umeå univ.) – landscape geometry, topography, bathymetry, DEM-model,

Sten Berglund, Emma Bosson, (SKB) **Per Olov Johansson** (Artesia Grundvattenkonsult AB), **Kent Werner** (Golder Associates AB) – description of climate, surface hydrology and near-surface hydrology,

Anders Engqvist, (Dept. of system ecology, Stockholm univ.) – oceanographic descriptions and modelling,

Björn Söderbäck, Sara Karlsson (SKB) – limnic description, limnic ecosystem, surface water chemistry,

Mats Tröjbom (Mopelikan), – chemistry descriptions in surface and shallow ground water, precipitation and soil,

Anders Löfgren (EcoAnalytica) – terrestrial description, terrestrial ecosystem, biosphere objects, safety assessment data,

Sofia Miliander (Swedpower AB) – human description, terrestrial fauna,

Per Erik Jansson, David Gustafsson (Dept. of Land and Water Resources Engineering, Royal Institute of Technology, KTH) – terrestrial ecosystem modelling (Coup model),

Erik Wijnbladh (SKB) **Bror Jönsson** (Dept. of System Ecology, Stockholm University), – marine description, marine ecosystem,

Ulrik Kautsky, Jacob Jones (SKB) – safety assessment and dose modelling,

Helena Nyman (SWECO Position) – Geographical Information System (GIS-modelling), biosphere objects.

The report has been reviewed by the following group: Tobias Lindborg, Regina Lindborg, Sten Berglund. This group provided many valuable comments and suggestions and is not responsible for any remaining shortcomings of this report.

Stockholm, December 2005

Tobias Lindborg
Site Investigations – Analysis

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 the Simpevarp area, 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 the ongoing natural processes that affect long-term development. 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 long-term development.
- One or several site descriptive models, in which the collected data are 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 of 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 is developed within the frame of the SurfaceNet project, with a main objective to produce a detailed description of the surface systems, based on available data from the Simpevarp area, and it is a supporting report to the site description project. The specific objectives of the work are 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 the safety assessment can use the site description in dose modelling and in descriptions of the site development in the near and far future, and
- show how the site models can be used to support simplifications and assumptions in the overall safety assessment of a repository in the Laxemar subarea.

1.3 The site location

The Laxemar 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 from the site.

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 independently, aiming at a deepened understanding of the patterns 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 serves as guidance for the reader and provides a short presentation of the different disciplines that together constitute the surface system.

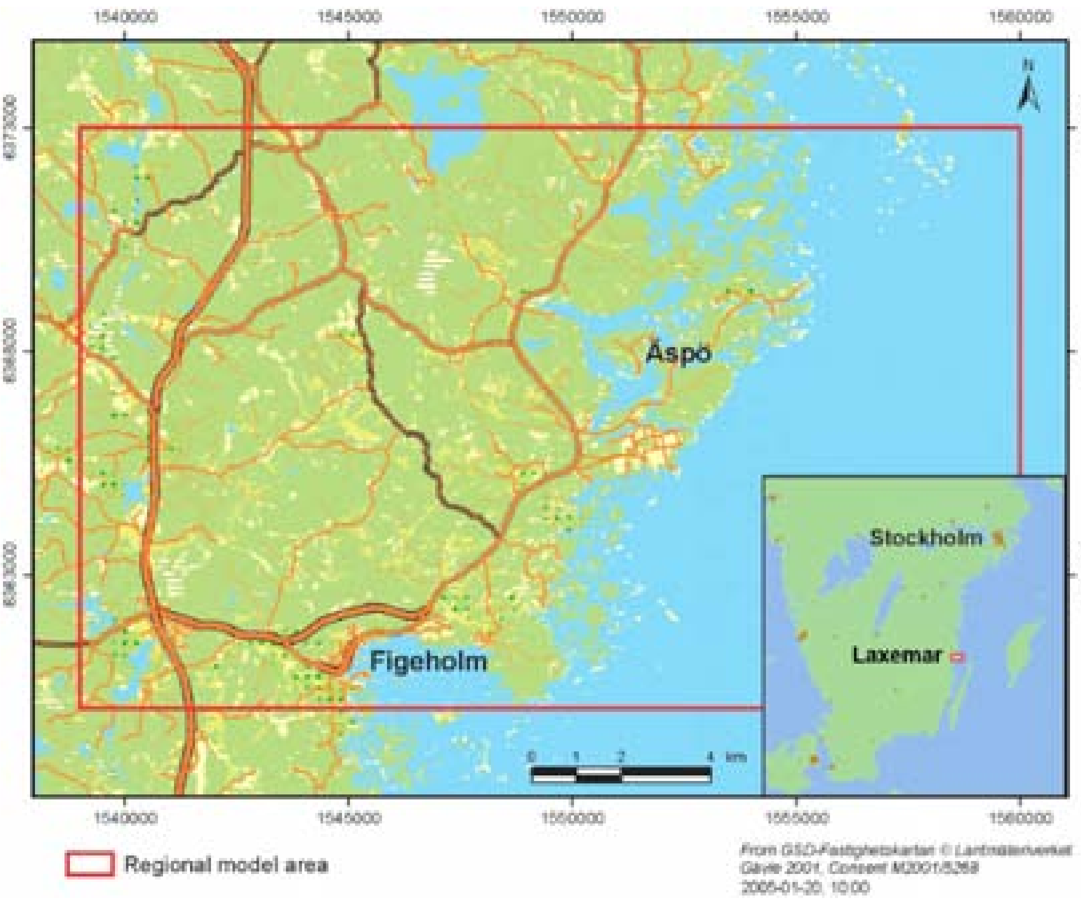

__Figure 1-1.__ Overview of the Laxemar area and identification of regional model area.

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 data that have been 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 main contents:

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 used the landscape during the last centuries /Berg et al. 2006/. These descriptions are a base for the predictions of future scenarios in the safety assessment. The historical description of the human population is not presented in this report, see /Berg et al. 2006/.

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

Regolith describes the geomorphological conditions at the site important for estimating transport of mater in the surface system. It is also an important predictor of the vegetation types at the site.

Climate, surface hydrology and near-surface hydrology describes a number of climate properties at the site, such as temperature and precipitation /Werner et al. 2005/. Climatic data sets the framework for many processes and serves as important input for the surface hydrological modelling. It also 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 an important input to e.g. the terrestrial ecosystem model.

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

Chemical properties compiles chemical data describing the chemical properties, 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 and interpretation of data describing the primary producers and the consumers in terrestrial environments. It includes both a general description of the biota and information on biomass, production, and turnover of tissue, and carbon content, used in the terrestrial ecosystem model.

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

Limnic biota is a compilation and interpretation 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 on biomass, production, and turnover of tissue, and carbon content, used in the limnic ecosystem model.

Human description presents 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 of radionuclides to 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 by using quantitative data presenting a carbon budget for a catchment area, one lake and three marine basins. The chapter is subdivided in the following sections:

- *The terrestrial ecosystem* presents the descriptive model for the terrestrial part of the selected model area.
- *The limnic ecosystem* presents the descriptive model for lake Frisksjön.
- *The marine ecosystem* presents the descriptive model for the marine basins.
- *An integrated ecosystem model* 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 basins.

Appendix 1 describes the biosphere objects at the site that are defined by the safety assessment.

Appendix 2 is a species list of the biota described in the report.

Appendix 3 is a map over the Laxemar subarea and its regional model area.

1.5 Development of ecosystem models

The development 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 groups of organism where it is possible. This requires 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 level of resolution. The data is presented in a GIS framework.
- Describing and quantification of processes affecting transfer and accumulation of matter within and between units in the landscape.

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 is the starting point for planning of field surveys, necessary for collecting the site-specific data in the next step (see conceptual models in Chapter 4).

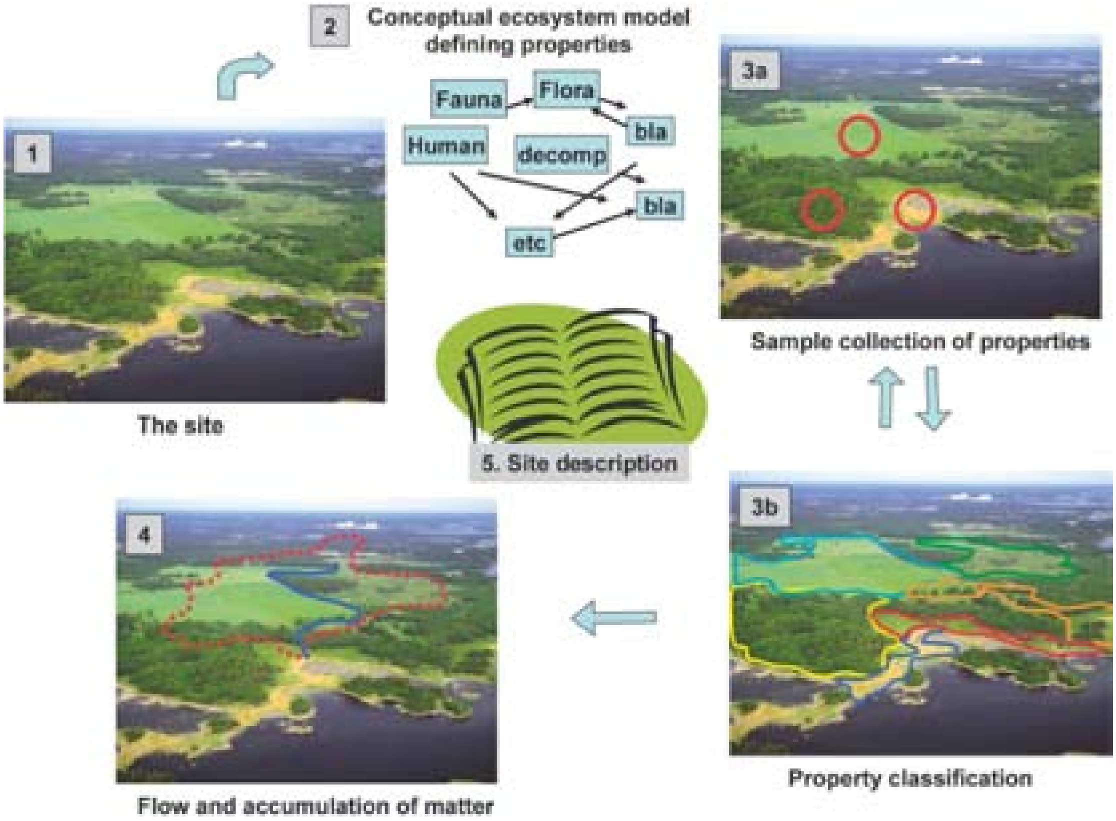

Figure 1-2. *The process of developing a site descriptive ecosystem model. The site (1) is defined. A conceptual model (2) is produced describing functional units, properties and the fluxes between them. Samples are collected at the site (3a) using quantitative statistics to describe the biotic and abiotic 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, catchment areas and site data (4). All information is compiled into the site descriptive ecosystem model.*

The general conceptual model can, after site specific data are collected, be adjusted to a site specific conceptual model. Thus, new information may be added or existing data omitted, i.e. a functional group needs to be re-considered or a biomass unit 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 report, the landscape was divided into three large-scale units: terrestrial, limnic and marine ecosystems. Further classification was done using units that potentially constitute the basis for budget calculation of organic matter. The units were then further divided 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. 2004b/. 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 also includes abiotic factors of importance for vertical or horizontal transport of matter, such as precipitation and groundwater movement.

1.5.2 Site specific data

The two Swedish sites considered as potential sites for a future repository of spent nuclear fuel are situated at the coast and do both include a large number of different ecosystems such as forests, agricultural land, wetlands, lakes and sea. In this step, the starting point was the conceptual model and we use site specific data to establish local budgets of standing stocks and flows of matter for the different units of resolution. The site-specific data is presented in a 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 a system, but may 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, and may also accumulate within the terrestrial system as peat. Accumulation often means that the matter leaves the short-term recycling, and 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, for example in lake sediments. The intention of this work is to construct a spatially explicit ecosystem model which describes 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 the most important component determining transport of matter /e.g. Blomqvist et al. 2000/, and is thus subjected to quantitative modelling and simulation using site specific data in order to understand vertical and horizontal movement of surface water and groundwater. The functional water units of the landscape are defined by catchment areas that are constructed from water divides in the landscape, Figure 1-3. This provides a tool to separate or link different sub-areas and ecosystems within the landscape. Moreover, using hydrology models it is possible to calculate turnover times for water and any dissolved component in 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 made, based on hydrology and water chemistry, providing information concerning transport of matter into running water and lakes. By quantifying recharge and discharge it is possible to calculate input and loss of matter in the lake. Matter transport in streams shows the actual leakage from the terrestrial systems, making 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. Transported solid matter is often accumulated in shallow bays, which consequently 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.

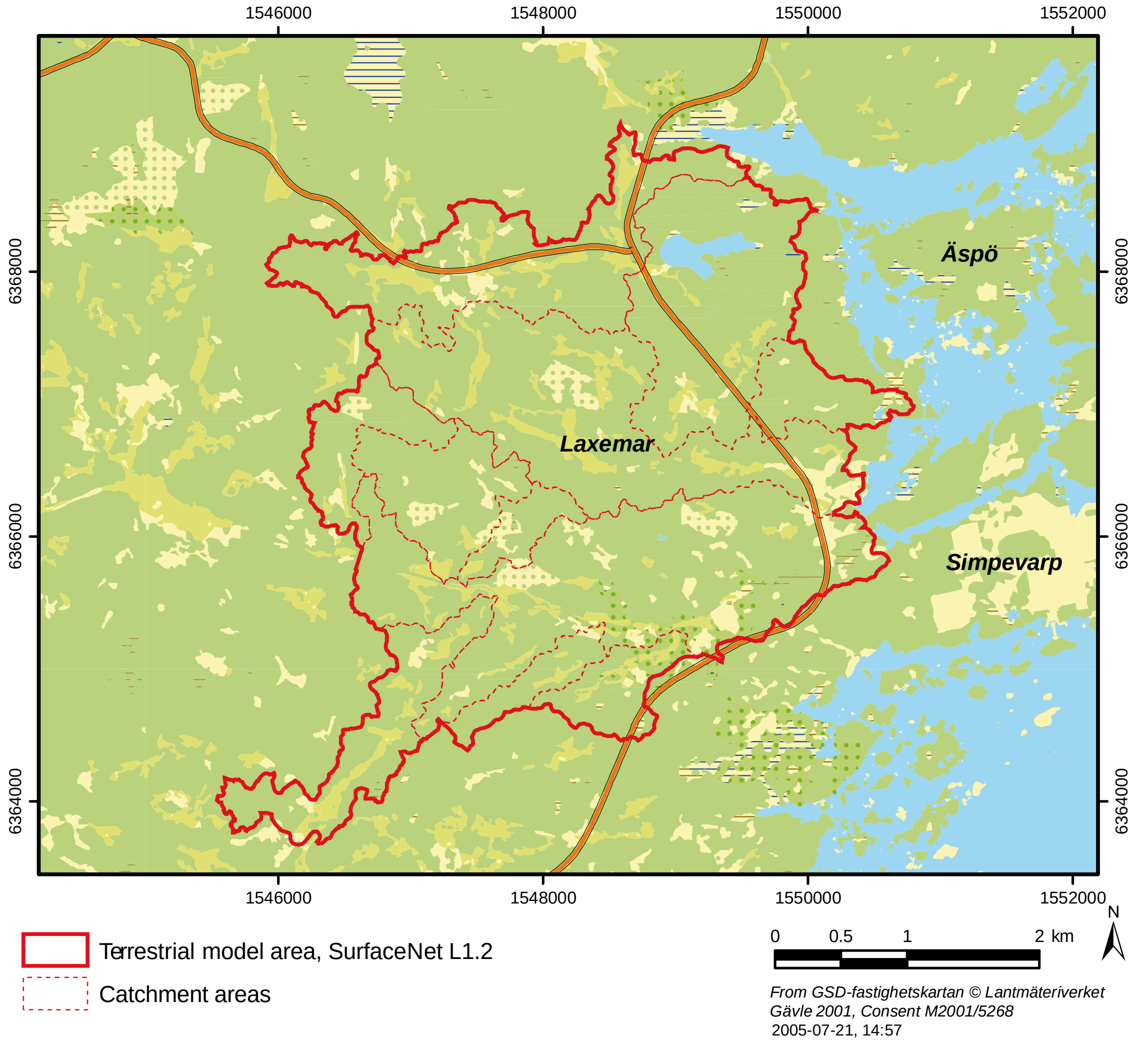

Figure 1-3. *Example of a model area in Laxemar. The drainage areas with there water sheds used as the model boundary. For further descriptions on modelling, see Chapter 3 and 4.*

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

In the 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/. 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 ecosystems 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 requires an inter-disciplinary work incorporating several scientific disciplines.

One of the great challenges with an ecosystem approach will be to integrate all relevant 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 detail, if necessary, due to the extensive site-specific database. This ensures that many of the simplifying assumptions made going from step 2 to 3 in Figure 1-2 may be modelled and tested. A mass-balanced ecosystem model with food webs provides a way of analysing how matter is 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, for example, the vegetation, to facilitate mass-balance 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.

If we describe standing stocks and flows 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. Thus, the safety assessment is provided with a tool /Kumblad et al. 2003/ to predict how and where radionuclides are transported and accumulated in the landscape, making it possible to calculate potential doses to humans at the specific site, an overview of the Laxemar site is shown in Figure 1-4. By adding the historical perspective on the landscape (Section 3.1), we will also be able to predict transport and accumulation of matter during succession and different management regimes.

Figure 1-4. *Aerial photograph of Laxemar subarea.*

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.
- Characterisation of running waters.
- Mapping of Quaternary deposits and soils.
- Marine geological investigations.
- Hydrological, hydrogeological and meteorological investigations.
- Inventories of peat lands and wetlands.
- Hydrogeochemical sampling and analysis of surface waters.
- Vegetation investigations at land, lakes and sea.
- Fauna inventories in lakes and sea.
- Mammal inventories in land.
- Establishment of and measurements in surface water level measurement stations.

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

The following section summarises the data that were available at the time of the Laxemar 1.2 site description and distinguishes data used and data not used in the modelling. The basis 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 them 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	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 in the terrestrial part of the Simpevarp regional model area	P-04-22 P-05-49 P-05-47	Description of surface distribution of Quaternary deposits in the terrestrial part of the Simpevarp regional model area Characterisation of bedrock and Quaternary deposits from excavations in the southern part of Laxemar subarea	3.3	
Maps of Quaternary deposits covering a large part of the sea bottom in the regional model area	P-04-254 P-05-35	Description of surface distribution of Quaternary deposits at the sea floor	3.3	
Map of soils in the terrestrial part of the Simpevarp regional model area	P-04-243 GIS database P-05-15	Distribution of soil types in the Simpevarp regional model area Soils and site types in the Oskarshamn area	3.3	
Stratigraphy and total depth of Quaternary deposits from the sea and lake floors	R-02-47 P-04-254 P-04-273 P-05-35	Description of stratigraphical distribution and total depth of Quaternary deposits at the sea floor	3.3	
Drilling and sampling of Quaternary deposits	P-03-80 P-04-22 P-04-121 P-04-317 P-05-49	Description of stratigraphical distribution and total depth of overburden in the terrestrial parts of the Simpevarp and Laxemar subareas	3.3	
Helicopter borne survey data	P-03-100	Description of surface distribution of Quaternary deposits in parts of the Simpevarp regional model area	3.3	The new map /P-05-49/ gives more accurate information
Electric soundings	P-03-17	Total depth of Quaternary deposits in the Laxemar and Simpevarp subareas	3.3	
Refraction seismic	P-04-134 P-04-201 P-04-298	Total depth of Quaternary deposits in the Laxemar and Simpevarp subareas	3.3	
Analytical data, including grain size, organic carbon, nitrogen, sulphur, soil pH and calcium carbonate.	P-04-243 P-04-273 P-05-49 R-05-15 R-02-47 SICADA	Chemical and physical properties of Quaternary deposit Soils and site types in the Oskarshamn area	3.3	
Meteorological data				
"Regional" meteorological data prior to the site investigations.	TR-02-03 R-99-70	Description of "regional" meteorological conditions.	3.4	

Meteorological data from Äspö (September 2003–June 2005 and Plittorp (July 2004–June 2005).	P-05-227	Comparison with "regional" meteorological data. Input to quantitative water flow modelling (MIKE SHE).	3.4	
Hydrological data				
"Regional" discharge data prior to the site investigations.	TR-02-03 R-99-70	Description of "regional" hydrological conditions (e.g. average regional specific discharge).	3.4	
Investigation of potential locations for hydrological stations.	P-03-04	Size of catchment areas for manual and automatic discharge measurements.	3.4	
Geometric data on catchment areas, lakes and water courses	P-04-242	Delineation and characterics of catchment areas, lakes, and water courses. Input to quantitative water flow modelling (MIKE SHE-MIKE 11).	3.4	
Manual discharge measurements in water courses.	P-04-13 P-04-75 P-04-246	Description of spatial and temporal variability of discharge.	3.4	
Surface-water levels in lakes and the sea	P-05-227	Description of spatial and temporal variability of surface-water levels.	3.4	
Surveying of water courses in catchment areas 6–9.	P-06-05	Input to quantitative water flow modelling (MIKE 11).	3.4	
Characterisation of running waters, including vegetation, substrate and technical encroachments.	P-05-40	Identification of "missing" (parts of) water courses. Interpretation of discrepancies between actual and model-calculated "flooded" areas.	3.4	"Missing" water courses and near-surface ditching/drainage operations will be included in future model versions.
Discrepancies between actual water courses and water courses in the SKB GIS database.	P-05-70	Identification of "missing" (parts of) water courses. Interpretation of discrepancies between actual and model-calculated "flooded" areas.	3.4	"Missing" water courses and near-surface ditching/drainage operations will be included in future model versions.
Hydrogeological data				
Inventory of private wells	P-03-05	General description of available hydrogeological information.	3.4	
Manually measured groundwater levels in QD.	P-05-205 SICADA	Description of spatial and temporal variability of groundwater levels in QD.	3.4	
Automatically measured groundwater levels in QD.	P-05-205	Description of spatial and temporal variability of groundwater levels in QD.	3.4	
Geological data from drilling in QD and installation of groundwater monitoring wells.	P-03-80 P-04-46 P-04-121 P-04-317	Conceptual-descriptive model of HSD geometry.	3.4	
Hydraulic conductivity from slug tests in groundwater monitoring wells in QD.	P-04-122 P-04-318	Conceptual-descriptive modelling of hydraulic conductivity in QD.	3.4	

Hydrogeological inventory in the Oskarshamn area.	P-04-277	General description of ditching-, draining- and other water related activities n the Simpevarp area.	3.4
Oceanographic data			
Regional oceanographic data	TR-02-03 R-99-70	Quantitative modelling	3.4
Chemistry data			
Surface water sampling	P-04-13 P-04-75	Characterisation and description of spatial and temporal variability of surface water chemistry	3.5

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

Available site data data specification	Reference	Usage in this work, analysis/modelling	Section in report	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 P-05-42	Description	3.7	
Mammal population survey	P-04-04 R-05-36	Description, modelling	3.7	
Amphibians and reptiles	P-04-36, /Andrén 2004a/	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	P-04-315	Modelling, shrub layer	3.7	
Biomass and NPP of the vegetation	P-05-80	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	
Ecosystem modelling	P-06-x, manuscript	COUP	3.7	
Limnic biota				
Limnic producers	P-04-242 P-04-253 P-05-40 P-05-173	Description, modelling	3.8	Neither the phyto-, nor the zooplankton data have been used in the ecosystem model, only the macrophyte data
Habitat borders	P-04-242	Description	3.8	

Limnic consumers	P-04-253 P-04-251 P-04-252	Description, modelling	3.8	
Marine biota				
Compilation of existing information 2002	R-02-10	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	No quantitative data
Macrophyte communities	P-03-69	Description, modelling	3.9	
Soft bottom infauna	P-04-17	Description, modelling	3.9	
Hard bottom infauna	(in press)	Description, modelling	3.9	
Reed	P-04-316	Description, modelling	3.9	
Fish sampling	P-04-19	Description, modelling	3.9	Investigation used to sample fish for future chemical analyses
Fish population estimates	In press	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	

Table 2-3. Reports in the SKB P, R, and TR-series referenced in Tables 2-1 and 2-2.

P-03-04	**Lärke A, Hillgren R.** Rekognoscering av mätplatser för ythydrologiska mätningar i Simpevarpsområdet (in Swedish).
P-03-05	**Morosini M, Hultgren H.** Inventering av privata brunnar i Simpevarpsområdet, 2001–2002 (in Swedish).
P-03-17	**Thunehed H, Pitkänen T.** Simpevarp site investigation. Electrical soundings supporting inversion of helicopterborne EM-data. Primary data and interpretation report.
P-03-68	**Tobiasson S.** Tolkning av undervattensfilm från Forsmark och Simpevarp (in Swedish).
P-03-69	**Fredriksson R, Tobiasson S.** Simpevarp site investigation. Inventory of macrophyte communities at Simpevarp nuclear power plant. Area of distribution and biomass determination.
P-03-80	**Ask, H.** Installation of four monitoring wells, SSM000001, SSM000002, SSM000004 and SSM000005 in the Simpevarp subarea. Oskarshamn site investigation.
P-03-83	**Boresjö Bronge L, Wester K.** Vegetation mapping with satellite data of the Forsmark, Tierp and Oskarshamn regions.
P-03-90	**Fridriksson, G, Öhr, J.** Assessment of plant biomass of the ground, field and shrub layers of the Forsmark area.
P-03-100	**Triumf C-A, Thunehed H, Kero L, Persson L.** 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. Oskarshamn site investigation.
P-04-03	**Brydsten, L.** A method for construction of digital elevation models for site investigation program at Forsmark and Simpevarp

P-04-04 **Cederlund G, Hammarström A, Wallin K.** Surveys of mammal populations in the areas adjacent to Forsmark and Oskarshamn. Results from 2003.

P-04-13 **Ericsson U, Engdahl A.** Surface water sampling at Simpevarp 2002–2003. Oskarshamn site investigation,

P-04-17 **Fredriksson R.** Inventory of the soft-bottom macrozoobenthos community in the area around Simpevarp nuclear power plant. Oskarshamn site investigation.

P-04-19 **Engdahl A, Ericsson U.** Fish sampling in connection with geophysical measurements at Simpevarp 2003.

P-04-20 **Andersson J.** Vegetation inventory in part of the municipality of Oskarshamn.

P-04-21 **Green M.** Bird surveys in Simpevarp 2003. Oskarshamn site investigation.

P-04-22 **Rudmark L.** Investigation of Quaternary deposits at Simpevarp peninsula and the islands of Ävrö and Hålö. Oskarshamn site investigation.

P-04-36 **Andrén Claes.** Oskarshamn site investigation, Amphibians and reptiles in SKB special area of investigation at Simpevarp.

P-04-46 **Ask, H.** Drilling and installation of two monitoring wells, SSM 000006 and SSM 000007 in the Simpevarp subarea. Oskarshamn site investigation

P-04-75 **Ericsson U, Engdahl A.** Surface water sampling in Oskarshamn – Subreport October 2003 to February 2004. Oskarshamn site investigation

P-04-121 **Johansson T, Adestam L.** Drilling and sampling in soil. Installation of groundwater monitoring wells. Oskarshamn site investigation.

P-04-122 **Johansson T, Adestam L.** Slug tests in groundwater monitoring wells in soil in the Simpevarp area. Oskarshamn site investigation

P-04-134 **Lindqvist G.** Refraction seismic measurements in Laxemar. Oskarshamn site investigation

P-04-201 **Lindqvist G.** Refraction seismic measurements in the water outside Simpevarp and Ävrö and on land on Ävrö. Oskarshamn site investigation

P-04-242 **Brunberg A-K, Carlsson T, Brydsten L, Strömgren M.** Identification of catchments, lake-related drainage parameters and lake habitats. Oskarshamn site investigation.

P-04-243 **Lundin, L, Björkvald, L, Hansson, J, Stendahl, J.** Surveillance of soils and site types in the Oskarshamn area. Oskarshamn site investigation

P-04-246 **Morosini, M, Lindell, L.** Compilation of measurements from manually gauged hydrological stations, October 2002–March 2004. Oskarshamn site investigation.

P-04-251 **Engdahl A, Ericsson U.** Sampling of freshwater fish. Description of the fish fauna in four lakes.

P-04-252 **Ericsson U, Engdahl A.** Benthic macro invertebrates. Results from sampling in the Simpevarp area 2004. Oskarshamn site investigation

P-04-253 **Sundberg I, Svensson J-E, Ericsson U, Engdahl A.** Phytoplankton and zooplankton. Results from sampling in the Simpevarp area 2003–2004. Oskarshamn site investigation.

P-04-254 **Ingvarson N, Palmeby A, Svensson O, Nilsson O, Ekfeldt T.** Oskarshamn site investigation, Marine survey in shallow coastal waters Bathymetric and geophysical investigation 2004.

P-04-273 **Nilsson, G.** Investigation of sediments, peat lands and wetlands. Stratigraphical and analytical data. Oskarshamn site investigation

P-04-277 **Nyborg M, Vestin E, Wilén P,** Oskarshamns site investigation. Hydrogeological inventory in the Oskarshamn area.

P-04-298 **Lindqvist, G.** Refraction seismic measurements in Laxemar autumn 2004. Oskarshamn site investigation

P-04-315 **Alling V, Andersson P, Fridriksson G, Rubio Lind C.** Estimation of biomass and primary production of birch. Birch biotopes in Forsmark and Oskarshamn.

P-04-316 **Alling V, Andersson P, Fridriksson G, Rubio Lind C.** Biomass production of Common reed (Phragmites australis), infauna, epiphytes, sessile epifauna and mobile epifaunal, Common reed biotopes in Oskarshamn's model area.

P-04-317 **Johansson, T, Adestam, L.** Drilling and sampling in soil. Installation of groundwater monitoring wells in the Laxemar area. Oskarshamn site invstigation

P-04-318 **Johansson, T, Adestam, L.** Slug tests in groundwater monitoring wells in soil in the Laxemar area. Oskarshamn site investigation

P-05-35	**Elhammer, A, Sandkvist, Å.** Detailed marine geological survey of the sea bottom outside Simpevarp. Oskarshamn site investigation**.**
P-05-40	**Carlsson, T, Brunberg, A-K, Brydsten, L, Strömgren, M.** Characterisation of running waters, including vegetation, substrate and technical encroachments. Oskarshamn site investigation
P-05-42	**Green M.** Bird monitoring in Simpevarp, 2002–2004, Oskarshamn Site investigations.
P-05-49	**Rudmark, L, Malmberg-Persson, K, Mikko, H.** Investigation of Quaternary deposits 2003–2004. Oskarshamn site investigation.
P-05-70	**Svensson, J.** Fältundersökning av diskrepanser gällande vattendrag i GIS-modellen. Platsundersökning Oskarshamn
P-05-80	**Löfgren A.** Estimation of biomass and net primary production in field and ground layer, and biomass in litter layer of different vegetation types in Forsmark and Oskarshamn. Oskarshamn/Forsmark site investigation.
P-05-173	**Aquilonius, K.** Vegetation in lake Frisksjön. Oskarshamn site investigation.
P-05-205	**Nyberg, G, Wass, E, Askling, P.** Groundwater monitoring program. Report for December 2002 – October 2004. Oskarshamn site investigation.
P-05-227	**Lärke, A, Hillgren, R, Wern, L, Jones, J, Aquilonius, K.** Hydrological and meteorological monitoring at Oskarshamn during 2003–2004. Oskarshamn site investigation.
R-99-70	**Lindell S, Ambjörn C, Juhlin B, Larsson-McCann S, Lindquist K.** Available climatological and oceanographical data for site investigation program.
R-02-10	**Berggren J, Kyläkorpi L.** Ekosystemen i Simpevarpsområdet – Sammanställning av befintlig information (In Swedish)
R-02-47	**Risberg J.** Holocene sediment accumulation in the Äspö area. A study of a sediment core.
R-04-11	**Miliander S, Punakivi M, Kyläkorpi L, Rydgren B.** Human population and activities at Simpevarp.
R-05-36	**Truvé J, Cederlund G.** Mammals in the adjacent areas to Forsmark and Oskarshamn, Population density, ecological data and carbon budget.
TR-02-03	**Larsson-McCann S, Karlsson A, Nord M, Sjögren J, Johansson L, Ivarsson M, Kindell S.** Meteorological, hydrological and oceanographical information and data for the site investigation program in the community of Oskarshamn.

3 Descriptive models

3.1 Historical description

3.1.1 Introduction

The Quaternary record gives information about past processes and climatic variations. The interpretation of this development is of fundamental importance when explaining the distribution of Quaternary deposits. This information can also be used when discussing future scenarios in the Simpevarp area. All results and interpretations that are discussed in this section have been obtained from investigations, which have been carried out within or in the surroundings of the Simpevarp model area.

3.1.2 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 of 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, Shackelton 1997/. The Quaternary period is subdivided into two epochs: the Pleistocene and the Holocene. The latter represents the present interglacial, which began 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 /Shackelton 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 of the glacial periods. 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 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 /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. Shackelton 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.

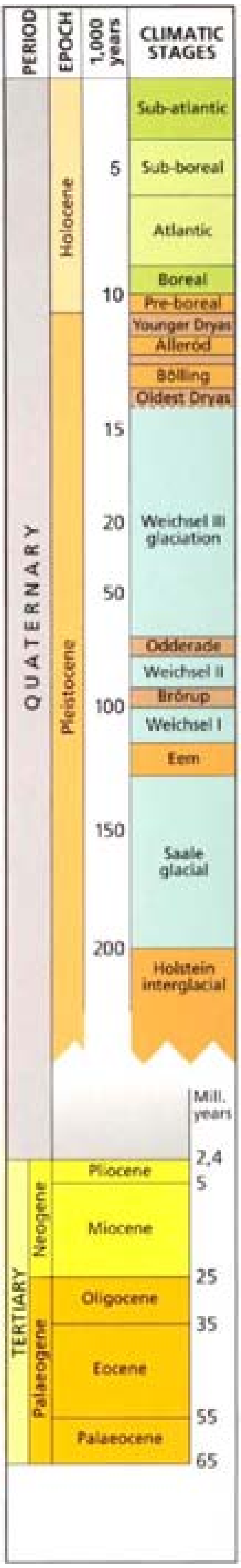

__Figure 3-1.__ The geological timescale showing the subdivision of the late Quaternary period with climatic stages from /Fredén 2002/. The ages approximate and given in calendar years before present From: Swedish National Atlas, www.sna.se.

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/. In Sweden the average erosion during the Quaternary period has been estimated to represent 12 m of fresh bedrock /Påsse 2004/. In the same report the average erosion of bedrock during one glacial cycle is estimated to be 1 m. 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.

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 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 Garcia 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, Holocene. The sea level was, at least periodically, higher then at present at large parts of the Swedish lowland was probably covered with brackish or marine water.

The latest glacial, the Weichselian started c 115,000 years ago. It was 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. The model presented by e.g. /Fredén 2002/ and /Lundqvist 1992/ is often used to illustrate the history of Weichsel (Figure 3-2). 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.

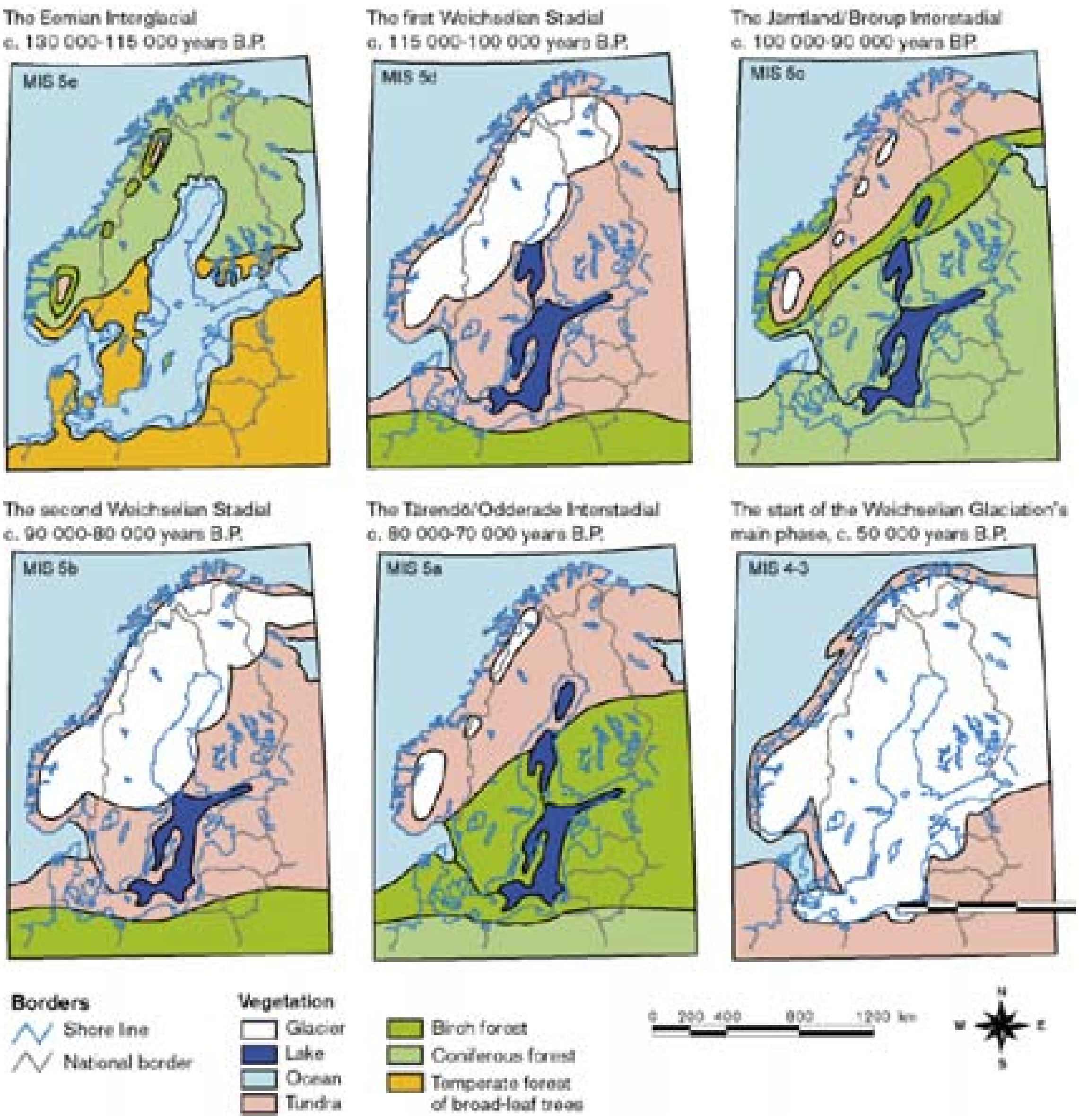

Figure 3-2. The development of vegetation and ice cover in northern Europe during the latest interglacial (Eem) and first half of the last ice age (Weichsel). The different periods have been correlated with the Major Isotope stages (MIS). The maps should be regarded as hypothetical due to the lack of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

Southern 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 agrees 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 the Mid Weichselian (c 70,000 years ago). Most of Sweden was thereafter covered by ice until the deglaciation. Parts of Skåne were, however, free of ice until a few thousand years before LGM.

The models presented by /Fredén 2002/ and /Lundqvist 1992/ have been debated (Figure 3-2). 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 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 /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 /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 maximum extent of the Weichselian ice sheet during MIS 2 approximately 20,000 years ago /from: Sveriges Nationalatlas, www.sna.se/.*

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 across Sweden are, however, problematic. In south-eastern 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 3-4a). The end of Younger Dryas marks the onset of the present interglacial, the Holocene. The ice retreated more or less continuously during the early part of the Holocene.

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 c 11,500 years ago the temperature increased and southern Sweden was first covered by forests dominated by *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), *Quercus* (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 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/.

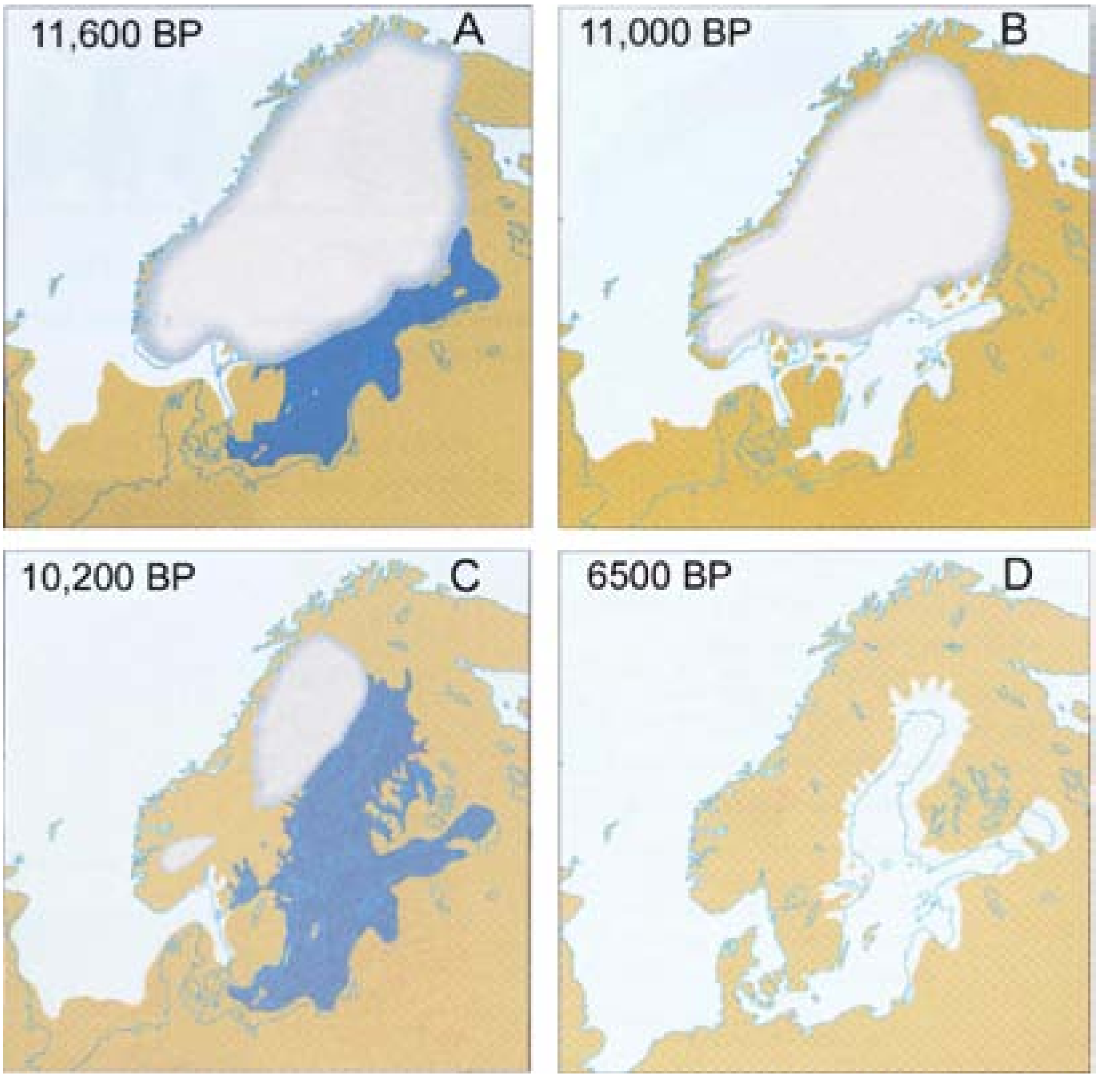

Figure 3-4. *Four main stages are characterising the development of the Baltic Sea since the latest deglaciation: a) the Baltic Ice Lake (15,000–11,550), b) the Yoldia Sea (11,500–10,800), c) the Ancylus Lake (10,800–9,500) and d) the Littorina Sea (9,500–present). Fresh water is symbolised with dark blue and marine/brackish water with light blue /from: Sveriges Nationalatlas, www.sna.se/.*

Development of the Baltic Sea after the latest deglaciation

A major crustal 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 at 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 had been depressed. The highest levels, nearly 300 m, are found along the coast of northern Sweden and sinks to levels below 20 m 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, melted ice and height of swell. 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. Freshwater conditions prevailed during most of the deglaciation of Sweden. Brackish conditions prevailed 11,300–11,100 years ago during the Yoldia Sea stage /Andrén et al. 2000/. The salinity in the open Baltic proper (south of Åland) varied between 10–15‰ during the brackish phase of the Yoldia Sea /Schoning et al. 2001/. The Baltic was thereafter characterised by freshwater conditions until the onset of the Littorina Sea around 9,500 years ago /Fredén 2002, Berglund et al. 2005/. Salinity was probably low during the first c 1,000 years of the Littorina Sea stage but started to increase 8,500 years ago. The salinity variations since the onset of the Littorina Sea have been summarised /Westman et al. 1999/ and is shown in Figure 3-5. The most saline period occurred 6,000–5,000 years ago when the surface water salinity in the Baltic proper was 10–15‰ compared with approximately 7‰ today /Westman et al. 1999/. Variations in salinity during the Littorina Sea stage has mainly been caused by variation of freshwater input and changes of the cross-section areas in the Danish Straits /cf Westman et al. 1999/.

The shoreline displacement in northern Sweden has been mostly regressive du 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 /e.g. Påsse 2001/.

Table 3-1. The four main stages of the Baltic Sea. The Littorina 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
Littorina Sea *sensu lato*	9,500–present	Brackish

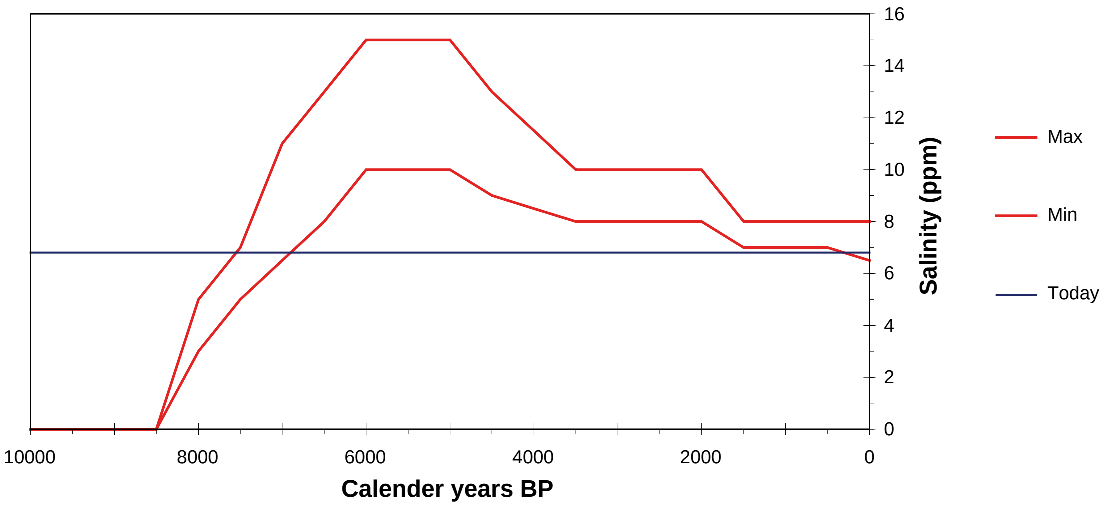

***Figure 3-5.** Salinity variations in the open Baltic proper outside Oskarshamn during the last 10,000 years /Westman et al. 1999/.*

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 SGUs mapping of Quaternary deposits in Västervik, c 40 km north of Simpevarp /Svantesson 1999/. It can therefore not be excluded that Quaternary deposits, older than the last glaciation, exist also in the Simpevarp area. Furthermore several sites with saprolites 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.

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 (Figure 3-2). 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 conditions 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^{-1} /Kristiansson 1986/. There are, however, indications of an ice marginal oscillation in the Vimmerby area /Agrell et al. 1976/ 40 km north-west of the regional model area. This 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 coastline in the Oskarshamn region is c 100 m above sea level /Agrell 1976/, and, thus the whole Simpevarp regional model area is situated below the highest coastline. In the Simpevarp region, shoreline regression has prevailed and the rate of land uplift during the last 100 years has been c 1 mm year^{-1} /Ekman 1996/.

The late Weichselian and early Holocene shoreline displacement in the Oskarshamn region has been studied with stratigraphical methods /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. There are no studies from the Oskarshamn area dealing with the shoreline displacement during the Littorina Sea stage.

Salinity variations in the open Baltic proper, outside Oskarshamn, since the onset of the Littorina Sea are shown in Figure 3-5. However, since the Simpevarp area has been situated close to the coast during most of the Littorina stage it can be assumed that salinity has been generally lower than what is shown in Figure 3-5. Results from a study c 100 km north of Simpevarp /Robertsson 1997/ suggest a regressive shoreline displacement during Littorina 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 Littorina time.

The estimated shoreline displacement since the last deglaciation has been reviewed and modified more recently by /Påsse 2001, Påsse 1997/ (Figure 3-6). 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/.

Pollen stratigraphical investigations from Blekinge show the succession of terrestrial plants in south-eastern 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 a 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.

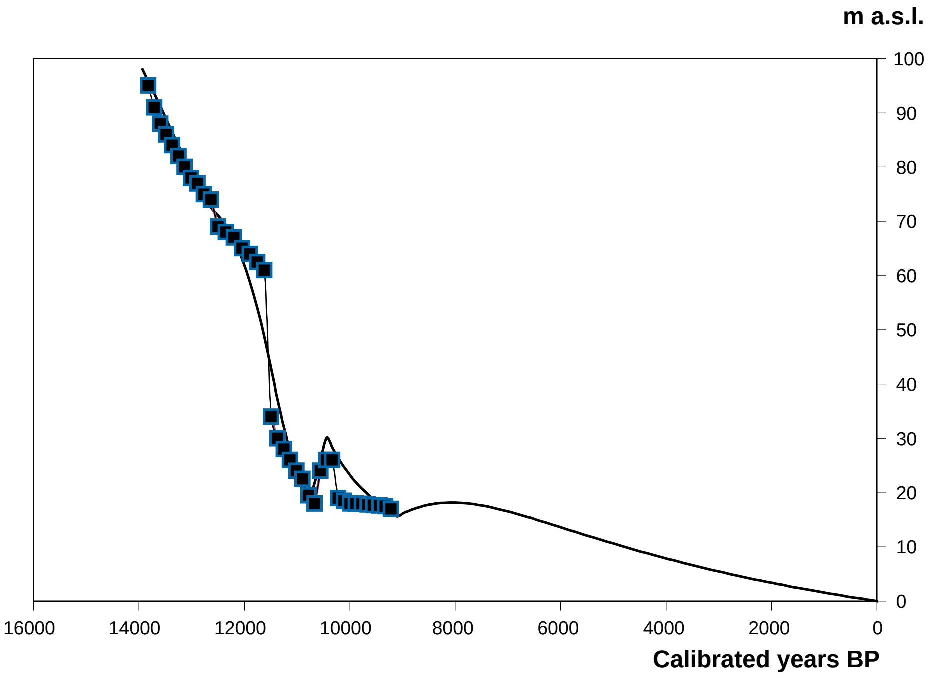

Figure 3-6. *The shore line displacement in the Oskarshamn area after the latest deglaciation. The blue symbols show a curve established by /Svensson 1989/ after a study of lake sediments in the region. The curve without symbols has been calculated by the use of a mathematical model /Påsse 2001/.*

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 south eastern 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), *Quercus* (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, has 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.

3.2 Geometry model DEM

3.2.1 Introduction

Many types of surface models – such as hydrological models and geomorphometrical models – use a DEM (Digital Elevation Model) as input data. DEM resolution is the size of DEM cells. DEM interpolates irregular spaced elevation data. In this model, we used the Kriging interpolation method. 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 predict 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.

Referenced to a common datum, a regular array of z-values allows a digital elevation model (DEM) to represent a continuous variable over a two-dimensional surface. Typically, digital elevation models describe terrain relief. Normally, a DEM has a constant value for sea surface (0 m above sea level) and constant values for lake surfaces. The DEMs for the Simpevarp area have negative values in the sea to represent the sea bottom level, but constant positive values for lake surfaces represent the lake elevations or varying values represent lake bottom elevations.

Input data for the interpolation have many different sources, such as existing DEMs, elevation lines from digital topographical maps, paper nautical charts, digital nautical charts, and depth soundings in both lakes and the sea. All data are converted to point values using different techniques. The Kriging interpolation was performed in ArcGis 8 Geostatistical Analysis extension.

3.2.2 Methods

Data catch from land areas

Two sources were used to collect elevation point data for land: the existing DEM from the Swedish national land survey (LMV) with a resolution of 50 m (Yellow areas in Figure 3-7) and the SKB DEM with a resolution of 10 m (Green areas in Figure 3-7) /Wiklund 2002/.

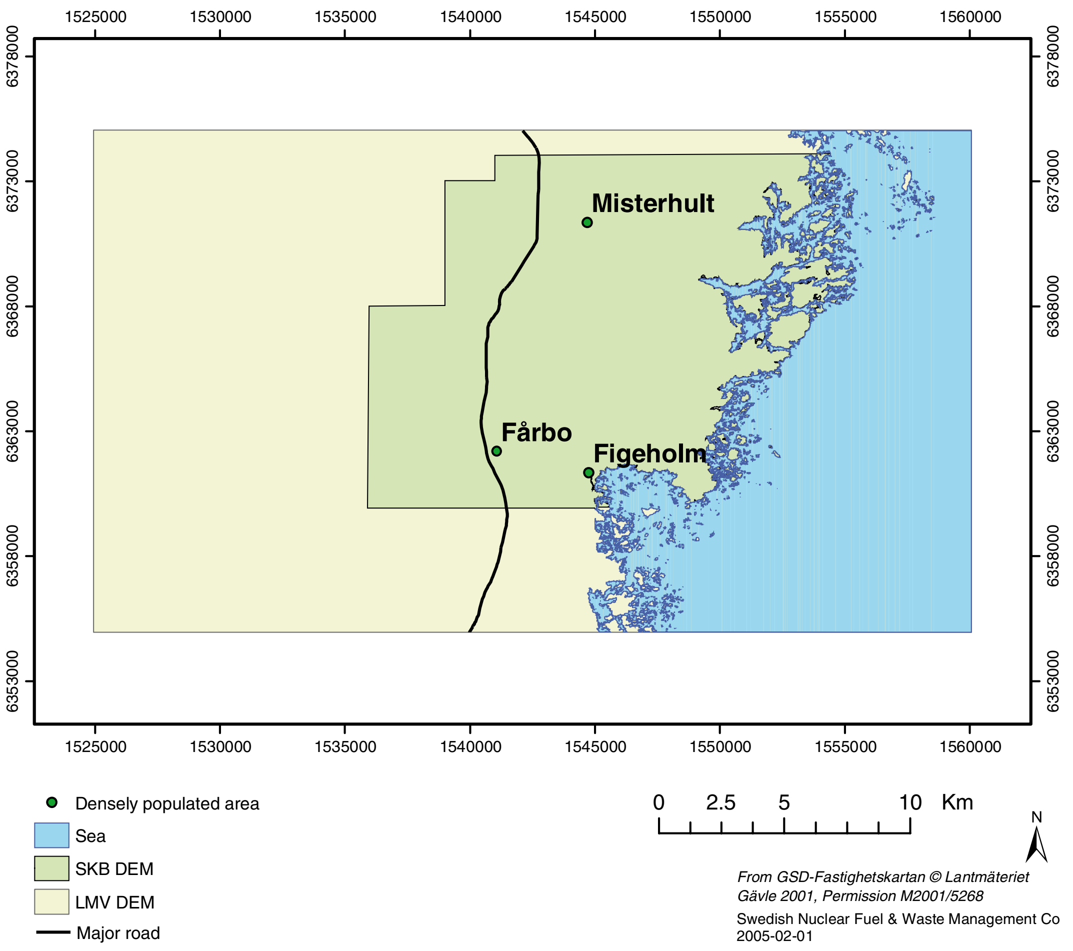

Figure 3-7. *Extensions of the LMV DEM and SKB DEM, respectively in the Laxemar area.*

The existing DEMs were converted to point layers in shape-format using ArcToolbox in ArcGis 8. The 10-metre model values for lake surfaces have errors. In Lake Frisksjön, for points situated at least 25 m from the shoreline the z-value has 41 unique values ranging from 2.01 to 2.56 m above sea level. Two values dominate these points – 2.31 in the western part of the lake and 2.09 in the eastern part. These areas are separated by a distinct straight north-south line that acts like a threshold in the lake surface at 0.22 m. This threshold seems to intersect with the border between two adjacent flying transects.

The same phenomenon exists in most of the lakes within the 10-metre model extension. All points placed within lakes with levelling measurements (Figure 3-8) were replaced by the measured values. It should be noted that these levels are not the mean lake levels but the levels at each measuring occasion. Because Lake Fjällgöl, in the centre of the map, has not been measured, the mean value for the elevation in the 10-metre model is used.

These two point-layers were merged into one single point layer, and all points placed on the sea surface polygon from the digital localities maps were deleted from the datasets. The final layer is in the Swedish national grid projection (RT 90 2.5 gon W) and in the Swedish national height system 1970 (RH 70).

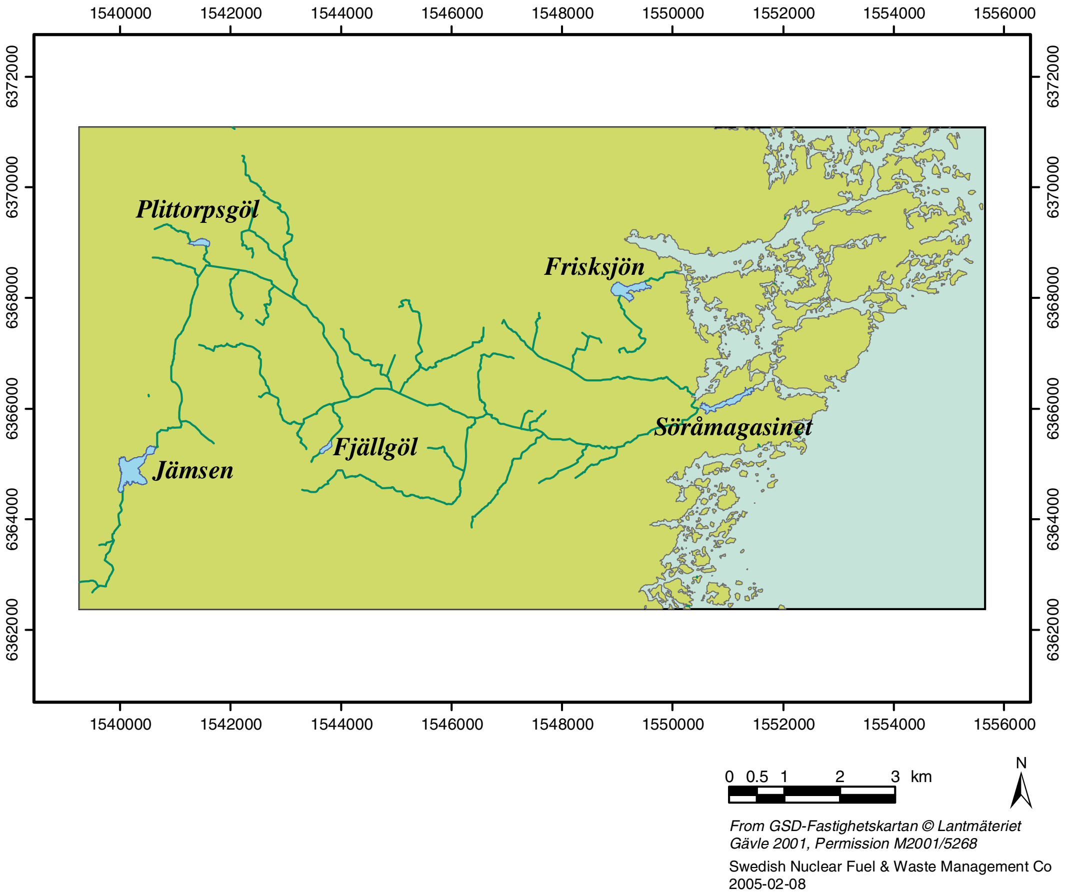

Figure 3-8. *Lakes in the Laxemar area where the SKB DEM points are replaced by measured values.*

Data catch from sea areas

Figure 3-9 shows the extensions for elevation data for the sea area. The elevations have been obtained from the following sources:

(i) the digital nautical chart (the Swedish Maritime Administration), blue area in Figure 3-9,

(ii) detailed depth soundings performed by the Geological Survey of Sweden, SGU /Elhammer and Sandkvist 2005/, yellow area in Figure 3-9,

(iii) regional depth soundings performed by the Geological Survey of Sweden, SGU /Elhammer and Sandkvist 2005/, black dots in Figure 3-9,

(iv) depth soundings of shallow bays performed by Marin Mätteknik AB (MMT), red area in Figure 3-9 /Ingvarson et al. 2004/,

(v) with DGPS measured shoreline points,

(vi) digitized shoreline points from IR orthophotos, and

(vii) the sea shoreline from the digital nautical chart.

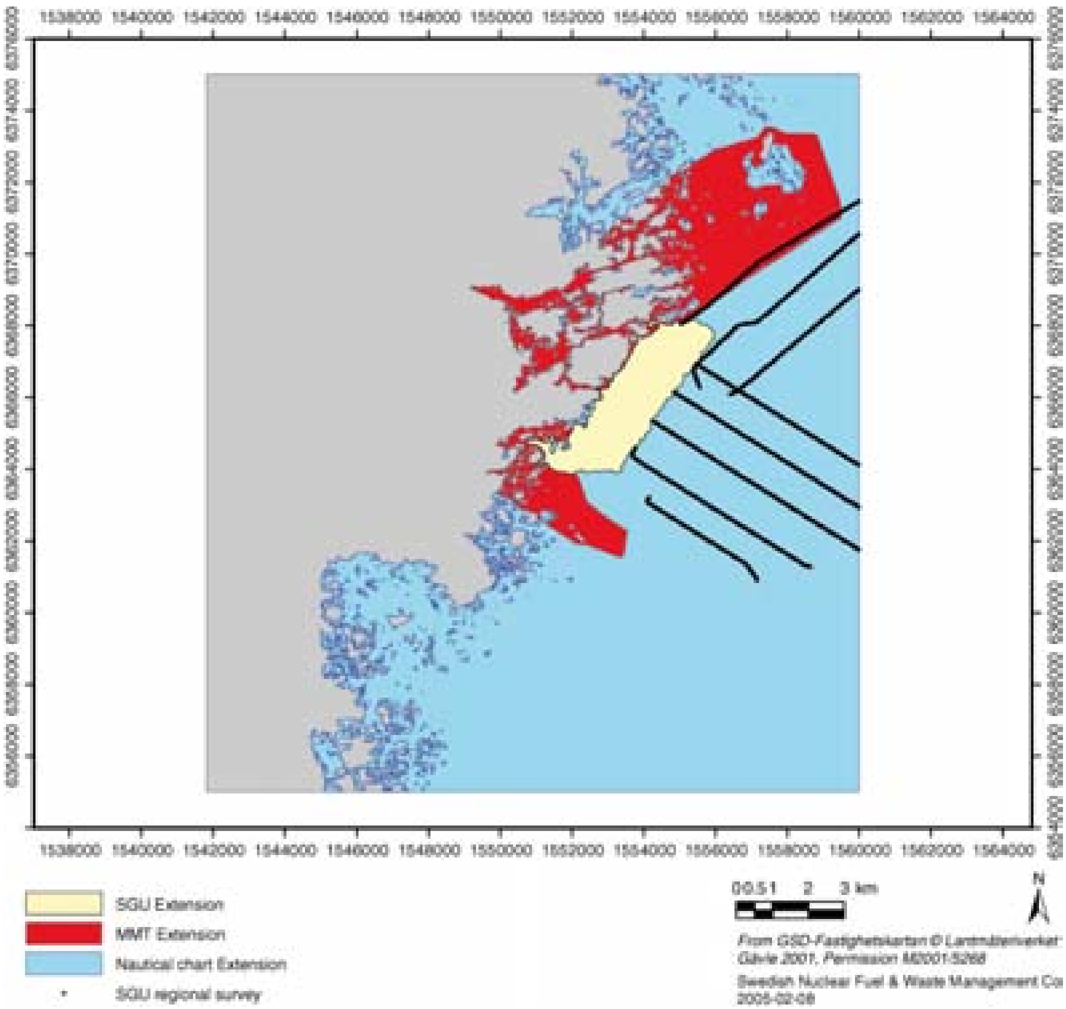

Figure 3-9. *Extensions for different data sources for the sea areas in the Laxemar area.*

The digital nautical chart has depth lines for 3, 6, 10, 15, 25, and 50 m. These line objects have been transformed into point objects in ArcView using the Avenue script LineToPoints.avx. The maximum distances between adjacent points were set to 5 m. 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 already stored as points. The water depth for "Stone in water surface" was set to –0.1 m and for "Stone beneath water surface" to –0.3 m. The total number of measurements is approximately 380,000.

The SGU depth soundings were delivered to SKB as 141 files in ASCII-format, generally one file for each transect in the survey /Elhammer and Sandkvist 2005/. The columns in the files consist of x-coordinates and y-coordinates with a resolution of 4 digits (0.1 mm) and a z-value with a resolution of two digits. The coordinate system is RT 90 and the z-values are corrected to RH 70. The ASCII-files were merged to one single comma separated ASCII-file using a small program written in Pascal. The total number of measurements is approximately 78,000.

The SGU depth soundings were not performed in the shallow bays due to size of the vessel. Therefore, a completing depth sounding using a small boat was performed by the company Marin Mätteknik (MMT) /Ingvarson et al. 2004/. The z-values (water depth) were recorded both with single and multi beam techniques. The total number of depth soundings in shallow bays is approximately 780,000 points.

Although a small boat was used in the shallow bay depth soundings, depth values are absent between the shoreline and approximately 0.7 water depth. When using the final DEM in modelling of the modern hydro-geological properties, the DEM of the sea shoreline must be very accurate. Therefore, a measurement of elevation points close to the present shoreline was performed.

There are four ways to obtain elevation points close to the sea shoreline:

(i) using the sea shoreline from the digital localities maps,

(ii) using the 0-line from the digital nautical chart,

(iii) manually digitizing the shoreline with the IR orthophotos as background, and

(iv) measuring the sea shoreline by walking the line with a DGPS.

The accuracy of the sea shoreline from the digital localities maps and the 0-line from the digital chart was tested using GIS and the IR orthophoto. The sea water level at the time for photographing was 0.06 m, so the distance between the digitized shoreline and the shoreline in RH 70 height system is small. The test shows that both the shorelines in the localities map and the nautical chart have low accuracies, but some localities have higher accuracy for the digital nautical chart. In addition, the test shows that low gradient shorelines are difficult to digitize using IR orthophotos if they are covered with reeds. Therefore, the most appropriate method for catching elevation data close to the zero level is to measure the sea shoreline by walking the line with a DGPS. This approach is too expensive to use for the whole area, so this was only performed for vegetated shores within the local model area that are difficult to observe using the IR orthophotos. The rest of the shorelines within the local model area were manually digitized with the IR orthophotos as background, and the sea shoreline from the digital nautical chart was used for the rest of the model.

During a post-processing procedure, each x/y-record was given a z-value using sea level data from a water level gauge in Oskarshamn. The time resolution of the gauge was one hour. The DGPS measurements were carried out during week 50 of 2004, and during this period the sea water level varied between +0.186 and +0.284 m in the RH 70 height system.

Handling data from overlapping data sources

Because some of the extensions of different point elevation data overlap, different tests were performed to determine whether both or only one of the datasets in the overlapping area should be used.

The tests are based on MMT depth soundings. They are estimated to be the most accurate for sea areas because these tests use modern equipment and use the SKB 10-metre model for land areas. The second most accurate depth measurements are estimated to be the SGU depth soundings. The five tests are as follows:

(i) the 10-metre model against the 50-metre model,

(ii) the digital nautical chart against MMT depth soundings,

(iii) the digital nautical chart against SGU depth soundings,

(iv) the SGU depth soundings against MMT depth soundings.

The point elevation data sets were joined against the MMT, SGU, or SKB 10 m point datasets. This GIS function (point to point join) gives a new attribute with the distance to the closest point in the join to dataset. Points in an actual data set with a distance shorter than 1 m were selected and the difference in z-value was calculated. If the dataset is classified as accurate as the join to dataset (one metre difference in XY-plane and one metre in z-value means at least a 45° slope), then the differences in Z-values are larger than one metre. This is a rare occurrence.

Based on the test results, the following datasets were used in the final interpolation procedure:

(i) when the 50-metres model overlapped the 10-metre model, only values from the 10-metre model were used,

(ii) when the digital nautical chart overlapped the SGU depth soundings, only the SGU dataset was used,

(iii) when the depth soundings of shallow bays overlapped the SGU depth soundings, both datasets were used, and

(iv) when the digital nautical chart overlapped the base map, only data from the base map was used.

There are also overlapping areas among different digital nautical charts. Three different charts are used in the data catch:

(i) digital chart number 624, an archipelago chart with scale 1:50,000,

(ii) digital chart number 6241, a special chart with scale 1:25,000, and

(iii) digital chart number 6241_Figeholm, a harbour chart with scale 1:5,000.

A comparison between the three charts shows that the degree of generalization increases from the harbour chart to the special chart, and even more from the special chart to the archipelago chart. Therefore, when the harbour chart overlaps the special chart, only data from the harbour chart is used. When the special chart overlaps the archipelago chart, only data from the special chart is used.

The total number of points in the merged point dataset after deletion of some of the overlapping datasets is approximately 3,330,000.

3.2.3 Results

Construction of the digital elevation models

All elevation point values were collected in two databases, and with these databases new digital elevation models were created, one representing land surface, lake water surface, and sea bottom, and one representing land surface, lake bottoms, and sea bottom.

The DEMs were created with a resolution of 10-metres. The interpolation from irregularly spaced point values to a regularly spaced DEM was done using the software ArcGis 8 Geostatistical Analysis extension. Kriging was chosen as the interpolation method /Davis 1986, Isaaks and Srivastava 1989/. The theoretical semivariogram model and the parameters scale, length, and nugget effect were chosen with the extension.

Because of the large size of the merged point file, it was impossible to construct the models by one single interpolation process. Therefore, the model was divided into 28 sub-models (Figure 3-10) that were processed one by one and finally merged together into one single model. Each sub-model was treated with regard to its conditions; i.e. different Kriging parameters were set to different sub-models.

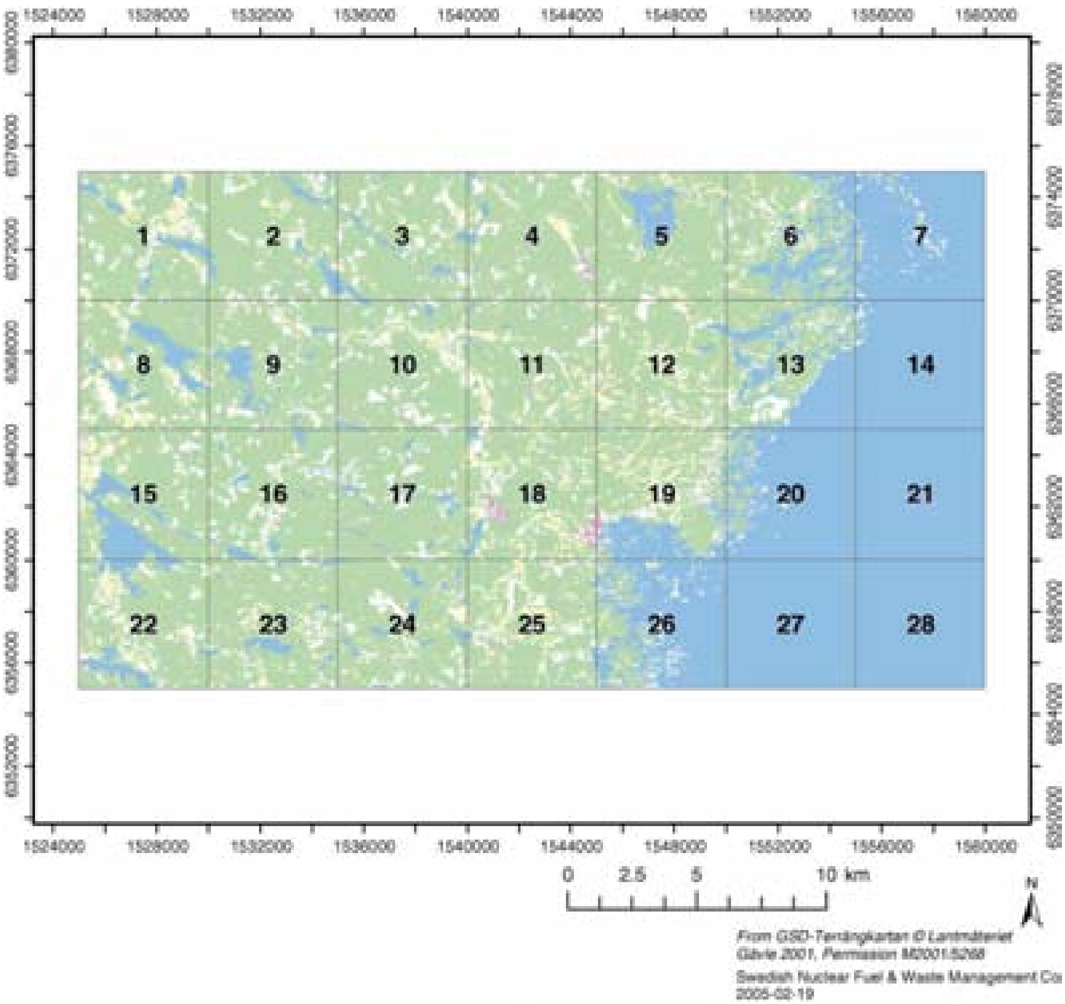

Figure 3-10. *The extensions of the 28 sub-models in the Laxemar area.*

Common to all sub-models are an Ordinary Kriging geostatistical method, a spherical theoretical model, and an elliptical search shape. The parameters that differ between different sub-models are the search size (the length of the major and minor semi-axis of the ellipses), the angle of the major semi-axis, the nugget value, the number of lags, and the lag size. Before the interpolations started, the models were validated both with cross-validation (one data point is removed and the rest of the data is used to predict the removed data point) and ordinary validation (part of the data is removed and the rest of the data is used to predict the removed data). Both the cross-validation and ordinary validation goals produce a standardised mean prediction error near 0, small root-mean-square prediction errors, average standard error near root-mean-square prediction errors, and standardised root-mean-square prediction errors near 1.

Cross validations with different combinations of Kriging parameters were performed until the standardised mean prediction errors were close to zero, but not necessarily the lowest values were always chosen. Because the aim was to determine the most valid model for both measured and unmeasured locations, care was taken to produce low values for the root-mean-square prediction errors and to minimise the difference between the root-mean-square prediction errors and the average standard errors. Different models were compared and the ones with the most reasonable statistics were chosen.

Finally, validations were performed with the most appropriate Kriging parameters in order to verify that the models fit unmeasured locations.

The quality of the digital elevation models

The validation procedure changed the Kriging parameters to minimise the prediction errors. The best combination of Kriging parameters is impossible to find, but the validation procedure was performed until only a minor change was noted by the prediction errors. The final choice of parameters is presented in /Brydsten and Strömgren 2005/.

Figure 3-11 shows the quality of the sub-grids as the values of root-mean-square prediction errors that should be low for a high quality grid. Sub-grids with low quality are those with only data from the digital nautical chart and those are also the sub-grids with lowest point density.

The coordinates of the starting point (upper left corner) were chosen so that the values from the SKB 10-metres 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-metre DEM. The digital elevation model with lake surface values is illustrated in Figure 3-12.

The final model had a size of approximately 35×20 kilometres, a cell size of 10-metre, 3,501 rows, and 2,001 columns: a total number of grid cells of 7,005,501 and a file size of approximately 28 MB (ESRI Grid format). The extent is 154995 west, 1560005 east, 6375005 north, and 6349995 south in the RT 90 2.5 Gon W coordinate system. As mentioned earlier, the height system is RH 70.

The area is undulating with narrow valleys situated at deformation zones in the bedrock. The range in elevation is approximately 151 m with the highest point at 106 m above sea level in the southwest part of the model and the deepest sea point at –45 m in the southeast part of the DEM. The mean elevation in the model is 24 m; 73% is land and 27% is sea. The flat landscape is also shown in the statistics of the slope grid where the mean slope is 2.79°, and 83.0% of the cells have slopes lower than 5° and 14.5% have slopes between 5 and 10°. As expected, almost all of the cells with slope steeper than 10° (2.5%) are slopes along the earlier mentioned narrow valleys or lakeshores.

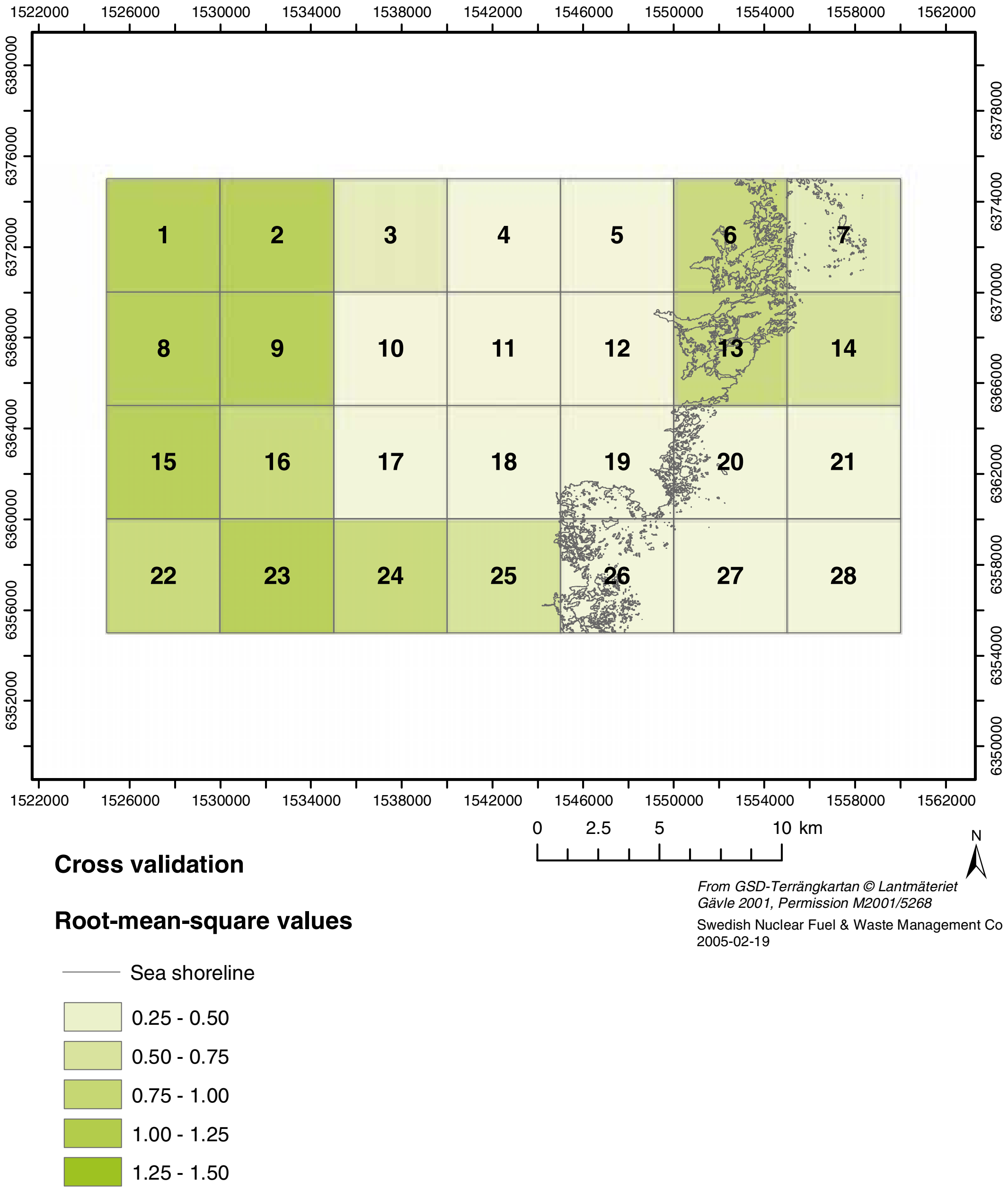

Figure 3-11. *Quality of the sub-models in the Laxemar area presented as the values of root-mean-square prediction errors.*

As a part of the quality control of the DEM, the DEM is simply looked at when displayed with different techniques, such as different classifying schemes or as images with different stretching values. Unfortunately, when displaying the DEM as image with maximum stretching value, the traces from the SGU regional survey can be observed as small darker circular areas (small local depressions) along strait traces (not shown in Figure 3-12). This phenomenon is an indication of errors in the DEM. As mentioned earlier, the depth soundings from SGU are treated as more accurate than the nautical chart, but deleting all the nautical chart values within the SGU regional survey area is not possible, although the distance between each trace in the SGU survey is as long as 1,000 m. We estimate that the local depressions is an existing phenomenon, but that they probably have too small extents. With shorter distance between traces in the SGU survey, many of the small depressions will be larger and fewer; i.e. they will be combined.

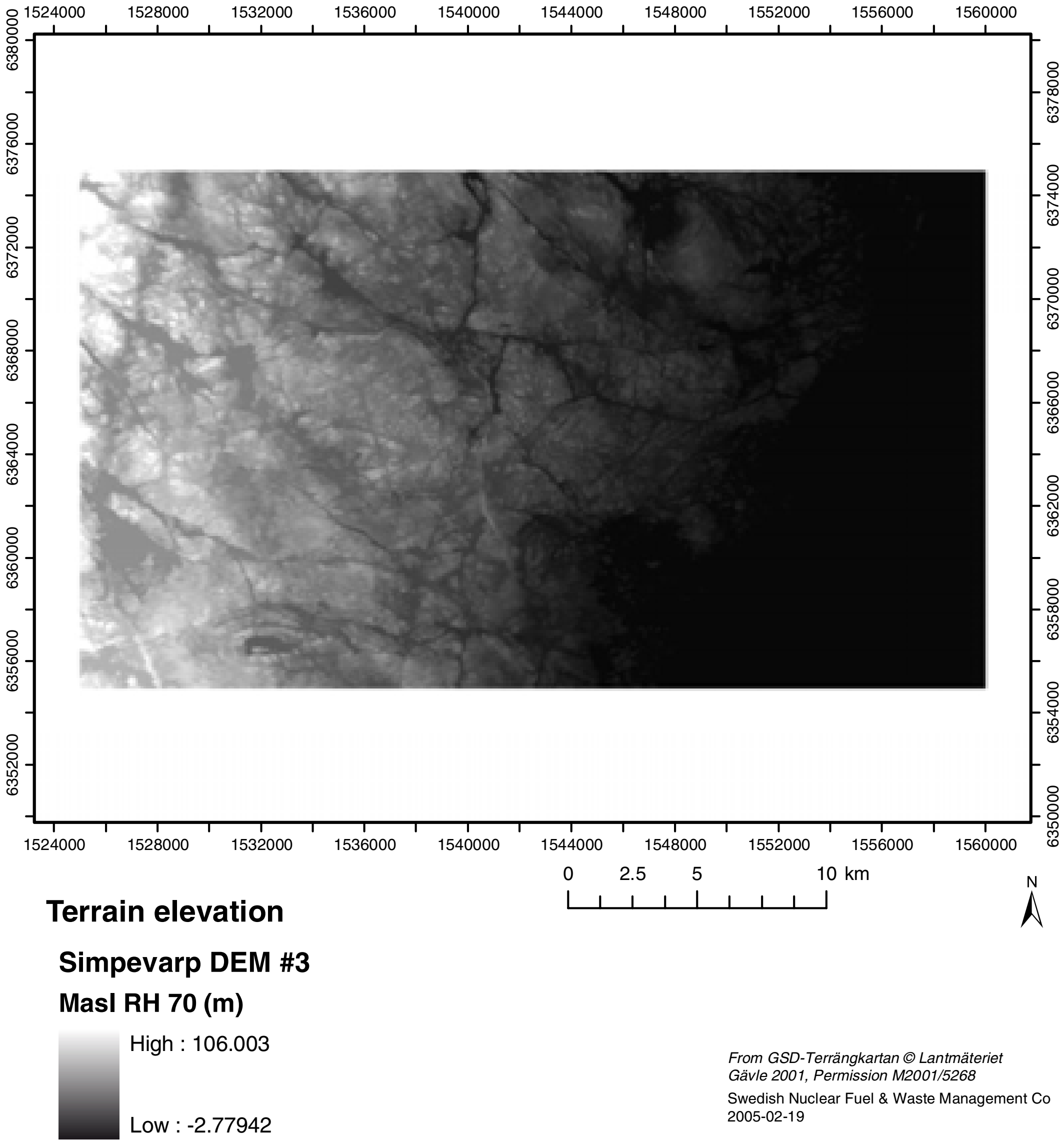

Figure 3-12. *The digital elevation model with land surface, sea surface, and lake sediment surface.*

3.3 Regolith (overburden)

3.3.1 Introduction

This chapter summarises the present knowledge regarding the overburden in the Simpevarp regional model area. The description includes maps, which show the surface and stratigraphical distribution of overburden in the whole model area. Available data concerning the physical and chemical properties of the overburden is also included. All known overburden in the area was formed during the Quaternary period, after or during the latest glaciation. The overburden is therefore at some places in the forthcoming text referred to as Quaternary deposits (QD).

The overburden models are and will be used as input for modelling hydrological, chemical and biological processes taking place in the uppermost geosphere. In the present report the overburden description is used for modelling the near surface hydrology (Section 3.4).

That model uses both the surface and depth distribution data of overburden. The total depth and stratigraphical distribution (simplified) of the overburden has been summarised in a model, which is further used in the hydrological models. The distribution of overburden in the discharge areas is of special interest since groundwater from the deeper bedrock may reach the surface through the overburden in these areas. Several of activities within the site investigation have and will therefore be focused on the distribution of overburden in wetlands and areas covered by water.

Results from soil and peat investigations are used for constructing a carbon budget for the Laxemar subarea (Section 4.4). In forthcoming reports the transport of elements (e.g. radionuclides) in the overburden will be modelled. The distribution of QD can be used for discussing potential future land use of the area. The studies of QD also improve the knowledge of the Late glacial and Holocen development in the Simpevarp area (Section 3.1).

3.3.2 Input data

The available amount of data concerning the overburden has increased significantly since the Simpevarp 1.2 description /Lindborg 2005b/ was produced. Since then the distribution of QD in most of the Simpevarp regional model area has been mapped, including areas covered by water. Data from studies dealing with the stratigraphical distribution and total depth (Figure 3-13) of the overburden has also increased significantly, especially in the Laxemar subarea.

Data concerning the overburden in the Simpevarp regional model area were collected during several activities. The results discussed in this report include:

- The surface distribution of QD and bedrock exposures in the Laxemar and Simpevarp subareas produced for presentation in the scale 1:10,000.
- The surface distribution of QD in the remaining parts of the River Laxemarån drainage area and around the glaciofluvial deposit, Tunaåsen, south of Fårbo (for the scale 1:50,000).
- An overview map of the QD in remaining parts of the Simpevarp regional model area.
- The superficial boulder frequency of the till and the effects of wave washing in the Laxemar and Simpevarp subareas and remaining parts of the Laxemar River drainage area.
- The direction of glacial striae on rock outcrops, which gives information on the direction of the ice movements during the latest glaciation.
- The horizontal and vertical distribution of QD on sea bottoms situated at water depths greater than 3 m (stratigraphical information from more than 19,000 sites).
- The horizontal distribution of QD at shallow bottoms and in the archipelago.
- Descriptions of soils from ten different land types. The soils were classified in eight profiles at two sites from each land type. The results were used to construct a soil map over the Simpevarp regional model area.
- Results of chemical analyses from the soil type investigation, which have been used to construct maps showing the distribution of soil organic carbon in the area.
- Results from 47 percussion bore holes and 17 cored bore holes to establish the total depth of Quaternary deposits.
- Results from 299 manually augered boreholes, weight soundings and trenches to establish the stratigraphy of the uppermost overburden.

- Stratigraphical data from the drillings of 38 monitoring wells.
- Stratigraphical information of peat and fine-grained sediments in lakes, shallow bays and wetlands. This data comprises altogether 21 cores from seven lakes/bays and seven cores from seven wetlands.
- The total depth of the overburden at altogether 22 sites obtained from vertical electrical sounding (VES).
- The total depth of overburden from refraction seismic measurements carried out in 31 profiles in the Laxemar and Simpevarp subareas.
- Analytical data, including grain size, bulk density, porosity, organic carbon, nitrogen, sulphur, trace elements, radionuclides, soil pH and calcium carbonate.

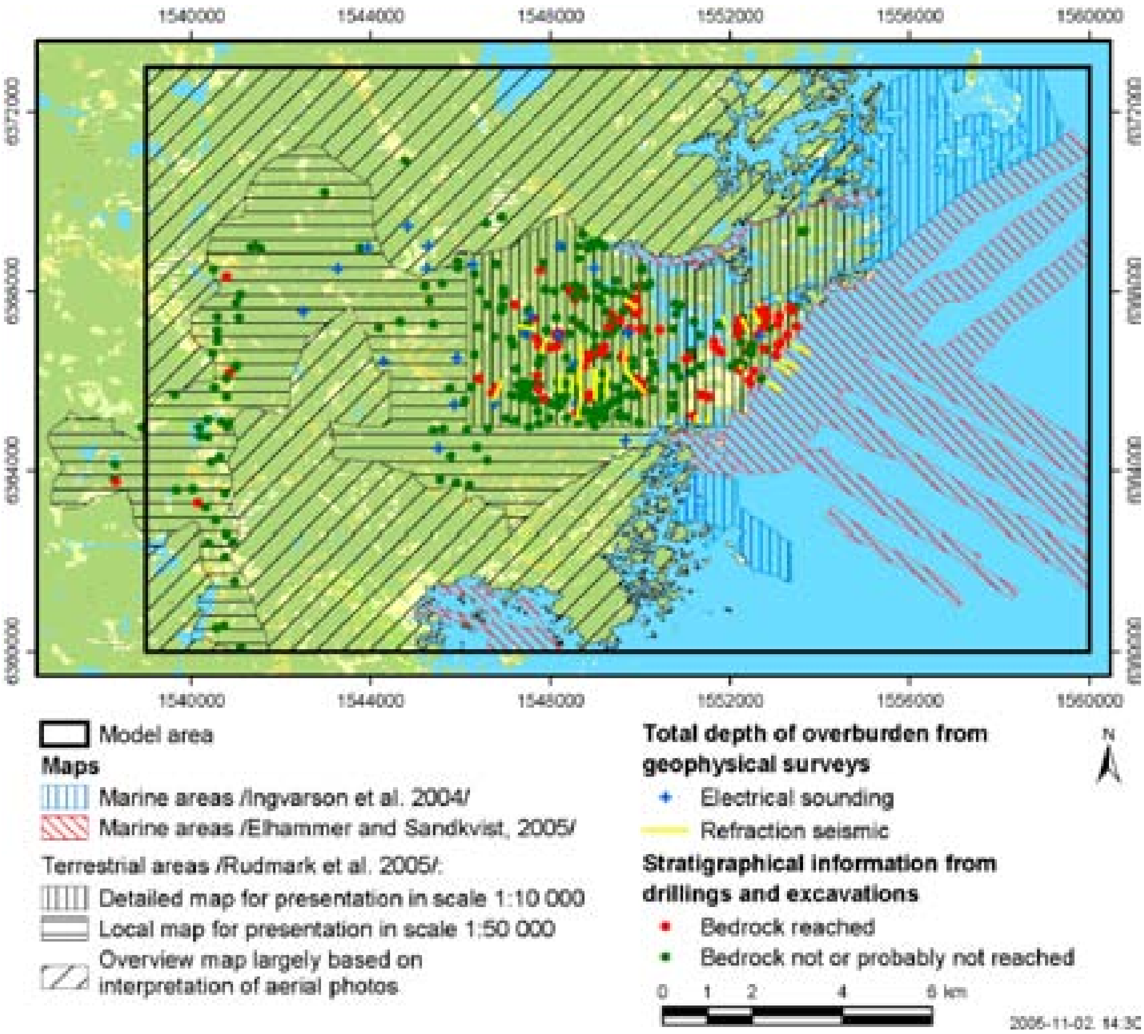

Figure 3-13. *Data used for modelling the surface and stratigraphical distribution of Quaternary deposits in the Simpevarp regional model area. I addition a soil map covering the whole terrestrial part of the regional model area has been produced by /Lundin et al. 2005/. Data from the marine areas mapped by /Elhammer and Sandkvist 2005/ include stratigraphy and total depth data of overburden from 19,237 points. The refraction seismic profiles include overburden depth data from totally 1,087 points.*

Data collected before the onset of the site investigation is also used and included:

- The total depth of glaciofluvial deposits in the Simpevarp regional model area (data from SGUs well archive).
- Geochemistry in peat and fine-grained sediments from Äspö and Borholmsfjärden.
- Depth of peat and fine-grained deposits in wetlands from the Laxemar subarea (22 cores), obtained during sampling of groundwater before the onset of the site investigation.
- Clay mineralogy and composition of siliceous microfossils in a sediment core sampled south of the island Äspö.

3.3.3 Methods and data evaluation

The methods used to map and determine the properties of the Quaternary deposits are shortly described in the forthcoming text. The section also includes evaluation of the data used in the models of the Quaternary deposits.

Quaternary deposits in the terrestrial part of the model area

Different methods were used during the mapping of QD in the Simpevarp regional model area (Figure 3-13). In the Laxemar and Simpevarp subareas QD were mapped for presentation in the scale 1:10,000. That means that the part of the map, which includes the two subareas, shows all identified bedrock exposures and QD that has a surface extension, which exceed 100 m^2. The remaining parts of the River Laxemarån drainage area and the glaciofluvial deposit, Tunaåsen, were mapped for presentation in the scale 1:50,000. (Figure 3-13). The smallest area is in general about 40×40 m. However, small observed bedrock outcrops have been symbolised with crosses. The same principle of classification has been used in the two areas. The area mapped with the two methods described above is referred to as the local area.

Remaining parts of the Simpevarp regional model area was also mapped for presentation in the scale 1:50,000. This part of the map is, however, to a large part based on interpretations of aerial photos, which only have been cheeked along the road net. A more generalised method of classification has been used in this area. It was not possible to access the areas around the village Värnamo. The distribution of QD in that area is therefore entirely based on interpretations of aerial photos.

Before the fieldwork started, aerial infrared photos were interpreted in order to identify different QD and bedrock outcrops. During the fieldwork, the information from the aerial photo interpretation was checked. New and correct boundaries showing exposed bedrock and the distribution of different QD at a depth of 0.5 m were drawn on the aerial photos. The till has, however, often a high frequency of stones and boulders and it is therefore difficult to check if the till layers overlying the bedrock exceed 0.5 m. Consequently it is likely that some of the areas mapped as till have a total overburden thickness of less than 0.5 m. Most areas mapped as bedrock lack a soil layer or are covered with a thin vegetation layer, e.g. roots and lichens. Thin layers (< 0.5 m) of predominantly till or peat may, however, occasionally occur in the areas mapped as bedrock. Peat areas with a thickness less than 0.5 m were also marked in field (e.g. peat overlaying gyttja clay).

The uppermost deposits were investigated using a spade and two different hand-driven probes. Stratigraphical investigations were carried out in 21 excavated trenches at localities with relatively thick overburden layers. These studies include description of bed geometry, sedimentary and deformational structures, lithology, sorting, particle roundness, colour etc. In order to determine from what direction the till was deposited, fabric analyses were made at two of these localities.

The stratigraphical distribution and the thickness of peat and fine-grained sediments were regularly determined to a depth of 1.5 – 2.5 m by hand driven boring (altogether 250 observations).

Grain size analyses, on material < 20 mm, were carried out on 27 samples. The grain size distribution of coarse material (20–0.063 mm) was determined by sieving and finer material with hydrometer /Standardiseringskomissionen i Sverige 1992ab/. The content of $CaCO_3$ in the till was determined (grain sizes < 63µ) using Passon apparatus /Almén and Talme 1975/.

During the mapping of QD, glacial striae directions were observed and measured at about 130 localities.

There were certain difficulties in mapping of QD:

- The superficial boulder frequency of the till varies throughout the area. It is, however, sometimes difficult to delineate surfaces with a certain boulder frequency.
- In areas with an extremely high boulder frequency, it is difficult to separate weathered and cracked bedrock surfaces from till surfaces with very high boulder frequency.
- It is difficult or impossible to separate the sandy till from the gravelly till in the field without extensive investigations. Therefore, all till areas are shown as the most common till type, sandy till.
- At some sites it was difficult to distinguish till boulders and stones from boulders and stones re-deposited by waves or sea ice.

Marine geology

In the area close to the Simpevarp peninsula and Ävrö the data was collected from boat in lines with a spacing of 100 m and further out in the regional Simpevarp area with a spacing of 1 km /Figure 3-18 in Lindborg 2005b/.

Surveying in areas with greater water depths than 6 m was made from S/V Ocean Survey, whereas a smaller boat was used at water depths between 3 and 6 m /Elhammer and Sandkvist 2005/. The areas close to the coast and in the archipelago was to a large part investigated within another activity /Ingvarson et al. 2004; see below/. 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. Thin surface layers of e.g. sand are also mapped.

The results from the reflection seismic were used to calculate the stratigraphy and thickness of till, glacial clay, post-glacial clay and post-glacial sand (data from almost 20,000 points). These results were also used to estimate the total thickness of QD.

The post-glacial clay often contains gas, which obstructs penetration with the seismic method. It has therefore not been possible to determine the stratigraphy and total depth of QD in many areas with post-glacial sediments.

Coastal areas

/Ingvarson et al. 2004/ investigated the coastal area and archipelago in the regional model area. In areas with a water depth exceeding 3 m a fully equipped survey vessel was used. A smaller vessel was used to survey the shallow areas. An offset of 80 m was used during the survey with the large vessel. The sea bottom was investigated with multi beam echo sounder side scan sonar and shallow seismic. The sediment stratigraphy and depth was recorded with the multi beam echo sounder. It was not possible to penetrate the till or hard sediments (e.g. gravel) with echo sounder. The stratigraphical information from this investigation can therefore only be used to estimate the thickness of sand and clay.

Stratigraphical information from the terrestrial areas

Stratigraphical information was obtained from weight sounding and soil/rock drillings /Johansson and Adestam 2004c/. The soil/rock drillings give information about the stratigraphy and total thickness of Quaternary deposits. The weight soundings do not give information about the total thickness of Quaternary deposits 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 collect information regarding the spatial variations of the stratigraphy of the uppermost overburden.

During the soil/rock drillings, samples 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 layers. At some of the drill sites groundwater monitoring wells have been installed.

Refraction seismic measurements were carried out in areas with a low frequency of exposed bedrock /Lindqvist 2004abc/. The results give information about the total depth of overburden. These results were used for determine the locations of trenches, which were used for detailed studies of QD and underlying bedrock.

A helicopter borne geophysical survey was carried out during 2002 /Triumf et al. 2003/, which covers large parts of the Simpevarp regional model area. The geophysical investigations do, however, not include the large glaciofluvial esker (Tunaåsen) in the western part of the regional model area. Electromagnetic (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 m. It can therefore be assumed that these data includes the electrical properties of all the overburden in the area. The EM data has been used to calculate the relative thickness of the overburden in areas with overburden thicker than 2.5 m.

Vertical electrical soundings (VES) were carried out on the ground to obtain information about the electrical resistively of the overburden /Thunehed and Pitkänen 2003/. The purpose of that investigation is to calibrate the EM data collected 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, but cannot 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. These data are therefore not used in the overburden depth model, which is presented in /Nyman 2005/ and in Section 3.3.5. The forthcoming investigations (e.g. soil/rock drillings and machine-dug trenches) will give more information about the total depth of overburden in the area. The EM data can then hopefully be useful in forthcoming overburden depth models.

Sediment and peat in shallow bays, wetlands and lakes

The thickness and stratigraphical distribution of peat and water laid fine-grained sediments in shallow bays, wetlands and lakes in the Simpevarp regional model area has been investigated by /Nilsson 2004/. The sediments were sampled with a hand operated Russian peat corer. The surface sediments were further sampled with a Willner gravity corer and an Ekman dredge. The Willner corer was used for retrieving undisturbed samples, which will be used for studies of the historical development of the lakes.

Altogether 69 samples were analysed for the total contents of carbon, nitrogen, sulphur, hydrogen and calcium carbonate. The grain size composition was determined on 64 samples.

The present report also includes stratigraphical information about peat and fine-grained deposits from 19 additional sites in wetlands. This information was collected before the onset of the site investigations /Laaksoharju and Gurban 2002/. That investigation was carried out to investigate the possible interactions between deep groundwater and biosphere.

Soil types

Soils from 10 different land types /Figure 3-17 in Lindborg 2005b/ were studied within the Simpevarp regional model area /Lundin et al. 2004a/. The land types were defined based on vegetation, land use, and wetness. Classifications of soil and Quaternary deposits were carried out in eight spade-dug profiles at two sites from each land type.

The aim of the soil type classification is to define soils with special properties, which then can be compared with soils from other areas. The soils were classified according to /WRB 1998/. The 2-3 uppermost soil horizons were sampled and analysed for pH, organic carbon, nitrogen and calcium carbonate.

The previous soil map /Lundin et al. 2005/ has been updated with the map of Quaternary deposits /Rudmark et al. 2005/ and in addition some changes were made in the soil map class definition. The new definition especially involved thin soils and bedrock, which previously underestimated the amount of exposed bedrock and thin soils in relation to thicker soil deposits. The new definition includes one class for exposed bedrock (Bedrock) and another for a mosaic of bedrock and thin soils frequently found in the Oskarshamn area (LP). The class names are in accordance with the Soil Classification /WRB 1998/, although they often embrace two WRB classes, in order to describe the special conditions in the area.

Besides the map of Quaternary deposits the classification was also based on vegetation maps (tree, field and ground layer), the topographical wetness index, and distance to the sea /Lundin et al. 2005/.

In the work to characterise the soils in the Oskarshamn area data was collected to calculate the carbon stocks for each dominant soil class. The soil carbon pools for each soil layer were calculated and added together using the following formula:

$$C_{pool} = \sum_{\text{i=soil layer}} (C_{conc}/100) \times BD \times DEPTH_i \times (1 - C_{stone}/100)$$

where C_{pool} is the carbon pool (kg m^{-2}), C_{conc} is the carbon concentration (%), *BD* is the bulk density (kg m^{-3}), *DEPTH* is the layer depth (m), and C_{stone} is the stone content (%).

The properties of the Quaternary deposits have a large effect on the soil forming processes. The maps of Quaternary deposits were therefore used together with other information (e.g. land use and vegetation maps) to produce a soil map covering the Simpevarp regional model area (Figure 3-23). Maps of organic carbon, nitrogen and pH in the different soil horizons were produced with the same method. Since the most detailed maps of Quaternary deposits cover the Laxemar River drainage area the reliability of the maps is higher in that area compared to remaining parts of the regional model area. Furthermore, when the maps were produced the QD map was not completed in the areas outside the Laxemar River drainage area.

Table 3-2. The soil types and abbreviations used on the soil map. The definitions of these soil types are described in Section 3.3.4.

Soil type	Abbreviation	Land type
Leptosol	LP	Rock Outcrops and thin soils, mostly coniferous forest
Podzol/Regosol	PZ/RG	Rock Outcrops and till, mostly coniferous forest
Podzol/Regosol (on glaciofluvial material)	PZ/RG-e	Glaciofluvial deposit (esker), mostly coniferous forest
Umbrisol-Regosol	UM/RG	Deciduous forest
Umbrisol-Gleysol	UM/GL	Meadow
Histosol, (forested peatlands)	HI-d	Drained peatlands covered by forest
Histosol (wet peatlands)	HI-w	Wetland covered by peat
Histosol (open wetland)	HI-a	Arable land on peat
Histosol (small peatlands)	HI-s	Small wetlands surrounded by exposed bedrock
Regosol/Histosol (shoreline areas)	RG/HI	Shore
Umbrisol/Gleysol, arable land	UM/GL-a	Arable land on minerogenic soil

3.3.4 Conceptual model

One aim of the results presented here is to construct models of the surface and stratigraphical distribution of the overburden in the Simpevarp regional model area. Another aim is to characterise the chemical and physical properties of the QD in the model area.

The overburden includes marine and lacustrine sediment and peat. Knowledge of the composition of the overburden is of 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 and is therefore referred to as Quaternary deposits (QD). In the Simpevarp area the latest deglaciation occurred c 14,000 years ago /Lundqvist and

Wohlfarth 2001/. Due to the pressure of the inland ice large parts of Sweden, including the whole Simpevarp regional model area, were covered by Baltic Basin water after deglaciation. The highest altitude covered by water in an area is referred to as the highest coastline.

The QD are subdivided in two main groups according to genesis and depositional environment: glacial and post-glacial deposits.

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

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

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 commonly well sorted with respect to grain size. The glacial clay and silt were mainly deposited at the deepest bottoms below the highest coastline. The glaciofluvial deposits generally 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. Clay, organic sediment, peat and re-deposited sand and gravel dominate the post-glacial deposits. Processes forming post-glacial deposits have continuously been active since the latest deglaciation.

Post-glacial clay was deposited after erosion and re-deposition 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.

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.

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. The peatlands are often subdivided into fens and bogs. The vegetation in the fens gains nutrients from the groundwater whereas a bog gains nutrient mainly from precipitation. The bogs are therefore poor in nutrients and are characterised by a coherent cover of *Sphagnum*-species.

There is no evidence of glacial deposits in the Simpevarp regional model area older than the latest glaciation. Older glacial till and fluvial sediment were, however, found during SGUs mapping of Quaternary deposits in Västervik, c 40 km north of Simpevarp /Svantesson 1999/. It can therefore not be excluded that Quaternary deposits, older than the latest glaciations, exist also in the Simpevarp area.

The typical stratigraphical distribution of Quaternary deposits in areas below the highest coastline is shown in Figure 3-14. The present investigations suggest that overburden in the Simpevarp area is distributed in a similar way (see below). For a thorough description of the genesis and distribution of QD in Sweden the readers are referred to /Lindström et al. 2000/ and /Fredén 2002/.

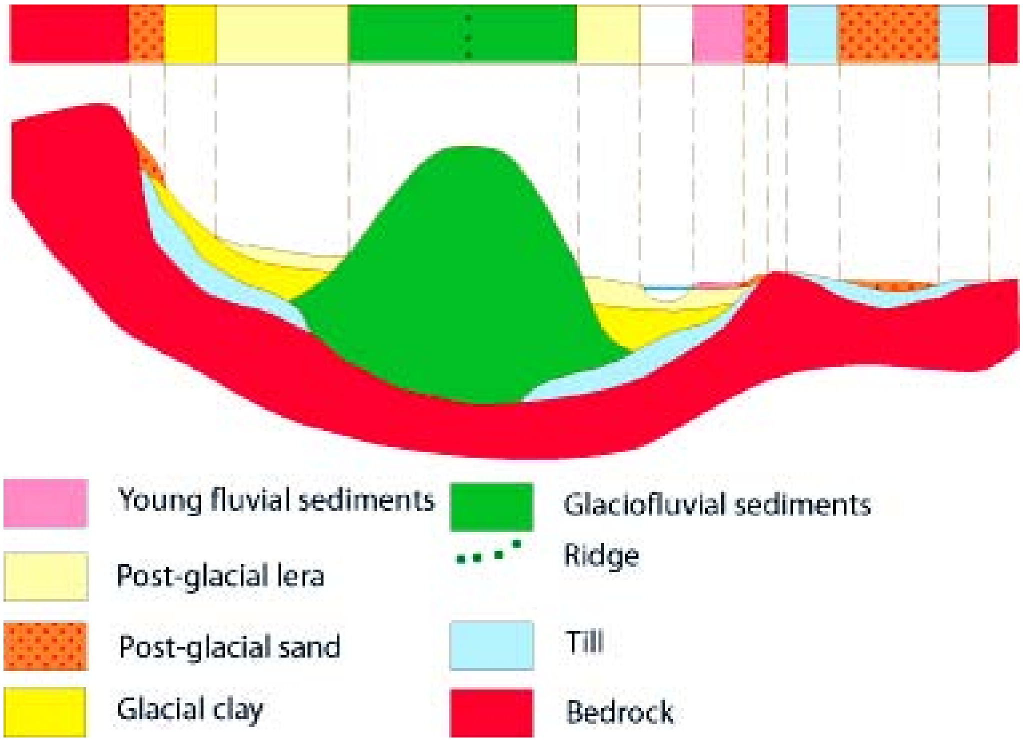

Figure 3-14. *A typical stratigraphical distribution of QD below the highest coastline. The present results imply that the QD in the Simpevarp area have a similar stratigraphy. It is, however, possible that the results from forthcoming drillings and excavations will modify this model.*

The Bedrock

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. Large parts of the Simpevarp regional model area consist of bedrock outcrops. The mineralogical composition of the local bedrock is most probably reflected in the nearby composition of the till. The mineralogy of the bedrock is therefore of importance not only for the areas with rock outcrops but also for the soil chemistry in the till. There is a detailed bedrock map covering the Simpevarp and Laxemar subareas with surroundings /Wahlgren et al. 2005/. Data concerning the mineralogical and bedrock composition of the overburden will be included in forthcoming descriptions.

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 many 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:

Bedrock

This class consists of bedrock outcrops, with a tree layer that is missing or consists of sparse pines, and a field layer of dry heath type. This class was assigned to bedrock areas with a field layer of dry heath type.

LP: Leptosol

This class covers a mosaic of bedrock outcrops and thin soils typically found in upslope locations in the area. The proportion of bare rock versus Leptosol soil is approximately 50/50 within this class. This class was assigned to bedrock areas with an existing tree layer except those areas with a field layer of dry heath type.

PZ/RG: Podzol/Regosol

This class consists of thin coniferous forest soils found on till and course sediment soil with fresh soil moisture class. This class was assigned to areas with course mineral soil according to the quaternary deposit. The criteria were further a tree layer of conifer trees and no arable land or meadows.

RG: Regosol

This class is found on the esker in the western part of the area with fresh or partly dry soil moisture class. The tree layer is dominated by pine. This class was assigned to areas located on glacifluvial deposits except those on arable and other open land.

UM/RG: Umbrisol-Regosol

This class consists of deciduous forest soils with fresh soil moisture class. Deciduous trees dominate the tree layer together although some mixed forests occur. This class was assigned to areas with till or course sediment soil and a tree layer consisting of deciduous or mixed trees. All arable land and meadows were excluded.

UM/GL: Umbrisol-Gleysol

This class include open pastures and partly forested moist soils in downslope locations. This class was assigned areas with ground layer of pasture and meadow type and areas with a high TWI value (> 9.5) on mineral soil parent material. Also, non-arable soil on clay and silt deposits was included in this class.

HI-w: Histosol, wetland

This class covers open wetland peat soils. This class was assigned to peatland areas with the exception of areas with any type of forest cover as well as arable land and meadows.

HI-f: Histosol, forested

This class consists of forest-covered drained peatland soils. These soil are often forested with monocultures of spruce in the area. This class was assigned to all peatland areas, which also had a forest cover. Arable land or meadows were excluded.

HI-a: Histosol, arable

This class consists of arable drained peatland soils. This class was assigned areas with peat according to the quaternary deposits were the ground layer was arable land or meadows.

HI-s: Histosol, small

This class cover small peatland areas, which are formed in small depressions in the bedrock areas. The method for assigning areas to this class was different from the other classes. Among the areas with peatland according to the quaternary map objects that were smaller than 5,000 m^2 and a TWI value smaller than 9.5 were selected. This located small peatland areas with a small catchment area.

RG/HI: Regosol/Histosol

This class is found along the sea shoreline and is influenced by the closeness to water. The class is a mixture of mineral Regosol soils and organic Histosol soil. This class was assigned to shoreline areas along the coast and formed a 10 m wide (one pixel) zone. Shoreline areas located on coastline bedrocks were not included in this class.

UM/GL-a: Umbrisol/Gleysol, arable

This class covers arable land on fine textured sediment soils. This class was assigned to areas with clay or silt deposits according to the map of quaternary deposits and arable land type according to the ground layer.

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

3.3.5 Results

Results from the investigations of QD in the Simpevarp regional model area are described below. Some of these results have been used to construct a model showing the stratigraphy and total depth of overburden in the whole Simpevarp regional model area.

Bedrock

The bedrock within the Simpevarp subarea mainly consists of Ävrö granite, quartz monzodiorite and fine-grained dioritoid (Figure 3-15). All over the Simpevarp subarea small areas with diorite to gabbro occur. Also in the Laxemar subarea granite and diorites dominate the bedrock distribution 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. The glacial till in the Simpevarp model area probably consists of fragments from the local bedrock (see below). It is therefore possible that the areas with diorite to gabbro have locally different soil chemistry (e.g. higher concentrations of plant available nutrients), which may have resulted in richer vegetation in these areas. The possible relation

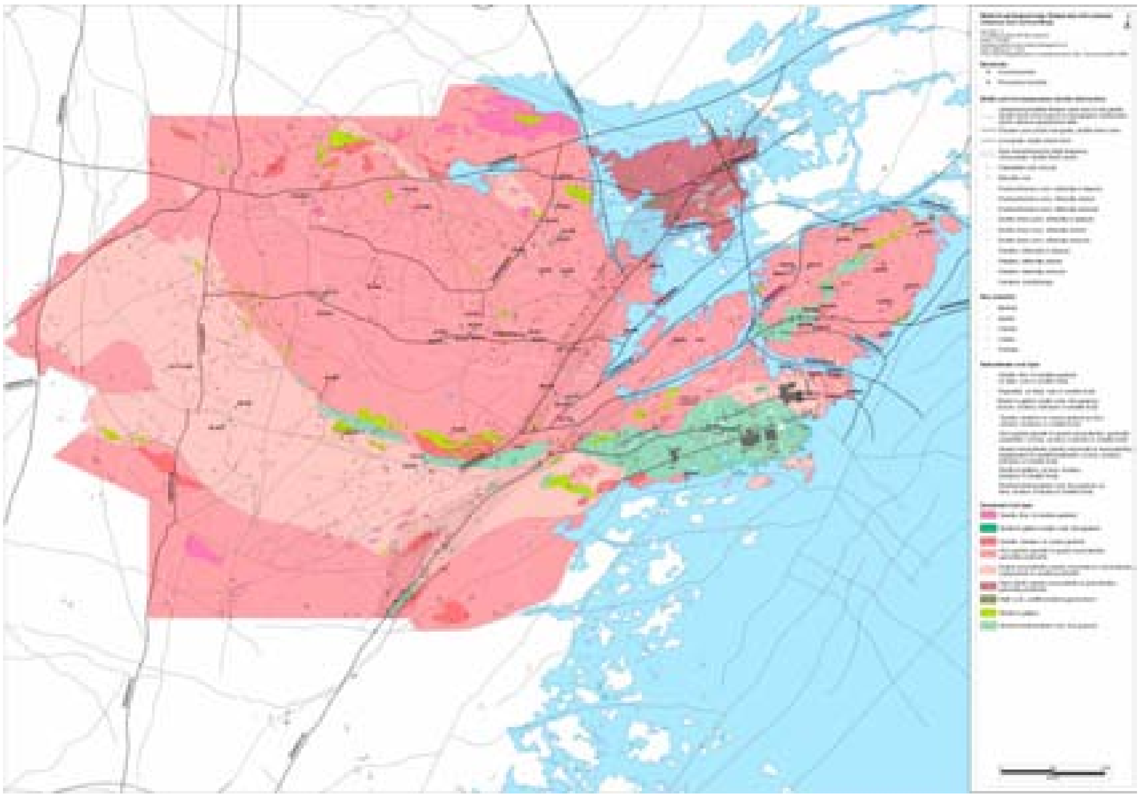

Figure 3-15. Bedrock geological map of the Simpevarp and Laxemar subareas with surroundings.

between soil chemistry, vegetation and local bedrock composition, in the Simpevarp regional model area, has not yet been studied. There are several known fracture zones in the Simpevarp and Laxemar subareas (Figure 3-15). It is possible that groundwater from the deep bedrock may reach the overburden and surface through these fracture zones, which often coincide with the long and narrow valleys characterising the investigated area. For a thorough description of bedrock geology and fractures zones, readers are referred to the preliminary site descriptions of the Simpevarp and Laxemar subarea /SKB 2005/.

Surface distribution of Quaternary deposits

Both the marine and terrestrial parts of the investigated area are characterised by a relatively flat bedrock surface with numerous fissure valleys, which in many cases can be followed for several kilometres. The highest topographical areas are dominated by bedrock and till exposures. The valleys constitute areas that have been sheltered from wave erosion and coastal streams. These low topographical areas have therefore during long time periods been favourable environments for sedimentation of clay. In the terrestrial part of the model area the groundwater level is high in the valleys. As a consequence of that, a layer of peat often covers the clay. Clay sediments are currently being deposited in the bays along the present coast. Exposed areas have been, and at some sites still are, subjected to wave washing, which has caused erosion and redeposition of some of the overburden. Sand and gravel is currently being transported at the bottom of the most exposed parts of the sea. A sand and gravel layer therefore often covers the valleys at the sea bottom.

The terrestrial part of the Simpevarp model area

/Rudmark et al. 2005/ have presented a map and a description of the overburden in the Simpevarp regional model area. In the present report the distribution of QD in the Simpevarp regional model area is shown on an overview map (Figure 3-16). The distribution of QD in the Simpevarp and Laxemar subareas is shown on two more detailed maps (Figure 3-17 and 3-18). The proportional distribution of different QD in the terrestrial parts of the Simpevarp regional model is summarised in Table 3-3. Although more detailed the new information confirms to a large extent the general description of QD in the Simpevarp regional model area, which was presented in the description of the surface system for the Simpevarp subarea /Lindborg 2005b/.

Table 3-3. The proportional distribution of Quaternary deposits in the Simpevarp area. The local area includes the whole area mapped for the sale 1:50,000, i.e. subareas I and II (see Figure 3-13).

Quaternary deposit	Coverage (%) Local area	Coverage (%) Regional area	Coverage (%) Laxemar subarea	Coverage (%) Simpevarp subarea
Peat	8.0	7.6	5.3	1.89
Gyttja clay	3.4	3.3 (all clay and silt)	5.8	0.05
Glacial clay and silt	1.4		0.7	1.06
Glaciofluvial deposits	3.0	1.4	0.1	0
Post-glacial sand and gravel	4.3	1.3	4.8	5.80
Till	43.3	51.7	45.2	35.04
Precambrian bedrock	34.5	34.6	38.2	38.22
Artificial fill	1.3	0.13		17.93

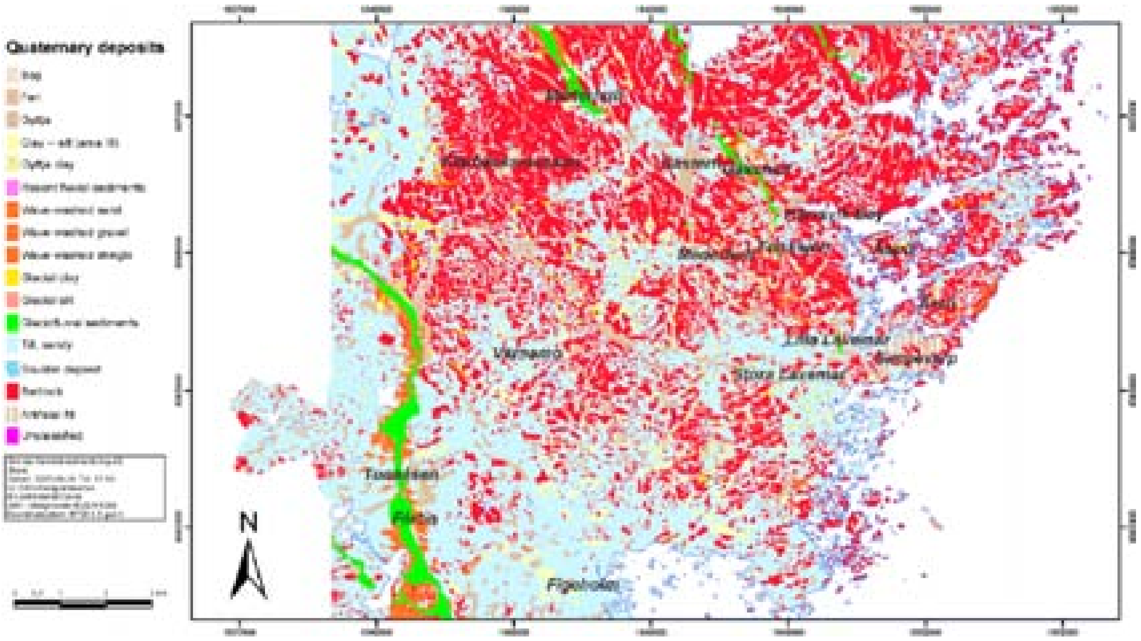

Figure 3-16. The distribution of QD in the terrestrial part of the Simpevarp regional model area. Subarea I was mapped for presentation in the scale 1:10,000 subarea II for presentation in the scale 1:50,000. Subareas I and II are in the text referred to as the local area. The distribution of QD in subarea III is interpreted from aerial photos, which has been checked from car. The white area around Värnamo was not assessable for fieldwork.

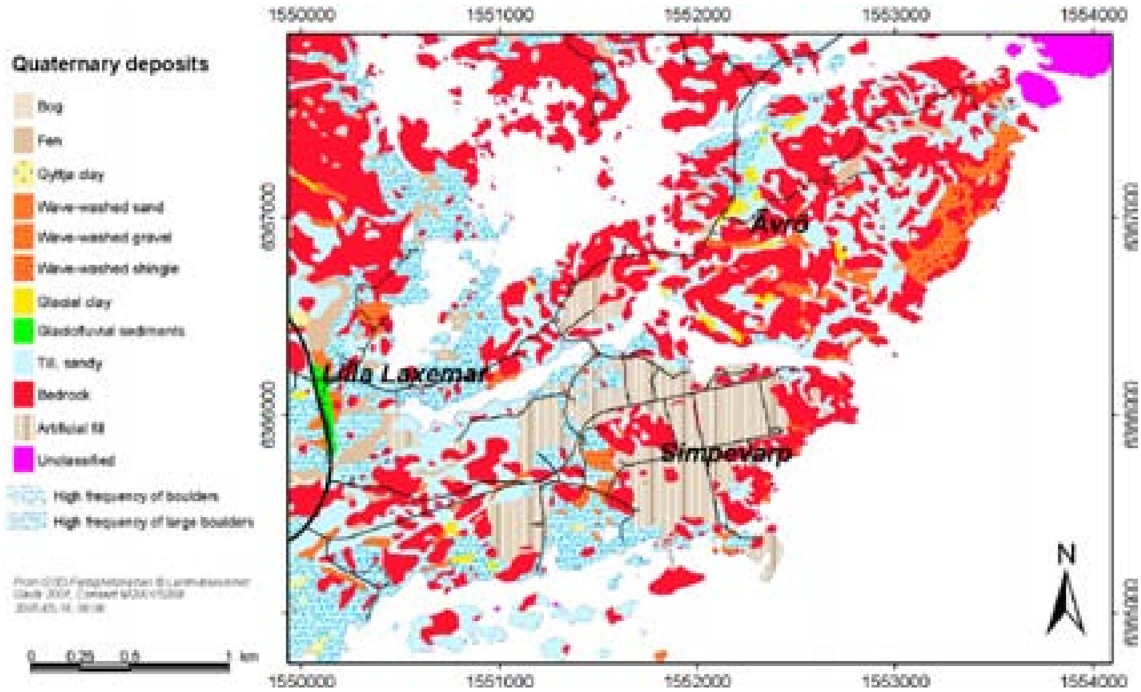

__Figure 3-17.__ The distribution of QD and the surface frequency of till boulders in the Simpevarp subarea.

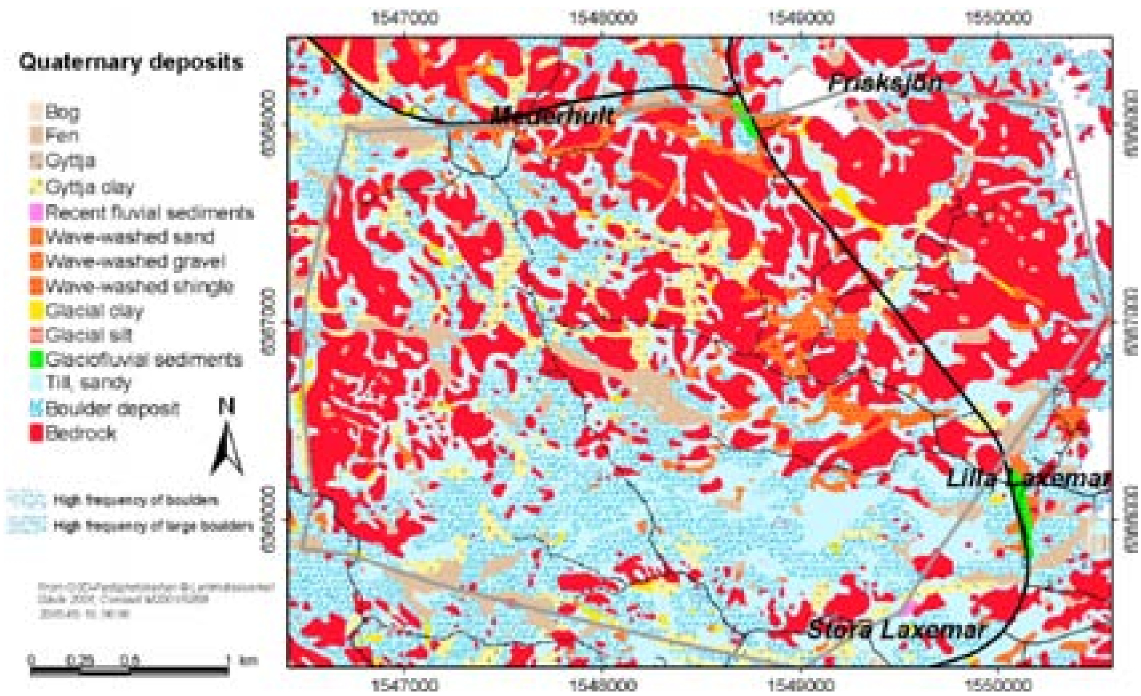

__Figure 3-18.__ The distribution of QD and the surface frequency of till boulders in the Laxemar subarea.

Altogether c 35% of the regional model area consists of exposed bedrock or areas with a thin cover (a few dm) of QD (Table 3-3). Most of the areas marked with red colour on the maps (Figures 3-16, 3-17 and 3-18) are, however, areas where the bedrock is not covered by QD. A thin layer of mosses or other vegetation often covers the bedrock in these areas. The frequency of exposed bedrock varies within the investigated area. Certain areas, e.g. the southern part of the local model area and the area to the west of the esker Tunaåsen, have a relative low frequency of exposed bedrock. On the other hand, areas in the north and in the archipelago have high frequencies of exposed bedrock.

Glacial till is the most common QD and covers half of the regional model area (Table 3-3). The surface morphology of the till normally follows that of the bedrock. There are some areas in the south-western part of the model area where the till forms low-relief hummocks. These small moraine hills were probably formed by more or less stagnant ice during the deglaciation.

The frequency of stones and boulders of the till surface varies throughout the investigated area (Figure 3-19a and b). In the Laxemar River drainage area (Figure 3-16) around half of the till areas have a normal surface frequency of boulders. Most of the remaining till areas have high frequencies of surface boulders, but some small areas have a high surface frequency of large boulders. As a consequence of wave washing the uppermost till often have a relatively high frequency of coarse material compared to underlying till. The internal frequency of boulders in till is in general intermediate. According to the composition of the matrix most of the till is sandy but also gravelly till has been found (see below). It was impossible to separate these two till types in the field and all till areas have therefore been mapped as sandy.

In the western part of the area there is a large glaciofluvial esker (Tunaåsen) with a north-south direction, which in the north changes to a north-west/south-east direction. This esker is in a morphological sense the most prominent QD in the regional model area. In general, the esker is 100–300 m broad and 5–10 m high. Heights of up to 20 m do, however, occur. Gravel and sand are the dominating grain sizes in the esker. The esker has been affected by wave action, which is reflected by shore ridges composed of sand and gravel on its sides. Alongside Tunaåsen there are wide flat areas of sand, which have been washed out from the esker.

The groundwater resources in the esker Tunaåsen have been estimated to be 5–25 l/s and the exploitation potential is therefore good /Pousette et al. 1981/. In the Village Fårbo close to the Lake Fårbosjön, there is a municipal well with a protection area. In connection with the mapping a spring with a yield of about 1 l/s was detected at the foot of the esker, 5 km north of Fårbo.

In the northern part of the model area there are three smaller glaciofluvial deposits with a north-south direction (Gässhultsåsen, Misterhultsåsen and a nameless deposit east of Lake Götemar). These deposits have a gentle morphology and are not prominent eskers in a morphological sense. Gässhultsåsen can be followed from Gässhult in the north southwards along the eastern side of the Laxemar subarea to Lilla Laxemar. During the fieldwork it was not always possible to conclude if sand and gravel around the esker are of glaciofluvial or post-glacial origin. That can only be resolved by future stratigraphical investigations. The post-glacial sand and gravel often rests upon clay whereas the glaciofluvial deposits rest directly upon till or bedrock. It would therefore be useful, for the forthcoming hydrological modelling, to delineate post-glacial sediments and glaciofluvial sediments separately. The groundwater resources in Gässhultsåsen are probably limited (< 1 l/s) /Pousette et al. 1981/. On-going groundwater investigations will, however, give more information on that issue.

Figure 3-19. *The till surface is often rich in stones and boulders. The maps of QD (Figures 3-17 and 3-18) show the distribution of till with different frequency of boulders. Figure 3-19a shows an area with a normal boulder frequency (photo: Lars Rudmark, SGU) and Figure 3-19b an area with high boulder frequency (Photo: Hanna Lokrantz, SGU).*

Different types of clay were only delineated from each other in the local area (Figures 3-17 and 3-18). Glacial and post-glacial clay mainly occur in the valleys where these deposits are common (Figure 3-20). The proportional coverage of glacial clay is, however, small compared to other areas along the coast of Småland /e.g. Svantesson 1999, Rudmark 2000/.

Figure 3-20. *Two valleys, which demonstrate the typical distribution of QD in the Simpevarp regional model area. The floors of the valleys are covered with post-glacial gyttja clay, which sometimes is covered with a thin peat layer. The higher areas constitute of bedrock exposures and glacial till. Many of these valleys are former fens, which has been ditched and today are used as arable land (Photos: Lars-Erik Olander and Lars Rudmark, SGU).*

A thin layer of sand and/or gravel often overlay the glacial clay. The post-glacial clay in the area often contains organic matter and is therefore referred to as gyttja clay (2–6% organic matter). Some of these sediments may, however, have an organic content higher than 6%.

Gyttja clay is the youngest clay sediment in the area and has been deposited in bays and along the coast. Most arable land in the local model area is situated in areas with gyttja clay.

The effects of wave washing can be observed at many sites, which have been or still are subjected to wave erosion. At some sites, which have been exposed to extreme erosion, the uppermost till consist of a stony layer, so called shingle. Such enrichment of stones can also be seen at several places along the present shore, especially on the island of Ävrö (Figure 3-21). Flat areas with post-glacial sand occur in many depressions, where the sand often covers the glacial clay.

The map of QD shows two types of peatlands: bogs and fens. There are several small bogs in the bedrock-dominated areas, e.g. on the northern part of Ävrö. The fens are characterised by sedges of different species such as reed and moisture-seeking herbs. Many of the fens are small and situated in bedrock depressions. Most of the larger fens have been drained by various types of ditches and are presently used as arable land or for forestry growth. Peat in such drained areas is oxidising and the underlying deposits, often gyttja clay, are slowly being exposed. A thin peat layer is often overlying the gyttja clay in areas used as arable land. The largest peatland that has not been drained is probably Klarebäcksmossen (PSM 006562), a bog surrounded by fen peat.

Around the Simpevarp nuclear power plant the ground has been changed by human activities. That explains the large proportion of artificial fill on the Simpevarp peninsula (Figure 3-17).

Figure 3-21. *The whole Simpevarp regional model area is situated below the highest coastline. Areas, which have been exposed towards the sea, have subsequently been subjected to erosion by waves. These processes are still active along the present coast. The photo shows a shingle field on Ävrö, which is formed by erosion of glacial till (photo: Lars Rudmark, SGU).*

The marine and lacustrine part of the Simpevarp model area

The map of QD on the sea floor is presented in Figure 3-22. The deepest areas were mapped by SGU /Elhammer and Sandkvist 2005/, and the archipelago and shallow areas by Marin Mätteknik /Ingvarson et al. 2004/. The proportional distribution of overburden and exposed bedrock is shown in Table 3-4.

The distribution of overburden on the sea floor is similar to that in the terrestrial part of the regional model. Fine-grained, water laid, sediments (sand and clay) are present in narrow valleys (Figure 3-22), which are surrounded by shallower areas dominated by exposed bedrock and till. The water depth in the valleys is often 15–20 m but the water depth is more than 30 m in certain areas. The narrow sediment covered depressions can in some cases be followed for several kilometres.

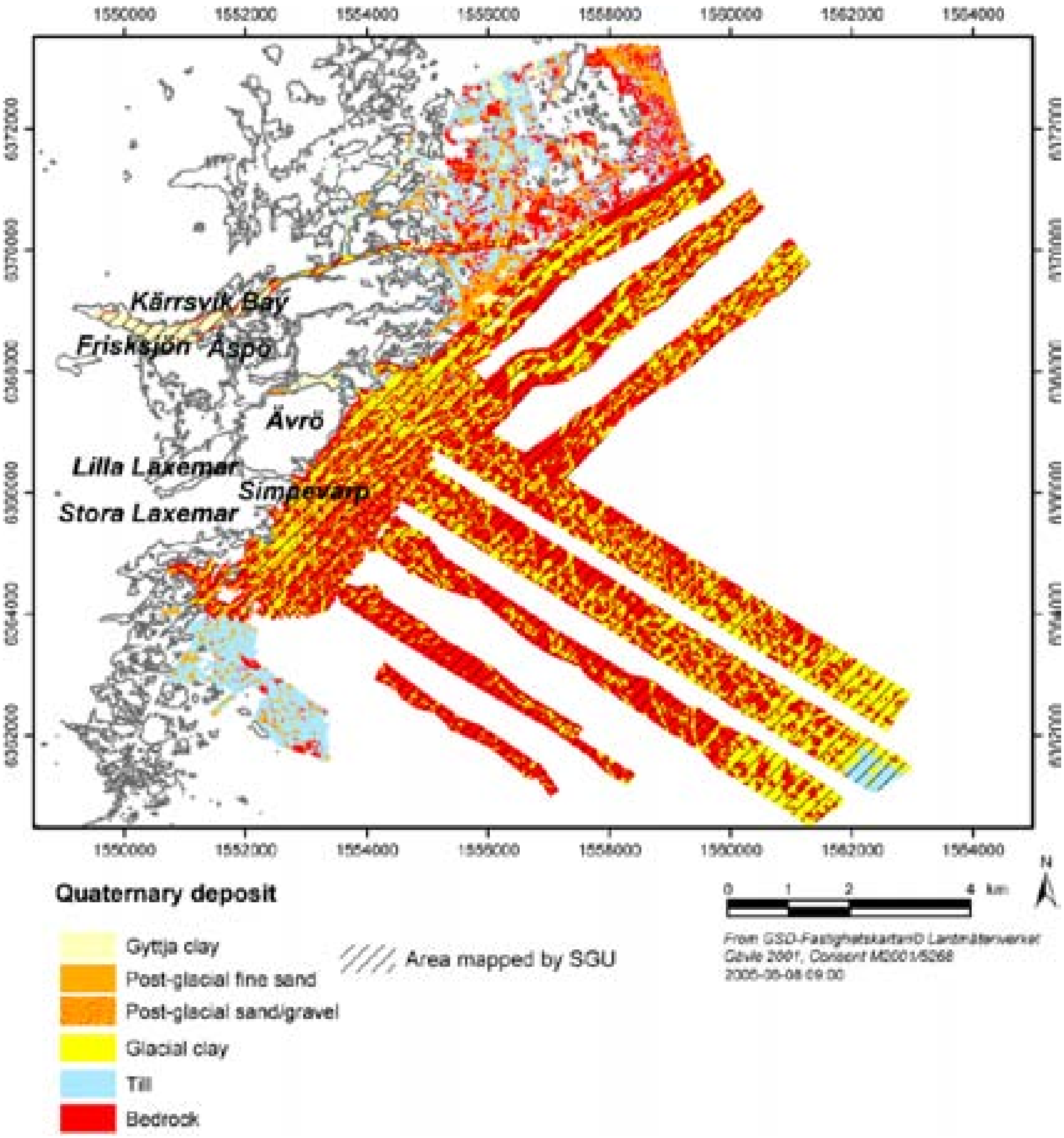

Figure 3-22. The distribution of QD in the marine part of the Simpevarp regional model area. The shaded areas were mapped by the Swedish Geological Survey and other areas by Marine mätteknik /Ingvarson et al. 2004/. In the shaded areas (SGU) the sea floor close to the Simpevarp peninsula and Ävrö was mapped with a line spacing of 100 m whereas a line spacing of 1 km was used further out.

Table 3-4. The proportional distribution of Quaternary deposits on the sea floor according to the survey performed by SGU /Elhammer and Sandkvist 2005/ and Marin Mätteknik /Ingvarson et al. 2004/.

	Kärrsvik Bay (%)	Simpevarp detailed (%)	Simpevarp regional (%)	Simpevarp total (%)	Archipelago and shallow areas (%)
Bedrock exposures	19.3	53.5	55	54.8	17.3
Glacial clay	3.1	42.4	37.5	38.4	
Post-glacial clay (including gyttja clay)	75.7		5.2	4.2	11.6
Post-glacial sand and gravel	2.0		0.1	0.1	13.7
Post-glacial fine sand		3.4	0.9	1.4	8.1
Till		0.6	1.2	1.1	49.3
Artificial fill		0.1		0	

The proportional distribution of overburden is more or less the same in the whole marine area mapped by SGU. 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 mapped by SGU consists of exposed bedrock. Adjacent terrestrial areas /Rudmark et al. 2005/ and sea floor area mapped by /Ingvarson et al. 2004/ have a much lower proportion of exposed bedrock and a higher proportion of till (Figures 3-16 and 3-22). In the Laxemar River area over 40% of the land is covered by till, whereas only 1% of the marine areas mapped by SGU consist of till.

This large difference in till coverage needs to be explained. There is no reason to believe that the conditions for deposition of till were less favourable in the marine areas mapped by SGU compared to the areas mapped by /Ingvarson et al. 2004/ and /Rudmark et al. 2005/. 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 (Bernt Kjellin SGU, oral communication). According to Kjellin some marine areas with a high frequency of stones and boulders have been mapped as exposed bedrock if the till layer has been interpreted as thin. Similar boulder and stone rich areas may have been mapped as till by the methods used by /Ingvarson et al. 2004/ and /Rudmark et al. 2005/. None of the investigations have identified any glaciofluvial deposits at the sea floor.

In the marine areas, mapped by SGU, glacial clay is the most common Quaternary deposit (almost 40%). A thin layer of sand often overlies the glacial clay. The surface of the sand is locally characterised by ripples, which shows that streams are currently moving the sand. The proportion of areas covered with glacial clay is much larger on the sea floor (SGU map) compared to the terrestrial parts of the Simpevarp subarea. One reason for this is probably that erosion by waves and streams during the land upheaval decreased the areas that formerly were covered by glacial clay. Another reason is that a layer of post-glacial gyttja clay often covers the glacial clay on land. Some areas of the sea floor are covered by thicker layers of sand, which probably often are underlain by glacial clay.

No areas constituting of glacial clay are shown on the marine geological map presented by /Ingvarson et al. 2004/. That map includes, however, large areas of sand and gravel (Table 3-4), which probably correspond to the thin layers of sand of gravel that covers the glacial clay in the areas mapped by SGU.

The deepest parts of the narrow bays, surrounded by land (e.g. Kärrsvik Bay), are covered with post-glacial gyttja clay. The capacity of 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. Also coring in the shallow bays north of Simpevarp has shown that the youngest sediments consist of post-glacial, gyttja rich, clay /Risberg 2002, Nilsson 2004/.

Soil types

A map showing the distribution of different soil types was produced /Lundin et al. 2005/ based on the field classifications and geographical information, such as maps of Quaternary deposits and vegetation types. The map presented in this report (Figure 3-23) is an updated of Lundin's map since that map underestimated the areas with bedrock and thin soil coverage. The spatial coverage of the different soil types is summarised in Table 3-5. Podzol and regosol dominate areas constituting of glacial till and glaciofluvial esker. The areas with leptosol consist mostly of areas with bedrock exposures, but the bedrock is partly covered by a few decimetre of soil. Gleysol is typically formed in areas with gyttja sediments, which seems to be common in the inner parts of the Simpevarp subarea. 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.

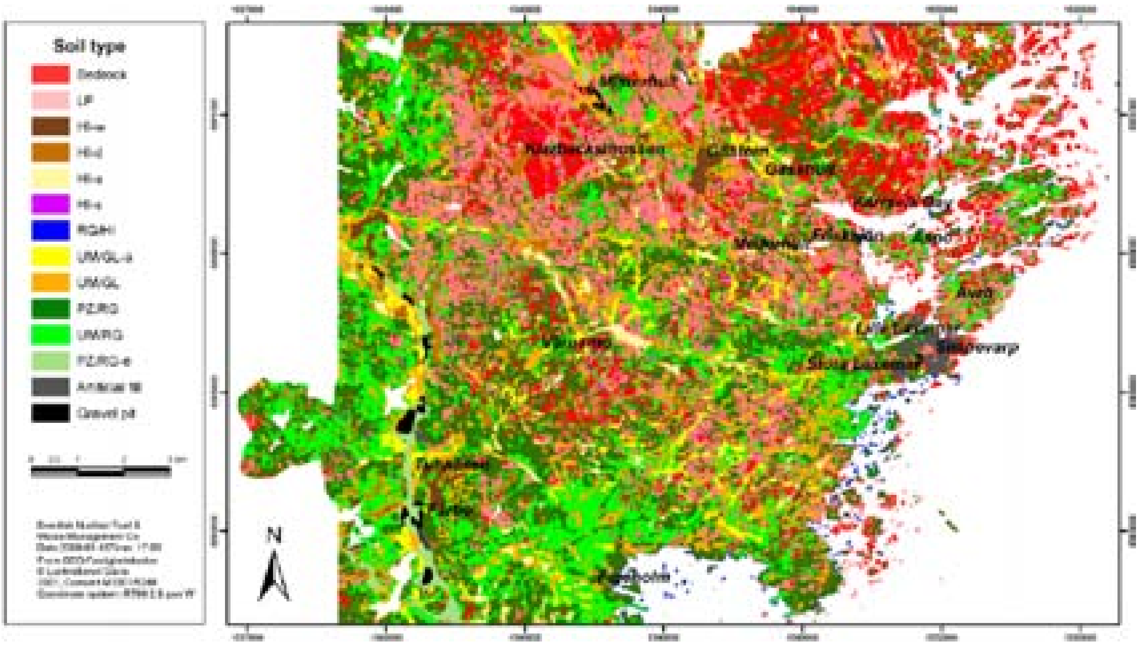

Figure 3-23. *The distribution of soils in the Simpevarp regional model area. The map is based on field studies and interpretations of other geographical information such as maps of QD and vegetation. Since the most detailed mapping of QD took place in the Laxemar River drainage area the soil map is more reliable in that area.*

Table 3-5. Spatial coverage of the soil types in the Simpevarp regional model area.

Soil class	GIS map soil class	Simpevarp regional model area Coverage (%)
Bedrock		11.1
Leptosol	LP	23.6
Podzol/Regosol	PZ/RG	25.2
Podzol/Regosol (on glaciofluvial material)	PZ/RG-e	1.4
Umbrisol/Regosol	UM/RG	15.7
Umbrisol/Gleysol	UM/GL	10.9
Histosol, (forested peatlands)	HI-d	3.7
Histosol (wetland)	HI-w	1.7
Histosol (arable land)	HI-a	1.7
Histosol (small peatlands)	HI-s	0.6
Regosol/Histosol (shoreline areas)	HI/AR	0.6
Umbrisol/Gleysol, arable land	UM/GL-a	2.8
Artificial fill		0.6
Gravel pit		0.4

The carbon stocks for the sites, which were studied during the fieldwork, have been calculated. The average carbon stocks for the soil classes shown in Figure 3-23 are presented in Table 3-6.

Table 3-6. Carbon stocks for the soil map classes in the Oskarshamn area.

Map class	Soil class	C tot (kg/m²)
Bedrock	Bedrock	0.00
LP	Leptosol	8.20
HI-w	Histosol (open wetland)	15.64
HI-f	Histosol (forested peatland)	44.19
HI-a	Histosol (arable peatland)	41.49
HI-s	Histosol (small peatland)	37.47
RG/HI	Regosol/Histosol (shoreline areas)	15.78
UM/GL-a	Umbrisol/Gleysol (arable land)	20.46
UM/GL	Umbrisol/Gleysol	39.42
PZ/RG	Podzol/Regosol	19.14
UM/RG	Umbrisol/Regosol	9.54
PZ/RG-e	Podzol/Regosol (on glaciofluvial material)	14.60

Stratigraphy and total depth of Quaternary deposits

In the terrestrial part of the Simpevarp regional model area stratigraphical information is available from machine cut trenches, weight sounding, soil/rock drillings and different geophysical investigations. (Figure 3-13). The results from the geophysical investigations in the marine areas give detailed information about the total depth of overburden but also about the thickness of the individual stratigraphical units.

The whole Simpevarp regional area is characterised by large areas dominated by till and exposed bedrock, which are intersected by long and narrow valleys. The thickest overburden occurs in these valleys whereas the overburden is generally thinner in other areas. There are, however, some exceptions from this. The glaciofluvial deposit in the western part of the model area, Tunaåsen, is an esker, which demonstrates among the largest thickness of overburden in the model area, over 20 m /data from SGUs data on wells, Brunnsarkivet, SGU 2005/. There are also areas, especially in the south-western part of the regional model area, which are characterised by a coherent, probably relatively thick, till cover and few bedrock exposures. One example of this is an area north of Stora Laxemar in the Laxemar subarea.

Results from drillings in the Simpevarp subarea show overburden depths of between 1.5 and 8.6 m. The average thickness recorded by drillings is 3.6 m. The drillings in the Laxemar subarea overburden show overburden depths of between 1.3 and 12.6 m. There are, however, no drillings down to the bedrock surface in the valleys of the Laxemar subarea, where a thick overburden can be expected. Results from weight soundings show, however, that the total thickness of overburden in one of the largest valleys in the subarea exceeds 12.6 m (PSM003545, 500 m west of Mederhult).

The Vertical Electrical Soundings (VES) give some information regarding the total thickness of the overburden. The results from the 22 stations show that the thickness of the overburden varies between 0 and 14.5 m. Only one of these stations is situated in the middle of a valley (PSM001526, 14.5 m).

Refraction seismic has been carried out in both the terrestrial part of the Simpevarp and Laxemar subareas and in the marine areas surrounding the Simpevarp subarea. Almost 50 m of overburden were recorded in a narrow strait north of Ävrö (LSM000192), which is the largest known thickness of QD in the whole model area. Refraction seismic in the till covered area situated north of Stora Laxemar show that the overburden thickness in that area varies between 0 and 9 m (average 3.6 m). The till in that area is probably thicker than generally is the case in the two subareas /cf Rudmark et al. 2005/. The rather small data set from the largest valleys indicates that the overburden depth commonly exceeds ten metres in the largest valleys. That is further supported by the results from the marine geological survey carried out by SGU.

The average depths of Quaternary deposits in the marine areas investigated by SGU are summarised in Table 3-7. Also on the sea floor the overburden is thickest in depressions. 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, often 10 m. At one place an overburden depth of more than 48 m was recorded. These results give a hint of the overburden depths that can be expected in the clay-covered valleys situated in the terrestrial part of the Simpevarp regional model area from which fewer results are available.

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 containing overburden with a high electrical conductivity, i.e. clay /Figure 3-29 in Lindborg 2005b/. These areas are situated in valleys where the environment probably has been favourable for the deposition of thick layers of Quaternary deposits. A comparison with the map of QD shows that the high conductivity areas fit roughly well with the areas mapped as clay. The QD map gives, however, much more detailed information regarding the distribution of clay. The present overburden thickness information received from EM data is also rather rough and that data is therefor not further used in the overburden models.

Table 3-7. The average depths of Quaternary deposits in the marine areas covered by SGU. Only sites with a thickness larger than 0.5 m were used.

	n	Average depth (m)	Max (m)	Standard dev
Till	4,575	3.6	48.5	2.6
Glacial clay	14,886	2.6	28.0	2.3
Post-glacial sand	2,405	0.8	2.9	0.3
Post-glacial clay/gyttja clay	2,359	1.7	4.7	0.8
Total depth of all Quaternary deposits*	18,312	3.4	48.5	2.9

*The average depth is most probably higher since it was impossible to obtain total depth information from some areas covered with post-glacial clay.

The results from the mapping of QD (Figure 3-24a and b) and the soil/rock drillings show that the till rests directly upon the bedrock surface. The following general stratigraphy was observed from the ground surface: peat, gyttja clay, sand, clay and till (Table 3-8). There are, however exceptions from this stratigraphy. In the broad valley west of Mederhult, a 3 m thick sand layer was observed between the clay and till. This sand layer may be of glaciofluvial origin and could be of importance for the hydrological modelling of the area.

The till has sand and gravel dominated matrix and was most likely deposited shortly before the latest deglaciation. The main (upper) till unit has a normal degree of consolidation. It is often rich in angular shaped cobbles and small boulders, which consist of the local bedrock type. Laminae and lenses of sorted gravel, sand and silt occur, and are unevenly distributed. In some cases the lower part of the till is silty. The till lacks enough distinguishing characteristics to make a detailed genetic interpretation but it can be concluded that it probably was deposited directly by moving ice. The fact that the bedrock surface generally has a rough appearance implies that the ice was not very erosive, but the main subglacial process was deposition of till.

There are observations of boulder clay and clayey till in samples from two soil/rock drillings in the Simpevarp subarea /Johansson and Adestam 2004c/. In the Laxemar subarea clasts of clay was observed in till studied in one of the trenches where stratigraphical studies was carried out /PSM005406, Rudmark et al. 2005/. It can, however, not be excluded that the clay in the till sampled during the drillings is due to contamination from overlying clay. Results from forthcoming stratigraphical studies will hopefully tell if clayey till commonly occur below the sandy till.

Results from the mapping indicate that sand and gravel dominate the glaciofluvial deposits. The glaciofluvial deposits are assumed to partly rest directly upon the bedrock. That has, however, not been properly verified. Stratigraphical studies in a trench situated in the peripheral part of the Gässhult esker west of Lake Frisksjön (PSM005401) indicate that the glaciofluvial material (c 2 m) at that site is underlain by till /Rudmark et al. 2005/. A nearby trench (PSM005402) in the central part of the same deposit shows that the glaciofluvial material (c 3 m) rests directly upon the bedrock. Data from the SGUs well archive (8 sites) shows that the esker Tunaåsen has an average depth of c 15 m. Less data is available from the three small eskers but it can be concluded that they have a total thickness of a few metres (round 5 m).

The till in the valleys is often covered with 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 glacial clay at many sites (also observed during the soil/rock drillings). A corresponding sand layer, overlying the glacial clay, was observed during the marine geological survey.

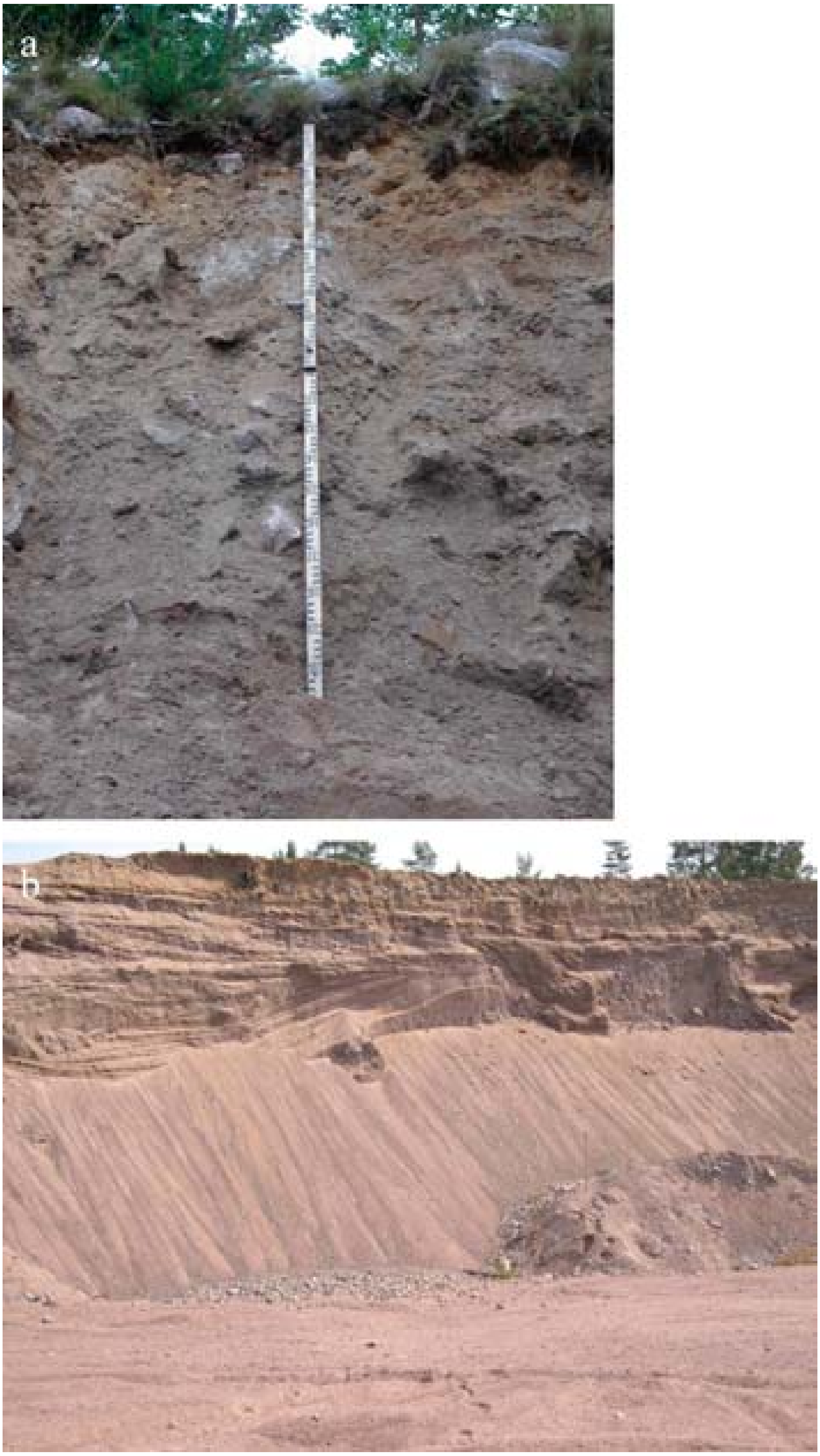

Figure 3-24. *Stratigraphical information was gained within several activities. Figure a) shows the most common QD in the Simpevarp area, sandy till. The observation was made in a machine-dug trench (photo: Kärstin Malmberg Persson, SGU). Figure b) shows the most prominent QD in the area, Tunaåsen, a glaciofluvial esker. The observation was made in a gravel pit north of Fårbo (photo: Hanna Lokrantz, SGU).*

Glacial clay is here referred to as clay with a low organic content, often below 0.5%, and represent both varved clay deposited during the deglaciation and younger clay deposited during the early Holocene phases of the Baltic Sea (the Yoldia Sea and Ancylus Lake).

The studies of sediment and peat in shallow bays, wetlands and lakes demonstrate a similar stratigraphy /Nilsson 2004/ as has been described in the terrestrial areas /e.g. Rudmark 2004, Johansson and Adestam 2004c, see also Table 3-8/. This is further confirmed by other investigations from bays and wetlands in the surroundings /Borg and Paabo 1984, Landström et al. 1994, Aggeryd et al. 1995, Risberg 2002/. The results from the terrestrial and marine parts of the regional model area described above indicate that this stratigraphy is common also in most of the clay-covered valleys characterising the whole Simpevarp area.

The lowermost sediment type is brownish, partly, varved glacial clay, which is overlain by homogenous, bluish, probably glacial clay. That unit is in turn overlain by a silt-sand-gravel layer. The contact between clay and overlaying silt-gravel is sharp, which indicate erosion by streams or waves. There is a successive transition from silt-gravel to gyttja clay. In the lakes gyttja clay is overlaid by gyttja which is currently accumulating. In the present wetlands a layer of peat covers the gyttja sediments. As mentioned above most of the former wetlands have been drained by ditches, but are still covered by a peat layer. The average thickness of peat (0.9 m) was calculated by the use of data from /Nilsson 2004/ and /Rudmark et al. 2005/.

There are, exceptions from the general stratigraphy presented in Table 3-8. The stratigraphy from Långenmossen is one such an example where a clay layer is surrounded by gyttja (PSM006564, 19 m above the present sea level). This clay layer may possible represent the Ancylus transgression, more than 10,000 years ago (see Figure 3-17 in Section 3.1), when the water depth in the area increased by almost 10 m /cf Påsse 2001/.

Table 3-8. The stratigraphical distribution of Quaternary deposits in the Simpevarp regional model area.

Quaternary deposit	Relative age
Bog peat	Youngest
Fen peat	↑
Gyttja clay/clay gyttja	
Sand/gravel	↑
Glacial clay	
Till	↑
Bedrock	Oldest

Indicators of ice movement directions

The direction of glacial striae and results from two till fabric analyses are used to reconstruct the direction of ice movements during the latest ice age. These studies can theoretically also give information about ice movement directions during older glaciations

The glacial striae indicate a youngest ice movement from the north-west (310°–320°). At six localities, two distinct systems of striae with somewhat more northerly striae direction has been observed (325°–345°). These striae probably indicate somewhat older ice movements or alternatively local deviations caused by the bedrock morphology. At the bottom of a trench (PSM005407), below a till bed, glacial striae indicating an ice movement from the north-east (45°) have been observed. These striae may have been formed during an earlier phase of the latest glaciation when glacial flow from the Baltic entered the area from the north-east. Glacial striae indicating ice movements from north-east have earlier been observed in the archipelago of Småland /Rudmark 2000/. The striae from north-east are overlain by the clayey till (PSM005406) described above. That till has a fabric indicating deposition from 344°, NNW (only 13 particle measurements). However, the high clay content in that till rather indicates transportation from the Baltic depression.

A five metre thick till bed was studied in a till quarry in the westernmost part of the mapped area (PSM005413). The fabric displays a girdle pattern centred around south-west (232°), which is not conceivable ice flow direction in this area. One single fabric analysis is, however, not enough to get a reliable result. The results from the present fabric analyses do not give conclusive information regarding the direction of till deposition in the model area.

The composition of the Quaternary deposits

The analyses performed hitherto include grain size distributions, bulk density, porosity, trace elements in till and the total contents of organic carbon, $CaCO_3$, nitrogen and sulphur. Additional chemical and mineralogical analyses are planned for the future. All contents discussed in this section are calculated from dry weight.

The grain size composition of Quaternary deposits (grains < 20 mm) have been analysed /Nilsson 2004, Bergman et al. 2005, Rudmark et al. 2005/. The results from grain size analyses of till are summarised in Table 3-9. Most till samples are totally dominated by sand and gravel and have clay contents lower than 5%. One till sample has a clay content of 12% (PSM005406). This clayey till was found below the sandy till and may have been deposited during an older phase of the last glaciation (see above).

The grain size composition of glacial clay has been analysed in seven samples and the results show that the average clay content is 66% (50–75%, standard dev. 9%). The 46 analysed samples of gyttja and gyttja clay have an average clay content of 30% (15–55% standard dev. 9%). The gyttja sediments may also contain coarser grained biogenic remnants such as diatoms.

Data concerning bulk density and porosity are presented below (Section 3.3.5). Some of that data has not been obtained during the site investigation but from the literature. The ongoing investigations will, however, deliver site-specific data.

The glacial clay has low organic carbon contents (below 1%). The gyttja clay in the bays has organic carbon contents between 10 and 20%. There is only one sample analysed from the areas mapped as gyttja clay in the terrestrial parts of the model area (16%). The gyttja clay in the terrestrial areas were, however, deposited in environments similar to the present bays and have probably similar organic carbon contents.

The gyttja in Lake Jämsen and Lake Frisksjön have organic carbon contents round 20% and gyttja from Lake Plittorpsgöl have organic carbon contents higher than 30%. The two peat samples analysed from Klarebäcksmossen (PSSM006562) have carbon contents round 50%.

Higher productivity in sheltered bays and lakes compared to the open sea probably caused the relatively high content of organic carbon preserved in sediments deposited in these environments. These sheltered environments are also more favourable for the deposition of fine-grained, organic-rich sediments.

All samples but one lack or contain only traces of calcium carbonate. One gyttja sample from Långenmossen, however, contains 12% $CaCO_3$, which probably is of biogenic origin.

Table 3-9. The average grain size composition of material < 20 mm in 31 till samples.

	Average	Max	Min	Standard dev
Gravel (%)	38.5	58.8	18.2	10.2
Sand (%)	44.9	64.7	29.3	8.3
Fine material (%)	16.7	34.1	5.8	7.08
Clay (%)	3.1	12.0	1.4	2.0

In all investigated lakes, C, S and N show an increasing trend from the oldest to the youngest sediments. The total contents of all these elements are relatively low in the glacial clay. The sulphur contents are higher than 1% in most sediment overlying the glacial clay and the highest values, almost 4%, were recorded in the organic rich gyttja sediments. Sulphur in the sediments may partly be associated with organic material, but most sulphur in post-glacial organic rich sediments is bound in iron sulphides /cf Sternbeck and Sohlenius 1997/. These sulphides are formed as a consequence of reduction of ferric iron and sulphate during the anaerobic breakdown of organic matter. It is therefore likely that the post-glacial gyttja sediments in the Simpevarp model area contain significant amounts of iron sulphides. Some of the organic rich lake sediment are, however, low in sulphur indicating low contents of iron sulphides. That may be due to oxidising bottom conditions and/or an effect of the relatively low sulphate content in fresh water. As mentioned above the high content of S in the gyttja clay reflects the occurrence of iron sulphides. Iron sulphides can easily oxidise if the groundwater table is lowered, due to e.g. artificial draining or isostatic land upheaval. Oxidation of iron sulphides may cause acid soil condition and increased leaching of trace elements /e.g. Åström and Björklund 1995/.

/Risberg 2002/ investigated the siliceous microfossil record and clay-mineralogical composition in a sediment core (SAS 48) from Borholmsfjärden south of Äspö. The sediment sequence consists of brownish clay overlain by bluish clay, sand/gravel and gyttja, i.e. in accordance with the general stratigraphy of the area (Table 3-8). The results show that both the bluish and brownish clays were deposited during the brackish phase of the Yoldia Sea. It is, however, not known if corresponding brownish and bluish clays described from lakes and bays /Nilsson 2004/ also were deposited in the Yoldia Sea. It is possible that different colours of the clay (bluish and brownish) are due to diagenetic processes taking place after sediment deposition.

/Tröjbom and Söderbäck 2006/ has evaluated data from analyses of till chemistry, which has been carried out by SGU before the onset of the site investigation /Andersson and Nilsson 1992/. The analyses were made by ICP-AES technique, which have been compared with results obtained from XRF analyses. The data shows that the chemical composition of the till in the Simpevarp area is relatively normal in a Swedish context. The content of lead is, however, approximately twice as high as the average for till in Sweden.

/Lindroos 2004/ discusses the potential fore ore industry in the Simpevarp area. The study includes results from the earlier analyses of till chemistry carried out by SGU /Andersson and Nilsson 1992/. Seven samples collected during the mapping of QD were also included in the study. Some of the results are compiled in Table 3-10. The study shows that the trace metal contents are low to moderate in the till and that the gold content is very low. It is concluded that it is highly unlikely that there will be any opening of ores in the Simpevarp regional model area.

Table 3-10. The content of Cu, Pb and Zn /Andersson and Nilsson 1992, in Lindroos 2004/.

Element	Cu ppm	Pb ppm	Zn ppm
Median	9.3	15.0	42.0
Max	66.7	340.0	180.0
N	19	19	19

Results from three radiocarbon dates shows that the gyttja overlying the sand/gravel layer in Borholmsfjärden started to accumulate in the Litorina Sea c 3,000 years ago. The accumulation rate calculated from the ^{14}C analyses is c 1.2 mm/yr. The sand/gravel layer represents a period of 7,000 years when no fine-grained sediments were deposited. The gyttja sediment started to accumulate when rising land areas sheltered the site. The results from the clay-mineralogical (XRD) analyses show similar distribution of those minerals in the bluish and brownish clays. Illite is the dominating clay mineral followed by chlorite and kaolinite. That is in accordance with other mineralogical studies of water deposited clays from other parts of Sweden, e.g. Uppland /Snäll 2004/. The results imply that the clays only to a small degree have been affected by chemical weathering /cf Snäll 2004/.

The chemical compositions of sediments from a wetland on Äspö and the sea floor of Borholmsfjärden (SAS 48) have been analysed before the onset of the site investigations /Landström et al. 1994, Aggeryd et al. 1995, Aggeryd et al. 1999/. The stratigraphies of these cores correspond to that presented in Table 3-8. It is suggested that gravel and sand layer, separating the clay from the gyttja clay, may act as important transportation paths for elements dissolved in the pore water. The brackish water has been leached out from the clays in the wetland. It is therefore suggested that clays deposited in brackish water may act as important sources for salinity to the groundwater /Aggeryd et al. 1999/. Uranium and thorium has accumulated in the peat in the wetland and it is likely that the groundwater act as a source of these elements.

/Lidman, in press/ has analysed radionuclides in peat and sediments from Klarebäcksmossen to assess the radionuclide transport during peatland development. The result indicates that Uranium has mobilised from underlying clay and accumulated in the gyttja and. Radium has leached out from the gyttja, which might have happened recently. The peat has low levels of radionuclides, but the contents are clearly higher in the fen peat compared to the bog peat.

/Lidman, in press/ has also used ^{210}Pb dates to calculate the peat growth rate. The accumulation rate is 1.45 ± 0.06 mm year^{-1} in Klarebäcksmossen according to these dates. That corresponds to an annual accumulation of material of 51.0 ± 0.8 g/m^2/year.

The overburden depth model

Information about the depth and stratigraphy of overburden has been obtained from drillings and geophysical investigations. The results from all these investigations were used to construct a model, using the GeoEditor graphical tool /DHI Water&Environment 2001/, which shows the distribution of overburden depths for the whole regional model area. The model also includes the stratigraphical distribution of till, glaciofluvial material, clay, peat and artificial fill. Forthcoming models will hopefully include more differentiated stratigraphical information (e.g. different kinds of clay). The GeoEditor is a graphical tool for geological modelling and editing in a GIS-environment (ArcView 3.3). The concept of the GeoEditor is to provide a simple GIS-based model in which the user can view existing observation data (boreholes, observation pits, seismic and geophysical data etc), interpolate geological formations based on the observation points, evaluate and adjust the interpolated layers and present the results as layers and in profiles. For a thorough description of the model the readers are referred to a report by /Nyman 2005/.

In the GeoEditor model the overburden was subdivided into three stratigraphical layers: Z1, Z2 and Z3 (Figure 3-25). Z1 refers to the uppermost parts of the overburden, which is affected by soil forming processes; Z2 and Z3 refer to the clay and till layers respectively. Layers of glaciofluvial deposits, artificial fill and peat are illustrated separately in the model.

There is a lack of depth and stratigraphical information from large parts of the terrestrial part of the regional model area. The marine geological investigation carried out by SGU comprises, however, a huge amount of such data (Table 3-7). The maps of QD cover most of the regional model area. These maps together with the present stratigraphical information suggest that the surface and depth distribution of overburden is similar throughout the model area. The average depths of different QD, evaluated from the marine geological survey, are therefore used when constructing the depth model for the terrestrial areas, which lack dense depth information. The depths of glaciofluvial deposits and peat has been calculated by using data from SGUs data on wells /SGU 2005/ and results from the site investigation /Nilsson 2004, Rudmark et al. 2005/ respectively.

The QD depth model is made by combining the maps of overburden with the general stratigraphy, which is presented in Table 3-8. An example: the total depth of overburden in an area covered by gyttja clay is the sum of the average values for till, glacial clay and gyttja clay (Table 3-8).

The marine areas partly lack information about the surface distribution of QD (Figure 3-22). In these areas the average depth of overburden from the area south east of the Simpevarp peninsula and Ävrö is used.

3.3.6 Conclusions and summary

The results from surface and stratigraphical investigation of QD are summarised in this section. Figures 3-16, 3-17, 3-18 and 3-22 show the surface distribution of QD in the regional model area. The general stratigraphy for the area is summarised in Table 3-8. There is no evidence of deposits older than the last glaciation, even though the existence of such deposits can not be excluded. The known surface and stratigraphical distribution of QD in the regional model area are in accordance with the conceptual model for the distribution of QD below the highest coastline in Sweden (Figure 3-14).

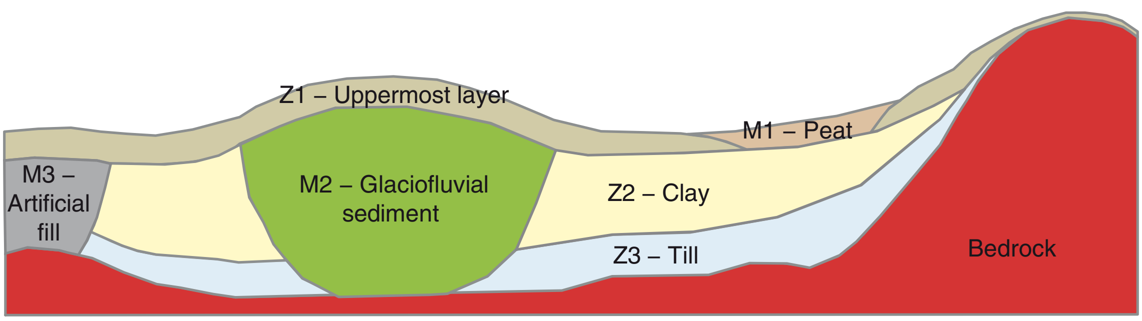

Figure 3-25. *The stratigraphical model which was used for modelling stratigraphy and total depth of QD in the Simpevarp regional model area /Nyman 2005/. The layer Z3 refers to the till, Z2 to the total thickness of clay and Z1 to the uppermost overburden.*

The bedrock surface in the model area is often rough indicating a low degree of glacial erosion. The absence of overburden predating the last glacial cycle indicates, however, that the Quaternary glaciers have eroded older loose deposit. The characteristic of the till indicates short distance of transportation and the mineral composition of the till probably reflects that of the local bedrock. That issue will, however, be further studied during the forthcoming investigations. The ice moved from the north-west during the last phase of the latest glaciation. There are indications of older ice-movements from the north-east. Material from the Baltic depression may consequently be incorporated in some QD.

There are three small and one large (Tunaåsen) glaciofluvial deposits in the regional model area. During the latest deglaciation the glaciofluvial material was deposited in tunnels beneath the ice by melt water running from the north. The occurrences of subglacially formed eskers indicate bottom-melting conditions during the deglaciation.

The distribution of fine-grained water laid QD is mainly related to the local bedrock morphology. These sediments are mostly restricted to the long and narrow valleys which are characteristic for the investigated area. The highest areas have been subjected to erosion from waves and streams. Periods with erosion have occurred also in the valleys but it is evident that also long periods with deposition of fine-grained material have taken place in these areas.

The oldest fine-grained deposit, glacial clay, has been deposited during the latest deglaciation when the water was relatively deep. As the water depth decreased, streams and waves started to erode the uppermost clay and deposited a layer sand/gravel on top of the clay. The lowest areas became sheltered bays as the water depth decreased and post-glacial clay containing organic material started to deposit. Figures 3-26a–c show the former shoreline at three occasions during Holocene. The maps clearly show that the present areas covered with gyttja clay coincide with areas, which once have been sheltered bays. The processes of erosion and deposition are still active at the sea floor and along the present coast. The floors of many of the valleys are former or present wetlands where layers of peat have formed. The areas consisting of wetlands have, however, decreased significantly due to artificial draining.

Four main type of overburden environments have been distinguished in the regional model area based on the present knowledge of QD:

I) The highest topographic areas, which are dominated by exposed bedrock, till and numerous small peatlands, classified as bogs or fens. The overburden in these areas is generally one or a few metres thick. It is possible that small pockets with thicker QD occur, e.g. in the small wetlands. This environment is completely dominated by forest.

II) Narrow valleys dominated by gyttja clay, peat and or wave washed material. Glacial clay and till underlie these deposits. The total thickness of QD is several metres in these environments. The floors of the valleys have often been drained and are used as arable land. At the sea floor the valleys close to the coast are dominated by gyttja clay, which is currently deposited. Glacial clay and sand dominate the valley floors outside the archipelago. These valley bottoms are characterised by erosion and transportation of sediment.

III) Areas with hummocky moraine and a low frequency of bedrock exposures occur in the south-western part of the model area, but also in the central part of the Laxemar subarea. The till in this environment is generally thicker than the till in overburden environment I.

IV) The areas constituting glaciofluvial deposits of which Tunaåsen in the western part of the model area is the most prominent. These deposits are well drained and are often covered with forest.

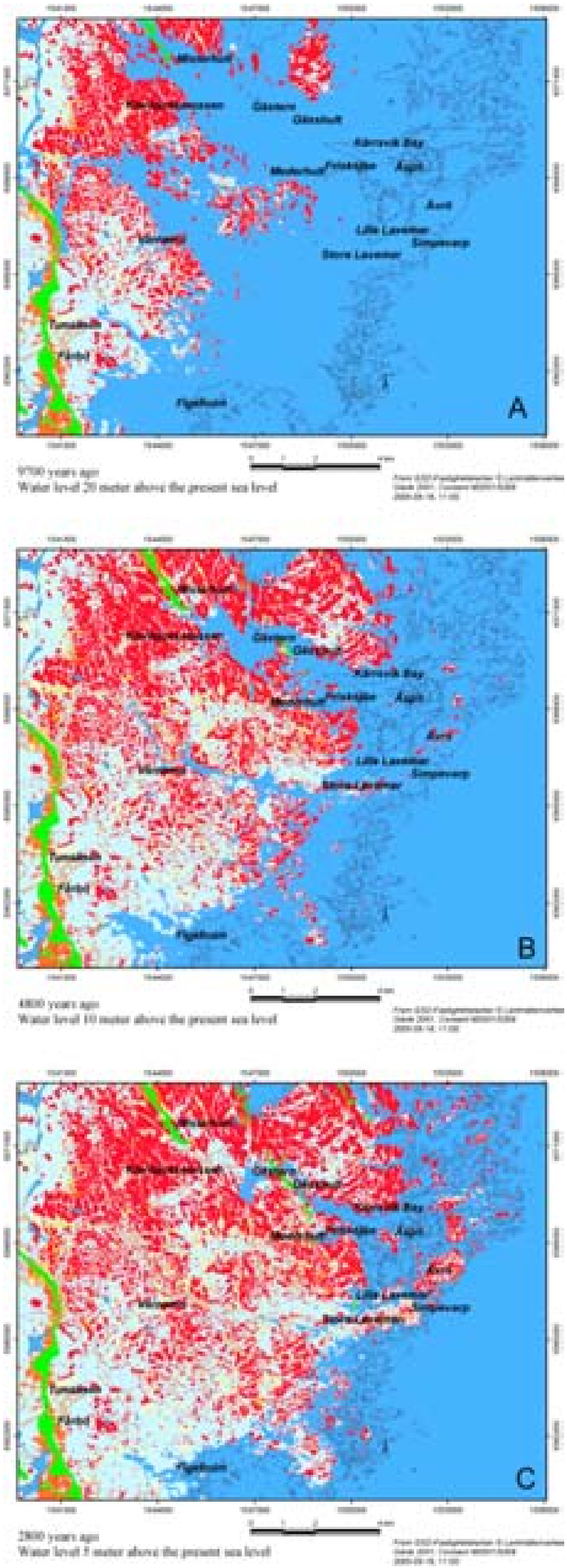

Figure 3-26. *The distribution of land and sea at three different occasions during Holocene, a) 9,700 years ago, b) 4,800 years ago, c) 2,800 years ago.*

The depth and stratigraphy of QD in the regional model area has been modelled with the GeoEditor tool /Nyman 2005/. This model is in turn used for constructing hydrological models (see Section 3.4). Figure 3-27 shows the depth of overburden in the Simpevarp regional model area. In most of the terrestrial areas the average depth of overburden has been calculated using the average depths of different QD from the marine areas where more data is available (Figure 3-13 and Table 3-7). The clay/peat-covered valleys and the glaciofluvial Tunaåsen are clearly visible on Figure 3-27 as zones with thick overburden. The depth model also includes some generalised stratigraphical information in profiles (Figures 3-28 and 3-29). The layer Z3 refers to the till and Z2 to the total thickness of clay. The uppermost overburden is referred to as Z1 and can be given different properties depending on land use, vegetation type, QD etc. Layers of peat, artificial fill and glacio-fluvial deposits are shown separately in the stratigraphical model. The overburden model will be improved when more stratigraphical data is available.

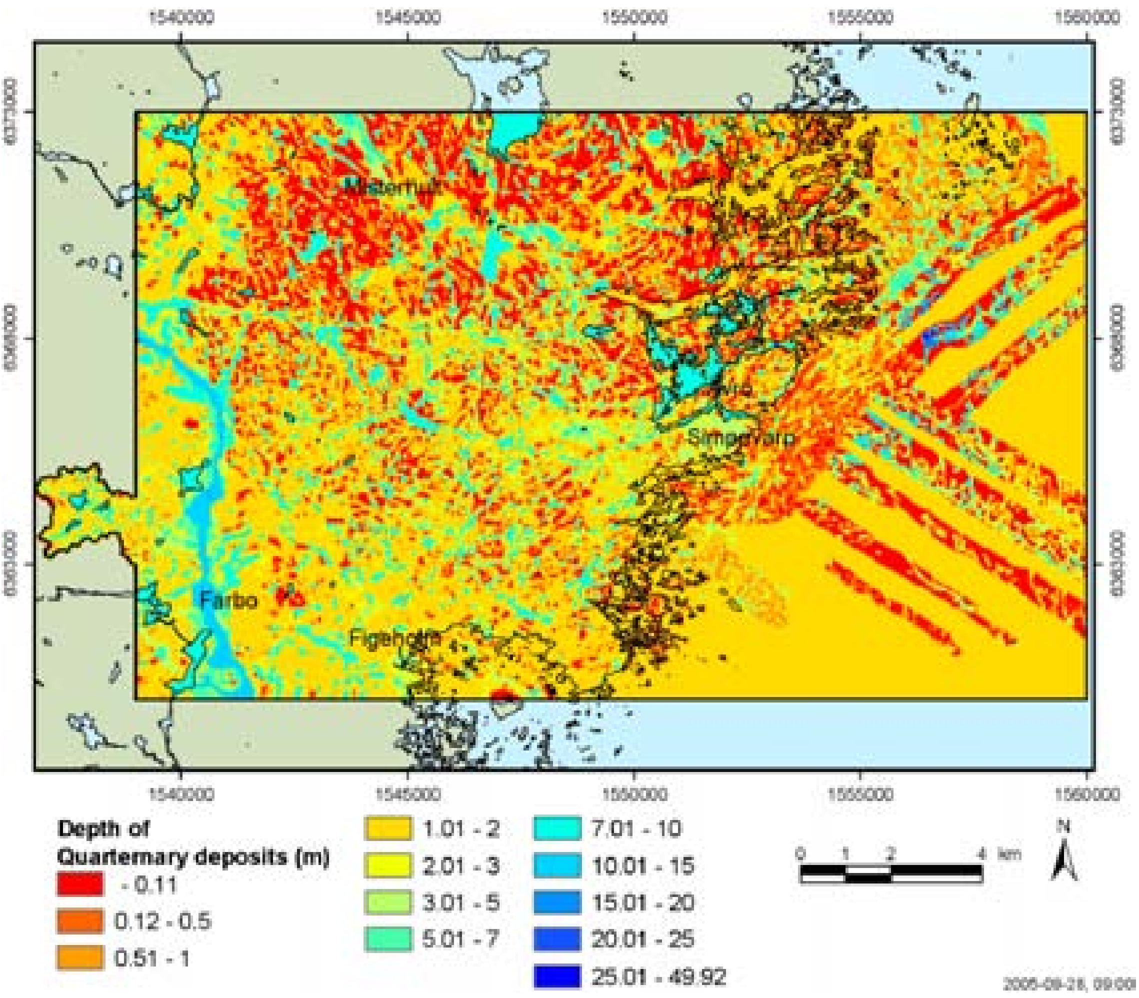

Figure 3-27. *The distribution of total overburden depths in the Simpevarp regional model area. The map was constructed after calculations with Geoeditor /Nyman 2005/. The marine part of the regional model area partly lacks field information. In these areas the average depth of QD in the marine areas mapped by the SGU was used.*

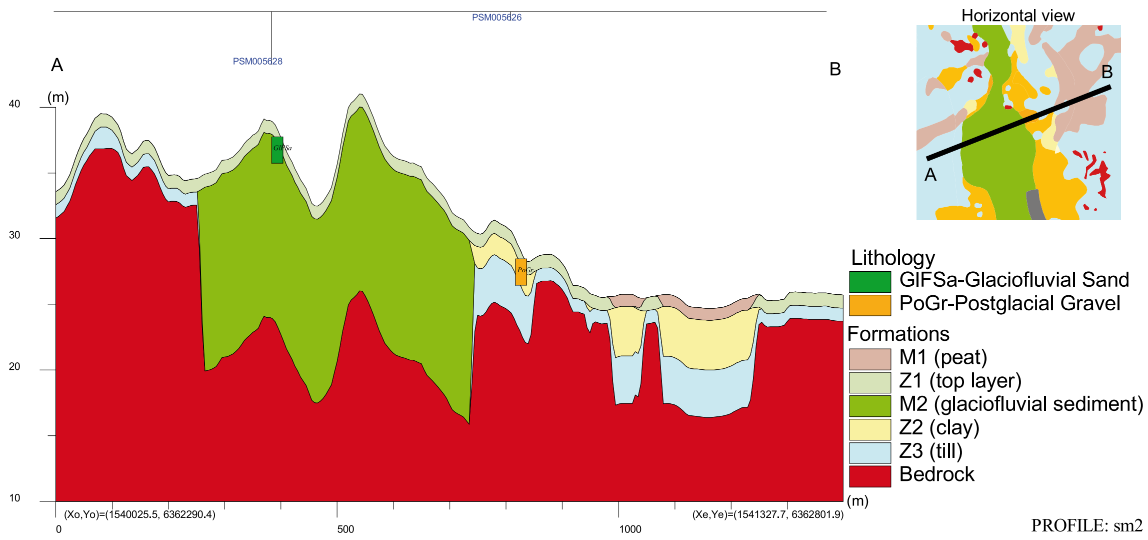

Figure 3-28. The profile shows the total depth and stratigraphy of overburden across the glaciofluvial esker, Tunåsen, north of Fårbo. The profile was constructed after calculations with Geoeditor /Nyman 2005/.

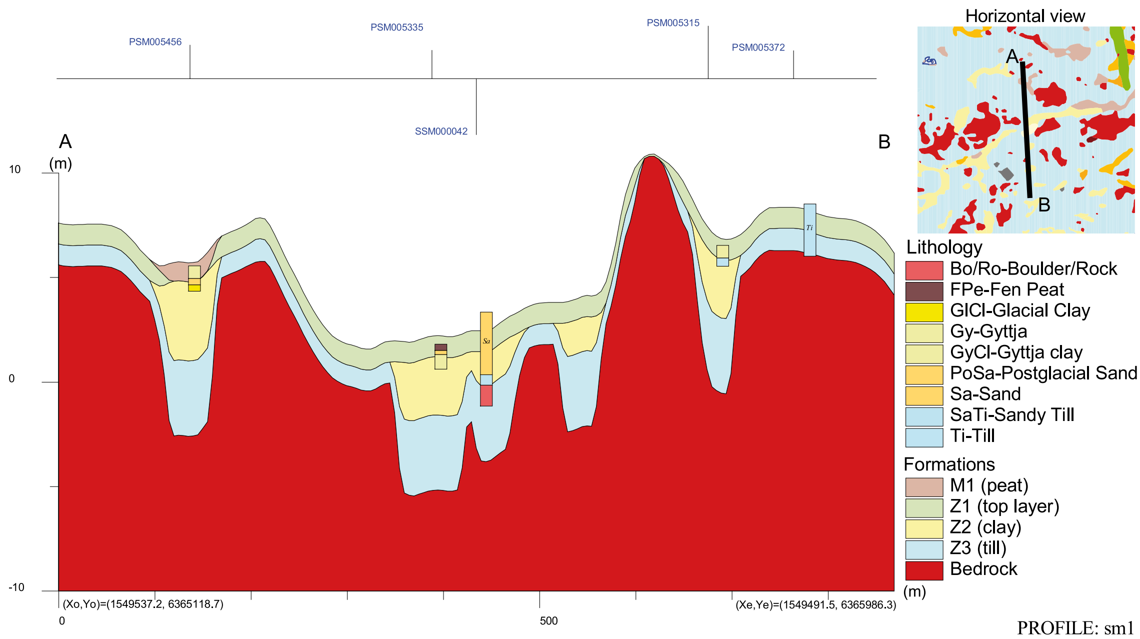

Figure 3-29. The profile shows the total depth and stratigraphy of overburden across a valley west of Lilla Laxemar. The profile was constructed after calculations with Geoeditor /Nyman 2005/.

Important physical properties, obtained from analyses of QD sampled the Simpevarp regional model area, are summarised in Table 3-11. The data from /Almén and Talme 1975/ has not been obtained from the site investigation. The data will be improved as the forthcoming site investigations deliver more data concerning the chemical and physical properties of the QD.

Table 3-11. Physical properties of the Quaternary deposits in the Simpevarp regional model area. The grain size composition of the till is shown in Table 3-9. The data from /Almén and Talme 1975/ has not been taken from the site investigation.

	Peat	Gyttja (lake sediments)	Gyttja clay (Bay sediments)	Sand/ gravel	Glacial clay	Till
Average thickness (m)	0.9±0.53[1]	1.7±0.8[2]*	1.7±0.8[2]*	0.8±0.3[2]	2.6±2.3[2]	3.6±2.6[2]**
N	41	2,539	2,539	2,405	14,886	4,575
Porosity (%)	0.926±0.03[3]	0.91±0.04[4]	0.9±0.03[4]	0.3[5]	0.71[4]	0.1–0.25[5]
N	10	19	22	–	–	–
Bulk density (kg/m^3)***	1,026 ± 57[3]	1,060±30[4]	1,100±30[4]	2,000[5]	1,460[4]	2,250[5]
N	18	19	22	–	2	–
Clay content (%)****	–	29.4±8.9[4]*	29.4±8.9[4]	–	66.4±8.5[1,4,6]	3.1±2.0[1,6]
N		46	46		8	31
Organic C content (%)	53[4]	22.1±6.4[4]	17.3±6.1[4]	–	0.5[4]	
N	2	20	42		1	

/[1]Rudmark et al. 2005, [2]Elhammer and Sandkvist 2005, [3]Lundin et al. 2005 ,[4] Nilsson 2004, [5]Almén and Talme 1975, [6]Bergman et al. 2005/. *The same value is used for gyttja and post-glacial clay. **Till thickness in areas covered by clay. ***Water saturated material. ****Clay content of material < 20 mm.

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 Laxemar 1.2 model. The objectives of the modelling reported here are to:

- analyse and present the data available in the Laxemar 1.2 dataset,
- update the conceptual-descriptive model presented in the previous Simpevarp 1.2 model version /SKB 2005, Werner et al. 2005a/,
- present the results of the quantitative water flow modelling, undertaken in order to develop the understanding of the site and to support the ecological systems modelling,
- summarise and present the results in the form of an updated site description.

The present section is based on the Laxemar 1.2 background report for climate, surface hydrology and near-surface hydrogeology /Werner et al. 2005b/, which provides a more complete description of the data and the modelling performed. In particular, a much more detailed reporting of the input data and the quantitative flow modelling is given in the background report.

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

Thus, it should be emphasised that although significant steps have been taken in the conceptual-descriptive and quantitative water flow modelling, there are still substantial uncertainties in the resulting site description. The main reason for this is the limited amount of site investigation data (primarily time series). It should also be noted that for many types of site investigation data, e.g. the detailed map of Quaternary deposits (QD) and exposed bedrock (see Section 3.3) and the groundwater levels in QD, the Laxemar 1.2 data freeze is essentially the first batch of data that provides information on the Laxemar subarea.

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

It should be noted that a complete conceptual-descriptive model of the hydrological and hydrogeological conditions at a site involves a description of the integrated (continuous) hydrogeological-hydrological system. This system includes groundwater in bedrock, groundwater in QD and surface waters. The focus of the present description is on the surface and near-surface conditions. For instance, the hydrogeological properties of the bedrock and the lower boundary condition used in the quantitative water flow modelling are not described here. Hence, in the present context the terms hydrology and hydrogeology refer to surface hydrology and near-surface hydrogeology, respectively.

3.4.2 Investigations and available data

Previous investigations

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

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

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

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

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

Discipline-specific data in Laxemar 1.2

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

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

Most notably, the additional discipline-specific data provided in the L1.2 data freeze include data from hydraulic testing in the Laxemar subarea. The monitoring that has started in the new meteorological station in Plittorp and in the new groundwater monitoring wells in Laxemar will be very important for the continued development of site understanding and descriptive models in future model versions.

Other investigations contributing to the modelling

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

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

Summary of available data

Table 3-12 provides references to site investigations and other reports that contain meteorological, hydrological and hydrogeological data used in the L1.2 modelling. Further, Table 3-13 provides the corresponding information with respect to other disciplines or types of investigations. Finally, Table 3-14 specifies the SKB reports referred to in Table 3-12 and 3-13. Note that these tables also include references associated with the previous model versions (S0, S1.1, and S1.2), such that they provide a cumulative account of the site data used to date.

Table 3-12. Available meteorological, hydrological and hydrogeological data and their handling in L1.2.

Available site data, data specification	Ref	Usage in L1.2 analysis/modelling
Meteorological data		
Regional Version 0 data:		
"Regional" meteorological data prior to the site investigations.	TR-02-03 R-99-70	Description of "regional" meteorological conditions.
Site Investigation data:		
Meteorological data from Äspö (September 2003–June 2005 and Plittorp (July 2004–June 2005).	P-05-227	Comparison with "regional" meteorological data. Input to quantitative water flow modelling (MIKE SHE).
Hydrological data		
Regional Version 0 data:		
"Regional" discharge data prior to the site investigations.	TR-02-03 R-99-70	Description of "regional" hydrological conditions (e.g. average regional specific discharge).
Site Investigation data:		
Investigation of potential locations for hydrological stations.	P-03-04	Size of catchment areas for manual and automatic discharge measurements.
Geometric data on catchment areas, lakes and watercourses.	P-04-242	Delineation and characterics of catchment areas, lakes, and watercourses. Input to quantitative water flow modelling (MIKE SHE and MIKE 11).
Manual discharge measurements in watercourses.	P-04-13 P-04-75 P-04-246	Description of spatial and temporal variability of discharge.
Surface-water levels in lakes and the sea	P-05-227	Description of spatial and temporal variability of surface-water levels.
Surveying of watercourses in catchment areas 6–9.	P-06-05	Input to quantitative water flow modelling (MIKE 11).
Characterisation of running waters, including vegetation, substrate and technical encroachments.	P-05-40	Identification of "missing" (parts of) watercourses. Interpretation of discrepancies between actual and model-calculated "flooded" areas.
Discrepancies between actual watercourses and watercourses in the SKB GIS database.	P-05-70	Identification of "missing" (parts of) watercourses. Interpretation of discrepancies between actual and model-calculated "flooded" areas.
Hydrogeological data		
Inventory of private wells.	P-03-05	General description of available hydrogeological information.
Manually measured groundwater levels in QD.	P-05-205	Description of spatial and temporal variability of groundwater levels in QD.

Automatically measured groundwater levels in QD.	P-05-205	Description of spatial and temporal variability of groundwater levels in QD.
Geological data from drilling in QD and installation of groundwater monitoring wells.	P-03-80 P-04-46 P-04-121 P-04-317 P-05-167	Conceptual-descriptive model of HSD geometry.
Hydraulic conductivity from slug tests in groundwater monitoring wells in QD.	P-04-122 P-04-318	Conceptual-descriptive modelling of hydraulic conductivity in QD.
Hydrogeological inventory in the Oskarshamn area.	P-04-277	General description of ditching-, draining- and other water related activities in the Simpevarp area.

Table 3-13. Input data from other disciplines and their handling in L1.2.

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

Table 3-14. Reports in the SKB series P, R and TR that are referred to in Tables 3-12 and 3-13.

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

P-05-167	**Henrik A, Morosini M, Samuelsson L-E, Ekström L, Håkanson N.** Oskarshamn site investigation. Drilling of cored borehole KLX03.
P-05-205	**Nyberg G, Wass E, Askling P.** Oskarshamn site investigation. Groundwater Monitoring Program. Report for December 2002–October 2004.
P-05-227	**Lärke A, Wern L, Jones J.** Oskarshamn site investigation. Hydrological and meteorological monitoring at Oskarshamn during 2003–2004.
P-06-05	**Strömgren M.** Oskarshamn site investigation. Surveying of watercourses in the Simpevarp area (prel. Title – report to be published).
R-99-70	**Lindell S, Ambjörn C, Juhlin B, Larsson-McCann S, Lindquist K.** Available climatological and oceanographical data for site investigation program.
R-05-08	**SKB, 2005.** Preliminary site description. Simpevarp subarea – version 1.2.
R-05-15	**Lundin L, Lode E, Stendahl J, Björkvald L, Hansson J.** Soils and site types in the Oskarshamn area (report to be published).
R-05-38	**Brydsten L, Strömgren M.** Digital elevation models for site investigation programme in Oskarshamn. Site description version 1.2.
R-05-54	**Nyman H.** Depth and stratigraphy of Quaternary deposits in the Simpevarp area. An application of the GeoEditor modelling tool.
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

Meteorological data

The meteorological conditions in the region around Simpevarp are described by /Larsson-McCann et al. 2002/. They list meteorological stations of interest for the region, and present long-term statistics for selected meteorological stations considered representative for different meteorological parameters. For the S0 and S1.1 model versions, meteorological data were available from these relatively distant meteorological stations only, operated by SMHI (the Swedish Meteorological and Hydrological Institute), Vägverket (the Swedish National Road Administration), and (for some meteorological parameters) from OKG, owner and operator of the nuclear power plant at Simpevarp. Further, data were only available for the period prior to the site investigations in the Simpevarp area.

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

Hydrological data

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

For SDM S1.2, a detailed delineation and land-use description of catchment areas was available for the regional model area. The relative areas of different types of wetlands were also calculated for each of the identified catchments areas in the Simpevarp regional modelling area. Main watercourses and lakes within the catchment areas were also identified, although no complete set of morphologic data (cross sections, bottom and surface water levels) was presented. Catchment areas and lakes in the regional model area are shown in Figure 3-30. In addition, a set of data from manual discharge measurements in some of the watercourses were reported to SICADA.

For L1.2, cross-section data (bottom levels and widths) are available from field surveying of the main watercourses in catchment areas 6 (Mederhultsån), 7 (Kåreviksån), and 9 (Ekerumsån) /Strömgren 2006/. Further, data are available from continued manual discharge measurements in some of the watercourses. There are also data on automatically measured water levels in some of the lakes and in the sea. However, there are yet no data on automatically measured water levels or calculated discharges in watercourses stored in the SICADA database. The reason is that rating curves (a station-specific empirical relationship between water level and discharge) for these automatic hydrological stations need to be established before the data are delivered to SICADA. The hydrological measurement stations providing data to the L1.2 modelling are shown in Figure 3-31, which also includes the meteorological stations (cf above).

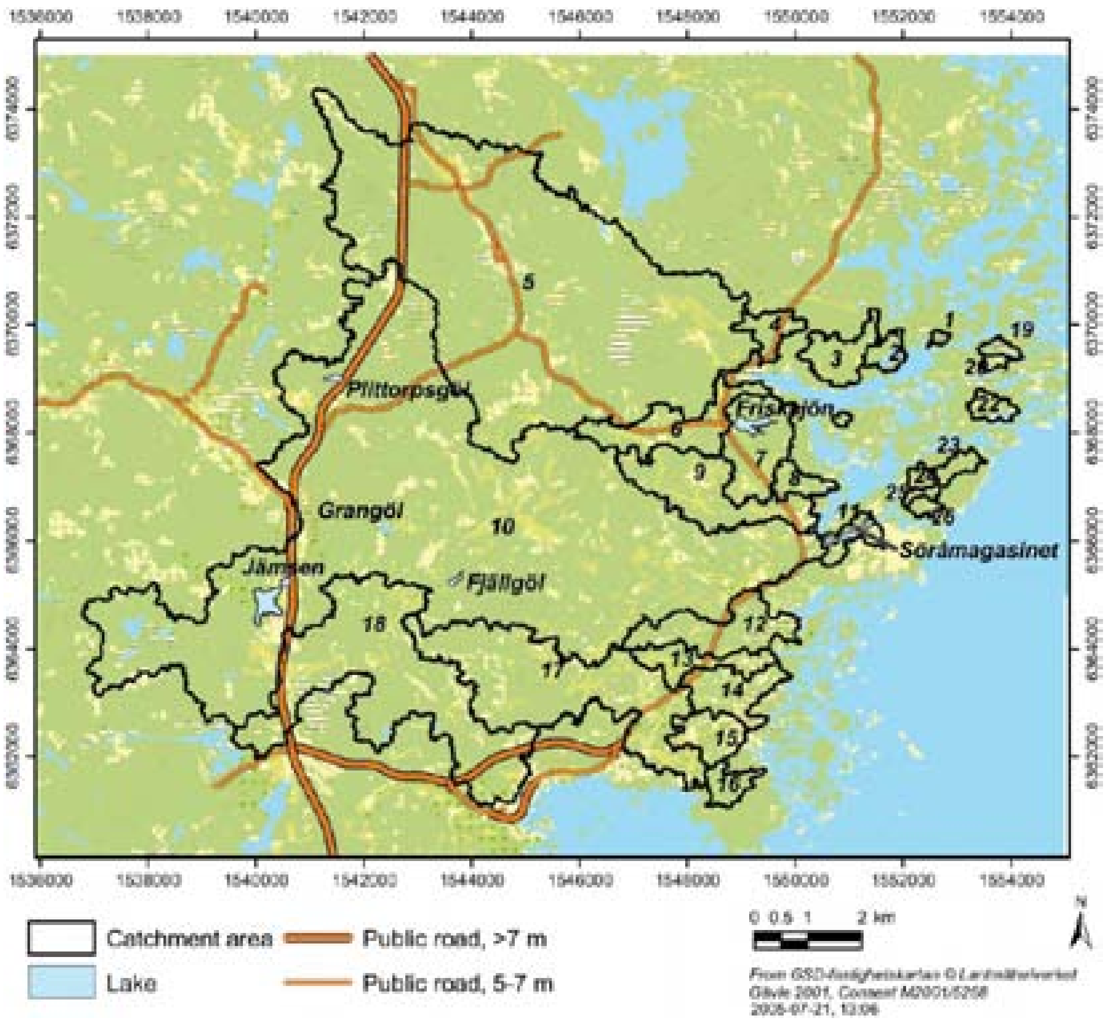

Figure 3-30. Delineation and numbering of the 26 catchment areas in the Simpevarp regional area /Brunberg et al. 2004/. The map also shows the locations of the 6 lakes in the area.

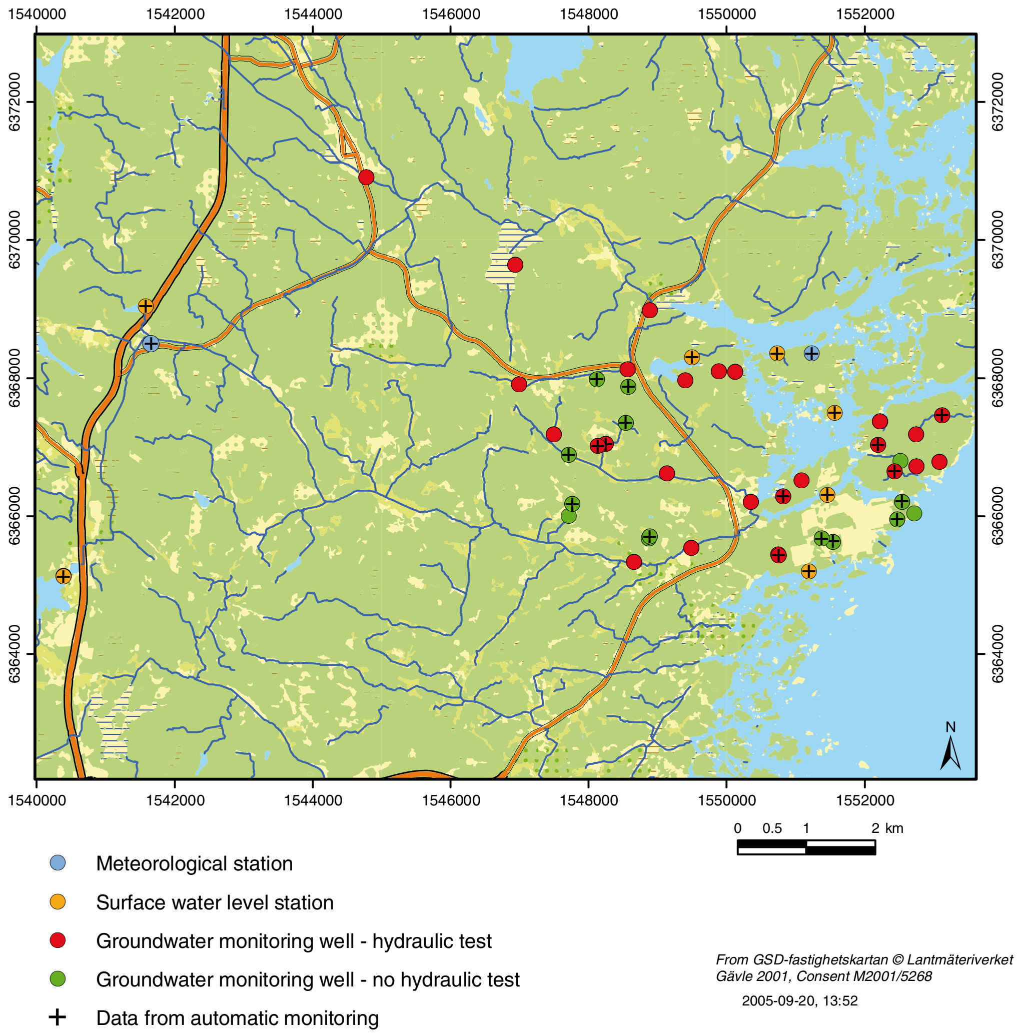

Figure 3-31. *Map showing the locations of meteorological stations, hydrological stations, and groundwater monitoring wells that contributed data to the L1.2 modelling. Measurement stations/ wells from which automatically measured data were available in L1.2 are marked "+" in the figure.*

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

Hydrogeological data

Hydrogeological properties

In S0 and S1.1, no site-specific hydrogeological properties data (hydraulic conductivity and storage parameters) were available for the QD or the interface between QD and near-surface bedrock. These previous model versions therefore included literature data and expected ranges for the hydraulic parameters for different types of QD typical for Swedish geological conditions. In the S1.2 data freeze, results from so-called slug tests /Johansson and Adestam 2004ab/ were reported to SICADA for 13 groundwater monitoring wells (11 wells in the

Simpevarp subarea and 2 wells in the Laxemar subarea). The purpose of slug tests is to provide estimates of the hydraulic conductivity (*K*) of the QD and/or the QD/bedrock interface, depending on where the well screen is placed. It is also possible to obtain an approximate value of the storativity (*S*) from slug tests; however, storativity data from these slug tests are not reported to the SICADA database.

Data from slug tests in 12 additional groundwater monitoring wells (all located in the Laxemar subarea) are included in the L1.2 data freeze /Johansson and Adestam 2004cd/. In addition, data from grain-size analyses (particle-size distribution curves, PSD) of QD samples are also available in the L1.2 data freeze. These data are used in order to obtain supplementary hydraulic conductivity data on the QD; depending on the soil structure and texture, slug tests and PSD curves can give very different results. The locations of all groundwater monitoring wells installed by the site investigation, and the investigations performed in them, are summarised in Figure 3-31. The figure also shows the locations of wells with data from manual and/or automatic groundwater level measurements. It should be noted that the well screen is located in till in almost all groundwater monitoring wells in the Simpevarp area.

Table 3-15 summarises the average *K*-values obtained for sandy (gravelly) till from the slug tests and the analyses of particle-size distribution curves (PSD). According to the table, the slug tests and the Hazen method provide approximately similar mean/median values for the hydraulic conductivity of the till (in the range c $1–5·10^{–5}$ $m·s^{–1}$), whereas the Gustafson method gives somewhat lower *K*-values (c $3–6·10^{–6}$ $m·s^{–1}$); see /Werner et al. 2005b/ for details on the evaluation of hydraulic conductivity data.

Table 3-15. Summary of average *K*-values for sandy (gravelly) till obtained from slug tests and PSD (particle-size distribution) analyses.

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

Groundwater levels in QD

Up to December 2004, 42 groundwater monitoring wells in QD had been installed in the Simpevarp and Laxemar subareas. From these wells, there are data on automatically measured groundwater levels in 18 wells, out of which measurements have been terminated in 9 wells (i.e. only short-term measurements were performed in these 9 wells). Further, data are available from manual groundwater level measurements in 29 wells; out of these 29 wells, both manual and automatic measurements have been made in 10 wells. In 5 of the totally 42 wells (including 1 dry well), no groundwater level measurements have been performed.

Figure 3-32 and 3-33 show plots of all automatically measured groundwater levels in monitoring wells in QD. Figure 3-32 shows the levels plotted in metres above sea level, whereas Figure 3-33 shows the same data, expressed in terms of metres below the ground surface. The locations of these wells are shown in Figure 3-34.

Figure 3-32 and 3-33 show that with some exceptions the groundwater level variations are relatively small, usually in the range 0.5–1 m. Furthermore, it is seen in Figure 3-33 that the groundwater table is generally located approximately 0.5–1.5 m below the ground surface. The exceptions are the wells SSM000004 and -11, which show a deeper groundwater table (depth c 2–2.5 m); especially SSM000004 demonstrates a deep groundwater table during most of the measured time period.

The figures also show that the available time series are relatively short, with the exception of those from three of the wells where the measurements have been terminated (SSM000002, -04 and 05). More detailed analyses would require groundwater level data, and associated meteorological and hydrological data, for a period of at least one (hydrological) year. This means that such analyses must be postponed to future model versions, when longer time series are available.

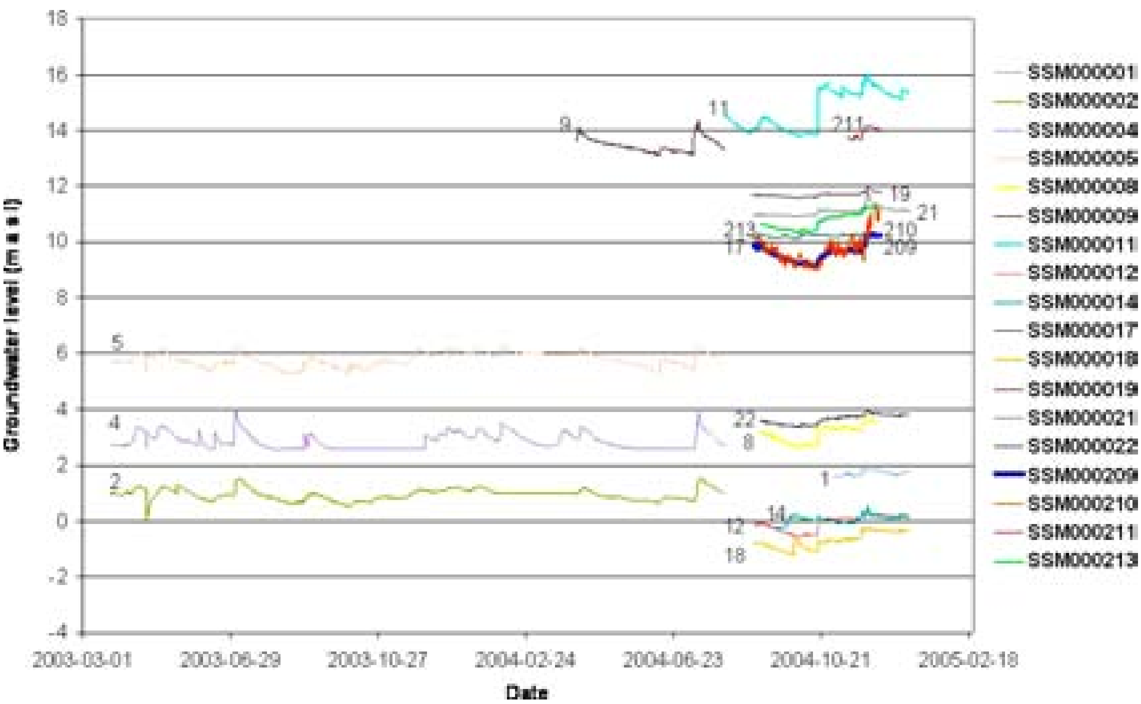

Figure 3-32. *Automatically measured groundwater levels in monitoring wells in QD, expressed in metres above sea level (m a s l).*

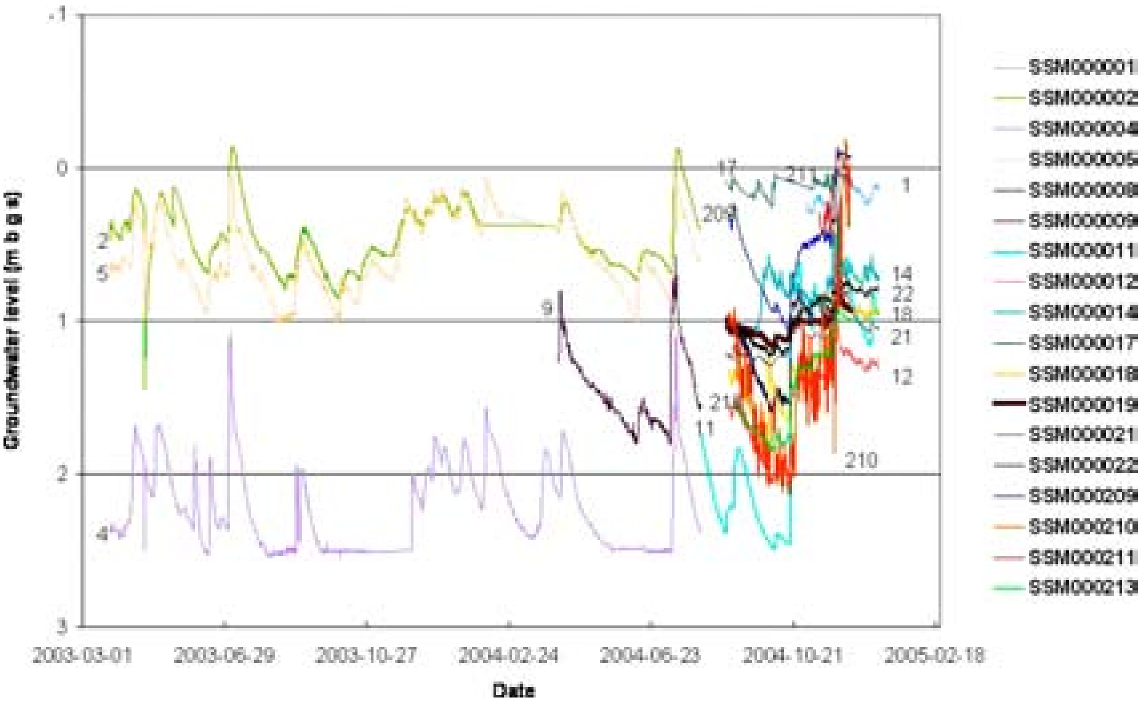

Figure 3-33. *Automatically measured groundwater levels in monitoring wells in QD, expressed in metres below ground surface (m b g s).*

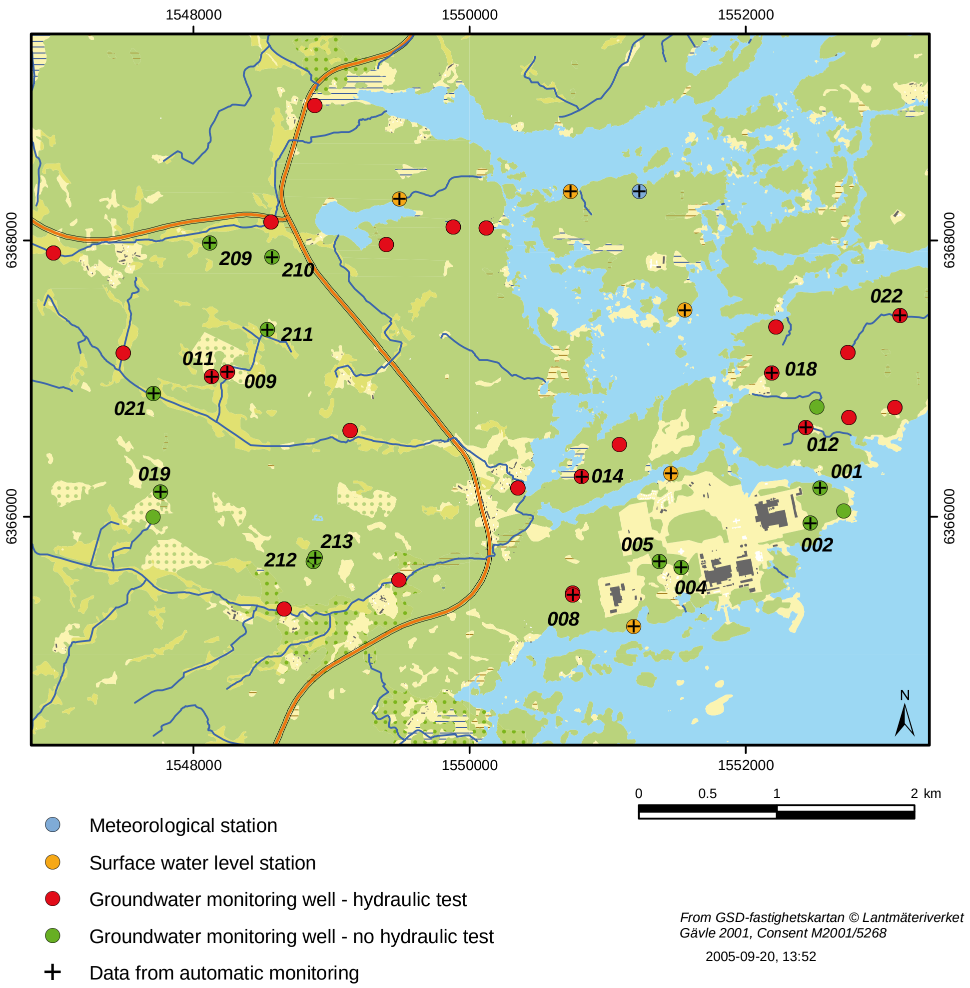

Figure 3-34. *Simplified ID numbers (e.g. SSM000011 is labelled 011) of groundwater monitoring wells providing data to the L1.2 modelling (cf Figure 3-32 and 3-33).*

Private wells and other water-related activities

Private wells in the Simpevarp regional area were investigated and summarised by /Morosini and Hultgren 2003/. For a list of these wells and basic data on them, we refer to their report and to /Werner et al. 2005a/. The latter report also provides a brief overview of the water handling at OKG, i.e. the handling of process water, storm water and waste water within the industrial area on the Simpevarp peninsula.

Many watercourses in the Simpevarp area are diverted and/or flows in conduits, and therefore diverge from the natural topography-controlled flow conditions /Carlsson et al. 2005, Svensson 2005/. In the SKB GIS database, there are missing (parts of) watercourses, in some cases because the watercourses flow in conduits /Svensson 2005/. A characteristic of the Simpevarp area is that it contains many areas that have been drained, mainly for agricultural purposes /Nyborg et al. 2004/. These areas would probably be lakes or wetlands without the drainage operations. Field investigations of ditches, drainages, and missing watercourses have been reported after the L1.2 data freeze /Carlsson et al. 2005, Svensson 2005/; these results have not been considered in the present modelling.

3.4.4 Modelling of near-surface and surface water flow

Conceptual-descriptive model

The framework and the overall objectives of the conceptual-descriptive modelling are presented in /Werner et al. 2005ab/. Due to the still limited amount of data (especially time series data), the conceptual-descriptive modelling is to large extent based on the general knowledge of the regional-scale meteorological, hydrological, and hydrogeological conditions.

The considered model area is the same as that covered by the detailed catchment area mapping /Brunberg et al. 2004/. It should be noted that the quantitative water flow model covers only four of the totally 26 catchment areas (catchment areas 6–9), and also near-coastal parts of land (i.e. areas with direct runoff to the sea) and the Baltic Sea (i.e. the inner parts of the bays that surround Äspö). It is assumed that the water divides for surface water and groundwater coincide. Hence, the boundaries between the catchment areas, see /Brunberg et al. 2004/, are assumed to be no-flow boundaries for the surface and near-surface water flows. The boundary towards the sea is treated as a prescribed head boundary.

The conceptual-descriptive model is based on three types of elements:

- **Type areas.** These are areas that are considered to be more or less similar units in a geological, hydrological and hydrogeological perspective.
- **Flow domains.** The overall SKB approach is to divide the system into bedrock domains (Hydraulic Rock Domains, HRD, and Hydraulic Conductor Domains, HCD) and overburden domains (Hydraulic Soil Domains, HSD). The focus in the present context is on the HSD, which are divided into several types of QD. These QD types are identified and described based on currently available site investigation data. In cases where no such data are available, generic (literature) data are used. In addition, flow domains relevant for the surface/near-surface system include lakes, watercourses and wetlands. An overview of the latter flow domains is given in /Werner et al. 2005b/; a detailed description is provided in /Brunberg et al. 2004/.
- **Interfaces between flow domains.** The interfaces between different parts of the hydrological-hydrogeological system (the flow domains) are identified and described, as these to a large extent control the flow of water between different subsystems (flow domains) and constitute the basis for identification of boundary conditions in numerical flow models.

Type areas

Based on presently available data on topography (the Digital Elevation Model, DEM; Section 3.2) and QD (the detailed map of QD and exposed bedrock; Section 3.3), four type areas are identified (1–3 were identified in the S1.2 model):

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

2: *Valleys* with postglacial sediments at the surface (gyttja clay, peat and/or wave-washed sediments). The postglacial deposits are usually underlain by glacial deposits (glacial clay and till). The thickness of the QD is several metres. Many valleys have been drained in order to create arable land and to improve the conditions for forestry. The QD in the submarine valleys close to the coast are dominated by gyttja clay. The valleys are assumed to be groundwater discharge areas.

3. *Glaciofluvial deposits*, of which the esker Tunaåsen in the western part of the regional model area is the largest. Three other small eskers (Gässhultsåsen, Misterhultsåsen and a nameless esker) exist in the northern part of the regional model area. The dominating vegetation type in this type area is forest. Generally, the glaciofluvial deposits are assumed to be groundwater recharge areas, but this assumption needs to be substantiated by field observations.

4. *Hummocky moraine areas*, with only small areas of exposed bedrock. This type area exists primarily in the south-western part of the regional model area and in the central part of the Laxemar subarea. Till is the dominating soil type in this type area, and he thickness of the QD is generally larger than in type area 1 (high-altitude areas). These areas have a small-scale topography, assumed to be characterised by small recharge and discharge areas.

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

Flow domains

The description of flow domains is focused on the Hydraulic Soil Domains (HSD); the description of lakes, watercourses and wetlands mainly concern their interfaces to the HSD. An overview of the surface water flow domains is given in /Werner et al. 2005b/; a detailed description is provided in /Brunberg et al. 2004/.

Based on several types of data (e.g. data from boreholes, geophysical investigations, the QD map, and the DEM), a geometrical model of the HSD has been developed using the ArcGIS extension GeoEditor /Nyman 2005/. In this model, the HSD in the largest part of the model area are divided into three QD layers, denoted Z1–Z3 (Z1 is the uppermost layer). The model also includes three additional QD layers, referred to as M1–M3. The latter layers represent peat (M1), glaciofluvial deposits (M2) and artificial fill (M3; not strictly QD).

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

The assigned hydraulic properties of QD in the L1.2 model version are shown in Table 3-16. Note that the hydraulic properties for near-surface bedrock shown in the table apply to the upper few metres of the bedrock. For larger depths in the bedrock, the modelling results and the associated data are taken from the S1.2 model of the hydraulic properties of the bedrock /SKB 2005/, as presented by the DarcyTools modelling team. As an approximation, the specific yield S_Y of the near-surface bedrock in the L1.2 modelling is assumed to be equal to the effective porosity, whereas the specific storage coefficient S_S (m^{-1}) of the bedrock is calculated according to an empirical relationship between the hydraulic conductivity K and S_S /Rhén 1997/.

Table 3-16. Assignment of hydraulic properties to QD /Werner et al. 2005b/.

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

[1]Assumed equal to the corresponding parameter for clay.
[2]Assigned 10 times the K_H-value for clay.
[3]Generic data from the literature /Domenico and Schwartz 1998/.
[4]Generic data from Blomquist-Lilja 1999 (unpublished SKB report).
[5]Generic data from the literature /Knutsson and Morfeldt 2002/.
[6]K_H for near-surface clay assigned 100 times K_H for deeper clay.
[7]Site-specific data from slug tests /Johansson and Adestam 2004bd/ and particle-size distribution curves.
[8]Based on the conceptual-descriptive model of till in the Forsmark 1.2 model /Johansson et al. 2005/.
[9]Assigned a value equal to 1/10 of S_Y.
[10]Assigned a value equal to 100 times the K_H-value for clay and 10^{-4} times the K_H-value for gravel.
[11]Generic data from the literature /Kellner 2003/.
[12]K_H and S_Y are the same as for the uppermost part of the bedrock in the DarcyTools data set (S1.2 model version), S_S is calculated based on an empirical relation between S_S and K_H in bedrock /Rhén 1997/.
[13]Assigned 1/10 of the K_H-value for gravel.
[14]Assumed to be equal to the value for sand and gravel.
[15]A K_H-value of $1\cdot10^{-2}$ $m \cdot s^{-1}$ is more reasonable for gravel, but the value was decreased to 1/10 in the MIKE SHE-MIKE 11 quantitative water flow modelling due to numerical instability.

The hydraulic conductivity (*K*) values of the till are assigned on the basis of results from hydraulic tests and particle-size distribution (PSD) curves. The average value of *K* in till, obtained from slug tests in QD, is $3 \cdot 10^{-5}$ m·s^{-1}, whereas the average *K*-value obtained by using the PSD curves (with the so-called Hazen method) is $5 \cdot 10^{-5}$ m·s^{-1}. In the conceptual-descriptive model, the till is assigned the average of these two estimates, i.e. $K = 4 \cdot 10^{-5}$ m·s^{-1}.

Interfaces between flow domains

The interfaces between different flow domains are important for the characterisation of surface water and groundwater flow, as these to a large degree control the flow of water between the domains. For instance, the interface to the QD is one of the most important factors to consider in the development of the descriptive model of the surface waters (lakes, watercourses and wetlands). In the L1.2 model, three important interfaces have therefore been identified /cf Werner et al. 2005a/:

- The interface between near-surface bedrock and deep bedrock. In the quantitative water flow modelling, this interface is placed at 150 m below sea level.
- The interface between QD and bedrock. In the L1.2 modelling, the main flow of water across this interface is assumed to take place at locations where bedrock fractures are in contact with QD. It should be noted that at present, there are no site investigation data available on this interface. For instance, no slug tests have yet been performed in wells with screens across the QD/bedrock interface.
- The interfaces between groundwater and surface water (i.e. lakes, watercourses, wetlands/peat areas, and the sea). In the L1.2 model, the QD at the bottoms of the lakes are assumed to consist of low-permeable layers of gyttja and clay, whereas the QD below peat areas (wetlands) and at the sea bottom are assumed to consist of gyttja (peat areas) and clay (the sea), respectively. The assignment of QD at these interfaces are based on site investigation data /Nilsson 2004/ and the conceptual-descriptive model of the QD in the Simpevarp area. The detailed QD investigations /Rudmark 2004, Rudmark et al. 2005/ provide input data also on the QD along the watercourses; however, it should be noted that a characterisation of the bottom conditions in the watercourses is presented by /Carlsson et al. 2005/.

Interpretation of the surface- and near-surface water flow system

The model area is characterised by a relatively small-scale topographical undulation and by relatively shallow QD. Almost the entire area is below 50 m above sea level, and the whole Simpevarp regional area is located below the highest coastline. Hydrologically, the area consists of a large number of relatively small catchments, and it also contains a relatively large number of watercourses (most of them are very small). A crude water balance for the regional model area, based on approximate ranges of actual precipitation and evapotranspiration (see below), yields a specific discharge in the range 150–180 mm·year^{-1} (4.7–5.7 l·s^{-1}·km^{-2}) /Larsson-McCann et al. 2002/.

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

A long-term regional-scale water balance, applying the general water balance equation, $P = E+R+\Delta S$, has previously been presented for the Simpevarp area, based on selected representative data on precipitation P and discharge R /Larsson-McCann et al. 2002/. Considering a time period of one year, it was assumed that the storage change $\Delta S = 0$. The average (corrected) precipitation P in the Simpevarp area is c 600–700 $mm \cdot y^{-1}$, and the average specific discharge R is estimated to be in the interval 150–180 $mm \cdot y^{-1}$ /Larsson-McCann et al. 2002/. Hence, the evapotranspiration E was estimated to be in the interval 420 $mm \cdot y^{-1}$ (600 minus 180) to 550 $mm \cdot y^{-1}$ (700 minus 150). The Laxemar 1.2 modelling shows differences in the specific discharge R between seasons, years and catchment areas. This is due to seasonal and inter-annual variability of the meteorological conditions, and also differences in land use, fraction of open water and other properties between catchment areas.

Recharge areas are generally associated with high-altitude areas, whereas discharge areas are located in low-altitude areas (valleys, watercourses and depressions). The degree of surface runoff (overland flow) may be large, as there are large areas with exposed or very shallow bedrock. However, as described above and in more detail in Section 3.3, there is often a thin layer of QD and/or vegetation present also in the areas mapped as exposed bedrock. This may act to reduce the degree of surface runoff. The impact of these thin QD and vegetation layers on the surface runoff is still somewhat unclear.

Even though there is yet no field evidence to support the assumption that precipitation and snowmelt are the only sources of groundwater recharge, the Laxemar 1.2 modelling (which includes Lake Frisksjön) indicates that the lakes do not contribute to groundwater recharge even during dry periods when groundwater levels are low. Many of the watercourses in the areas are dry during long time periods, and these are considered to be discharge areas. As the groundwater table is generally located close to the ground surface, evapotranspiration-precipitation cycles have a strong effect on the groundwater level in QD /Werner et al. 2005b/.

The whole system is transient due to the fact that the meteorological conditions (primarily precipitation and temperature) vary with time. Concerning seasonal variability, Sweden can be divided into 4 regions based on the typical variations of the groundwater level during a year /Knutsson and Fagerlind 1977/. In the region where Simpevarp is located, the groundwater level in the near-surface groundwater is generally lowest during late summer/early autumn. During this period, most of the precipitation is consumed by the vegetation. The groundwater level increases during late autumn, and the levels are highest during spring. This implies that 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.

From areas with exposed or very shallow bedrock, a large part of the precipitation/snowmelt is assumed to be diverted, in the form of surface runoff, into surrounding areas with QD or as overland flow into surface waters (watercourses, lakes or wetlands). The distribution of the total discharge on surface/overland and subsurface flows is determined by a variety of properties, such as the hydraulic properties of the QD and the boundary conditions for groundwater flow, the gradients in the ground surface elevation, and the presence or absence of conduits and ditches.

Each catchment area can be divided into recharge areas and discharge areas. In general, recharge takes place in areas of relatively higher altitudes and discharge in lower-lying areas. However, the transient nature of the system 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 macro pores may take place, but can be assumed to be insignificant from a quantitative point of view.

Some of the above concepts are illustrated in Figure 3-35. In a generalized form, the figure illustrates the conceptual-descriptive model of the surface-hydrological and near surface-hydrogeological conditions across a hypothetical valley in the regional model area. The figure also illustrates one of the identified interfaces between flow domains (the QD/bedrock interface).

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 (discharge) areas. However, the depth to the groundwater table is usually smaller in lower-lying areas than in higher-altitude areas.

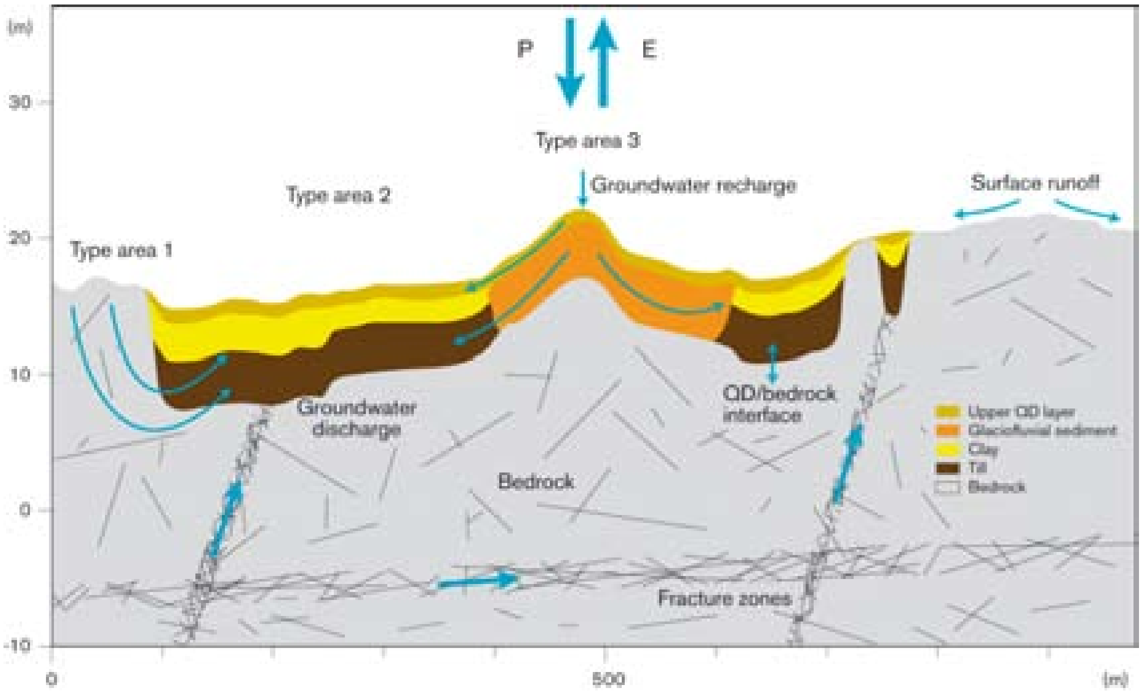

Figure 3-35. *Schematic cross section, obtained from the geometrical model of the HSD /Nyman 2005/, which illustrates some aspects of the descriptive model of the surface-hydrological and near surface-hydrogeological conditions in the regional model area. Note that the vertical scale of the QD is exaggerated. The figure schematically illustrates type areas 1–3, the QD/bedrock interface, and the principle of groundwater recharge, groundwater discharge, and surface runoff. P and E denote precipitation and evapotranspiration, respectively.*

Watercourses are considered to be discharge areas. The manual discharge measurements in the watercourses indicate that there is no water flow in many of the watercourses during long periods of the year. The fact that there are many small catchment areas implies that groundwater recharge and also the discharge of water into the watercourses are highly transient processes. In its simplest form, the conceptual model is that these processes mainly take place in connection to precipitation events and/or snowmelt. Likewise, (relatively short) periods with large groundwater discharge and discharge in watercourses imply that simple averaging of a few individual measurements may lead to erroneous estimates of the total long-term average discharge.

The hydraulic interaction between lakes and near-surface groundwater is highly dependent on the hydraulic conductivity of the bottom sediments. Lakes can act as both discharge and recharge areas; a lake can be a recharge area during periods when near-surface groundwater levels are low, and shift to be a discharge area when near-surface groundwater levels are high. Moreover, wetlands (bogs and mires) can either interact with the groundwater and constitute typical discharge areas, or be separate systems with low-permeable bottom sediments and little or no interaction with the groundwater zone. Based on the field investigations reported in /Nilsson 2004/, the layers below wetlands, peat areas and lakes are assumed to consist of low-permeable materials, hence limiting the interaction between groundwater and surface water in these areas.

Interactions between near-surface groundwater in QD and groundwater in the uppermost part of the bedrock take place at all locations with QD above the bedrock. The main flow of water across the QD/bedrock interface is assumed to take place at locations where bedrock fractures are in contact with QD. Discharge from the bedrock into the QD probably mostly takes place in the topographically defined major discharge areas.

As mentioned above, the regional specific discharge is estimated to be in the range 150–180 mm·year^{-1}. However, the actual sizes of recharge and discharge areas, and the magnitudes of the groundwater recharge and discharge in these areas, need to be quantified by means of quantitative water flow models (see below). The manual groundwater level measurements show that there is a small depth to the groundwater table (usually less than one metre). 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 groundwater flow.

The groundwater flow in the identified glaciofluvial deposits (eskers) and the flow across their interfaces with the surrounding QD are not shown in the conceptual model in Figure 3-35. However, the groundwater flow in the three identified eskers can in its most simple form be conceptualised as channel flow, taking place parallel to the esker orientation. Depending on their hydraulic interactions with their surroundings (and the differences in groundwater levels between the eskers and their surroundings) the eskers can discharge groundwater to the surroundings, or groundwater recharge can take place from the surroundings into the eskers.

Quantitative water flow modelling

The quantitative water flow modelling serves two main purposes:

- To produce output data necessary for other models and applications, i.e. modelling of groundwater flow in the bedrock, ecological systems modelling (cf Chapter 4), modelling of radionuclide transport in Safety Assessment, and Environmental Impact Assessment.

- To evaluate the conceptual-descriptive model, in order to further develop the overall understanding of the hydrological, meteorological and hydrogeological conditions in the Simpevarp area, and to provide a basis for future model versions.

The S1.2 model version included MIKE SHE-MIKE 11 process-based modelling of the Simpevarp 7 catchment area, and GIS-based modelling (using the Hydrological Modelling extension in ArcGIS 8.3) of all 26 catchment areas in the Simpevarp area /Werner et al. 2005a/. The present quantitative modelling does not include the above-mentioned GIS-based modelling, as the main input data to this modelling, the DEM and the regional estimate of the annual average specific discharge, have not been subjected to major changes since the S1.2 model version. Thus, the L1.2 quantitative water flow modelling is focused on process-based modelling, using the MIKE SHE-MIKE 11 software packages /DHI Software 2004/. Brief summaries of the modelling tools MIKE SHE and MIKE 11 are provided in the background reports /Werner et al. 2005ab/. In addition, extended GIS-based hydrological modelling has been performed, applying the PCRaster-POLFLOW modelling approach /Jarsjö et al. 2005/.

In the L1.2 quantitative water flow modelling, the overall methodology in the setup and application of the MIKE SHE-MIKE 11 model can be summarised as follows:

- Integrate data from the previous stages of the site investigation (and, in some cases, generic and pre site-investigation data) with data from the L1.2 data freeze to establish an updated numerical water flow model of selected parts of the Simpevarp area.
- Define and simulate an initial base case, which provides the basis for the sensitivity analysis (cf below). All the simulations use local meteorological data measured at the Äspö meteorological station during the year 2004.
- Define and simulate a series of sensitivity cases, in order to investigate the sensitivity of the model output to, primarily, the hydraulic properties of the QD and the vegetation-related parameters LAI and K_c /Werner et al. 2005b/.
- Define an updated base case based on the results of the sensitivity analysis. The sensitivity cases and the resulting updated base case are used in a broader context, to develop the understanding of the conditions for water flow in the Simpevarp area, and also to identify key data as a basis for planning of continued site investigations. Furthermore, the updated base case is used to produce output data to the ecological systems modelling within the SKB SurfaceNet project.

For a detailed description of the base cases, the sensitivity cases, and the associated modelling results, we refer to the background report /Werner et al. 2005b/.

3.4.5 Some results from the MIKE SHE-MIKE 11 modelling

Model area and boundary conditions

The model area (the horizontal projection of the 3D model domain) includes catchment areas 6–9 and near-coastal parts of land (i.e. areas with direct runoff to the sea) and the Baltic Sea (see Figure 3-36). The model area includes the catchment areas with highest density of relevant site investigation data. The MIKE SHE-MIKE 11 model area includes catchment areas 6–9 only. The part of catchment area 10 that is included in the terrestrial ecosystems modelling (Section 4.1) is excluded from the hydrological modelling due to the lack of local input data. The hydrological input to the ecosystems modelling of this area was obtained from the results for catchments areas 6–9.

The upper boundary (the top surface) of the model follows the DEM /Brydsten and Strömgren 2005/, whereas the bottom of the model is located in the bedrock at a level of –150 m above sea level. In the present modelling, the bottom boundary is assumed to be a no-flow boundary. This simplification was made after initial simulations with a head boundary condition obtained from the DarcyTools modelling team /SKB 2005/ showed unrealistic results (very large flow rates in the vertical deformation zones), probably due to the differences in resolution in the topographic models and/or too high hydraulic conductivities in the QD and/or upper part of the rock.

Obviously, the coupling between the groundwater in the rock and that in the QD must be further studied, in order to facilitate the development in integrated flow and transport models. However, since the flow across the QD/rock interface is expected to be small compared to the flow in the surface/near-surface system, the approximation of a no-flow boundary in the rock is considered reasonable for the purposes of the present analysis. The vertical boundaries, i.e. the outer boundaries displayed in Figure 3-36, are also treated as no-flow boundaries, except for the constant-head boundary in the sea. The horizontal spatial resolution of the model is 20 m, whereas the vertical discretisation of the calculation layers follows that of the geological (QD) layers, see /Werner et al. 2005b/ for details.

Figure 3-36. *Map showing the catchment area boundaries (black lines), and the boundaries of the MIKE SHE-MIKE 11 model area (red line). Note that the model area includes land areas close to the sea, outside (downstream) of catchment areas 6–9, cf /Brunberg et al. 2004/.*

Water balance and specific discharge

The updated base case involves an adjustment of the vegetation-related parameters LAI and K_c relative to the initial base case /Werner et al. 2005b/. Figure 3-37 illustrates the model-calculated water balance (mm·year^{-1}) for the updated base case, and the exchanges of water between different compartments of the model. The water balance in the figure considers all land areas within the model boundary, hence excluding the sea part of the model area but including near-coastal land areas with direct runoff to the sea. Note that the boundaries of catchment areas 6–9 delimit the areas that contribute to the discharge into the watercourses in the model area (see the schematic watercourse in the figure).

As shown in Figure 3-37, the model-calculated average specific discharge is 136+24+14+15 = 189 mm·year^{-1} (c 6 l·s^{-1}·km^{-2}) during the considered year (Äspö meteorological data from 2004). The specific discharge includes overland and groundwater flow into the watercourses and the sea. The water losses due to interception, transpiration, and evaporation (including snow evaporation) are 186, 200 and 80 mm·year^{-1}, respectively, which means that the total average evapotranspiration is 466 mm·year^{-1}.

For the updated base case summarised in Figure 3-37, Table 3-17 shows the model-calculated total annual discharges and the average specific discharges (in l·s^{-1}·km^{-2} and mm·year^{-1}) for the catchment areas 6–9 and the coastal area with direct runoff to the sea. The average specific discharge for each "inner" catchment area is calculated as the ratio between the accumulated annual discharge into the associated main watercourse (cf Figure 3-37), and the total area of the catchment area. The much smaller discharges through overland flow and groundwater discharge that take place due to differences between the field-controlled catchment boundaries /Brunberg et al. 2004/ and those calculated in the MIKE SHE model are also included. Conversely, discharges in the form of overland and groundwater flows are the dominant discharge components for the coastal area.

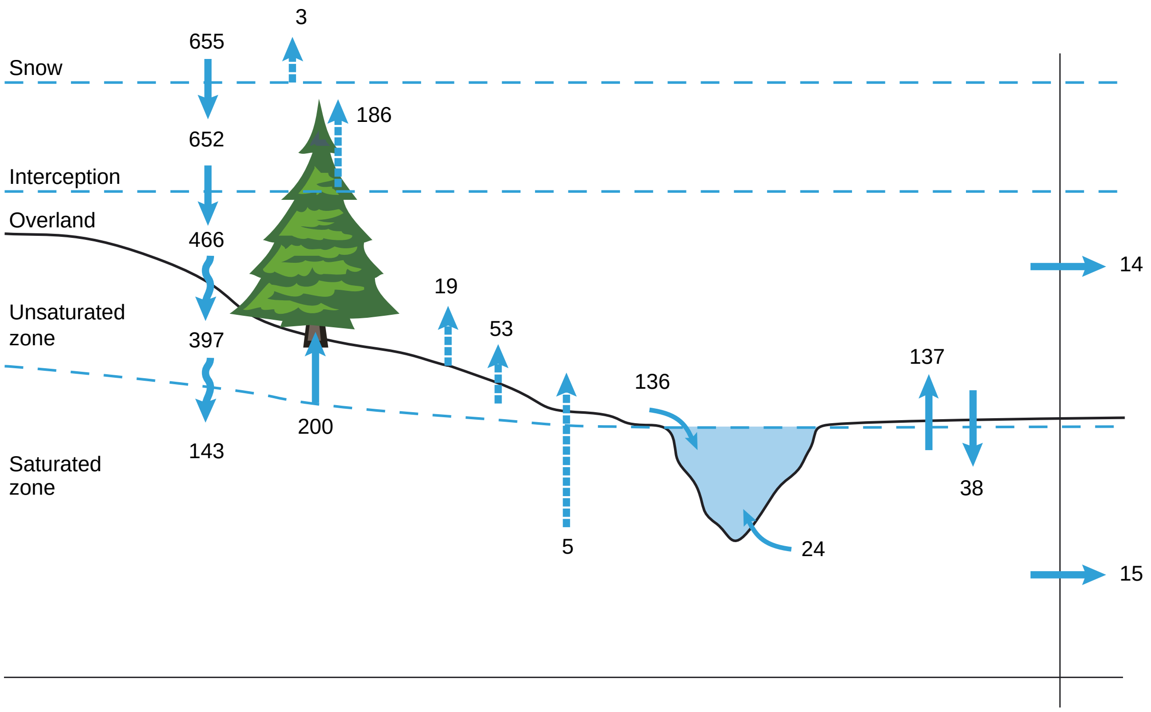

Figure 3-37. *Illustration of the model-calculated water balance (mm·year^{-1}) for the land areas in the model area for the updated base case.*

Table 3-17. Model-calculated annual average discharge into watercourses, and the associated specific discharge, for catchment areas 6–9. Results are shown for the updated base case.

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

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

According to Table 3-17, there are some differences in specific discharge between the modelled catchment areas. The largest annual average specific discharges are those of catchment area 8 and the coastal area (just above 200 $mm \cdot year^{-1}$), whereas the smallest one is that of catchment area 7 (approximately 180 $mm \cdot year^{-1}$). The main difference between catchment area 7 and the others is that area 7 is the only one that contains a lake. In catchment area 7, which was the only catchment considered in the previous Simpevarp 1.2 modelling /Werner et al. 2005a/, Lake Frisksjön may act as a reservoir, thereby increasing the evaporation and decreasing the discharge from the catchment. It can be noted that the specific discharge calculated for catchment area 7 in the present L1.2 modelling (c 180 $mm \cdot year^{-1}$) is somewhat larger than that reported in S1.2 (c 150 $mm \cdot year^{-1}$). One important reason for the increased discharge is that the precipitation measured at the Äspö station during 2004 is larger than that in the reference dataset considered in S1.2; however, part of the increased precipitation is compensated by a larger evapotranspiration in the calculated L1.2 water balance.

The model-calculated specific discharges for the updated base case in (Table 3-17) can be compared to other independent estimates of the discharge. Based on long-term discharge observations (Forshultesjön Nedre; 1955–2000) and discharge calculations with the HBV model, using on long-term meteorological data (Laxemarån and Gerseboån; 1962–2001), the annual average specific discharge is estimated to be in the range 4.7–5.7 $l \cdot s^{-1} \cdot km^{-2}$ /Larsson-McCann et al. 2002/. Applying the PCRaster-POLFLOW approach (a GIS-based hydrological modelling approach) to the Simpevarp regional area, /Jarsjö et al. 2005/ calculated an annual average specific discharge of c 4.0 or 5.9 $l \cdot s^{-1} \cdot km^{-2}$, using two different methods to calculate the actual evapotranspiration. To simulate a spatially variable precipitation and temperature in the Simpevarp area, /Jarsjö et al. 2005/ used spatial interpolation and extrapolation of the long-term annual average data from the SMHI stations Målilla, Oskarshamn and Ölands Norra Udde /Larsson-McCann et al. 2002/.

The average specific discharge calculated for the land areas in the model area (189 $mm \cdot year^{-1}$) using meteorological data from Äspö for the year 2004 is slightly higher than other estimates /Larsson-McCann et al. 2002, Jarsjö et al. 2005/. However, it must be pointed out that the specific discharge is not a static property of the Simpevarp area, as the meteorological conditions demonstrate both large variations between years, and also vary from place to place /Werner et al. 2005b/. For instance, the use of precipitation data from Ölands Norra Udde station leads to an underestimation of the precipitation in the Simpevarp area; on average, the annual precipitation is c 100 mm less there compared to Oskarshamn /Werner et al. 2005b/. Furthermore, the short time series presently at hand indicate that there is a relatively large difference in precipitation between the two local meteorological stations, which probably must be taken into account in the forthcoming modelling /Werner et al. 2005b/.

Figure 3-38 illustrates some of the results from the sensitivity analysis, where the hydraulic conductivity *K* in the QD is increased or decreased by one order of magnitude relative the initial base case, BC. In the sensitivity cases "SA_1a" and "SA_1b", the *K*-value is changed in all QD layers, whereas *K* is changed in the uppermost layer only in the sensitivity cases "SA_1c" and "SA_1d". The figure shows the associated effects on the overland and groundwater flow into the watercourses, and the effects on the groundwater flow into the sea. As can be seen in the figure, the overland flow into the watercourses increases for all these sensitivity cases; the effect is largest when *K* is increased or decreased in all QD layers (SA_1a–b).

In comparison, the effects on the groundwater flow into the watercourses and the sea are somewhat smaller; both decrease with *K* in the QD, in particular when *K* is increased or decreased in all QD layers. Changing *K* in the uppermost QD layer only (cases SA_1b and SA_1d) has a small influence, or no influence, on the groundwater flow to the sea. This may be due to the fact that this outflow is dominated by deeper groundwater flow paths, which are relatively insensitive to the hydraulic conductivity of the upper QD layer.

Much larger differences than those displayed in Figure 3-38 are observed when comparing the discharge terms in Figure 3-38 with those in Figure 3-37. These differences, which essentially quantify the differences between the initial and updated base cases, are mainly due to changes in the vegetation parameters that determine the interception and transpiration processes. Thus, it can be seen that these parameters, LAI and K_c /Werner et al. 2005b/, have large effects on the results. The present sensitivity analysis indicates that uncertainties in the vegetation parameters are much more important for the overall uncertainty associated with the hydrological/hydrogeological model than uncertainties related to, for instance, the hydraulic properties of the QD. However, the analysis of input data to and results from the sensitivity study shows that the values assigned to LAI and K_c in the initial base case were unrealistic, thereby probably over-estimating the sensitivity to these parameters.

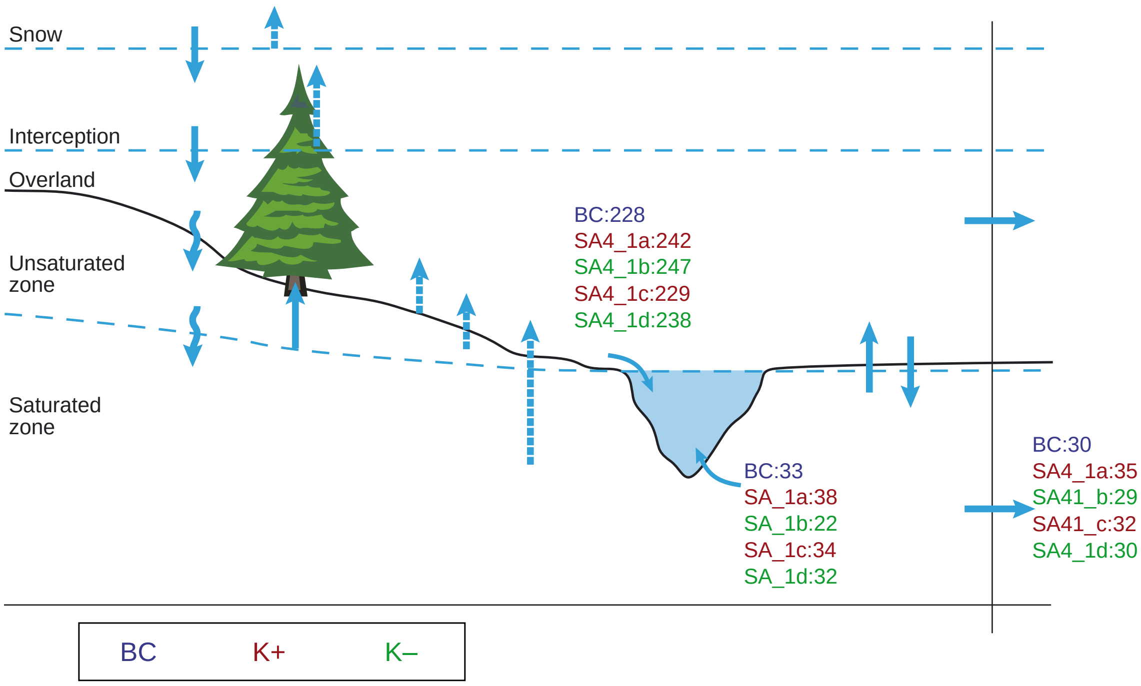

Figure 3-38. *Illustration of the effects of changing the hydraulic conductivity K one order of magnitude in all QD layers (SA_1a–b) or in the upper QD layer only (SA1c–d) on the overland and groundwater flows into the watercourses, and on the groundwater flow into the sea; flows are given in mm·year^{-1}. Note that BC denotes the initial base case, whereas SA_1a–d are the different sensitivity cases.*

Groundwater levels

For the updated base case, Figure 3-39 shows the calculated annual average depth to the groundwater table in the model area. As can be seen in the figure, the groundwater table is shallow and located within at most a few metres below ground in the largest part of the model area. The deeper groundwater levels are mainly found in high-altitude areas, associated with groundwater recharge. There are also areas with a calculated hydraulic head above the ground surface. Hence, these are groundwater discharge areas, including e.g. Lake Frisksjön and areas in the vicinity of the main watercourses, i.e. (local) low-altitude areas according to the DEM /Brydsten and Strömgren 2005/.

There are not actual lakes, wetlands and/or watercourses in all areas where there is surface water in the model. In most cases, this is due to the fact that these areas have been drained, which is a general characteristic of the Simpevarp area /Nyborg et al. 2004/. Without these land-management operations, these areas would most likely have been lakes or wetlands, in accordance with the model. Ditches, drainages, and "missing" watercourses /Carlsson et al. 2005, Svensson 2005/ are not included in the L1.2 model version, but will be considered in future model versions.

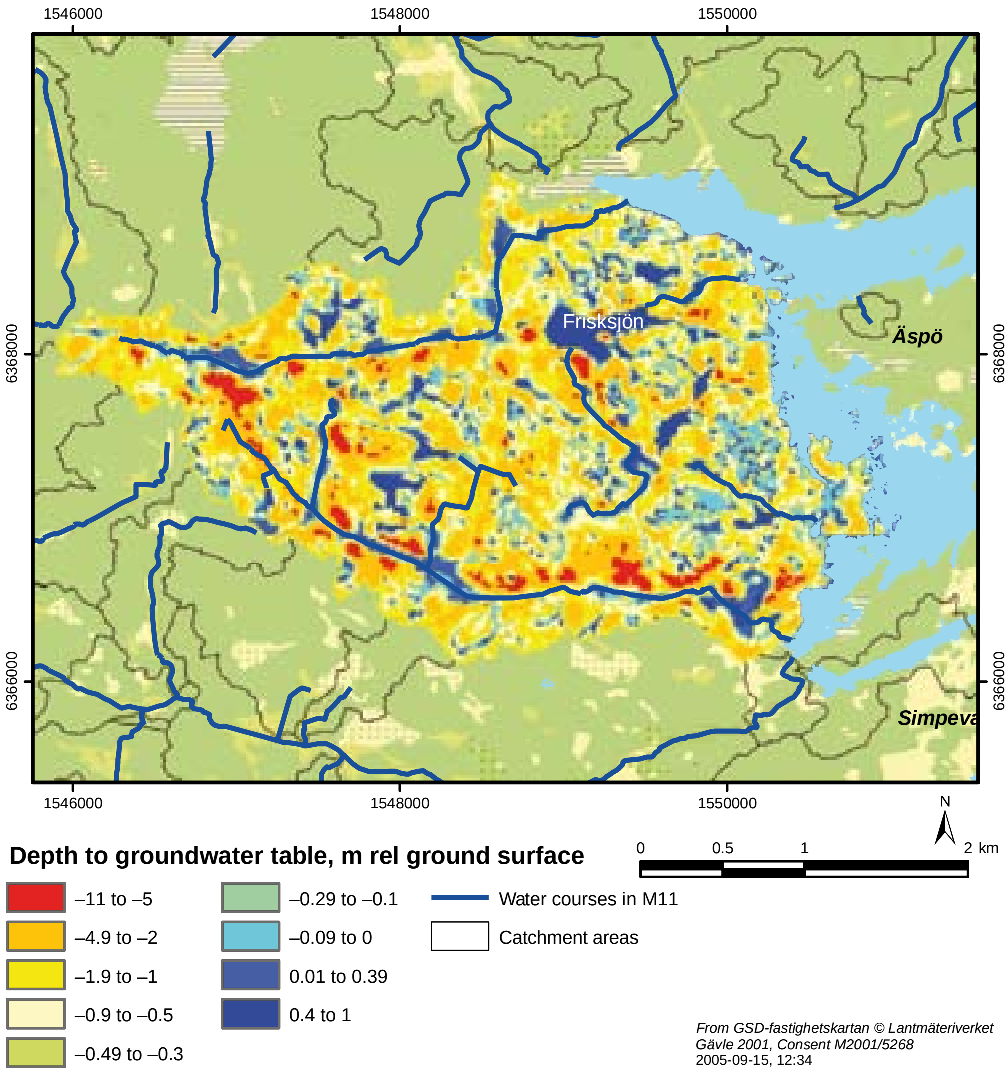

Figure 3-39. *Annual average depth to the groundwater table (metres relative to ground surface) for the updated base case. Positive values indicate ponded water on the ground surface. M11 is an abbreviation for MIKE 11.*

The MIKE SHE-MIKE 11 model was also used to study the transient effects of time-varying meteorological conditions at the ground surface on the groundwater level in the QD. Results from the initial base case and a number of sensitivity cases were used, representing different values of the hydraulic conductivity and the storage properties of the QD. The results were analysed at different observation points within the model area, reflecting areas with different types of QD and different topographical conditions. As expected, these results for individual observation points were more sensitive to parameter variations than the integrated water balance components shown in Figure 3-38. Specific results and conclusions from this study are discussed in /Werner et al. 2005b/.

Surface water levels and discharge

Consistent with the description above, the MIKE 11 modelling results show large temporal variability in the discharges in the watercourses during the year. The results also show that there is a strong correlation between the surface water discharge variations and the temporal variations of the precipitation. There are long periods of very small or zero calculated discharges in the watercourses, and relatively short periods with large discharges. These model results agree with the observations from the manual discharge measurements /Werner et al. 2005b/.

As an example, Figure 3-40 shows three calculated hydrographs (plots of the discharge versus time) in the watercourse Mederhultsån, located in catchment area 6 (updated base case). Hydrographs are shown at three observation points at distances of c 120 m, 1,800 m and 4,110 m from the most upstream point of the watercourse in the model area (length coordinates). Thus, length coordinate 4,110 m represents the most downstream point.

As shown in Figure 3-40, the calculated discharge is larger at downstream observation points, which is because these have larger catchment areas. It can also be noted that the peaks of the discharge occur more or less simultaneously at the three observation points.

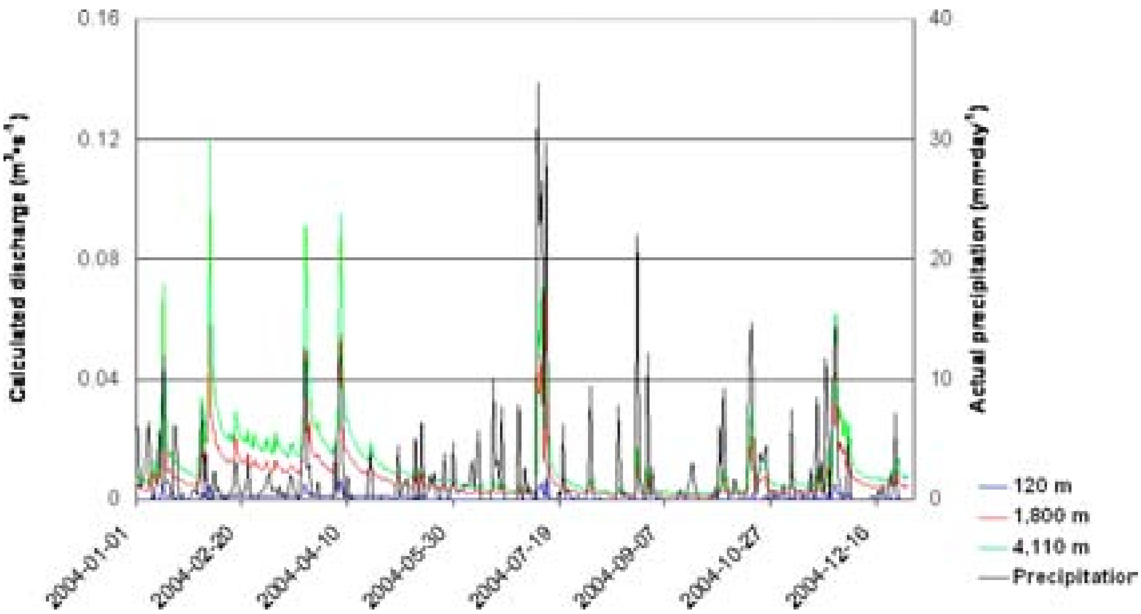

Figure 3-40. *Time series of calculated discharges at three positions along the main watercourse in catchment area 6 (Mederhultsån) for the updated base case. The figure also shows the measured actual precipitation at the Äspö meteorological station during the simulated period.*

This is due to the fact that there are no lakes along Mederhultsån, which otherwise would reduce the peaks of the discharge at observation point downstream of the lakes. The peaks of the discharge are associated with precipitation events (Äspö meteorological data); for instance, the maximum discharge that occurs in the summer (mid July) during a period with heavy summer rains.

For the updated base case, Figure 3-41 shows the model-calculated annual average depth of overland water within the model area (cf Figure 3-36), i.e. the average depth of water above the ground surface. The figure also shows the main watercourses in the whole area covered by the figure (including the areas outside the model area). These results can be compared to Figure 3-39, showing the average depth to the groundwater table. The latter figure shows that the model produces areas with the water table above the ground surface, e.g. Lake Frisksjön and areas in the vicinity of the main watercourses.

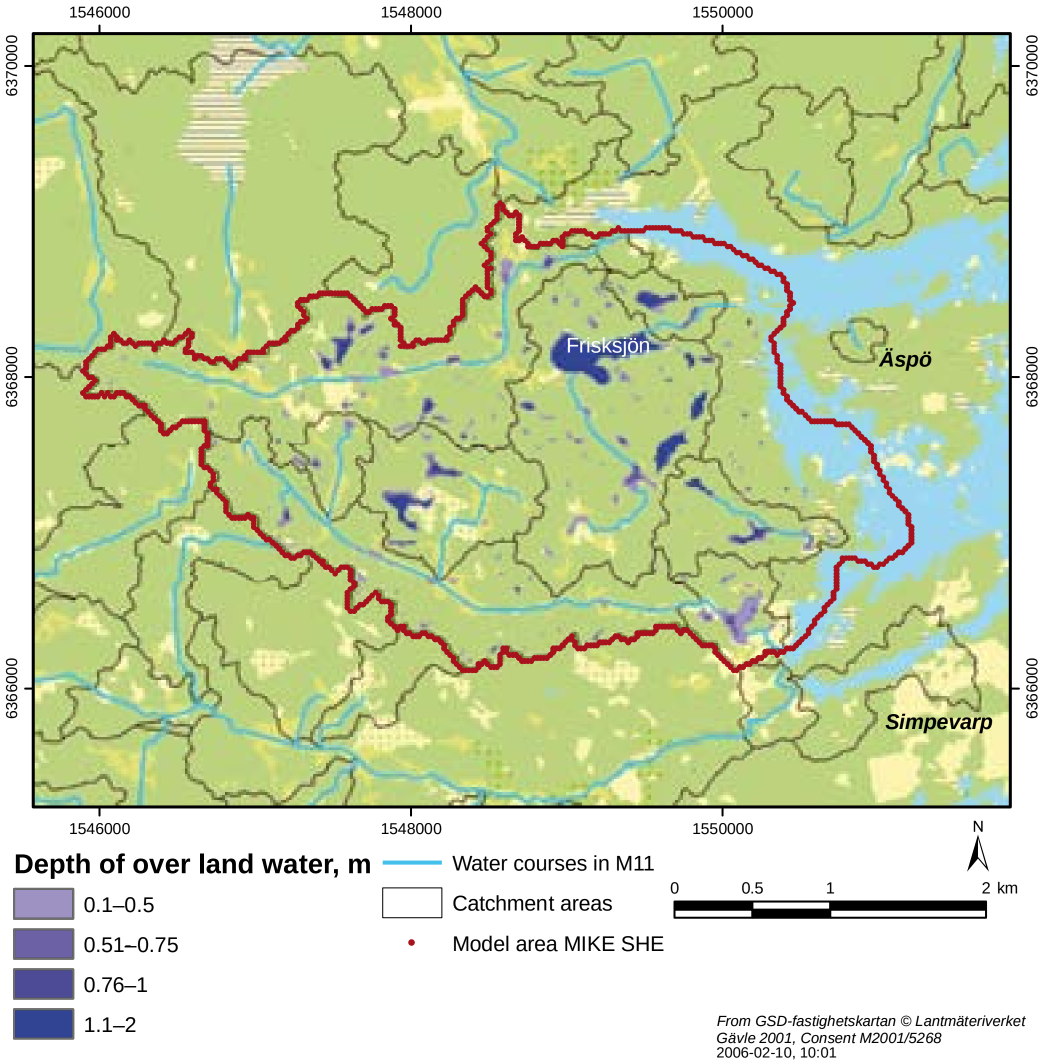

Figure 3-41. *Calculated annual average depth of overland water within the MIKE SHE model area for the updated base case. The figure also shows the main watercourses in the whole area covered by the figure (M11 is short for MIKE 11).*

In reality, there is not surface water in all areas where there is overland water in the model (Figure 3-41). As described above, many of these areas have been subject to water management operations involving ditches or other drainage systems. Most areas with discrepancies between model-calculated and actual flooded areas in Figure 3-41 were checked in the field during the summer of 2005. It was observed that these areas are in fact drained, which calls for modifications of the MIKE SHE-MIKE 11 model. These field observations will be considered in future model versions.

Groundwater recharge and discharge areas

The conceptual-descriptive model of groundwater flow implies that within each catchment area, groundwater recharge is associated with (local) high-altitude areas, whereas discharge of groundwater takes place in (local) low-altitude areas. In the present context, the identification of groundwater recharge and discharge areas is an important issue. For instance, radionuclides from a deep repository may enter the surface system in some of the (near-surface) discharge areas.

Figure 3-42 shows the model-calculated (updated base case) annual average difference in hydraulic head between the ground surface and calculation layer 5, located c 8–10 m below the ground surface (the difference is first calculated in each time step, then temporal averaging is performed). This head difference indicates the vertical direction of the groundwater flow (i.e. upward or downward) at each location. Using this quantity as a measure of local recharge or discharge, the red and yellow areas in the figure represent recharge areas, whereas the blue areas are discharge areas. The light blue lines indicate the main watercourses in the model area. The average discharge areas are found in the vicinity of the main watercourses, in and around Lake Frisksjön, and also along the coastline towards the bays of the Baltic Sea. In general, discharge areas are associated with a shallow groundwater table, or a "groundwater table" above the ground surface (surface water). In some of the calculated discharge areas in Figure 3-42, the model indicates flooded conditions (cf Figure 3-41).

Due to temporally variable meteorological conditions at the ground surface, the surface and near-surface water flow system is transient. One potentially important effect of a transient water flow system is that the locations of recharge and discharge areas may vary during the year. For the updated base case, Figures 3-43 and 3-44 show the vertical groundwater flow component in the upper calculation layer (layer 2) during a wet period (end of October) and a dry period (mid August), respectively.

A comparison between the two figures shows that the distribution of recharge and discharge to some extent varies with time, due to (seasonally) variable meteorological conditions; there are somewhat larger discharge areas during a dry period (Figure 3-44), compared to a wet period (Figure 3-43). Examples of areas where large changes take place are indicated by the circles in Figure 3-43 and 3-44. However, there are permanent recharge and discharge areas. For example, areas in the vicinity of the main watercourses and Lake Frisksjön are permanent discharge areas, whereas the high-altitude areas are permanent recharge areas.

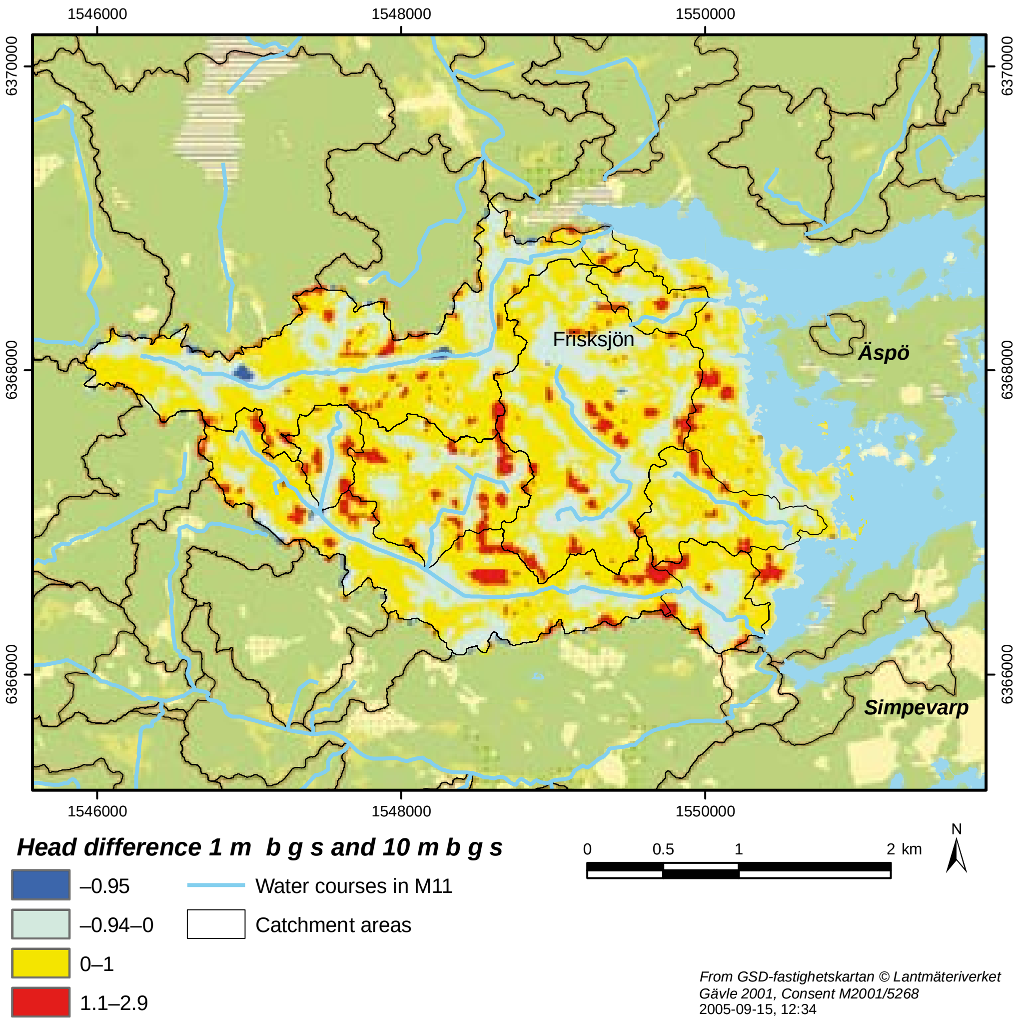

Figure 3-42. *Annual average head difference between the ground surface and calculation layer 5, located c 8–10 m below the ground surface. The red and yellow areas in the figure are (average) recharge areas, whereas the blue areas are discharge areas. The light blue lines are the main watercourses in the area covered by the figure (M11 is short for MIKE 11).*

3.4.6 Resulting site description

Developments since previous model version

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

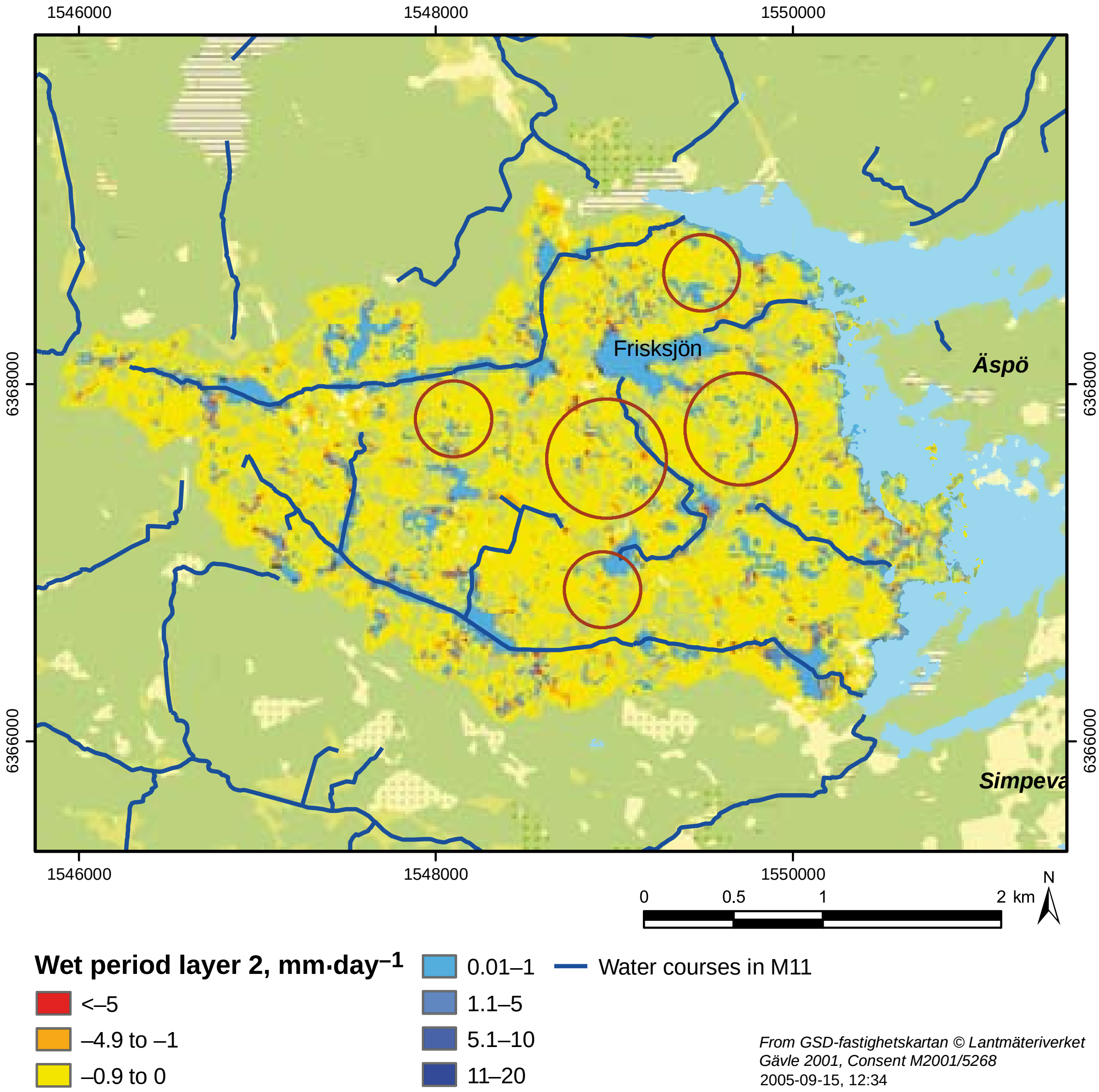

Figure 3-43. *Vertical groundwater flow (mm·d^{-1}) in QD layer 2 during a wet period (end of October); blue areas have upward flow (discharge) and yellow to red areas downward flow (recharge). Results are shown for the updated base case. Areas within circles show large differences between wet and dry periods, cf Figure 3-44.*

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

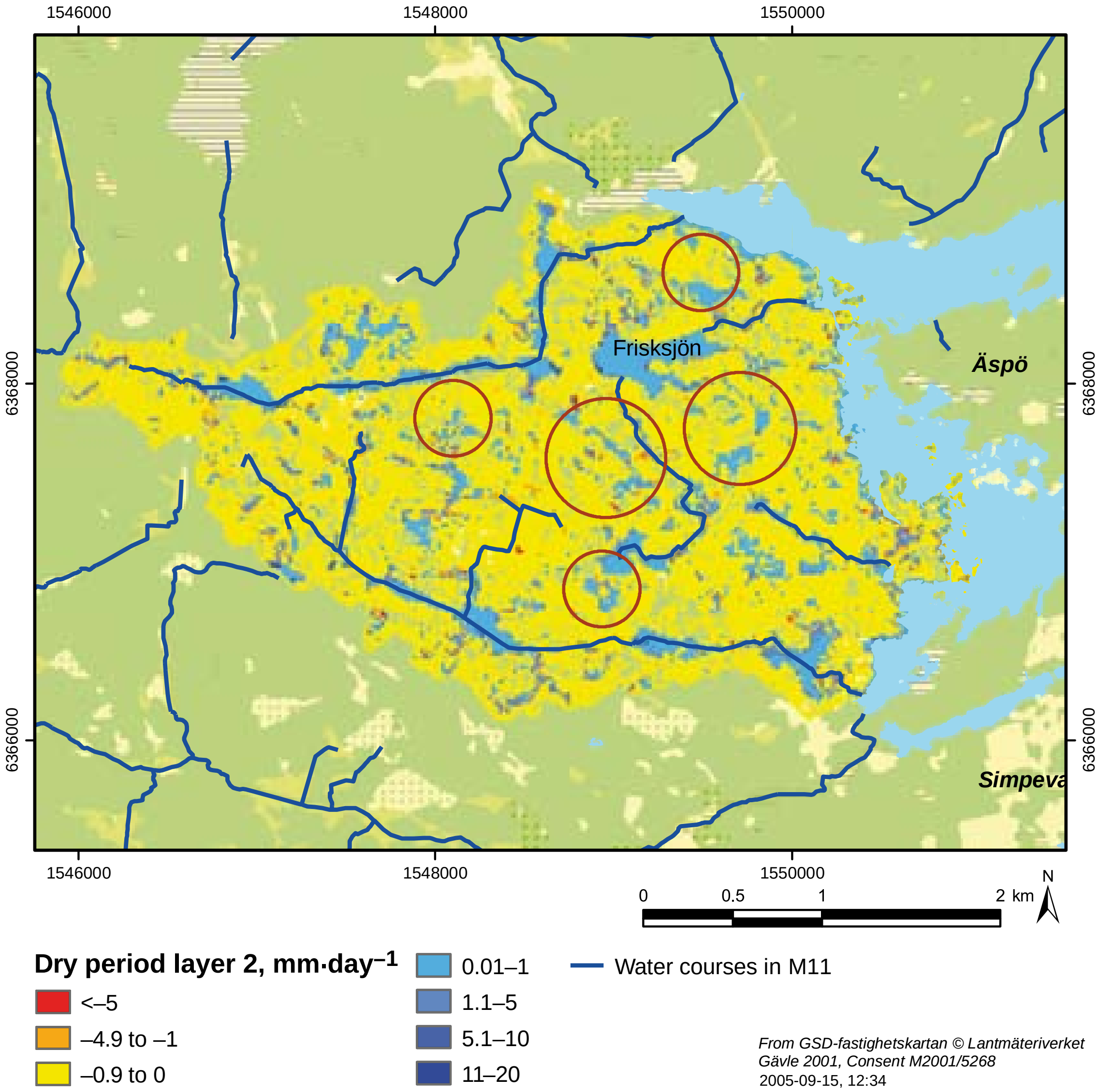

Figure 3-44. *Vertical groundwater flow (mm·d^{-1}) in QD layer 2 during a dry period (mid August); blue areas have upward flow (discharge) and yellow to red areas downward flow (recharge). Results are shown for the updated base case. Areas within circles show large differences between wet and dry periods, cf Figure 3-43.*

The development of the hydrogeological data includes hydraulic conductivity data obtained from slug tests in 12 additional groundwater monitoring wells, all located in the Laxemar subarea. A number of particle-size distribution curves for QD samples are also available in the L1.2 data freeze. These are used to obtain supplementary hydraulic conductivity data on QD. Up to December 2004, totally 42 groundwater monitoring wells have been installed in QD within the Simpevarp regional model area. From these wells, there are data on automatically measured groundwater levels in 18 wells (out of which measurements have been terminated in 9 wells). Further, data are available from manual groundwater level measurements in 29 wells; out of these 29 wells, both manual and automatic measurements have been made in 10 wells.

The L1.2 dataset has provided the basis for improvements of the conceptual-descriptive model of climate, surface hydrology, and near-surface hydrogeology in the Simpevarp area. The local and regional meteorological data have provided a better knowledge of site-specific meteorological conditions (especially the precipitation), and which SMHI station(s) that may be most suitable for assessment of the long-term meteorological conditions in the Simpevarp area. The surveying along watercourses is a key input, primarily to the quantitative water flow modelling. It has also been found that parts of many watercourses in the Simpevarp area are diverted and/or flow in conduits, and therefore diverge from the natural topography-controlled flow conditions. Due to the conduits, there are some missing (parts of) watercourses in the SKB GIS database. An important input to the conceptual-descriptive modelling is the finding that the Simpevarp area generally is characterised by many ditched/drained areas. Without these ditches/drainages, many areas would probably be lakes or wetlands.

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

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

Äspö meteorological data from 2004 are used in the L1.2 modelling. In the previous S1.2 modelling, the meteorological input was SMHI data from Ölands Norra Udde for the selected "representative year" 1981. The analysis of meteorological data performed as part of the L1.2 modelling indicates that the use of precipitation and potential evapotranspiration data from Ölands Norra Udde underestimates the discharge in the Simpevarp area.

An initial base case has been established using the MIKE SHE-MIKE 11 model, and a comprehensive sensitivity analysis was performed as a part of the L1.2 modelling. In this analysis, the hydraulic properties of the QD and the vegetation-related parameters LAI and K_c were varied. Based on the sensitivity analysis, an updated base case was identified, and the updated base case results have been delivered to the ecological systems modelling. The results of the base cases and the sensitivity cases have provided a basis for further development of the conceptual-descriptive model, in terms of the understanding of the surface water and near-surface groundwater flow system in general and for estimates of reasonable ranges for the input parameters in particular.

Summary of present knowledge

Conceptual-descriptive modelling

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

- The annual (corrected) precipitation in the Simpevarp area is 600–700 mm. The long-term (1961–1990) average precipitation at the SMHI station in Oskarshamn is 633 mm, whereas the corresponding value for Ölands Norra Udde is c 530 mm. During 2004, the precipitation on Äspö was 660 mm, as compared to only 441 mm on Ölands Norra Udde. Hence, the precipitation in the Simpevarp area is underestimated on average if inferred from data measured at Ölands Norra Udde.
- Based on long-term regional data, the annual average specific discharge has previously been estimated to be in the range 150–180 mm /Larsson-McCann et al. 2002/; the annual average evapotranspiration has been estimated to be in the range 420–550 mm. However, the L1.2 modelling shows that there are large variations of the specific discharge between years (and, of course, also during years) due to variations in the meteorological conditions. There is also a spatial variability in the specific discharge, e.g. between different catchment areas, in the Simpevarp area. This variability is mainly due to differences in, for example, the fractions of exposed bedrock and open water, the land use (vegetation), and the local meteorological conditions. For the year 2004, the present modelling results show a slightly larger specific discharge (c 190 mm·year^{-1}) than the regional estimate given above. Further analyses, involving evaluations of discharge measurements and sensitivity studies related to the meteorological input data, are required before any firm conclusions can be drawn concerning the water balance and the specific discharge in the Simpevarp area.
- The topography of the Simpevarp area is characterised by a relatively small-scale undulation. The area consists of a large number of catchment areas and small water-courses. Most watercourses have a low discharge or are dry during large parts of the year. Consequently, most of the annual discharge takes place during few relatively short periods with large discharge, associated with heavy precipitation events and/or snow-melt.
- In many areas, the surface hydrology is affected by human activities, primarily in the form of ditches and other drainage systems. This implies that actual flow directions in some areas deviate from those obtained from the DEM. It also implies that many areas most likely would have been lakes or wetlands without the ditches/drainages. In the SKB GIS database, there are also missing (parts of) watercourses, in some cases because the watercourses flow in conduits.
- There is a large fraction of areas with exposed or very shallow bedrock (c 35% of the land surface area of the regional model area), primarily in the high-altitude areas. Sandy (at some locations sandy-gravelly) till is the dominating type of QD; till covers c 43% of the land surface of the regional model area. The thickness of the QD is generally small, and the average depth of QD is c 2 m with exposed/shallow bedrock areas included, and c 3 m with those areas excluded. The thickest QD are located in the valleys, where the QD thickness can be several metres.
- The measured groundwater level in the QD is generally shallow, on the order of 0.5–1.5 m below the ground surface. The differences between the measured maximum and minimum levels are also generally small, c 0.5–1 m. However, there is likely a bias in the measured groundwater level data towards shallow groundwater levels, because most of the monitoring wells are located in the valleys. Further, groundwater levels are not measured in any of the eskers, which likely have larger depths to the groundwater table (such that it is not as closely related to the topography as in other areas). It follows

from the near-surface groundwater levels in the QD that the topographic surface water divides of the 26 catchment areas may coincide with near-surface groundwater divides.

- As a framework for the conceptual-descriptive modelling, the following types of hydrological elements are identified:
  - Type areas.
  - Flow domains.
  - Interfaces between flow domains.

These are described in detail in /Werner et al. 2005b/ (see also Section 3.4.4). In the base case, the QD are assigned hydraulic properties according to Table 3-16.

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

Quantitative water flow modelling

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

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

- The sensitivity analysis performed as a part of the L1.2 modelling shows that the vegetation-related parameters LAI (leaf area index) and K_c (crop coefficient) have large effects on the modelling results. For example, the average specific discharge of overland flow into the watercourses is c 230 mm·year^{-1} in the initial base case used in the sensitivity analysis and c 140 mm·year^{-1} in the updated base case, where the main update is that of vegetation parameters. Although a re-analysis of the input data showed that the values of the vegetation-related parameters in the initial base case must be considered unrealistic, it is clear that these parameters should be further analysed in the forthcoming modelling.
- For the updated base case, the model predicts a generally shallow groundwater table, which is in agreement with available site investigation data and the conceptual-descriptive model. However, in the present modelling, no well-by-well comparison between model-calculated and measured groundwater levels has been made, as there are still few (and short) time series on groundwater levels in QD available. This type of comparisons (and model calibrations in general) is expected to be important components of the forthcoming modelling. Furthermore, the representativity of the existing wells should be investigated; there is likely a bias in the present dataset, due to the fact that the wells are located primarily in lower-lying areas.
- In agreement with available site investigation data, the calculated discharges in the watercourses are characterised by long periods of small or zero discharges, interrupted by relatively short periods with peaks in the discharge; these short periods are associated with heavy precipitation events and/or snowmelt periods.
- In some areas, there is a discrepancy between modelled and actual areas with surface water. During a field campaign in the summer of 2005, it was observed that these discrepancies generally are due to water management operations changing the flow conditions from those associated with the natural topography.
- In the MIKE SHE-MIKE 11 model area, the groundwater discharge areas are found in the vicinity of the main watercourses, Lake Frisksjön, and also along the coastline towards the innermost bays of the Baltic Sea. In general, discharge areas are associated with a shallow groundwater table, or a hydraulic head above the ground surface (surface water).
- The transient nature of the water flow system implies that there are somewhat larger discharge areas during a dry period, compared to a wet period (during a single year). Hence, the extent and spatial distribution of recharge and discharge varies with time, due to (seasonally) variable meteorological conditions. There are also permanent recharge and discharge areas. For instance, areas in the vicinity of the main watercourses and Lake Frisksjön are permanent discharge areas, whereas the high-altitude areas are permanent recharge areas.

Evaluation of uncertainties

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

- **Uncertainties in the geometrical description of the system:** In general, these uncertainties have been reduced in the L1.2 modelling, compared to the previous S1.2 model. There are still uncertainties in the DEM; there are discrepancies between the actual topography and the DEM in some areas, which affect the modelling. On the other hand, the geological description (the detailed map of QD and exposed bedrock), as well as the geometrical model of the HSD, now cover both the Simpevarp and Laxemar subareas. Further, cross-sections have been surveyed along the main watercourses in the L1.2 model area (catchment areas 6, 7, 8 and 9). There are some missing (parts of) watercourses in the SKB GIS database, and there are many ditched/drained areas which are not treated as such in the present quantitative water flow model. However, many of these discrepancy areas have now been investigated in the field, and that information will be considered in future model versions.
- **Uncertainties in the description of hydrogeological properties of site-specific materials:** For some QD in the conceptual-descriptive model, there are no site data on the hydraulic parameters available. However, there is a relatively large amount of (hydraulic conductivity) data for till, which is the dominating type of QD in the Simpevarp area. The L1.2 dataset has enabled an improved descriptive model of the QD types and the geometry of the HSD, although there is still a low potential for quantification of the uncertainty related to spatial variability. Furthermore, the site-specific database is restricted to hydraulic conductivity data (with a few exceptions). The S1.2 dataset mainly included data from the Simpevarp subarea. Additional data have now been provided from hydraulic testing in the Laxemar subarea.
- **Uncertainties in the vegetation-related parameters:** The sensitivity analysis performed as a part of the L1.2 modelling shows that variations in the parameters quantifying the interactions between water and vegetation (leaf area index, LAI, and crop coefficient, K_c) have relatively large effects on the modelling results. The values of these parameters can be considered uncertain, making this uncertainty an important topic for further studies.
- **Uncertainties in the modelling of interfaces between flow domains:** In the present work, no attempt was made to model the hydrogeological interactions between the near-surface system and the deep rock; the modelling was performed with a no-flow boundary at c 150 depth in the rock. Thus, the uncertainties associated with these interactions remain. Furthermore, the hydraulic properties of the materials in the QD-rock contact zone are uncertain, as no hydraulic tests have been performed across this interface. There is also a lack of quantitative information on the properties of the materials determining the groundwater-surface water interactions.
- **Uncertainties in the description of temporal variability of hydro-meteorological properties:** The site investigation data indicate significant transients in the discharges in the watercourses. Still, there is no detailed quantitative information available on these transients; only data from sparse manual discharge measurements have been presented so far. The data status is (almost) the same concerning groundwater levels in QD. Longer time series on meteorological parameters are now available compared to the S1.2 data freeze. However, a combination of meteorological data with data on surface water levels, discharges and groundwater levels is crucial for the evaluation of the hydrological/hydrogeological temporal variability.

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

As described above, significant uncertainties remain regarding the quantitative aspects of the model, especially time series for model improvement and calibration. In particular, prolonged time series of groundwater level data are expected to contribute significantly to the site understanding. The identified type areas, flow domains and interfaces between flow domains need to be further developed, detailed and parameterised with site-specific data. A thorough sensitivity analysis, primarily focusing on the vegetation-related parameters and the hydraulic properties of the QD, has been reported in this model version /Werner et al. 2005b/. In addition, updated statistics of measured hydraulic conductivities are presented, which gives an indication of the uncertainty associated with spatial variability. However, although the present description is more elaborated than that in S1.2, no systematic or complete quantification of uncertainties has been performed in the L1.2 model version.

3.5 Coastal oceanography of the Laxemar area

3.5.1 Methodology

The Baltic coastal waters act as an intermediary link of 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 3-45) 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 study is to quantify the water exchange of the coastal area in the vicinity of the planned repositories in 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 Laxemar coastal area (Figure 3-46), the year 1981 was chosen as the most representative year /Larsson-McCann et al. 2002/.

The ventilation of the Äspö basins has been modelled earlier /Engqvist 1997/ but it is not known if any circulation model has been applied to the coastal zone in the direct vicinity of the Laxemar area. South of this location, the water exchange of the Oskarshamn harbour has been modelled /Nordblom et al. 1998, Svensson and Erlandsson 1998, Svensson 2000/. The coastal section of Mönsterås /Ivarsson 1999/ has been subjected to modelling and validation against current measurement data /Ambjörn and Wickström 1990/.

To obtain quantitative time-based estimates of particle turnover in general reservoirs, /Bolin and Rodhe 1973/ formulated a strict foundation in statistical terms. One of these well-defined concepts was independently adapted to water circulation models by introducing its volume-specific counterpart /England 1995, Engqvist 1996/. The naming of this concept has been somewhat variable and vague over the years that followed. A clarifying nomenclature fully compatible with the volume-specific concepts has recently been suggested by /Delhez et al. 2004/ and will be adopted henceforth. Looking at a particular water parcel present in a reservoir at a given moment and following it individually while measuring the time

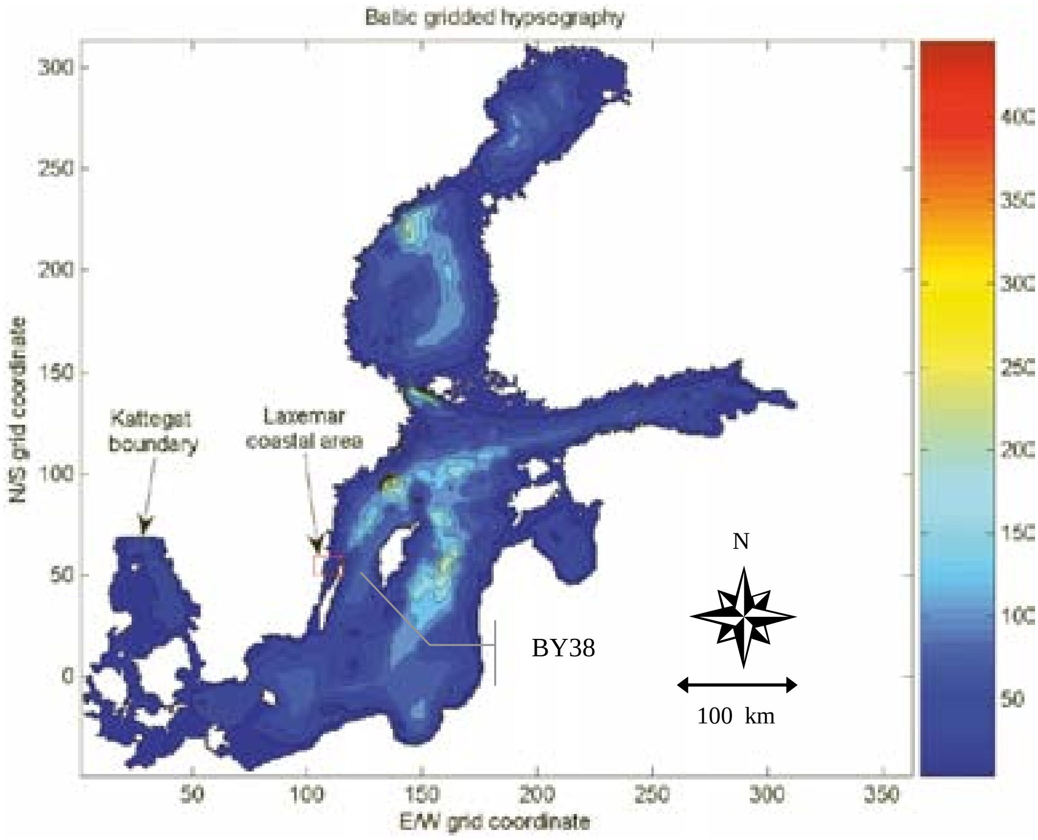

***Figure 3-45.** The Baltic model grid displaying the Warnemünde hypsographic data. Legend denotes depth in (m). The approximate location of the Laxemar model area is indicated as are the off-shore station BY38 and the Kattegat model boundary to the Skagerrak.*

it takes until it leaves, yields its residence time. The ensemble average over all parcels present at a given instance in the specified reservoir gives the *average residence* (*AvR*) time. Backtracking the same parcels in reverse time until the point in time it entered the reservoir gives analogously the time measure 'age' of that water parcel and analogously the average age over the water parcel ensemble give the *average age* or *AvA*. The sum of *AvA* and *AvR* gives the *average transit time* or *ATR*-time, which is sometimes referred to as (hydraulic) turn-over time, since these were proven equal by /Bolin and Rodhe 1973/. *AvA* thus denotes the length of time a particular water parcel of originally exogeneous water (or parts thereof) on the average has spent within a defined connected body of water. This could be discharged freshwater and/or water entering from any other connecting water body with a boundary across which water is exchanged. The relationship between two of those measures is given by /Björkström 1978/

$$AvA = \frac{ATR}{2} + \frac{\sigma^2_{ATR}}{2ATR}, \qquad (1)$$

where σ^2_{ATR} is the variance of the ensemble's *ATR*. For an orderly and steady plug-flow situation, as through a canal, all water parcels pass through in exactly the same time, so the variance equals zero. According to equation (1) this means that the *AvA*-value is exactly half of the *ATR*-value for such a flow regime. This minimum quotient means that the exiting water has maximum age and this ratio will be exceeded when exiting water has any other age distribution, which occurs for example at well-mixed conditions.

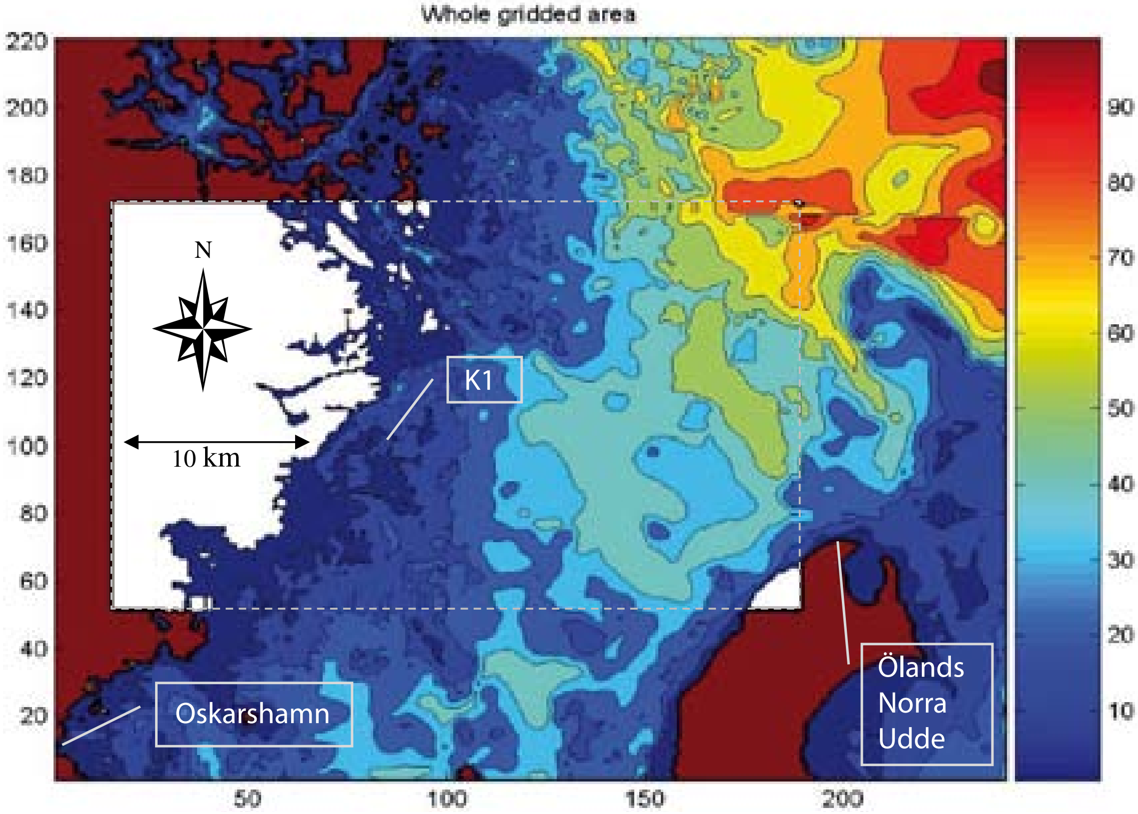

Figure 3-46. *The water depth in (m) of the entire Laxemar area that was gridded from digital charts. The finally chosen model area is indicated with a broken white line and is presented in Figure 3-47. Close to the eastern part of northern boundary the transition zone to the adjacent chart is noticeable which facilitated this actual choice.*

What is regarded as interior and exogeneous water must thus be specified. Once this has been decided, then the time development of *AvA* of the entire defined volume can readily be computed, possibly subdivided into vertical layers. This case will be referred to as individually computed *AvA*-values. Alternatively, different horizontal partitions (sub-basins) of the entire interior area may be evaluated and compared, which case is called **collective** *AvA* since the sub-basins have a delimiting boundary to the exogeneous water in common, that may or may not coincide with any of individual sub-basins borders.

Computationally, the scalar variable *AvA* of exogeneous water (whether it enters though boundaries or is administered by discharge) can be straightforwardly implemented in a numerical model. The *AvA*-values of the exogeneous water (and possibly also of the internal water as to obtain initial values) is set to zero (measured in units of e.g. [days·m^{-3}]), and then the internally contained water is allowed to be aged one (1) time step unit for each time step it resides in the specified actual reservoir. In the numerical model it is thus treated as a passive scalar variable (e.g. salt) subjected to both advective and diffusive processes, computed simultaneously with all the other state variables of the model, thus taking advantage of the model's full spatial and temporal resolution. The *AvA* variable will attain a quasi-steady equilibrium of all the water parcels that the model resolves between decrease (by entering zero-age water and exiting aged water through the boundaries) *vs.* increase by aging of water staying resident. *AvA*-values of the entire Baltic have been computed by /Meier 2005/.

Given information on the mixing time scales in relation to the advective time scales, it is possible to use the *AvA* concept to obtain an overview estimate of the water exchange over long-term periods, typically one year, by computing its average, maximum and minimum values. These values together with an estimate of the variance, e.g. the standard deviation (S.D.) can be computed from instantaneous *AvA*-values. These *AvA* snapshots should be sampled with a shorter time period than the time-scales set by the temporal variation of the imposed forcing. The advantage is that diffusive processes are included, all sources of exogeneous water can be accounted for simultaneously and no post-processing is needed.

Because the exchange of the stratified coastal waters normally follows internal surfaces of constant density (isopycnals) and thus is mainly horizontal, averages in the horizontal direction represent a valid data reduction, retaining information on how the various vertical layers are renewed /e.g. Engqvist and Andrejev 1999/. An estimate of the corresponding water exchange would then be

$$Q_i = \gamma \cdot \frac{V_i}{A_i}; \qquad (2)$$

where *Q*, *V* and *A* denote volume flux, volume of the layers and *AvA* respectively, while the index (*i*) indicates the layer's order number. In such regimes the water passage is restrained by narrow and shallow straits. This means that the time scales of horizontal mixing increase relative the advective time scale so that horizontally well-mixed conditions ensue. The parameter γ would take a value of unity for more secluded landlocked areas, provided they are sufficiently well-mixed in both the vertical and horizontal directions. 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 to 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 center of the region could in principle age indefinitely, making the estimated *Q* progressively smaller with time, which is in accordance with the associated decrease of the effective exchange rate. This applies as well to stratified water. Any level of diffusive mixing in the interior will under such circumstances make the estimate of *Q* attain a plateau level.

Vertical mixing, up-/downwelling and other baroclinic processes will act to equalize the *AvA* of adjacent layers, but this information will be 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 be well-mixed also when entering through the border. The up-/downwelling instances occur with a period time that is normally longer than the *AvA*, mitigating the temporal impact it will have on the long-term average. When averaging the *AvA* measure over water bodies with different through-flow regimes e.g. vertical averages of different layers, γ-values beyond the range interval 0.5 to 1.0 may ensue.

The *AvA* concept must thus be used with due caution when the associated flows are to be inferred from it, in particular if the *AvA*-values reach parity with the designated one-year cycle time scale that is derived from ecological modeling considerations. The highest *a priori* likelihood for this eventuality to occur concerns the decisively landlocked areas, which will thus consistently be modelled separately. When water exchange estimates are used in integrated ecological models, the fluxes are computed directly from the actual model without recourse to the *AvA*-measure. Dedicated trajectory computations /Döös 1995/ can also be performed at the expense of an off-line computational effort.

The bottom along the Laxemar coast gradually slopes in the offshore direction; there are few topographic features that naturally indicate a well-defined delimitation line. In the absence of evident bathymetrical delimitation, an average distance of 5 km off the coastline has been used. This line delimits the inshore waters of the coastal zone (IWCZ), an area that can be regarded as an intermediary stage for the eventual water exchange to the Baltic, Figure 3-47. This choice mainly coincides with the average internal Rossby radius of convergence which delineates a near-shore distance where up- and down-welling takes place /Fennel et al. 1992/. The coastal area has been further partitioned into a number of non-overlapping sub-basins (SBs) based on the consideration of present underwater structures that, in the future with the current land rise, potentially will accentuate the confinement of the water movements to a progressively more shallow bathymetry, until lakes are eventually formed. These areas are presented in Figure 3-48. The existence of internal straits, however, recommends an additional split of three of these SBs into a pair of directly connected basins due to oceanographic considerations. Altogether this analysis thus entails 14 SBs. Four of these are located in the open coast and will be referred to as **outer** SBs, while the other group will be called **inner** SBs.

The location of some of these SBs also coincides with anticipated leakage points connecting to the geosphere. The water exchange of such a particular SB area relative the Baltic Sea then can be achieved in two steps. First, all of these SBs are collectively subjected to

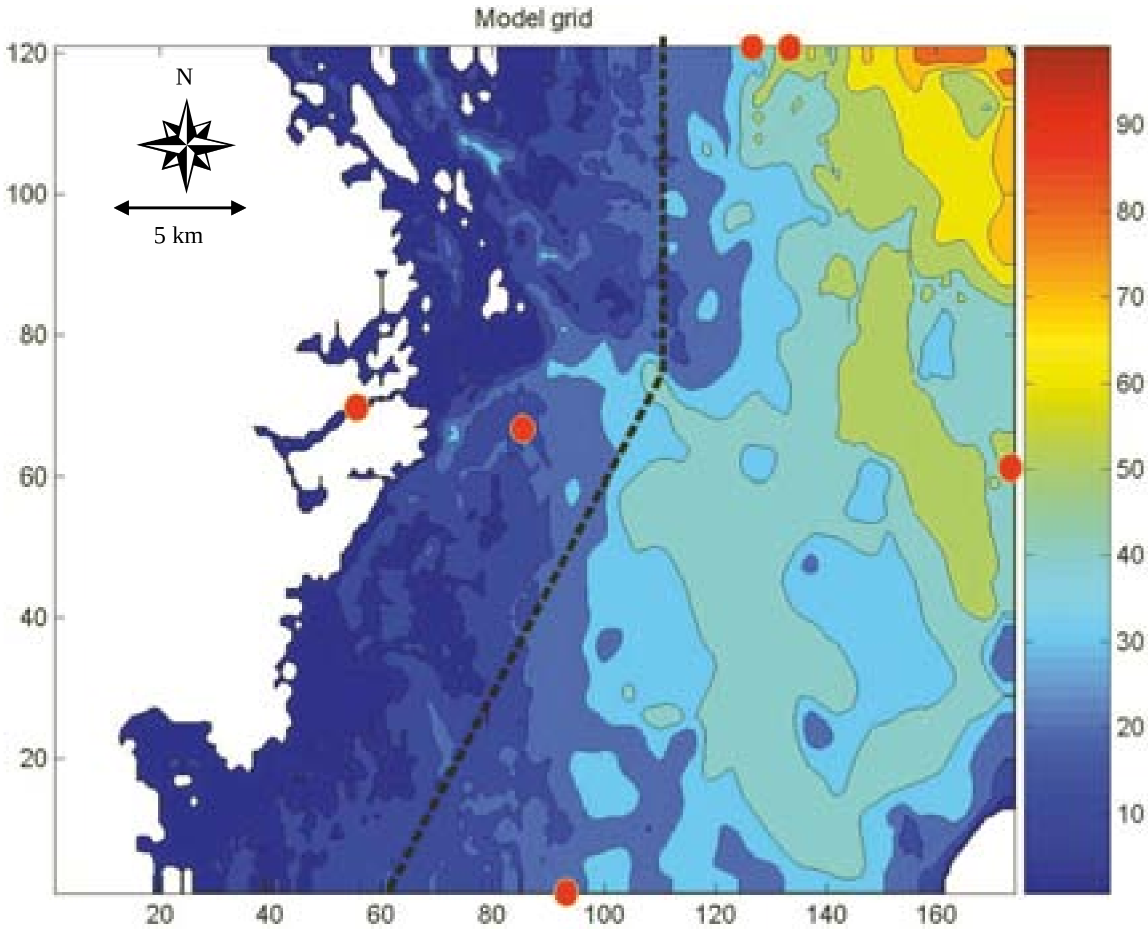

Figure 3-47. *The bathymetry of the chosen model area with depths in (m). Some of the grid cells are manipulated manually in order to connect the inner basins to the coastal water. In the southeast corner a bit of the Öland island can be seen. The broken black line delineates inshore waters of the coastal zone (IWCZ) approximately 5 km off the coastline. The sites of the six measurement stations where oceanographic instruments were deployed for the 2004 field program are indicated as red spots.*

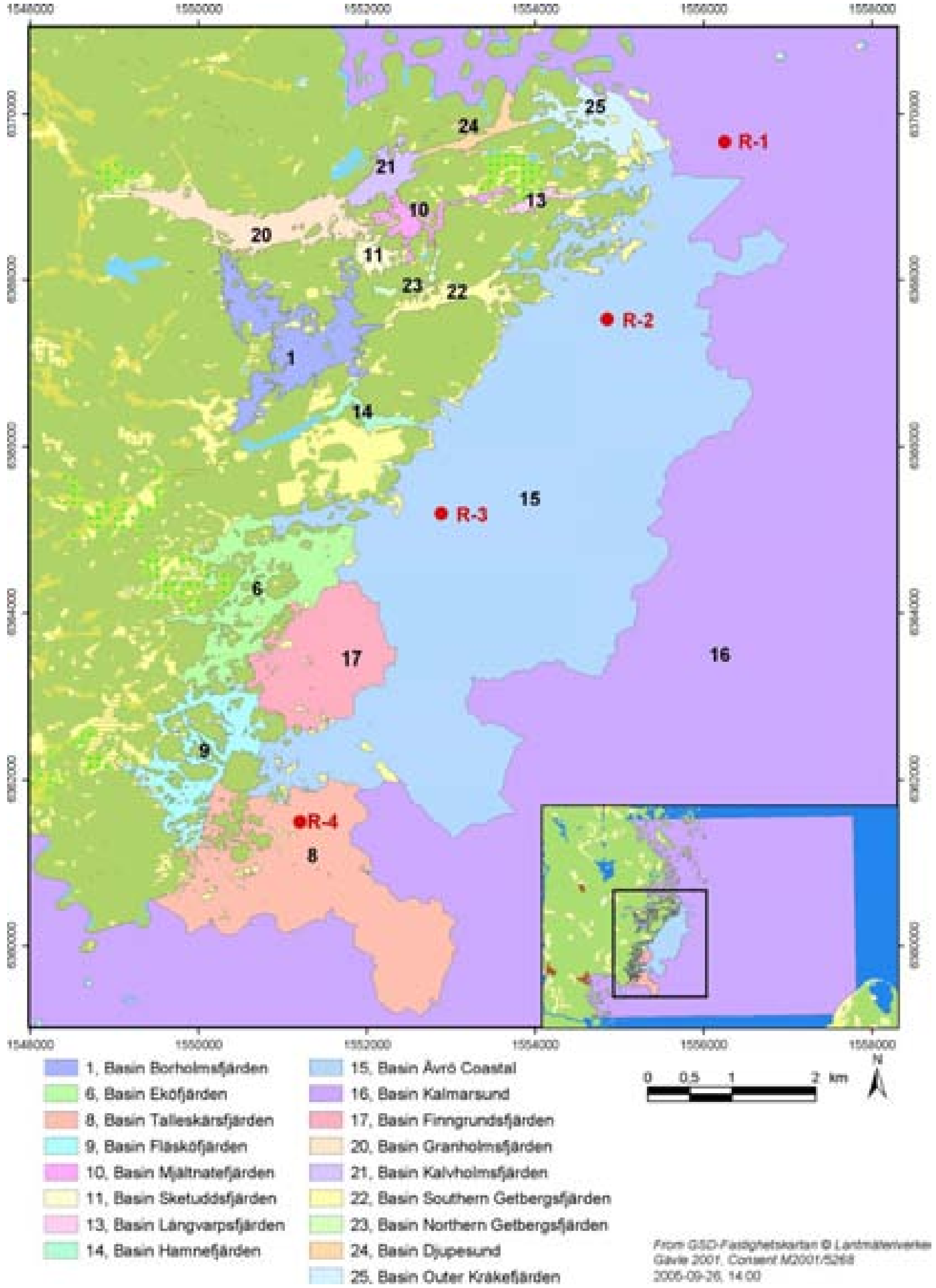

Figure 3-48. *The partitioning of the Laxemar coastal area into sub-basins (SBs) together with their numbering and naming. The inshore water coastal zone basin (IWCZ) is not depicted, but the model area is shown in the inset picture in the lower right corner. The locations for which the density profiles computed by the 3D-model are used to force the DB-model (Figure 3-49) have been indicated by R-1 through R-4. The following basins have been split in two for oceanographic reasons: Kråkefjärden (SB18) into SB24 and SB25, Granholmsfjärden (SB2) into SB20 and SB2, and Getbergsfjärden (SB3) into a northern (SB22) and a southern (SB23) part. (bassangindelning_ 20050926_1400.mxd).*

estimation of their *AvA*-measure, counting only the IWCZ water as exogeneous. Second, the *AvA* of the IWCZ relative the Baltic is computed. The uncertainty of this method may be estimated to be confined within the *AvA*-values that ensue when using the coastal SBs both excluded and included to the IWCZ.

3.5.2 Description of conceptual models

The bathymetry of the Laxemar coastal area can be described 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 3-47. 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 of less than 6 m except for a small dredged channel.

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 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 because all possible interactions of in- and outgoing internal waves cannot be handled numerically. A common method also presently employed is to create a buffer zone over which the incoming and outgoing surface waves, and similarly also two-way internal density wave modes are permitted to be relaxed. The sea level fluctuations produced with this method will reflect the temporal resolution of the wind forcing and may display less temporal variance than the real sea level.

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'×4' (latitude×longitude [nautical miles] in spherical coordinates) based on the Warnemünde hypsographic data. The horizontal eddy diffusivity is nominally set to 30 ($m^2 \cdot s^{-1}$), 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. 2004ab/. 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 would more likely produce a prognosis of ensuing air temperatures, while other factors determining the heat exchange (insolation, relative humidity and nebulosity) would be less available.

The 3D-domain grid has been computed from a DEM based on national digitized charts, and complemented with shoreline information from economical maps, resolving the shoreline better. 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 Laxemar coastal area was resolved horizontally into 0.1×0.1 nautical mile (projected flat coordinate system) grid with square cells (Figure 3-47). This final choice of the actual model area 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 the inner basins has been modelled with coupled 1-D models in which each basin resolves only the vertical stratification /Engqvist 1996, 1997, Engqvist and Andrejev 2003/. This discrete basin (DB) approach places a constraint on the resolved time-scales which must be compatible with horizontal well-mixed condition. The baroclinic forcing is provided by connecting the coupled basins via four interfacial straits (R-1 through R-4) to the 3D-model domain, Figures 3-48 and 3-49. Freshwater is discharged according to measurement data and as direct precipitation. The heat exchange through the surfaces of the basins is performed in the model by prescribing the surface temperature from measurements. The strait exchange formulation follows /Stigebrandt 1990/ with addition of arranging for soft transition when the sea level is lowered to even fall below the crest of a sill, forming a temporary lake of the attached embayment. The wind mixing is performed according to the dynamics of the well-mixed layer (WML) /Stigebrandt 1985/ with an adaptation taking the hypsographic features of the basins into consideration. This applies also to the mixing of the layers beneath the WML. The effect of ice cover is handled by reducing the wind mixing to 10% of its nominal value. The influence of ice cover on the thermal exchange is fully covered by forcing the top layer beneath the ice to the freezing temperature.

3.5.3 Input data and data evaluation

Site-specific data

The motive of making an inventory of available oceanographic data is three-fold: i) to use as forcing data for numerical models in order to obtain estimates of an useful measure of the water renewal time-scale; ii) to provide water exchange estimates between different areas (SBs) to be subsequently used in ecological models; iii) to assess data for validation purposes including observations of currents, sea level and the density-determining variables salinity and temperature. A complete set of oceanographical *forcing* data, necessary to make realistic computations of the water movements, consists in general of the following items:

1. Meteorological data (including wind speed and direction, air temperature, precipitation and humidity).
2. Freshwater discharge in the interior of the studied area.
3. Sea level data at the boundaries of the studied area.
4. Density fluctuations at the boundaries of the studied area.
5. Sea surface temperature and ice formation and melting observation, or alternatively, insolation in combination with a heat balance model by which the sea surface temperature can be calculated.
6. Special anthropogenic facilities or activities that may influence the water exchange significantly such as cooling water of nuclear reactors, sewage treatment plants and ship propellers.

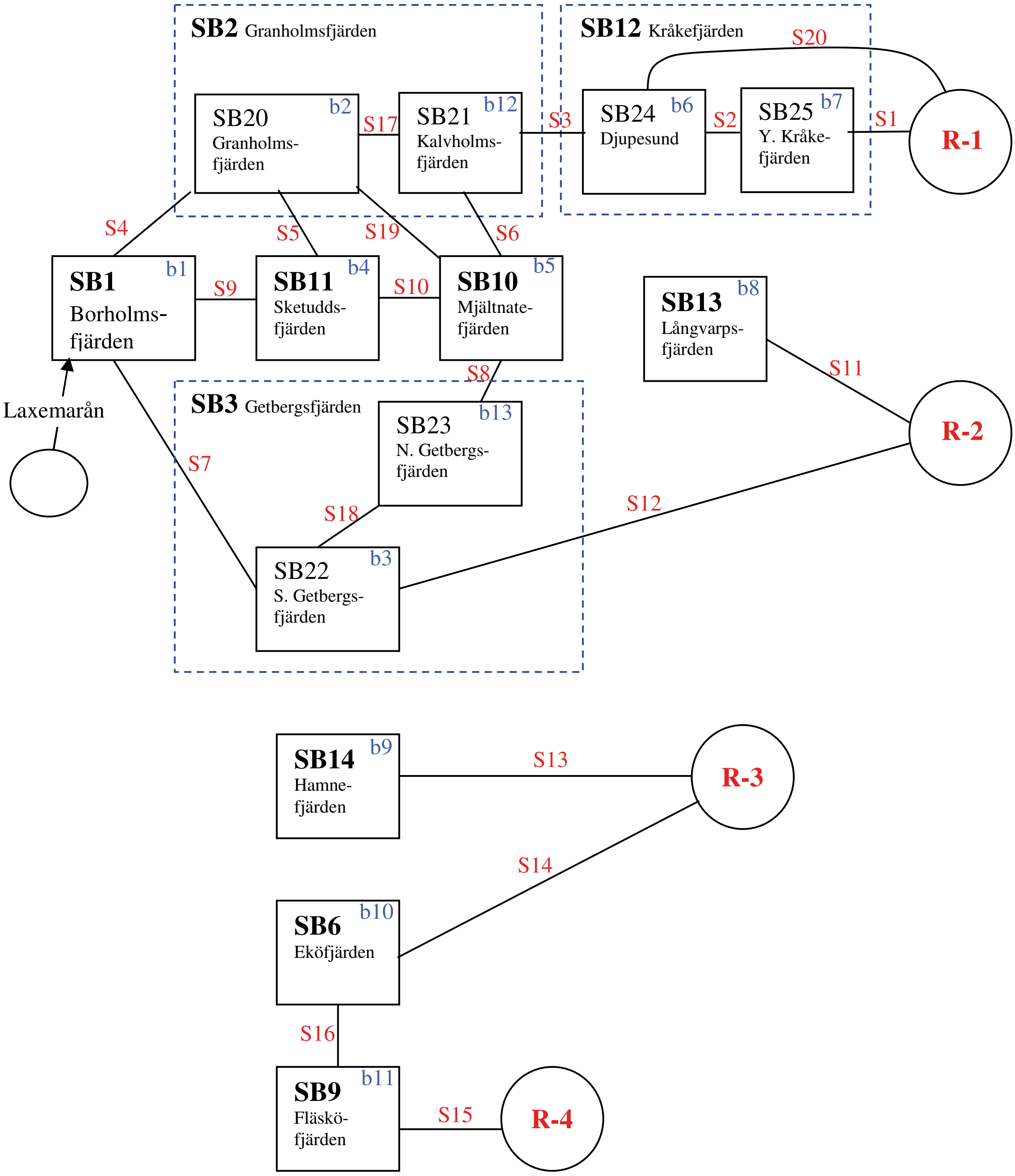

Figure 3-49. *Basin and strait configuration for the computation of ATR-times of the inner basins of the Laxemar area. The basins denoted with bold capital ID-labels (e.g. SB10, Mjälnatefjärden) refer to the SKB partitioning and are chosen with regard to their topographic features /Brydsten and Strömgren 2005/. Three of these basins also possess narrow internal passages that constrain the water exchange, motivating a further subdivision from an oceanographic point of view; this is indicated by blue broken lines. The lower-case basin ID-labels in blue (e.g. b10, Eköfjärden) in the upper right corner are the systematic consecutive labelling used in the model computations. The corresponding labels of the straits are given in red letters. The connections with the coastal basins are labelled R-1 to R-4, see Figure 3-48. The sea level together with the salinity and temperature profiles at these locations have been computed with the Laxemar coastal fine-resolution 3D-model.*

The first two items (i.e. local meteorology and river discharge) in this list are documented in /Larson-McCann et al. 2002/. For the Laxemar area the availability of the remaining data items in the list above have been investigated for a time period beginning approximately a couple of decades ago /Larson-McCann et al. 2002/, but they are decisively more scarce both in their spatial and temporal coverage. It thus seems appropriate to reiterate an overview of the comprised data in Table 3-18. The least available parameters are obviously salinity and sea level measurements in the coastal zone.

Table 3-18. Reproduction of Table 2-17 in /Larson-McCann et al. 2002/. At the offshore station BY38 salinity is measured, which was not stated in the original table.

Station name	RT90 coord.		Measurement parameters			Bottom depth	Time period	Resolution	Comments
			salin-ity	temp	sea level				
K1	6365204	1554387		x		~22 m	1971–1973		Only partially covered
BY38	6333805	1612564	x	x		~110 m	1980–	monthly	
TSNV	6365892	1550772		x		~2 m	1997–2000		Only partially covered
OKG1-V	6365190	1553288		x		~15 m	1995–	bi-monthly	
O1-V	6360457	1546026		x		~8 m	1995–	bi-monthly	
Oskarshamn 2085	6349740	1540730			x	–	1996–2001		

The site-specific data collected during the past couple of decades and pertaining to oceanographic forcing of water movements in the coastal zone are very limited, if local investigations of the near-field currents influenced by the reactor cooling water are exempted.

Concerning the bathymetry of the coast, both the digital charts of the National Maritime Administration (used for outer basins in the open coastal area) and the specifically compiled DEM /Brydsten and Strömgren 2005/ (used for the inner basins and which is also partly based on digital chart information) exist, giving possibilities to such a detailed resolution that considerations of the numerical modelling effort for a foreseeable time will impose the limitation on the employed resolution. The comparatively small-scale straits connecting the semi-enclosed embayments may constitute possible exceptions.

Certainly some of these data may also serve the purpose of validation, provided that the actual data are not simultaneously used as forcing. However for a type-year study with 1981 as the chosen year, very few, if any, of the available data for that year could be used for validation. As a remedy, a particular field program was launched in spring 2004 with the sole purpose of collecting such data as to make a complete and thorough validation possible. An overview of these site-specific data is presented in Table 3-19 and the positions and measured parameters of the instruments deployed by SMHI to obtain validation data are given in Table 3-20.

Table 3-19. Overview of forcing and validation data needed for the validation period spanning the second quarter 2004 through the first quarter 2005.

Forcing	Entity	Data-source	Temporal resolution	Laxemar coastal area							Remarks
					2004				2005		
				4th	1st	2nd	3rd	4th	1st	2nd	
Synoptic meteorology	Mesan data	SMHI	3 h	D	x	x	x	x	x		Mesandata converted to Mueller-format
Freshwater discharge	Laxemarån	SKB	week	D	x	x	x	x	o		Data computed by Pulse- or HBV-models
	Gerseboån	SKB	week	D	x	x	x	x	o		Data computed by Pulse- or HBV-models
Cooling water	volume flow	SKB	month	D	x	x	x	x	o		
	excess temp.	SKB	–	D	x	x	x	x	o		
	shut-off period	SKB	month	D	x	x	x	x	o		
Surface heat exchange	Surace temp.	SKB	1–2 week	x	x	x	x	x	x		Latest data from 050315
	Ice form./ melting	SKB	dates	x	x	x	–	o	o		Ice information about winter 04/05 is missing
Validation data:											
(coastal area:)	S/T init data	ICES	–	D							Climatic background data
	S/T profiles	SMHI	1 h			x	x	x	x		
	currents	SMHI	1 h			x	x	x	x		
(sub-basins:)	sea level	SKB	1 h			x	x	x	o		Data from 3 stations (040528 through 050101)
	sea level	SKB	1 h		x	x	x	x	o		PFM010038: 040115–041231

Symbol legend: x = corresponds to data accessed for the entire period, o = data to be accessed for the entire, period, D = data restricted to December 2003, – = not applicable.

Table 3-20. Overview of the deployed instruments for the validation period spanning the second quarter 2004 through the first quarter 2005. The position of the stations is indicated on the map in Figure 3-47. Measurement parameters designate:

Meas. stations	Meas. param	SKB stnID	SMHI stnID	Position WGS84 lat	long	RT90		Depth (m)	Vertical position	Deployment depth (m) under surface			
North boundary	4xC/T, PT	PSM6927	Si21	57° 32.0'N	16° 55.5'E	6379228	1567074	66		1.5 or 5*	10	17.5	30
	U/V/W	PSM6928		57° 32.0'N	16° 54.5'E	6379212	1566076	42	bottom				
East boundary	C/T/ U/D	PSM6929	Si22	57° 26.0'N	17° 03.0'E	6368174	1572062	50	bottom				
South boundary	U/V/W, PT	PSM6930	Si23	57° 20.0'N	16° 48.0'E	6356840	1559912	26	bottom				
Inner point	3xC/T	PSM6931	Si24	57° 26.5'N	16° 46.8'E	6368886	1558535	28		1.5 or 5*	10	17.5	–
	11xT	PSM6931	Si24T	57° 26.5'N	16° 46.8'E	6368886	1558535	28		Split in equal depth intervals**			
Djupe-sund	C/T/ U/D	PSM6932	Si25	57° 27.0'N	16° 41.0'E	6369735	1552719	4.2	bottom				

Symbol legend: C = Conductivity, T = Temperature, U, V, W = Current velocities in E/W, N/S and up/down directions, D = Current Direction, P = Pressure.
*During period with expected icecover, i.e. the 1st quarter of 2005.
**Only deployed during expected ice-free period

Model data

Atmospheric forcing

Synoptically gridded (1°×1°; latitude×longitude in spherical coordinates) so-called Mueller-data /SMHI 2006/ are consistently used from which wind components, air pressure and temperature are extracted every 3 h. The wind forcing data used are presented in Figure 3-50. For estimates of distant future coastal water exchange, more refined and explicit atmospheric thermal forcing (e.g. humidity, insolation and nebulosity) can most likely not be relied upon, since these will most likely be unavailable. There are, however, no surface temperature records nor observations of ice formation and melting events available for the actual SBs during 1981; therefore these data have been based on observations from an interior coastal embayment (Kvädöfjärden) that is located a few kilometers to the north, recorded by Fiskeriverket (Jan Andersson, pers. comm.).

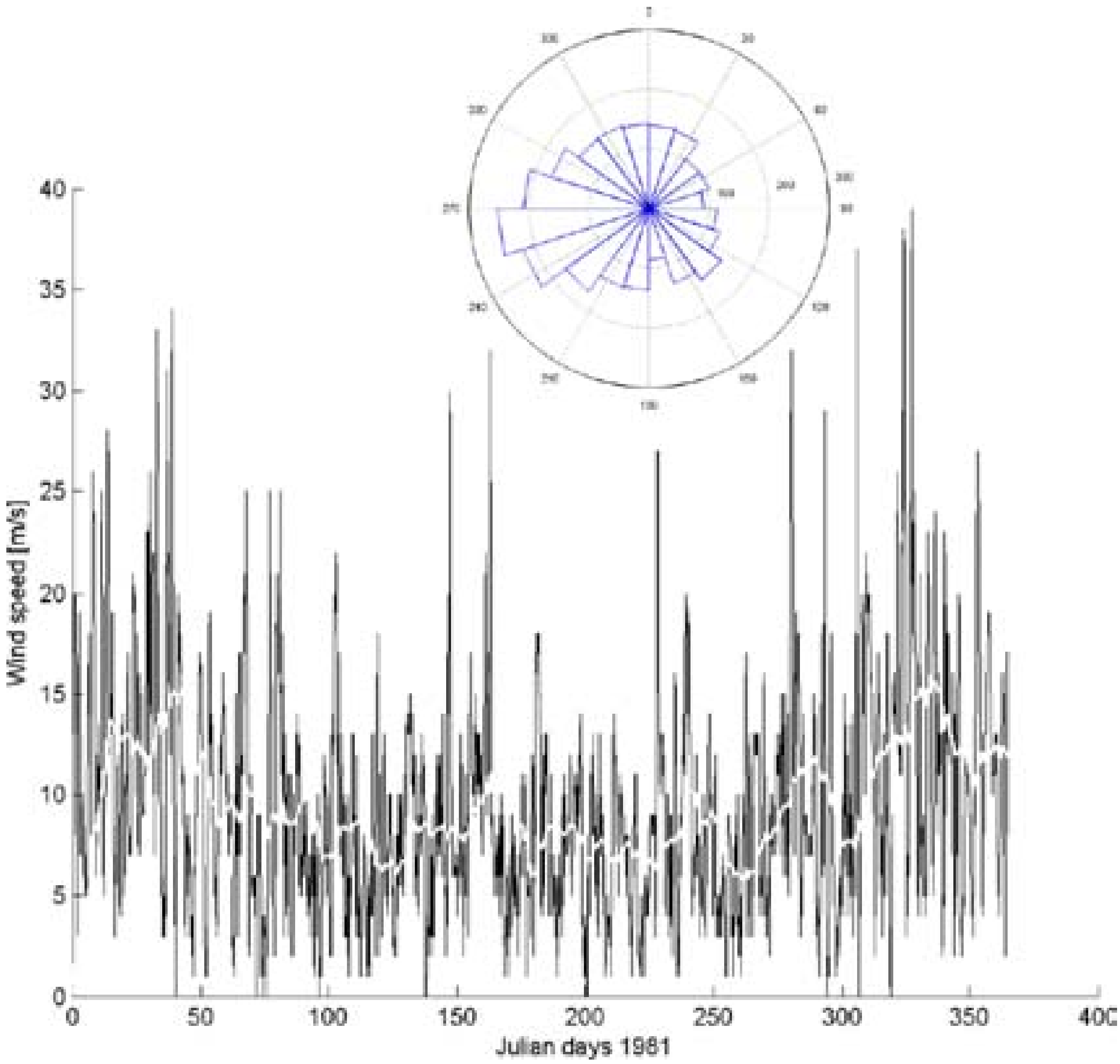

Figure 3-50. *Wind forcing as measured at Ölands Norra Udde 1981 with 3-h resolution. A running average of approximately 3 weeks is shown as a white broken line. A wind rose, showing that the predominant wind directions is from WSW, is inset at the top.*

Kattegat boundary data

For the Baltic model the sea level, salinity and temperature of the Kattegat model border also need to be estimated. 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 and provides data from which the geostrophically adjusted flow can be computed. 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/. 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 become available, procedures of data assimilation can be performed.

Freshwater discharge data

The freshwater discharge of the two streams Laxemarsån and Geseboån (retrieval ID: Sicada_04_77) have a discharge capacity (Figure 3-51) 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 peaks. These fluxes have been calculated from the HBV-model (Jenny Ryman, SMHI; pers. comm.) for the actual type-year 1981.

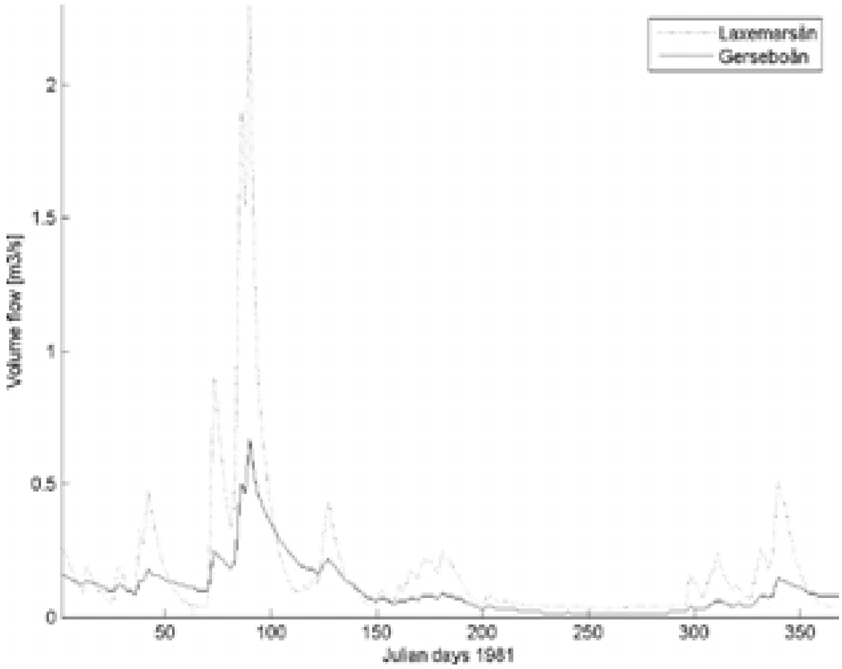

Figure 3-51. *Discharge of the two major streams Laxemarsån and Gerseboån 1981. Only Laxemarsån discharges into the discrete basin model area.*

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/. 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 continued development and is presently being used in several ongoing Baltic oceanographic studies: /Engqvist and Andrejev 2003, Andrejev et al. 2004ab/.

Coupling of two cascaded AS3D-models was performed by /Engqvist and Andrejev 1999/. The Laxemar area (Figures 3-46 and 3-47) with its planned repository 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 ($m^2 \cdot s^{-1}$) 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 *AvA*-values for some of the SBs (presented in Table 3-23 below) and sea level forcing data corresponding to the stations R-1 through R-4 (Figure 3-52), which together with the salinity and temperature profiles at these locations (Figure 3-53) are used for forcing of the DB-model. The 1-year mean of the *AvA*-values computed by the 3D-model with all interior basins conjoined to the IWCZ, is depicted in Figure 3-54.

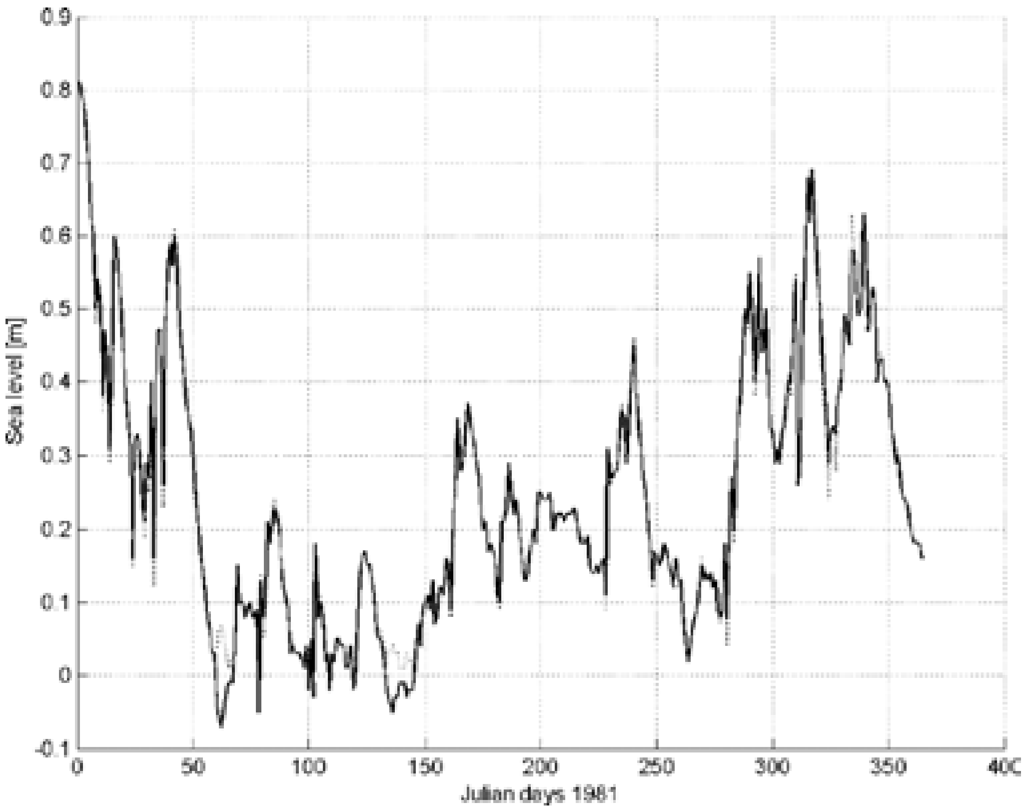

Figure 3-52. *Sea level forcing of the coastal stations R-1(solid) and R-4 (broken). Only during a few periods (e.g. around day 60 and day 130) is there a noticeable difference between these curves. The computed sea levels of R-2 and R-3 fall within these limits.*

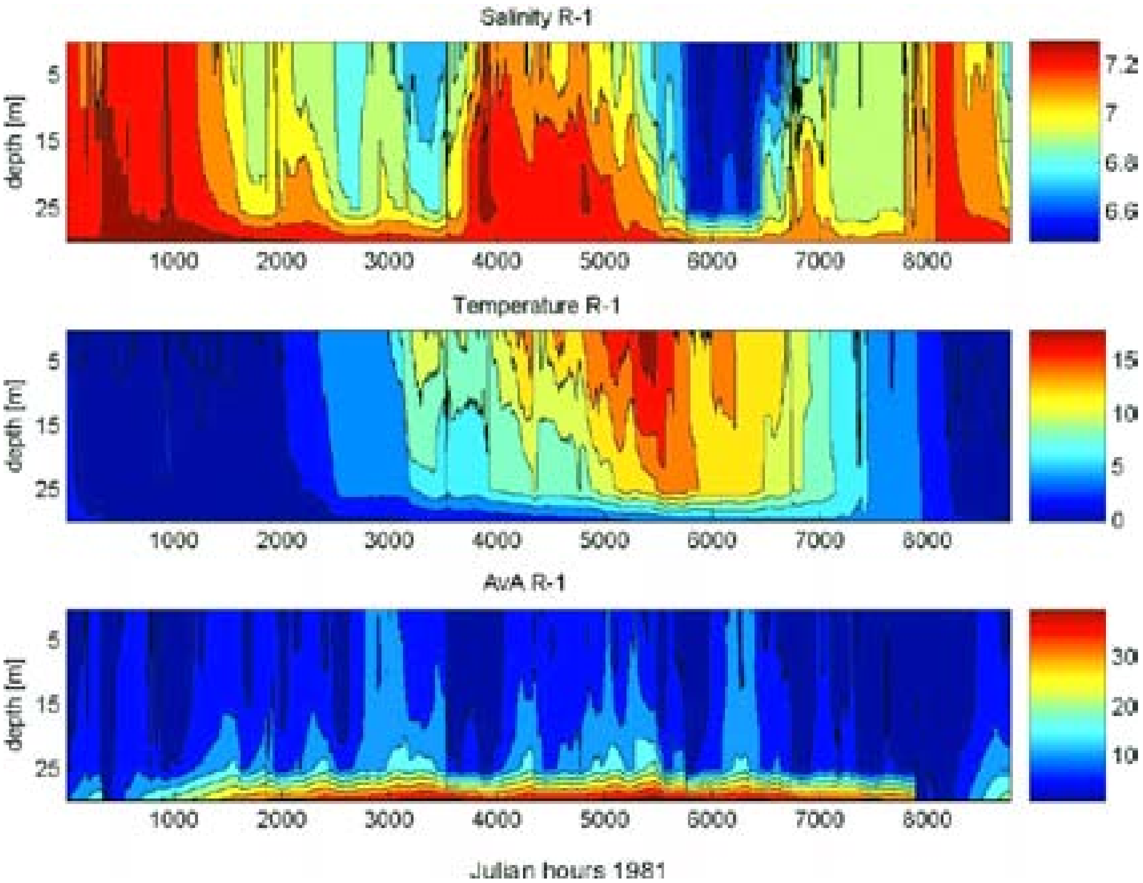

Figure 3-53. *Computed salinity (psu-scale), temperature (°C) and AvA (days) contours during the type-year 1981 at a location corresponding to the location R-1 in Figures 3-48 and 3-49. The entire model domain boundary is delimiting what is considered as exogenous water. The incidences of up- and downwelling occasions are clearly seen as is the stabilizing thermal stratification during the summer period. The other three boundary stations R-2 through R-4 display similar profile dynamics with small variations. The elevated AvA-values near the bottom are due to a local bottom cavity that retains the contained water which is forced to leave mainly by the slower process of vertical diffusion or by being rapidly replaced by up-welled denser water, which occurs by the end of the year. The slower vertical diffusion is responsible for the inverted age profile w.r.t. depth at this location compared to the average profiles in Figure 3-54. This presence of this cavity is, however, of no consequence for the baroclinic forcing of the DB-model, since the connecting straits are considerably shallower.*

The inner SBs 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 in analogy to /Engqvist 1997/, Figure 3-49, but the partitioning into SBs is more articulated in the present study. A complication is that in spite of refined qualities of the DEM /Brydsten and Strömgren 2005/, this does not resolve some of the straits with a comparable width to the inherent resolution of the DEM, i.e. 10 m. Moreover, bathymetric information of some of the shallow areas is nonexistent. The basin hypsographic data presented in Table 3-21 are thus best resolved and most accurate above the nominal sea level. Using different maps also give rise to problems, e.g. for SB13 the DEM gives a surface area of 0.002 km^2; while the economic map (LM GSD-fastighetskartan) states 0.0891 km^2. This considerable disparity is mainly explained by the existence of a shallow area in the DEM that does not occur in the economic map.

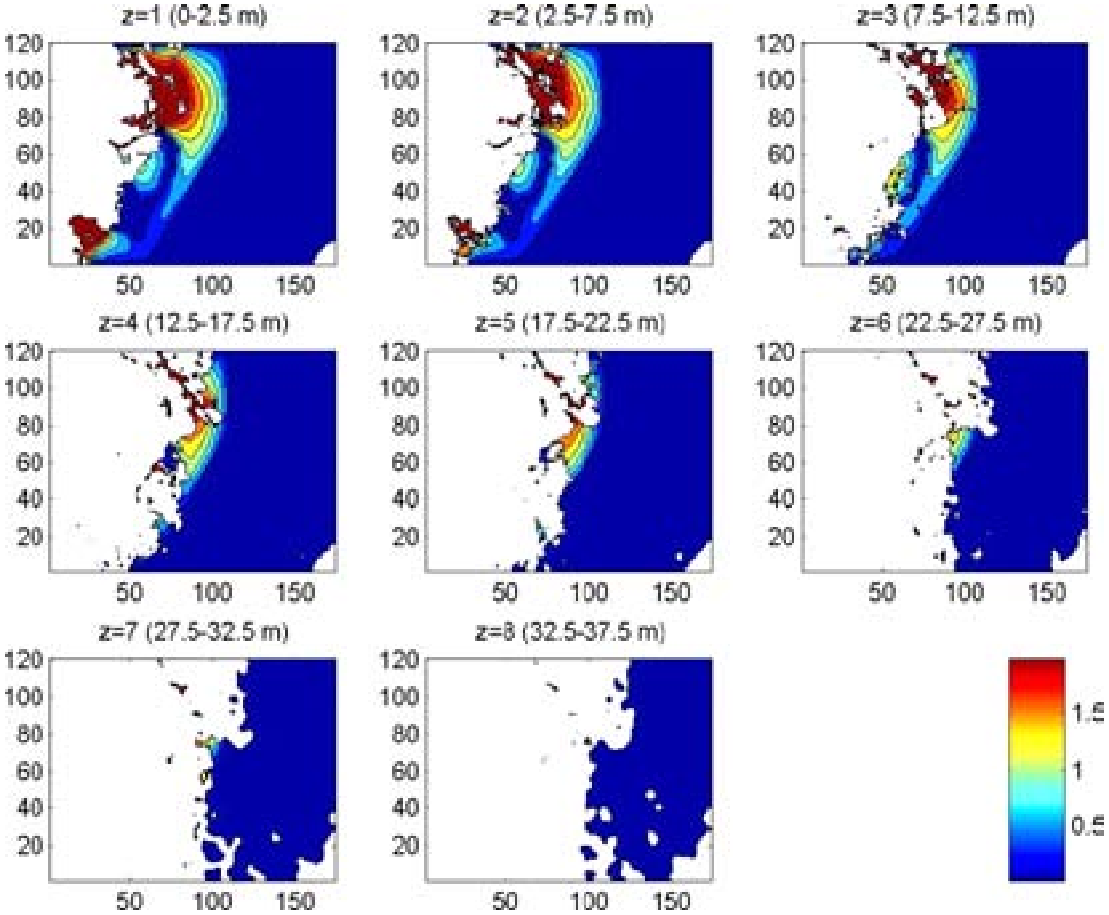

Figure 3-54. *AvA-values of individual grid cells calculated as a yearly average of the type-year 1981 considering all the SBs conjoined to obtain a conservative estimate. The colorbar denotes AvA (days). Exogenous water is entering from outside the 5 km offshore boundary that delimits the inshore waters of the coastal zone (IWCZ) and also as discharge from the two streams, Figure 3-51. The calculation is based on bi-monthly samples of the AvA for the different strata down to a depth (42.5 m) that exceeds the deepest part of the IWCZ. Even for the innermost SBs that are also separately modelled with the DB-model, the AvA are much smaller than one year. The comparatively lower AvA-values toward bottom are an indication of baroclinically forced water exchange in addition to wind-induced exchange that primarily affects the surface layers but also ultimately causes up- and downwelling by Ekman-dynamics.*

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 turns out to not be the case, a more refined strait exchange formulation /Engqvist and Stenström 2004/ can be employed. It seems, however, that the exchange flows are usually not hydraulically controlled, with the possible exception being the narrow passage (strait S3) between Granholmsfjärden and Kalvholmsfjärden, and thus the simplified scheme has been used.

Table 3-21. Hypsographic features of the discrete SBs into which the Laxemar area is partitioned.

Basin ID:	**SB1**	**SB2**		**SB3**		**SB6**	**SB9**	**SB10**	**SB11**	**SB12**		**SB13**	**SB14**
SubBasin:		**SB20**	**SB21**	**SB22**	**SB23**					**SB24**	**SB25**		
Systematic ID:	**b1**	**b2**	**b12**	**b3**	**b13**	**b10**	**b11**	**b5**	**b4**	**b6**	**b7**	**b8**	**b9**
max depth (m):	**8**	**18**	**16**	**12**	**3**	**14**	**7**	**3**	**3**	**9**	**21**	**1**	**7**
depth (m)							**Area (km²)**						
–1	1.197	0.872	0.299	0.241	0.055	1.433	0.835	0.217	0.129	0.211	0.615	0.072	0.133
0	1.165	0.858	0.282	0.238	0.047	1.385	0.744	0.204	0.116	0.199	0.610	0.002	0.127
1	0.825	0.759	0.254	0.215	0.018	1.172	0.165	0.080	0.066	0.175	0.539	0.000	0.098
2	0.447	0.671	0.230	0.196	0.004	0.717	0.121	0.021	0.019	0.161	0.473		0.063
3	0.212	0.605	0.205	0.175	0.000	0.489	0.070	0.000	0.000	0.109	0.425		0.046
4	0.075	0.523	0.186	0.132		0.370	0.013			0.083	0.382		0.030
5	0.025	0.450	0.162	0.085		0.268	0.009			0.060	0.338		0.014
6	0.008	0.359	0.134	0.050		0.192	0.005			0.041	0.297		0.006
7	0.001	0.284	0.108	0.033		0.130	0.001			0.017	0.259		0.001
8	0.000	0.228	0.087	0.022		0.078				0.011	0.225		
9		0.183	0.068	0.012		0.038				0.003	0.193		
10		0.143	0.051	0.003		0.023					0.155		
11		0.108	0.036	0.001		0.014					0.131		
12		0.080	0.026	0.000		0.001					0.116		
13		0.062	0.017								0.100		
14		0.046	0.005								0.083		
15		0.034	0.002								0.067		
16		0.025	0.000								0.053		
17		0.015									0.044		
18		0.001									0.035		
19											0.024		
20											0.016		
21											0.007		

To make up for the shortcoming of the DEM with regard to the strait hypsography, the straits S4 through S11, S15, S16 and S18 (Figure 3-49) were manually sounded in August 2005. The strait S20 means an additional passage of water into Djupesund. It contains both a deeper but narrower passage and a wider but shallower section to the north. From the available data an appropriately representative strait has been formed, see Table 3-22. In order to take the frictional effects of the long channel Djupesund (B24) into account, the area of the strait S3 has been modified according to the strait width reduction factor

$$swrf = \left(1 + \frac{2C_D LB}{S}\right)^{-1} \qquad (3)$$

where C_D (= $1.3 \cdot 10^{-3}$) is a drag coefficient, L (1,500 m) is the length of the channel, B (50 m) the wet perimeter and S (300 m^2) the section area. With these parameters, *swrf equals* 0.6, and the widths of this strait have been reduced accordingly in the model.

Table 3-22. Hypsographic features of the straits connecting the SBs of the Laxemar area.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Source:	**DEM**	**DEM**	**DEM**	**Meas**	**Meas**	**Comb**	**Meas**	**Meas**	**Meas**	**Meas**	**Meas**	**DEM**	**DEM**	**DEM**	**Meas**	**Meas**	**TR-97-14**	**Meas**	**Estim**	**DEM**
Remark:				**reef growth**			**Bridge**		**Culvert**		**Bridge**						**+chart**			**+Adapted**
fr model basin:	**b7**	**b7**	**b12**	**b2**	**b4**	**b12**	**b3**	**b13**	**b4**	**b5**	**b8**	**b3**	**b9**	**b10**	**b11**	**b11**	**b12**	**b13**	**b5**	**b6**
to model basin:	**R-1**	**b6**	**b6**	**b1**	**b2**	**b5**	**b1**	**b5**	**b1**	**b4**	**R-2**	**R-2**	**R-3**	**R-4**	**R-3**	**b10**	**b2**	**b3**	**b2**	**R-1**
max depth (m):	**12.9**	**5.1**	**4.7**	**1.7**	**1.4**	**2.5**	**2.5**	**1.1**	**0.4**	**1.7**	**0.8**	**5.5**	**5.5**	**11.2**	**2.8**	**2.1**	**2.7**	**2.1**	**2.5**	**3.1**
area (m^2):	**6,619**	**143.8**	**174.6**	**12.57**	**31.02**	**154.8**	**21.23**	**3.38**	**0.66**	**23.15**	**1.68**	**225.3**	**311.0**	**3,193**	**60.90**	**81.6**	**95.47**	**6.73**	**49.52**	**295.1**
Depth (m)											**Strait width (m)**									
–1	1,771.0	75.0	81.0	22.5	266.3	274.5	29.2	41.7	3.5	223.6	66.1	297.7	114.1	2,691.0	70.6	305.1	82.2	6.0	48.0	45.0
0	1,578.0	53.8	56.0	14.6	45.8	100.0	12.4	4.0	3.3	31.0	4.2	171.8	94.0	1,726.0	45.9	90.0	53.4	4.0	32.0	35.0
1	1,190.0	44.4	49.5	6.2	11.6	80.0	10.3	2.5	0.0	9.0	0.0	61.1	81.9	869.8	25.3	30.0	44.2	3.9	25.6	25.0
2	981.7	35.6	42.5	0.0	0.0	33.0	6.3	0.0		0.0		42.0	68.5	354.3	14.1	12.0	25.6	1.5	10.6	15.0
3	792.8	23.1	35.0			0.0	0.0					19.1	55.7	295.9	0.0	0.0	8.2	0.0	0.0	0.1
4	739.4	13.8	23.0									11.5	40.3	183.4						0.0
5	654.1	0.0	0.0									7.6	23.5	142.9						
6	471.6											0.0	0.0	127.8						
7	349.3													112.8						
8	241.1													90.2						
9	153.1													75.2						
10	125.0													60.2						
11	95.6													30.1						
12	38.1													0.0						
13	0.0																			

The individual AvA computations of the 14 sub-basins are given in Table 3-23 and depicted in Figure 3-55a. For the discrete basins the resulting average γ-factor is consistently greater than unity. This indicates that the water exchange is unevenly distributed so that the water layers nearer the bottom are subjected to less intense water exchange and thus contribute to an unevenly distributed aging. Due to the stratification the γ-factor varies between the inner basins, but the correlation coefficient between the sum of the averaged exchanged flows $(Q_p – Q_n)/2$ (Table 3-26) and the AvA for each basin is high (ρ = 0.994, N = 13).

Table 3-23. Individual basin AvA-time (days) estimates for the 14 SBs. The vertically integrated volume averaged statistics for the inner sub-basins SB1 through SB14 are computed with the coupled discrete basin model based on earlier extracted hypsographic data, while for SB18 and SB19 these volume averages are calculated directly from 3D-model results, which have a temporal resolution of one hour. Tne inner SBs are computed with the DB-model; the outer with the 3D-model.

Basin	Min (days)	Mean –S.D. (days)	Mean (days)	Mean +S.D. (days)	Max (days)	γ (–)	Computed with model type	Remark
SB1	0.39	3.21	8.88	14.5	22.7	0.69	DB	
SB2	14.1	20.6	25.7	30.7	38.5	1.4–3.2	DB	Further subdivided into B20 and B21
SB3	1.05	1.62	2.70	3.79	7.03	1.2–3.0	DB	Further subdivided into B22 and B23
SB6	0.18	0.28	1.23	2.18	4.06	2.25	DB	
SB9	0.32	0.86	2.51	4.16	10.5	1.87	DB	
SB10	0.30	0.95	1.50	2.04	3.56	1.39	DB	
SB11	1.24	3.37	5.47	7.56	11.2	1.87	DB	
SB12	0.15	0.57	1.12	1.68	2.94	1.4–3.2	DB	Further subdivided into B24 and B25
SB13	0.40	0.58	1.83	3.08	5.00	3.69	DB	
SB14	0.17	0.30	1.49	2.68	4.81	2.97	DB	
SB15	0.09	0.38	0.58	0.79	1.00	1.29	3D	
SB16	–	–	–	–	–	–	–	Includes the whole model area
SB17	0.03	0.07	0.09	0.11	0.13	0.30	3D	
SB18	0.02	0.08	0.13	0.17	0.22	0.82	3D	
IWCZ	0.36	0.85	1.29	1.74	2.16	–	3D	Individual AvA-values – all adjacent SBs are considered as exogenous water

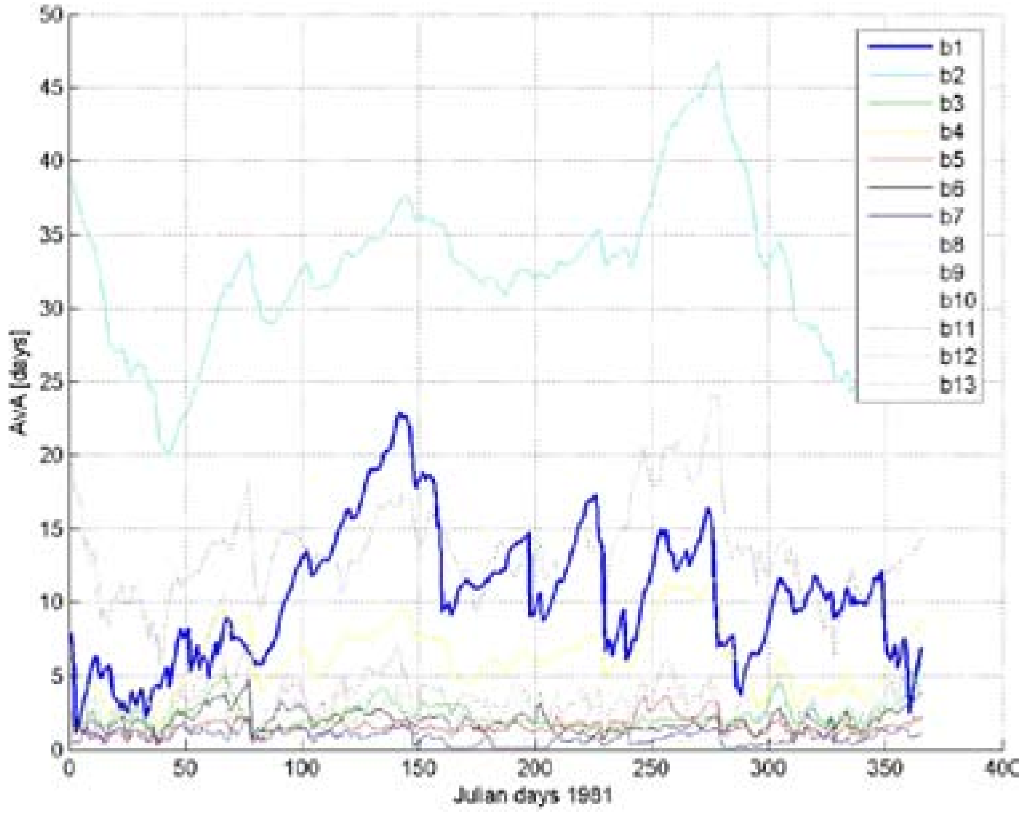

Figure 3-55a. *Calculations of the individual basin volume averaged AvA during 1981 of the SBs (b1 through b13 in systematic basin numbering order) with any of the adjacent basins counted as exogenous water. The highest individual AvA-values occur for the secluded inner basins Borholmsfjärden (b1) and Granholmsfjärden (b2 and b12). Sketuddsfjärden (b4) marks a transitional AvA-level to the majority of basins that display AvA-values lower than five days for most of the year. These volume-averaged data form the basis of the statistics presented in Table 3-23.*

The corresponding collective AvA-values with the discrete basins treated as an entity and the IWCZ as the exogeneous water – in addition to the freshwater – are presented in Table 3-24 and Figure 3-55b.

Table 3-24. Collective basin AvA-values (days) estimates for the 13 systematically numbered basins of which three pairs have been conjoined to form the 10 SBs of the discrete basin (DB) model. The major inshore water coastal zone (IWCZ) is regarded as exogeneous water. For labelling reasons only, SB4 and SB5, SB6 and SB7 are missing. The AvA of the IWCZ *collectively* with only offshore waters is regarded as exogeneous. SB16 denotes the whole 3D-domain and its AvA-values has not been computed.

	Systematic BasinID	Minimum (days)	Mean –S.D. (days)	Mean (days)	Mean +S.D. (days)	Maximum (days)	Model type	Remark
SB1	b1	9.7	26.2	38.1	49.9	68.4	DB	
SB2	b2 and b12	33.5	48.2	60.3	72.5	78.8	DB	
SB3	b3 and b13	2.8	6.5	12.8	19.1	38.9	DB	
SB6	b10	0.2	0.3	1.4	2.5	4.4	DB	
SB9	b11	0.6	1.3	3.2	5.0	11.9	DB	
SB10	b5	22.3	41.4	52.3	63.3	71.0	DB	
SB11	b4	1.2	3.3	5.4	7.5	11.1	DB	
SB12	b6 and b7	0.7	2.6	4.7	6.7	10.7	DB	
SB13	b8	0.4	0.6	1.8	3.1	5.0	DB	
SB14	b9	0.2	0.3	1.5	2.7	4.8	DB	
SB15	–	0.09	0.38	0.58	0.79	1.00	3D	
SB17	–	0.03	0.07	0.09	0.11	0.13	3D	
SB18	–	0.02	0.08	0.13	0.17	0.22	3D	
IWCZ	–	0.04	1.05	1.85	2.66	3.78	3D	Collective AvA – all SBs are included in IIWCZ

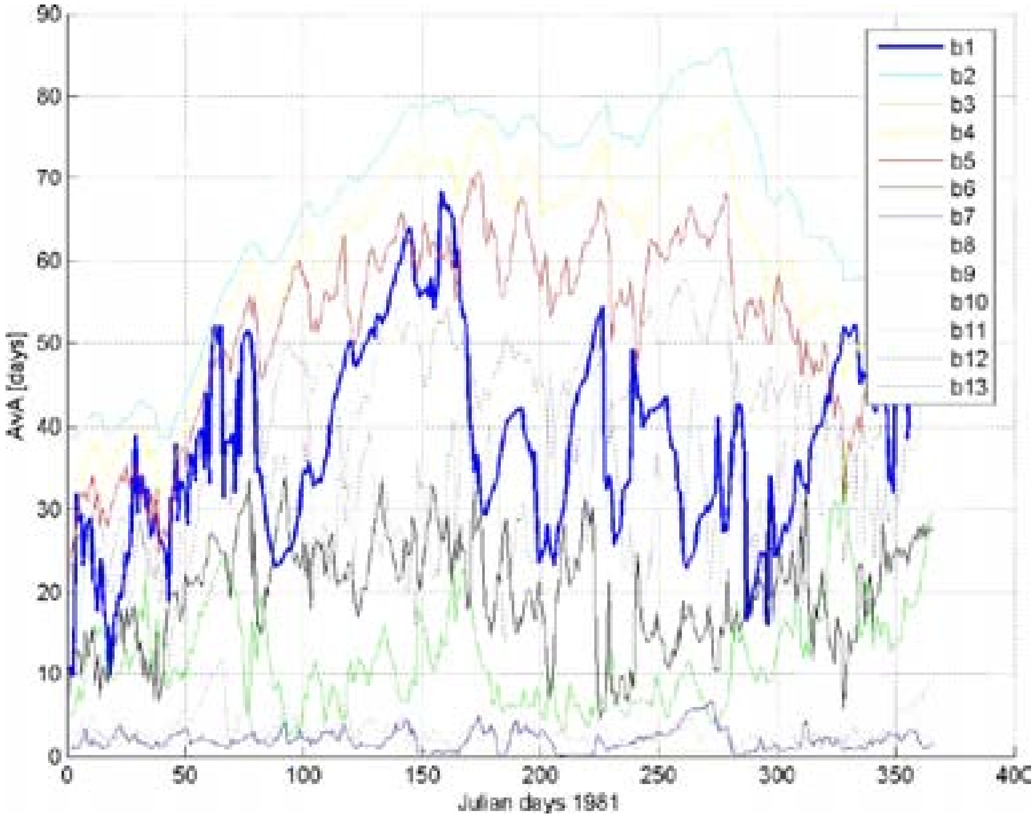

Figure 3-55b. *Calculations of the collective basin volume-averaged AvA-values during 1981 of the SBs (b1 through b13 pertaining to the systematic basin numbering order) with only the fictive boundary basins R-1 through R-4 counted as exogenous water in addition to the discharged freshwater. This gives generally higher AvA to the innermost SBs, compared to Figure 3-55a, since those SBs import water aging on its way from the coastal zone. The freshwater discharge to Borholmsfjärden (b1) lowers the AvA of this SB. The smaller and shallower basins closer to the coast (e.g. Långvarpsfjärden, b8) display low AvA-values due to barotropic exchange in spite of having straits with very small cross-sections. These volume-averaged data form the basis of the statistics presented in Table 3-24.*

3.5.5 Confidence and uncertainties

A thorough testing of the 3D-model approach in comparison to measured data 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 /Engqvist and Andrejev 2003/. This evaluation thus strongly increased confidence in the AS3D-model.

One instance of checking the used synoptic wind data set against local measurements did not give any reason for concern; on the contrary, the local wind measured at Örskär in the Forsmark area 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 (Öland Norra Udde) with the local wind of the Mueller synoptic data revealed that the differences in computed *AvA*-values were so minute that such excerpts of the synoptic data set could be used confidently if the necessary corrections were applied.

The water exchange of semi-enclosed landlocked waters is different from that of the open offshore waters because the confinement to channels means a reduced degree of freedom of current directions. When quantifying the exchange of landlocked basins, two principally different approaches are available: the first is to employ another 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 3-49. The 3D-based method may potentially necessitate more sophisticated (non-hydrostatic) numerical models when applied to landlocked areas, spanning the length scales between narrow straits and wider basins /Engqvist and Stenström 2004/, making the second coupled 'discrete basins' 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 strongly influences 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 is normally the major cause of vertical is mixing /Stigebrandt 1985/. Basins that receive freshwater discharge also display a noticeable 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 observation of ice formation and melting. If this would be regarded as appropriate for making it possible to base the heat exchange with the atmosphere on more detailed forcing, this can be included in a new version of the model, as for example /Omstedt 1999/.

A primary point for a discrete coupled basin model with free water surfaces of each basin is the choice of appropriate time steps. There are two kinds: one for the baroclinic (dT) and one for the barotropic (dt) computing cycle, which are kept separate in the model /Engqvist and Stenström 2004/. The quotient of these (dT/dt) is set beforehand to a fixed value of the order 1,000:1. This is a reflection of the fact that the long barotropic surface waves adjust faster then the long internal baroclinic waves in approximately this proportion. This means that the detailed dynamics of the sea level adjustment can be mimicked very accurately by the model, so that the neglected long wave in the basin and the lack of detailed information about how the sea level behaves between the 1-h sampling intervals becomes influential on the solution. On one hand it is desirable to have a short time step to resolve the rapid transients of the basins with the shortest response time; on the other hand neglected inertial forces that impede such transients will be mitigated by choosing a longer time step. The smallest possible time step from a practical point of view is also determined by the available computing resources. The lowest practical starting value would be $dT = 0.1$ h. Increasing this value while comparing the average sum of positive and absolute (no sign) negative exchange flows over a one-year cycle for each strait gives that $dT = 0.25$ h and $dT = 0.5$ h yield almost exactly the same relative deviation in comparison to the smallest dT, while for a time step of a full hour the deviation is considerably higher. From these deliberations $dT = 0.5$ h was finally chosen.

No model simulation is complete without a sensitivity analysis. An encompassing such analysis with regard to sensitivity of *AvA* variations of the AS3D-model to the forcing factors was performed in /Engqvist and Andrejev 2000/. An analogous sensitivity analysis has presently been performed with the discrete coupled basin model, and the results are presented in Table 3-25 where the dependency of the model outcome has been divided into both morphometrical and forcing factors for which a ± 10% variation has been imposed when applicable. The dependency on sea level has been determined by imposing the same harmonic as in /Engqvist 1997/, with a Nyquist frequency of 2 h and an amplitude of 1 cm to compensate for lesser temporal resolution (3 h) of the wind forcing. This gives a combined sea level variance that is close to measurements /Engqvist 1999/.

From Table 3-25 it is seen that the DB-model is shown to be most sensitive (average impact: –21%) to the barotropic formulations. This is made clear when manipulating the sea level forcing, which affects the *AvA* estimates of virtually all basins. An exception is for SB14, which has a small surface area and is directly attached to the coast by a strait (S13) with a comparatively large section area. Adding freshwater to all basins except SB1 in direct proportion to their surface area and the measured average precipitation (that for the type year 1981 amounted to a little more than 600 mm /Larson-McCann et al. 2002/) gave the second largest impact (–8%). This gives an aberration relative the nominal run that is comparable to diminishing all the basin areas (and thus the basin volumes) by 10%. In particular the shallow SB13 is affected by this induced baroclinic component. Decreasing all strait widths by 10%, yields an average 4% increase in *AvA*-values, the same impact as lowering the wind speed 10% or increasing the salinity 10% on the boundary (R-1 through R-4), but with opposite signs.

Table 3-25. Sensitivity analysis of the DB-model. The deviations with regard to the various manipulations are the relative changes of the AvA-values of the systematically numbered sub-basins compared to the results of the collective basin nominal run, in Table 3-24 and Figure 3-55b. Obviously the DB-model is most sensitive to manipulations of sea level, added small freshwater discharges corresponding to the annual precipitation, and reducing the basin areas, which alterations affect the AvA-values of most basins.

	Morphometric manipulation				Manipulation of forcing							
	Basin		Straits		Freshwater flow			Wind		Boundary salinity		Sea level
Systematic sub-basinID	+10% increased basin area	–10% decreased basin area	+10% increased strait width	–10% decreased strait width	+10% incr. of Laxemarsån	–10% decr. of Laxemarsån	Added average annual precip.	+10% increase of wind speed	–10% decrease of wind speed	+10% incr. of boundary salinity	–10% decr. of boundary salinity	Added sea level high freq. fluct.
b1	0%	–14%	–1%	–4%	–5%	1%	5%	1%	–17%	–7%	–5%	–32%
b2	3%	–9%	–1%	0%	–2%	1%	–5%	1%	–5%	–4%	0%	–29%
b3	3%	–11%	–1%	–1%	–3%	–1%	–10%	4%	–10%	–5%	2%	–17%
b4	3%	–9%	–1%	0%	–2%	1%	–7%	0%	–5%	–3%	–1%	–30%
b5	3%	–9%	–1%	1%	–2%	1%	–9%	1%	–4%	–3%	0%	–30%
b6	2%	–12%	2%	1%	0%	3%	–18%	4%	–8%	–4%	–1%	–33%
b7	6%	6%	–2%	–4%	2%	–9%	4%	–5%	15%	–7%	3%	6%
b8	5%	–4%	0%	0%	0%	0%	–46%	0%	0%	–1%	–1%	–40%
b9	8%	–8%	0%	0%	0%	0%	7%	0%	0%	–6%	1%	0%
b10	8%	–8%	0%	0%	0%	0%	11%	1%	0%	–6%	3%	–1%
b11	8%	–8%	0%	0%	0%	0%	–3%	0%	0%	–2%	1%	–13%
b12	3%	–10%	–1%	1%	–2%	2%	–27%	2%	–6%	–4%	1%	–33%
b13	3%	–9%	–1%	0%	–2%	0%	–7%	1%	–5%	–4%	0%	–27%
average:	4%	–8%	–1%	–1%	–1%	0%	–8%	1%	–4%	–4%	0%	–21%

Scarcity of Baltic salinity and temperature data for initialization or assimilation purposes limits the prospect of differentiating the interannual Baltic hydrography. It seems safe to infer that the interannual variations must be smaller than those of the intra-annual for a foreseeable future. For longer time scales, sensitivity analyses of the Baltic dependence on its forcing may possibly be used /Gustafsson 2004/. The encompassing field data program with the sole aim of collecting systematic validation data (for measurement stations, see Figure 3-47) over a full-year cycle in the Laxemar area will determine the level of confidence with which these models and data can be invested.

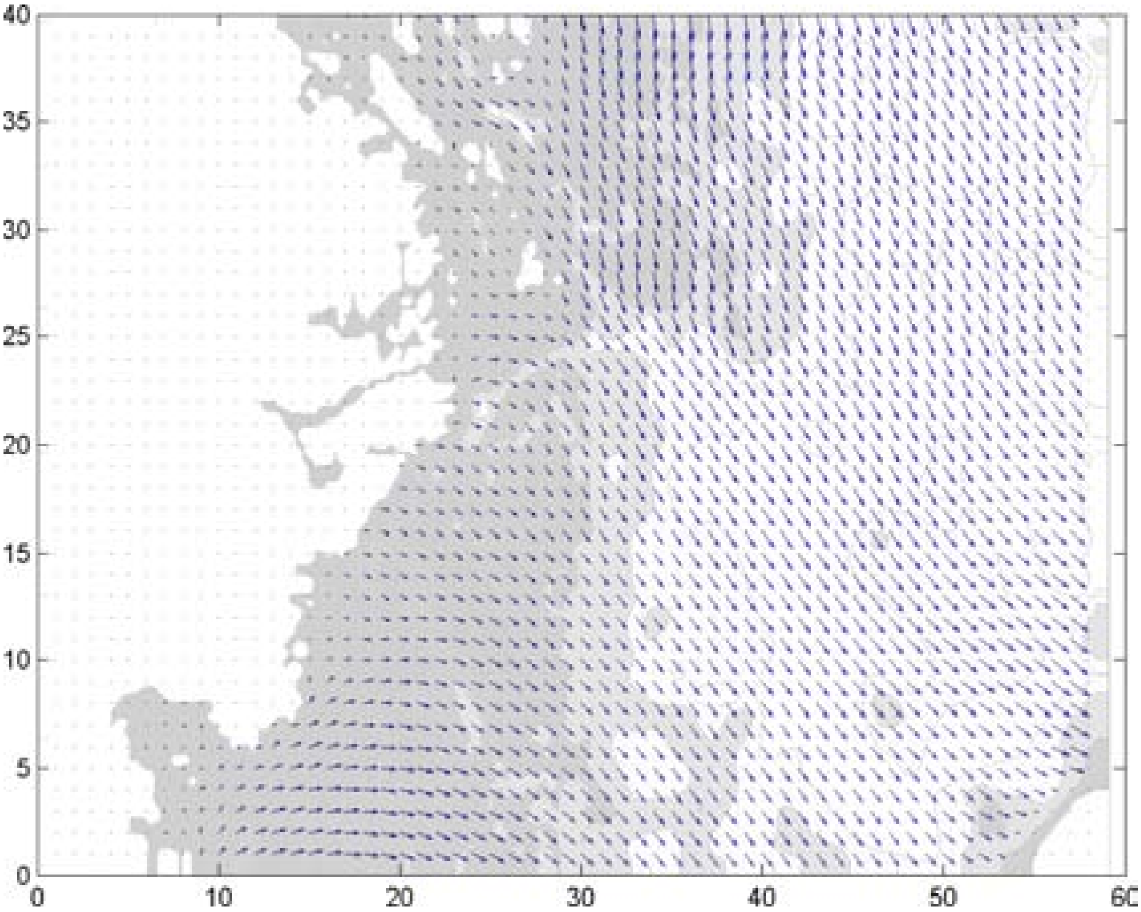

Figure 3-56. *Residual surface currents averaged over the year 1981. Maximum velocities are about 40 (cm s^{-1}). The southward setting Baltic residual current at the northern boundary is deflected eastward by a compensatory weaker coastal current flowing north in the southeastern part of the model area. Residual currents are not, however, reliable indicators of the actual water exchange that takes place episodically on events with intense winds. The inshore water coastal zone (IWCZ) is defined to be located west of the broken line.*

3.5.6 Characterization of the water exchange of the Laxemar area

The water exchange of the outer SBs is considerably more intense compared to the inner SBs. This is evident from Table 3-24 in which the *AvA* of the outer basins amounts to less than one day (the IWCZ exempted) while the *AvA* of the innermost SBs is several weeks. An intermediary group (SB6, SB9, SB13 and SB14) located in direct contact with the coastal water possesses *AvA*-values of a couple of days *i.e.* comparable to the inshore water coastal zone (IWCZ) in spite of its greater area. The length scale of this zone is about 20 km, which means that a current of 10 (cm s^{-1}) in the N/S-direction can completely exchange all water in four days, corresponding to an *AvA* of two days. The residual surface currents (Figure 3-56) are in general of this magnitude, but display the large-scale circulation pattern of the Baltic Proper with cyclonic (counter-clockwise) south-setting coastal current north of the Laxemar area. The entrapment of this current by the narrowing Kalmarsund induces a compensatory current in the southern part. Superposed on this average flow, there are induced event-oriented events, primarily induced by wind forcing. On storm occasions, not only are the surface layers set in motion, but also the Ekman-dynamics is induced, resulting in up- (down)-welling depending on whether the along-shore wind is northerly or southerly. Such events represent an efficient mechanism to ventilate the bulk of the water mass in the studied area /Stigebrandt 2001/. Certainly there are features of the ragged Laxemar coast that even the fine-resolution 3D-model cannot resolve, which emphasizes the need for caution when using the results.

The inner group of more or less landlocked basins is also subjected to episodic water exchange events. This applies to the time-varying freshwater discharge with an accentuated peak in springtime (Figure 3-51) affecting foremost the innermost basins SB1 but also its neighboring SB:s that connect to the coast. Along those passages an estuarine circulation is induced as seen from Table 3-25, also manifesting itself at the mouth (Kråkefjärden, SB12) of the estuary. Increased precipitation to the extent of being twice the amount of 1,981 would have a thorough impact on the water exchange of all SBs, but would be most noticeable on the shallow Långvarpsfjärden (SB13). This SB is connected to the coast via a strait with a very small cross-section area so that an induced estuarine circulation mode in addition to the other available modes of exchange, i.e. those that pertain to sea level fluctuations and the varying density of the coastal water. In many coastal areas along the Swedish coast the latter (baroclinic) mode of water exchange is normally dominant /Engqvist and Omstedt 1992/, but for the SBs around Äspö island, this mode is mitigated by the comparatively long and narrow connecting basins. In Table 3-26 the yearly average positive and negative flows for each of the straits of the inner SBs are given. The inferences that can be made from Table 3-25 are based on the computed individual *AvA*-values and it is therefore reassuring that a high correlation exists between those and the sum of the volume fluxes in and out from the respective SBs is high.

The contemporary water exchange situation in the Laxemar area gives no cause for concern that waterborne hazardous material might not be sufficiently diluted and flushed off-shore. All water is flowing and the quantified volume fluxes in Table 3-26 give the input data for the integrated ecological models to compute the trade-off with increasing exposure risks with slower water exchange. The potential stagnant water is most likely to be found in local isolated depths in the coastal zone (cf Figure 3-53), but even the water of those is likely to be exchanged either by a slower vertical diffusion or by a faster up-welling event /Engqvist 1997/. In either case the associated *AvA* is likely to be considerably lower than one year.

Table 3-26. Average volume flows between the SBs over one year. These flows are used for the ecological marine model. Prior to computing the averages, the volume fluxes are separated into a positive direction (defined as flowing from a basin with higher order number to one with a lower) component and a negative component regardless of the vertical position of the layers. The sum of inflow and outflow (with opposite signs) for all basins balances the volume difference due to the sea level change over the year (Figure 3-52).

From	To	Strait	Average volume fluxes ($m^3 \cdot s^{-1}$)		
model basin	model basin	ID	Qp	Qn	netQ
b7	R-1	S1	134.7	–134.7	0.017
b7	b6	S2	2.87	–2.88	–0.004
b12	b6	S3	2.47	–2.46	0.013
b2	b1	S4	0.60	–0.61	–0.010
b4	b2	S5	0.13	–0.13	–0.004
b12	b5	S6	1.22	–1.22	0.005
b3	b1	S7	1.03	–1.23	–0.203
b13	b5	S8	0.17	–0.20	–0.026
b4	b1	S9	0.05	–0.05	0.000
b5	b4	S10	0.25	–0.26	–0.006
b8	R-2	S11	0.02	–0.02	0.003
b3	R-2	S12	4.35	–4.11	0.235
b9	R-3	S13	7.42	–7.41	0.002
b10	R-4	S14	85.0	–85.6	–0.579
b11	R-3	S15	3.48	–2.86	0.623
b11	b10	S16	3.04	–3.65	–0.607
b12	b2	S17	1.42	–1.44	–0.011
b13	b3	S18	0.25	–0.22	0.028
b5	b2	S19	0.52	–0.53	–0.012
b6	R-1	S20	0.99	–0.97	0.012
IWCZ	SB12	–	81.4	–88.9	–7.500
SB15	SB12	–	41.2	–34.0	7.258
SB15	IWCZ	–	5,031	–4,997	33.640
SB6	SB15	–	32.9	–25.1	7.780
SB17	SB15	–	337	–345	–7.579
SB17	SB6	–	50.8	–43.0	7.756
SB8	IWCZ	–	1,803	–1,843	–40.40
SB8	SB15	–	158	–118	40.47
SB9	SB15	–	10.1	–10.3	–0.131
SB9	SB17	–	9.70	–9.60	0.138

The three nuclear reactors at standard operation produce about 90 (m^3 s^{-1}) water with an elevated temperature of 10–11 (°C) relative the intake water. These figures correspond to a heating power of about 0.3 (GW). With a heat loss of 100 (W m^{-2}), this heat could be dissipated to the atmosphere in a surface area comparable in size to only one grid cell. The thermal impact thus seems inconsequential. The induced circulation between the intake and the discharge points would be visible as a residual current if it were included in Figure 3-56 because of its persistent flow pattern. To the purpose of making the present simulations comparable to simulations projected into the far future, however, this source of local water circulation is purposely exempted from the present models.

In the longer time perspective, the landrise may prevail in spite of other possible processes that act to increase the total volume of the world's oceans and thereby also of the Baltic Sea. When lowering the sea level, a series of transition stages will follow during which stagnant water bodies may appear. Eventually the connection to the coast will be permanently lost for some of the contemporary SBs. At the point when they irrevocably become lakes, their study does not need to involve coastal oceanography other than as a potential discharge source of freshwater.

3.6 Chemical properties

3.6.1 Introduction

The description of chemical properties of surface ecosystems in the Simpevarp area is based on data from surface waters (sampling sites in streams, lakes and the sea), shallow groundwater (soil tubes and private wells), and regolith (samples from till, soil and sediment). Moreover, there are also some data available on the concentration of different elements in precipitation, and of the element content in roots of amphibious plants. All data available in Sicada in May 2005 has been included in the analyses when nothing else is stated. A detailed compilation and statistical evaluation of the primary data is given in /Tröjbom and Söderbäck 2006/.

3.6.2 Input data and data evaluation

Data on surface water chemistry has been collected biweekly to monthly from October 2002 and onwards, and the sampling programme includes 18 stream, 4 lake and 5 sea sampling sites (Figure 3-57). The number of sampling sites has been reduced since the start of the programme, but for all sites there is a time series of at least one year. Analysed parameters include, for most samples, major cations and anions, nutrients, organic carbon and O_2 (see Table 3-27). Water temperature, pH, conductivity, salinity and turbidity were determined in the field. Moreover, trace elements were analysed at one sampling occasion, 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 2004ab/, together with a compilation of primary data from the first year of sampling. Data on the water chemistry of precipitation have been collected regularly from one sampling location.

Shallow groundwater has been sampled from totally 30 soil tubes, i.e. shallow boreholes (Figure 3-58). Each soil tube has been sampled at 1–3 sampling occasions. The number of analysed parameters varies greatly, from only pH and electrical conductivity in some objects, to a complete chemical characterisation, including stable and radiogenic isotopes (see Table 3-27). In addition, groundwater has been sampled from 47 private wells during the period 1989–2005.

The chemical analyses of Quaternary deposits performed hitherto mainly include total contents of organic carbon, calcium carbonate ($CaCO_3$), nitrogen and sulphur. In total, 27 till samples have been analysed for $CaCO_3$. The contents of carbon, nitrogen, hydrogen and sulphur have been analysed on sediments from peatlands (7 samples), and on marine and lacustrine sediments from bays and lakes (20 samples) (Figure 3-59). The contents of carbon and nitrogen have been analysed in different soil horizons from ten typical site types in the Simpevarp area. For a more detailed description of the samples collected from surface waters, groundwater and the regolith, and of the parameters analysed, see /Tröjbom and Söderbäck 2006/.

Figure 3-57. *Location of 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.*

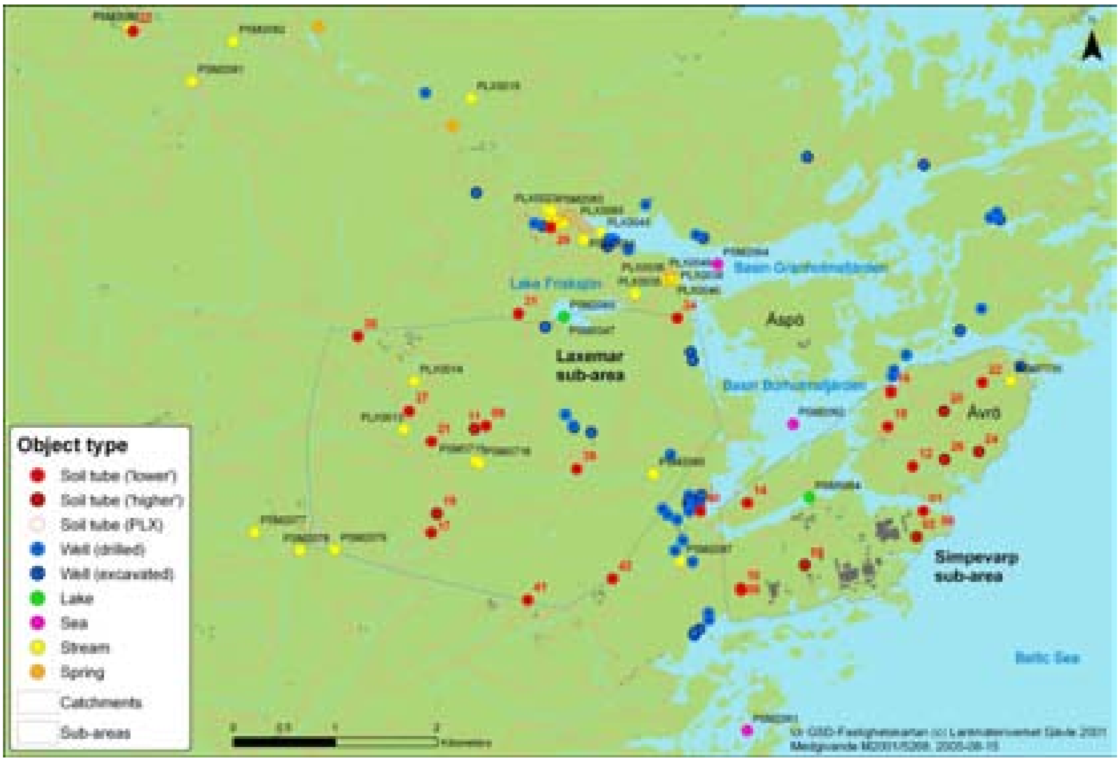

Figure 3-58. *Location of the sampled soil tubes and private wells in the Simpevarp area. Identities for soil tubes are marked in red (SSM0000XX). In addition, sampling sites in surface waters are marked on the map for orientation. Based on coarse topographical considerations, the soil tubes are preliminary classified into the categories 'higher' and 'lower', corresponding to possible recharge and discharge characteristics /see Tröjbom and Söderbäck 2006/. The catchments are described in /Brunberg et al. 2004/.*

Table 3-27. Parameters analysed in the site investigation programme for chemical properties in surface waters and shallow 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 (Part. Org. N), POC (Part. Org. C), DIC (Dissolved Inorganic C), DOC (Dissolved Org. C), TOC (Total Org. C), 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, ^{3}H and ^{87}Sr
Other data	Temperature, pH, conductivity, salinity, turbidity and O_2

***Figure 3-59.** Map showing the sampling sites in till, sediments and soil in the Simpevarp area.*

3.6.3 Description and conceptual model

Surface water

The freshwater systems in the Simpevarp area can generally be characterised as mesotrophic, brown-water types. Most freshwaters in the area are markedly coloured due to a high content of humic substances, leading to very high levels of dissolved organic carbon. Both streams and lakes are also relatively rich in nitrogen and phosphorus (Figure 3-60). These high levels of dissolved organic carbon and nutrients implies poor light conditions in the lakes, and periodically also high levels of chlorophyll in the surface water and poor oxygen conditions in the bottom water of the lakes.

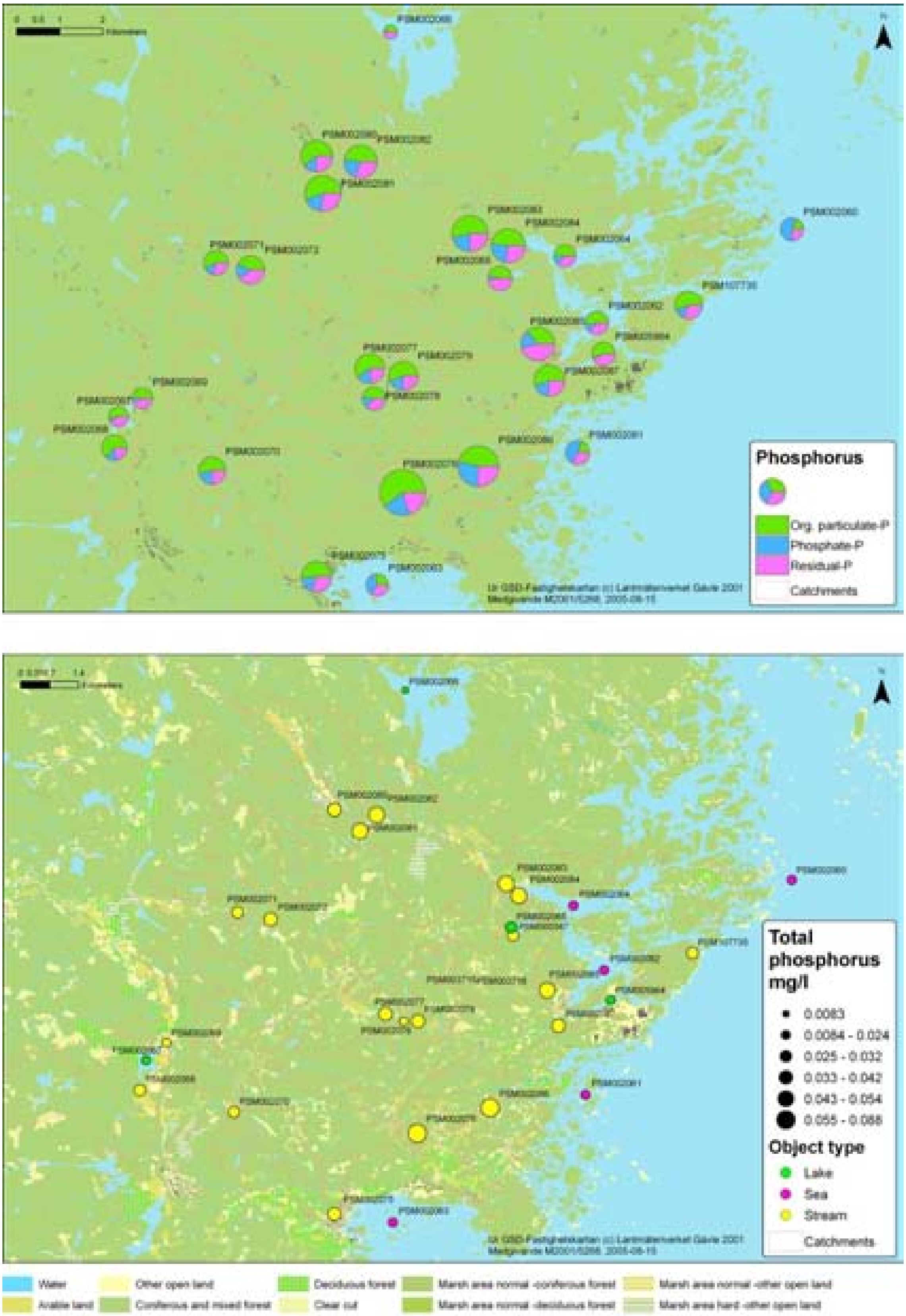

***Figure* 3-60**. *Phosphorus in surface water in the Simpevarp area. The pie charts are sized proportionally to the mean concentration of total phosphorus, and the relative fraction of each phosphorus species is shown. The residual phosphorus is calculated as the difference between total phosphorus, phosphate phosphorus and particulate organic phosphorus. Mean values of total phosphorus per sampling site (lower map).*

Most fresh water sample sites show ‘moderately’ to ‘slightly acid’ pH values and an alkalinity corresponding to ‘good buffering capacity’ according to the Swedish Environmental Quality Criteria /Naturvårdsverket 2000/. There are, however, a few stream sampling sites which show ‘very acid’ pH-values and ‘no or negligible’ buffering capacity, indicating presence of acidified waters in the Simpevarp area.

A substantial proportion of the Simpevarp area is covered by a very thin layer of Quaternary deposits or bare bedrock, giving prerequisites for acidification in the small water courses draining the catchments dominated by these thin soils. The spatial distribution of alkalinity and pH are, however, rather contradictory, as topographically higher catchments in many cases seem to exhibit higher pH values and higher alkalinity compared to the lower levelled sampling sites. The observed pattern is probably reflecting several superposed processes, such as acid precipitation, oxidation of sulphide bearing minerals in the Quaternary deposits, and liming activities in arable land, and possibly also in lakes and watercourses.

The electrical conductivity and the content of dissolved ions is slightly elevated compared to most lakes and watercourses in Sweden. Generally, the concentrations of major ions, e.g. calcium, sodium and chloride, in watercourses seem to increase downstream, and the highest levels are observed at the sampling sites near the outlets in the Baltic. There is also a tendency for an increasing gradient from north-west to south-east that coincides with increasing depths of the Quaternaty deposits.

The contents of sulphur and silicon are markedly higher in the Simpevarp area compared to the rest of Sweden. Silicon also shows increased levels compared to the region of Kalmar County, indicating locally enhanced levels. Also fluoride and iron concentrations are markedly higher in the Simpevarp area. The elevated levels of iron are probably connected to the high levels of dissolved organic substances, whereas the elevated fluoride levels probably are part of a regional pattern as the levels are generally elevated in Kalmar County compared to the rest of Sweden.

Among the trace elements vanadium and several other heavy metals are elevated approximately ten times compared to the levels normally seen in Sweden. Other examples are chromium, molybdenum, copper, nickel and uranium. A possible explanation for the elevated levels of these metals is the high contents of dissolved organic substances in the area which may increase the mobility of the metals.

Zirconium shows markedly elevated concentrations in the surface waters of the Simpevarp area. The median concentrations are approximately 100 times higher than the normal concentrations in lakes in Sweden. Also the rare earth elements, e.g. lanthanum, and ytterbium, show about 10 times elevated concentrations in the area compared to normal levels in Swedish lakes.

Temporal variations

Many parameters show temporal variations connected to season, run-off or primary production. In the lakes, nutrients and carbon, in particular the particulate species, show typical seasonal variations connected to the primary production during the warm season. The content of phosphorus, as well as of the nitrate-nitrogen species (cf Figure 3-61), show considerably variation throughout the year, whereas the content of dissolved ions are more or less constant. Silicon, which is included in the biochemical cycles of phytoplankton, shows a clear seasonal pattern with low values during summer.

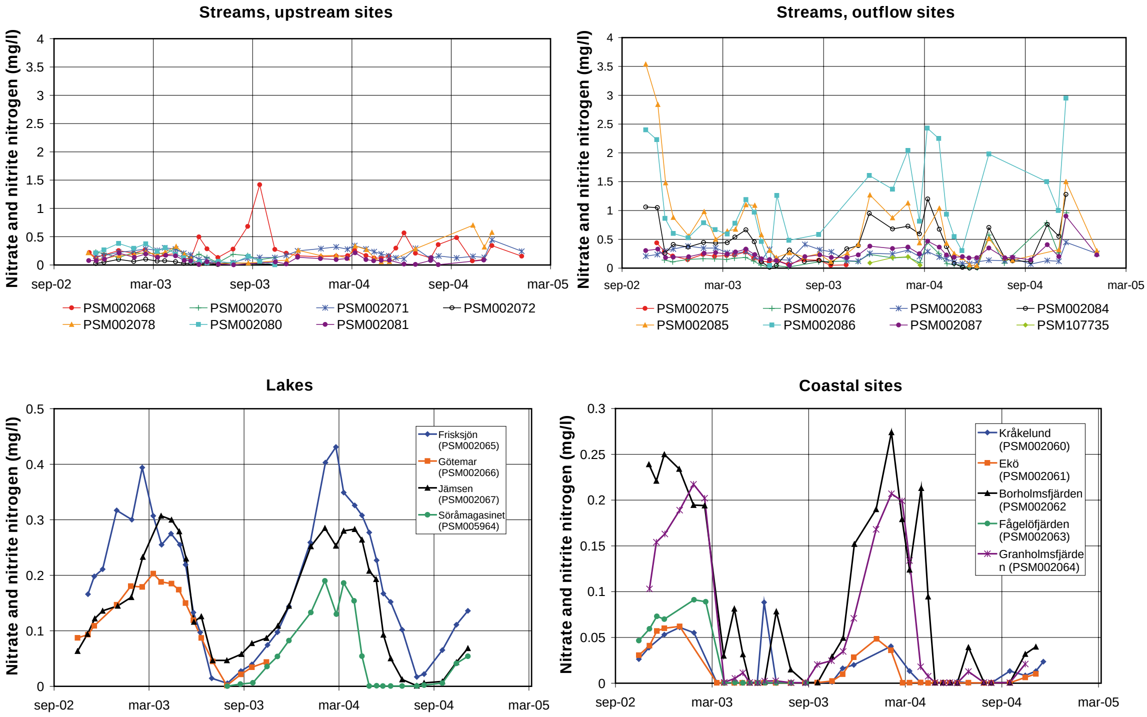

Figure 3-61. *Temporal variations in the concentration of nitrate and nitrite nitrogen in streams, lakes and at coastal sites in the Simpevarp area.*

The content of chlorophyll shows a very clear seasonal pattern in the lakes, with high values during late summer. In the bottom water, dissolved oxygen as well as ammonium nitrogen shows a variation opposite to chlorophyll, with low levels during late summer and early autumn. The anoxic conditions are caused by decomposition of organic matter, produced by primary production in the lakes and of terrestrial origin supplied by discharging streams.

The basins of Granholmsfjärden and Borholmsfjärden show vigorous variations of most parameters due to different mixing proportions between sea water and fresh water discharging from the streams (see for example Figure 3-62). This dilution derived variation is in most cases overshadowing other sources of variation in these closed basins. Chlorophyll and dissolved oxygen in the bottom water show, however, a typical seasonal pattern due to variations in primary production, similar to the lakes.

The 'open sea' coastal sites show only minor variations compared to the lakes and brackish basins. There are slow changes in the contents of the major dissolved ions, coupled to the large scale variations of salinity in the Baltic, as well as seasonal variations of for example calcium and silicon, coupled to primary production.

The concentrations of most elements in the watercourses show more or less strong variation, both due to dilution effects caused by variations in runoff, and to seasonal variations coupled to primary production and the mobility of for example carbon species. During winter when the water in the superficial soil layers is frozen, the content of carbon and carbon related elements is usually low in the streaming water. The seasonal variations of dissolved ions are less accentuated and probably principally controlled by variations in water flow.

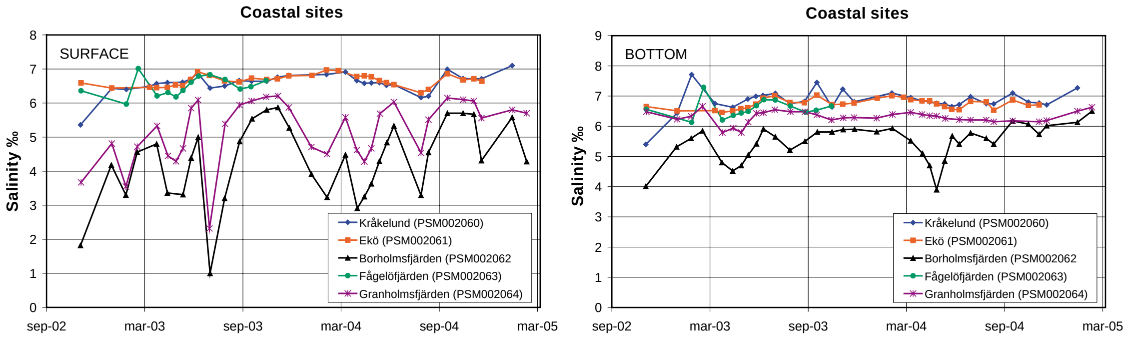

***Figure 3-62.** Temporal variations in the field measured salinity in surface and bottom water at the coastal sites in the Simpevarp area.*

Spatial variations

The concentration of dissolved ions in surface waters in the Simpevarp area seems to be coupled to the characteristics of the Quaternary deposits. The north-western part of the area is dominated by thin deposits and bare bedrock, whereas the south-eastern part contains richer deposits and more arable land. Accordingly, the surface waters in the south-eastern part show higher levels of most dissolved ions than waters in the north-western part.

Total and dissolved organic carbon is more evenly distributed throughout the Simpevarp area compared to especially nitrogen, which shows higher concentrations in downstream areas with high proportions of arable land.

Two minor catchments show deviating characteristics from most of the other catchments in the Simpevarp area. The catchment of Ekerumsån (PSM002085) shows deviating high content of calcium, high alkalinity and elevated pH-values. This catchment contains a relatively high proportion of arable land and the deviating chemistry may be caused by agricultural activities as liming.

The small catchment of Vadevikebäcken (PSM107735) at the Island of Ävrö, shows deviating concentrations of lithium and possibly also of calcium and bicarbonate. This could be either indications of discharging deeper groundwater or a deviating chemistry of the deposits in the area. Observations of shallow groundwater in this catchment also show deviating characteristics of for example tritium and carbon-14, which may possibly indicate discharge of groundwater of deeper origin.

Shallow groundwater

The shallow groundwater in the Simpevarp is characterised by neutral or slightly acid pH-values, normal content of major constituents, and alkalinity ranging from high to very low. Groundwater in the area is influenced by marine relics, resulting in elevated content of e.g. chloride and sulphate in both soil tubes and fresh surface waters (cf Figure 3-63).

Several parameters show large deviations when the Simpevarp area is compared to normal conditions of Sweden. Iron and manganese show markedly elevated concentrations of about an order of magnitude, and also fluoride, iodide, strontium, and some trace elements, show higher concentrations in the area compared to Swedish reference data from shallow groundwater and surface waters.

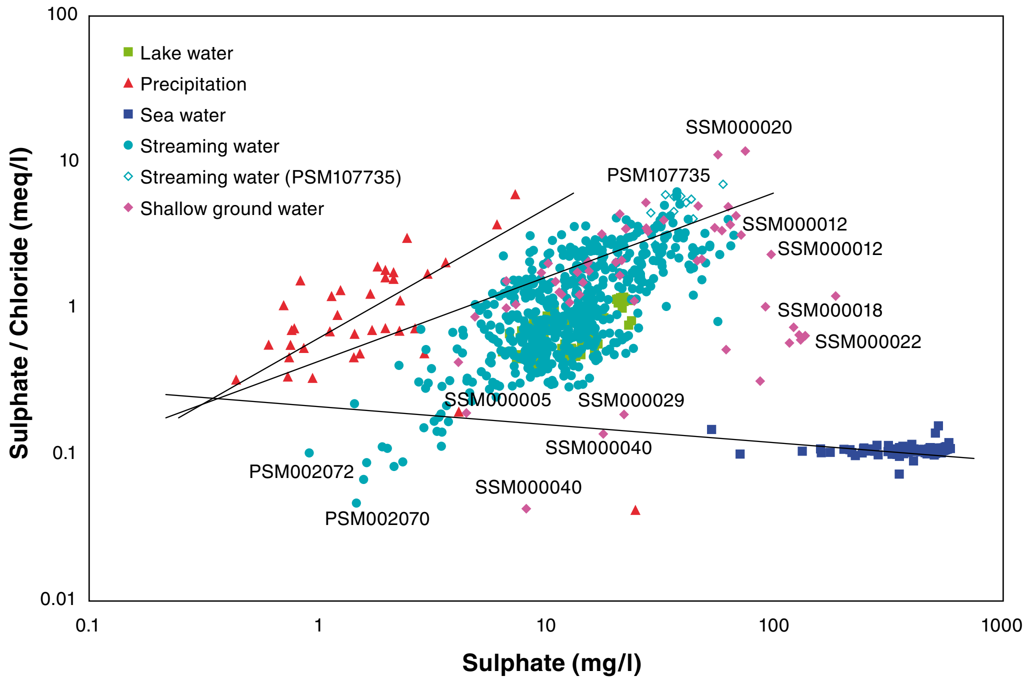

Figure 3-63. *Plot showing the sulphate concentration versus the molar sulphate/chlorine ratio in the Simpevarp area.*

Major and minor constituents

The shallow groundwaters in the Simpevarp area range from Ca-HCO_3 to Na-Cl types. All soil tubes at 'higher' levels are classified as Ca-HCO_3 type, whereas the 'lower' located soil tubes show both Ca-HCO_3 and Na-Cl characteristics. Typical values of major and minor constituents are summarised in Table 3-28. When the concentrations of the 'higher' located soil tubes differ from the 'lower' soil tubes the concentration of the 'lower' category is shown in brackets. The former category approximately corresponds to recharge areas and the latter to discharge areas.

The content of calcium, magnesium, sodium and potassium are normal in the Simpevarp area compared to most shallow groundwater in Sweden. The content of chloride and sulphate is slightly elevated, probably due to the marine relics and to the proximity to the Baltic Sea. In addition to the marine sources, sulphate is also added through long distance deposition and by weathering of minerals containing sulphur. The longer time-series available from a private well in the area indicates a decreasing content of non-marine sulphate in the shallow groundwater, a finding consistent with the diminishing sulphate deposition during the last decades.

The silicon levels in groundwater in the Simpevarp area are almost twice the levels in groundwater in the Forsmark area, and this is also true when streaming waters from the Simpevarp area are compared to the typical silicon level noted in the national survey of Swedish streams /IMA 2005/.

Manganese and iron occur in markedly elevated concentrations in the shallow groundwater of the Simpevarp area compared to the rest of Sweden. A similar, but not that pronounced elevation is also seen in the surface waters in the area. The manganese concentrations are elevated about 40 times compared to the median value of undisturbed shallow groundwaters of Sweden. As there is no obvious explanation for this discrepancy from the national reference data, methodological reasons could not be excluded. A similar elevation of manganese and iron can be seen in the Forsmark data, supporting this explanation.

Table 3-28. Summary of typical values of major and minor constituents (mg/l) in the Simpevarp area. The parameters are sorted after decreasing concentrations. If the concentrations in the 'higher' located soil tubes deviate from the 'lower' soil tubes, the concentration of the 'lower' category is shown in brackets.

Element	Abbreviation	Concentration (mg/l)
Bicarbonate	HCO_3	100
Calcium	Ca	35
Sulphate	SO_4	20 (100)
Silicon	Si	11
Magnesium	Mg	8
Sodium	Na	7 (25)
Chloride	Cl	6 (12)
Iron	Fe	6
Potassium	K	5
Nitrate-nitrogen	NO_3-N	1
Fluoride	F	1 (2)
Manganese	Mn	0.5
Bromide	Br	<0.2
Strontium	Sr	0.1
Barium	Ba	0.06
Phosphate phosphorus	PO_4-P	0.05
Iodide	I	0.01
Lithium	Li	0.01 (0.02)

Fluoride shows about five times elevated concentrations in groundwater from the soil tubes in the Simpevarp area, both compared to Kalmar County and to the whole of Sweden. An analogue pattern is seen when surface water in the Simpevarp area is compared to Swedish lakes.

Alkalinity and pH

The shallow groundwater in the Simpevarp area is characterised by slightly acid pH values and the major part of the observations range from pH 6 to pH 7 (Figure 3-64). A typical pH value in the area is 6.7.

According to the Swedish environmental quality criteria /Naturvårdsverket 1999/, the alkalinity in the shallow groundwater from the Simpevarp area range from 'very high' to 'very low'. Most measurements of alkalinity are classified as 'high' according to these criteria. There are, however, examples of soil tubes at higher topographical locations showing 'low' alkalinity in combination with low pH-values, indicating low buffering capacity and ongoing acidification. These conditions are promoted by the fact that a substantial proportion of the Simpevarp area is covered by bare bedrock or thin layers of overburden almost free of lime. The pH-levels and alkalinity in the private wells of the Simpevarp area are normal compared to wells of Kalmar County and Sweden.

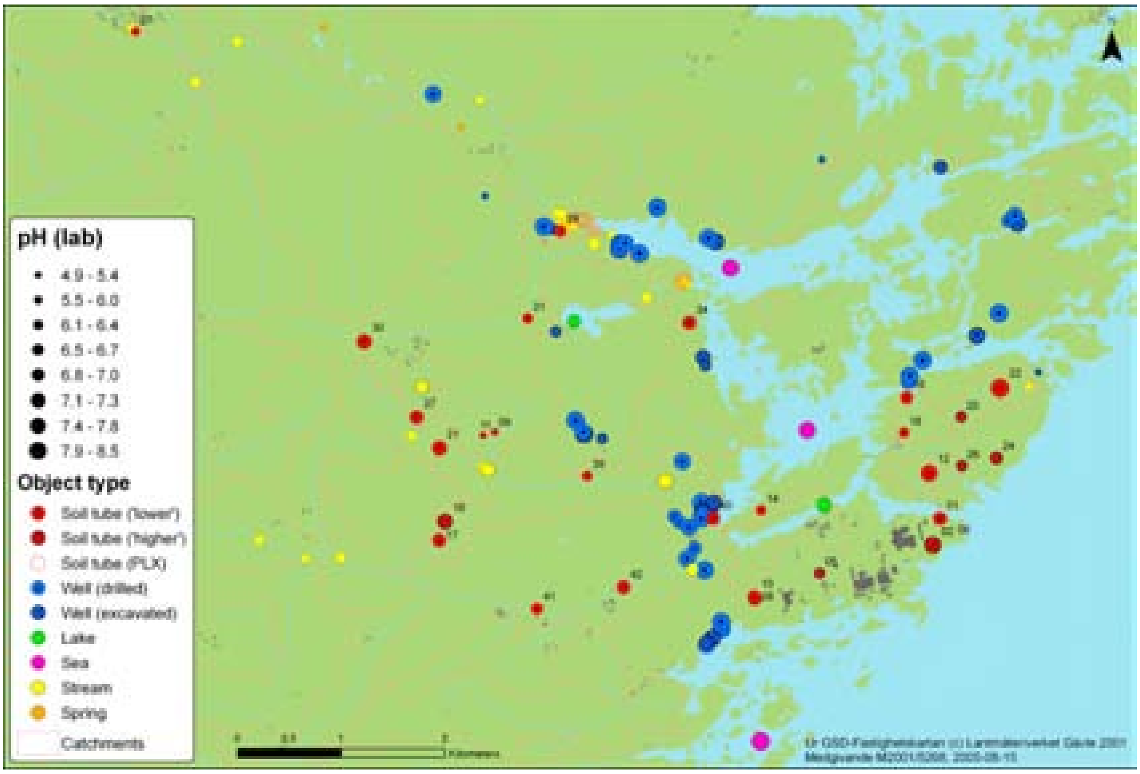

Figure 3-64. *pH values in the Simpevarp area. The dots represent mean values of available data from soil tubes, private wells and surface waters. The figures in black corresponds to the last two digits of the id-codes of the soil tubes.*

Redox potential

The coarse classification of redox potential, based on a scheme from the Swedish Environmental Quality criteria for groundwater /Naturvårdsverket 1999/, shows that the redox potential is 'low' or 'very low' in all soil tubes in the Simpevarp area. The reducing conditions are also indicated by the presence of hydrogen sulphide, and also that a substantial fraction of the iron occurs as the Fe^{2+} ion in all soil tubes.

Trace elements

About thirty trace elements have been measured in shallow groundwaters and surface waters. Some conclusions concerning these elements are summarised below:

- The rare earth elements (e.g. lanthanum and ytterbium) occur in about ten times higher concentrations in the Simpevarp area compared to groundwater from soil tubes in the Forsmark area. When the concentrations of these elements in streams in the Simpevarp area are compared to the concentrations in 242 Swedish lakes, a corresponding pattern is revealed, indicating elevated concentrations also in a national perspective.
- The vanadium concentrations are about ten times higher in the shallow groundwater in the Simpevarp area compared to Forsmark. A similar pattern is seen when fresh surface waters are compared to 781 lakes of Sweden, indicating generally elevated levels in the Simpevarp area. Other metals such as chromium, copper, molybdenum, and nickel show similar elevations in the surface waters, possibly indicating a similar pattern in shallow groundwaters. There are no reference data available for groundwater to validate this speculation.

- Rubidium show elevated concentrations, both compared to Forsmark soil tubes and when Simpevarp surface waters are compared to Swedish lakes.
- The zirconium content in the shallow groundwater is usually about ten times higher in the Simpevarp area compared to the soil tubes in the Forsmark area. When the Simpevarp surface waters are compared to Swedish lakes, the levels are elevated even more, approximately 100 times.
- Thorium show ten times higher concentrations in the shallow groundwater compared to typical Swedish groundwater. A corresponding difference is not seen when surface waters in the Simpevarp area are compared to Swedish lakes.

Isotopes

Deuterium and *oxygen-18* data of precipitation and most observations of shallow groundwater, plot close to the Global Meteoric Water Line (GMWL), indicating a meteoric origin of most shallow groundwaters (Figure 3-65). This conclusion is also supported by the fact that the variation along the GMWL-line of groundwater is centred on the variation interval observed in precipitation.

Data from streams and lakes forms an 'evaporation line', indicating enrichment of the heavier isotopes due to evaporation. This is also seen as a gradual decrease of the deuterium deviations along the flow path from recharge areas to streams, lakes and finally the Baltic Sea. Median values are –76 (precipitation), –77 (soil tube), –77 (stream), –65 (lake) and –57 (sea), respectively.

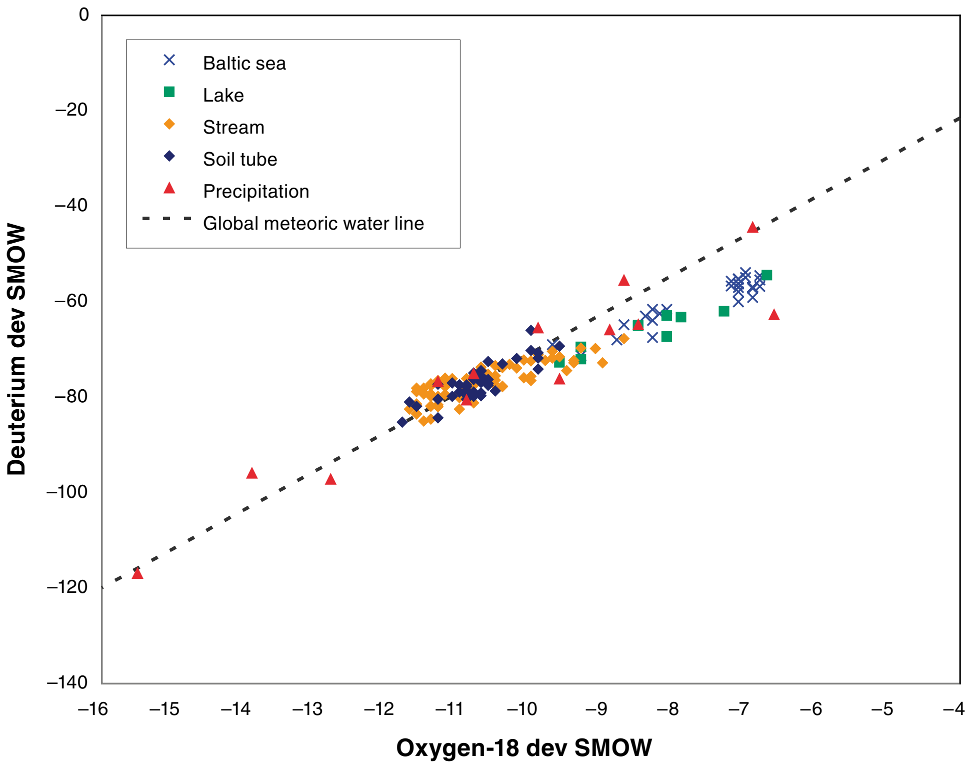

Figure 3-65. *Data on deuterium and oxygen-18 from shallow groundwater, surface water, and precipitation in the Simpevarp area, plotted together with the GMWL.*

The *tritium* levels in most soil tubes range from 8–15 TU, an interval that overlap the range of surface waters and precipitation of approximately 9–19 TU. In SSM000022 on the Island of Ävrö, low tritium values corresponding to sub modern levels have been observed. The low fraction modern carbon in this soil tube also supports the hypothesis of groundwater of older origin. Low carbon-14 values may also originate from dissolution of calcites, depleted in carbon-14.

The *boron-10/boron-11* ratios found in the Simpevarp area are slightly lower than the natural abundance ratio. Boron-10 is most depleted in SSM000022 located at the Island of Ävrö. The highest enrichment is found in SSM000005, located near the nuclear power plant at the Simpevarp Peninsula. The latter soil tube shows a deviating water chemical composition with respect to several other parameters, e.g. calcium.

The recorded values of *sulphur-34* in shallow groundwater vary within a wide range between –15‰ to 23‰ CDT. Fresh surface waters range between –1‰ and 15‰ CDT with most of the samples between 2‰ and 8‰ CDT. All measurements of sea water are very close to 20‰ CDT. Three soil tubes (SSM000022, SSM000029 and SSM000037) show enriched content of Sulphur-34, corresponding to the levels found in sea water.

Strontium-87 is generally enriched relative the natural abundance ratio (Sr-87/Sr-86) by 2‰ to 33‰. Strontium-87 is least enriched in SSM000002 and SSM000034 where the ratios are only slightly higher than the ratios of seawater in the area (0.710). The highest enrichments are found for SSM000005 and SSM000016.

The *radium-226* activities are significantly higher in the Simpevarp soil tubes compared to the median values of the reference data of drilled wells in Sweden, whereas the *radon-222* activities are in the same order of magnitude compared to the excavated wells of Sweden.

Spatial variation

In this section, conclusions concerning shallow groundwater are summarised per sub-area or catchment, in order to make the compilation compatible with the corresponding work on surface waters. The compilation per catchment area is appropriate for shallow groundwater as the catchment boundaries often coincide with the groundwater divides. The measurements of streaming waters and lakes may also be seen as the sum of groundwater discharge in the area, which especially is the case when local recharge-discharge patterns dominate.

The Laxemar sub-area

The Laxemar sub-area extend over several catchments, and the watercourses Mederhultsån, Kåreviksån, Pistlanbäcken, Ekerumsån and Laxemarån discharge into the brackish basins of Granholmsfjärden and Borholmsfjärden at the eastern border of the Laxemar sub-area.

The different soil tubes in the Laxemar sub-area show considerable differences in water chemical composition. The differences seem to be coupled both to the different sub-catchments and to the topographical locations of the tubes.

In the sub-catchment of Ekerumsån (9:1–3), the levels of calcium and bicarbonate are generally elevated in both surface waters and in shallow groundwater of lower topographical heights. The soil tubes in this catchment also show elevated content of potassium, silicon and barium compared to the adjacent catchment of Mederhultsån (6:1). One explanation to the deviating water chemical characteristics in the catchment of Ekerumsån may be agricultural activities in the area.

In the sub-catchment of Ekerumsån there are two 'higher' located soil tubes which show highly deviating water chemical characteristics by having very low alkalinity and low pH (SSM000009 and SSM000011). These soil tubes are presumably representative for soil tubes located at topographical heights, dominated by bare bedrock or thin layers of quaternary deposits. Hitherto, no other parameters have been analysed on groundwater from these soil tubes, but it may be expected that several other parameters also will show deviating concentrations.

There are a number of soil tubes located close to coast of the Brackish basins of Granholmsfjärden and Borholmsfjärden (SSM000029, SSM000034 and SSM000040), which show elevated content of several major and minor constituents, e.g. magnesium, sodium, potassium, chloride and bromide, and depleted contents of strontium-87.

The Simpevarp subarea

The Simpevarp sub-area consists of the Simpevarp Peninsula and the Island of Ävrö, on which a few smaller catchments have been identified.

The soil tubes in the Simpevarp sub-area are characterised by rather normal levels of most major and minor constituents. Sulphate and fluoride levels are lower at the Simpevarp Peninsula compared to the rest of the Simpevarp sub-area. The soil tubes at the Island of Ävrö show, contrary to the Simpevarp Peninsula, elevated sulphate and fluoride levels.

SSM000022 at the Island of Ävrö and SSM000005 at the Simpevarp Peninsula show deviating characteristics in respect to many parameters. SSM000022 in the small catchment of Vadevikebäcken (23:1) at Ävrö show high pH, elevated concentrations of uranium and fluoride, and low content of tritium and modern carbon, which may indicate groundwater of older and probably deeper origin compared to most other soil tubes.

SSM000005 deviates by showing remarkably high iron and manganese concentrations in combination with high calcium and fluoride content. The isotopes boron-10, chlorine-37 and strontium-87 also show deviating characteristics in this soil tube. A possible explanation to the deviating chemical characteristics in this soil tube could be influences from the prevailing artificial landfills in the area close to the nuclear power plants.

Regolith

Till

When data on the chemical content of till in the Simpevarp area are compared with regional and national data, only minor differences are revealed, indicating that the chemical contents of the till in the Simpevarp area are relatively normal in a Swedish context.

The levels of magnesium and iron are slightly elevated in the Simpevarp samples according to the ICP-AES analyses. A corresponding pattern is however not seen for the total contents analysed by XRF-technique. The content of the trace metal cobalt is less than half the typical values of Sweden, whereas the content of lead is approximately doubled, when comparing ICP-AES data. When comparing XRF-data, the cobalt content is only slightly lower, whereas lead show elevated levels in accordance with the ICP-AES analyses.

Three observations in the south-eastern part of the area, at the peninsula east of Figeholm, show deviating chemical composition of till with respect to several elements. For example is the strontium content low, whereas the lead content is somewhat elevated in this area.

All till samples in the Simpevarp area show very low content of calcium carbonate and may be regarded as free of lime. The measurements range from 0.1% to 0.6% calcium carbonate per dry weight, with a median value of 0.3%.

Sediment

The content of calcium carbonate in the sediments is usually negligible, except for one sample from Långenmossen (PSM006564), where the contents of calcium carbonate are 12% at a depth of 220–227 cm in the sediment profile. There is a large spread in the content of carbon, nitrogen, hydrogen and sulphur depending on both sample site and depth in sediment profile. For many of the sampling sites, the content of carbon, nitrogen, sulphur and hydrogen is decreasing with depth. The carbon content ranges from 0–60%, nitrogen from 0–2%, sulphur from 0–4% and hydrogen from 0–6%.

Soil

The analyses of top soil samples from the Simpevarp area are in general close to the Swedish mean values, indicating rather normal pH-values and normal content of carbon and nitrogen.

Element content in amphibious plants

Many metals, e.g. iron, cobalt, chromium, copper, and especially molybdenum, occur in elevated levels in amphibious plants in the Simpevarp area, when compared to regional and national conditions. Lead occurs at normal levels, whereas manganese occurs at lower levels when data from the Simpevarp area are compared with the available reference data.

3.6.4 Confidence and uncertainties

The knowledge of chemical properties of surface systems in the Simpevarp area has increased considerably compared to the previous model version. New data, especially from near-surface groundwater, precipitation and regolith, have been obtained and analysed, and the data and results that are summarised in the previous sections are presented in detail in /Tröjbom and Söderbäck 2006/. To conclude, knowledge of typical concentration levels of most major and minor constituents in surface waters, as well as in near-surface groundwater, is good. The same is true for the spatial and temporal variations in concentrations in surface waters.

There are, however, remaining uncertainties in the description of chemical properties of the surface systems, mainly due to limited availability of site data for some elements and from some media. The description of trace elements and radiogenic isotopes in both surface waters and near-surface groundwater relies on a single or a few sampling occasions per sampling site. This means that parameter values are associated with large uncertainties since we cannot describe the temporal variation. Moreover, the availability of chemical and mineralogical analyses of till, soil and peat from the Simpevarp area, as well as of site data on the element contents of biota, are still limited. Therefore, both the estimated levels and the spatial variation of element content in these media are still associated with large uncertainties.

3.7 Terrestrial biota

A good knowledge of the terrestrial biota in a region is a prerequisite for being able to preserve threatened species, minimize anthropogenic damage on the environment, understand ecosystem functions, and to understand historic and future ecosystem development. This section is devoted to the description of a number of aspects of the terrestrial biota at Simpevarp site and is divided into producers and consumers.

3.7.1 Primary producers

This section covering the primary producers is divided into two parts. The first part is a general description of the vegetation in the regional model area, which includes a description of dominating vegetation, species composition, description of taxa, such as species lists for various organism groups belonging to the plant kingdom, e.g. vascular plants, bryophytes, algae and lichens, and fungi that are found in the area. The purpose of this first part is to characterise the vegetation, but also to assist in the classification of functional groups, such as tree, shrub, field and ground layer species. A complete list of all species in the area is however not provided. The second part is constructing spatial models describing parameters that are used in the terrestrial ecosystem model, such as pools and fluxes in the terrestrial environments.

Description of vegetation

Vegetation

The vegetation is highly influenced by the bedrock composition, quaternary deposits and human land management. Bedrock in the Simpevarp area does mainly consist of granites. The quaternary deposits are mainly wave washed till while silt and clay have been deposited in the valleys (Section 3.3). This is 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 3-66) /Boresjö Bronge and Wester 2003/ along with Table 3-29 that lists the vegetation types and their relative coverage.

The forests are dominated by dry Scots pine (*Pinus sylvestris*) 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 the ground layer. When these pine forests get moister *Vaccinium vitis-idaea* and *Vacinium myrtillus* becomes more common in the field layer. Norway spruce (*Picea abies*) becomes abundant where a deeper soil cover is found, while deciduous tree species are an important constituent near the coast, i.e. mainly *Quercus robur* but also *Corylus avelana*, *Sorbus aucuparia*, *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.

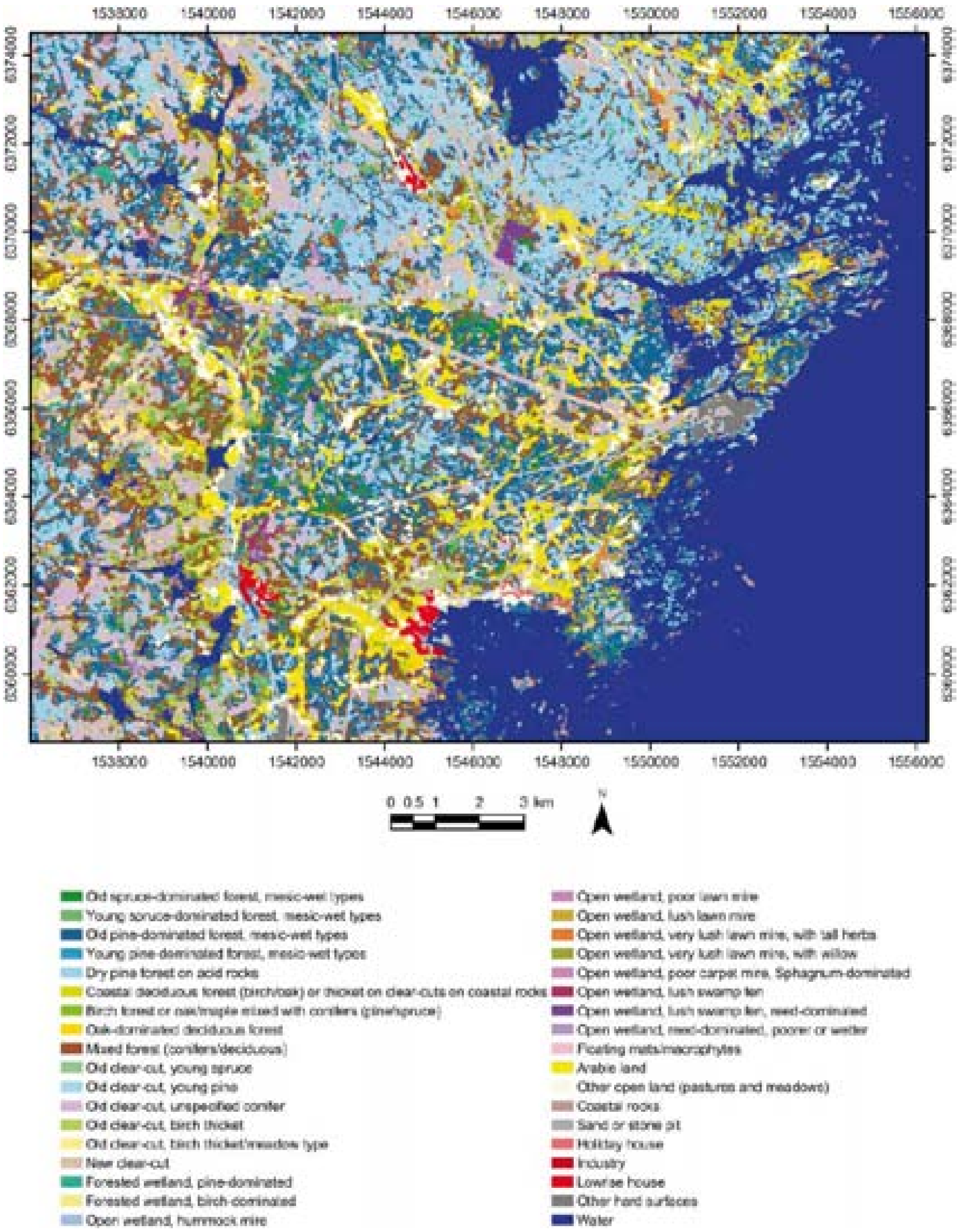

Figure 3-66. *Vegetation map covering the Simpevarp area from /Boresjö Bronge and Wester 2003/.*

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. As a consequence of the forestry activities in the area many clear-cuts of different successional stages are found (Table 3-29). *Betula pendula* is the dominating species in many of the earlier successional stages until it is replaced by young *P. abies or P. sylvestris* depending on soil type and/or management.

Table 3-29. The spatial coverage of different vegetation types in relation to the total land area, following the vegetation map by /Boresjö Bronge and Wester 2003/. The columns describe the number of objects, their total area, min and max size of the objects, and their relative cover of the total area.

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

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, rock pools (Sw: *hällkar*), are formed /Lundin et al. 2005/. These obtain all their water from precipitation and have therefore a S*phagnum*-dominated community, much bog-like, with *Rhododendron tomentosum* and *P. sylvestris,* and a peat layer accumulating on the bedrock. These vary a lot in size and may in some cases be large.

Species composition

The flora in this region has been investigated within the project "The flora of Oskarshamn" /Rühling 1997/, which 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, twenty four additional plots are located by SKB within the area, using the same methodology for taxa as "National survey of forest soil and vegetation" /Andersson 2004/.

Red listed species

All information concerning redlisted plants from the site has been obtained from the Swedish Species Information Centre (Sw: *Artdatabanken*) and is presented in Table 3-30. Further information concerning the actual species is presented in /Berggren and Kyläkorpi 2002/.

Table 3-30. 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 of these areas are extensively protected, while others lack protection so far. The sensitive areas are listed in /Kyläkorpi 2005/. There are today three areas that have the status as nature reserves (Figure 3-67, Table 3-31).

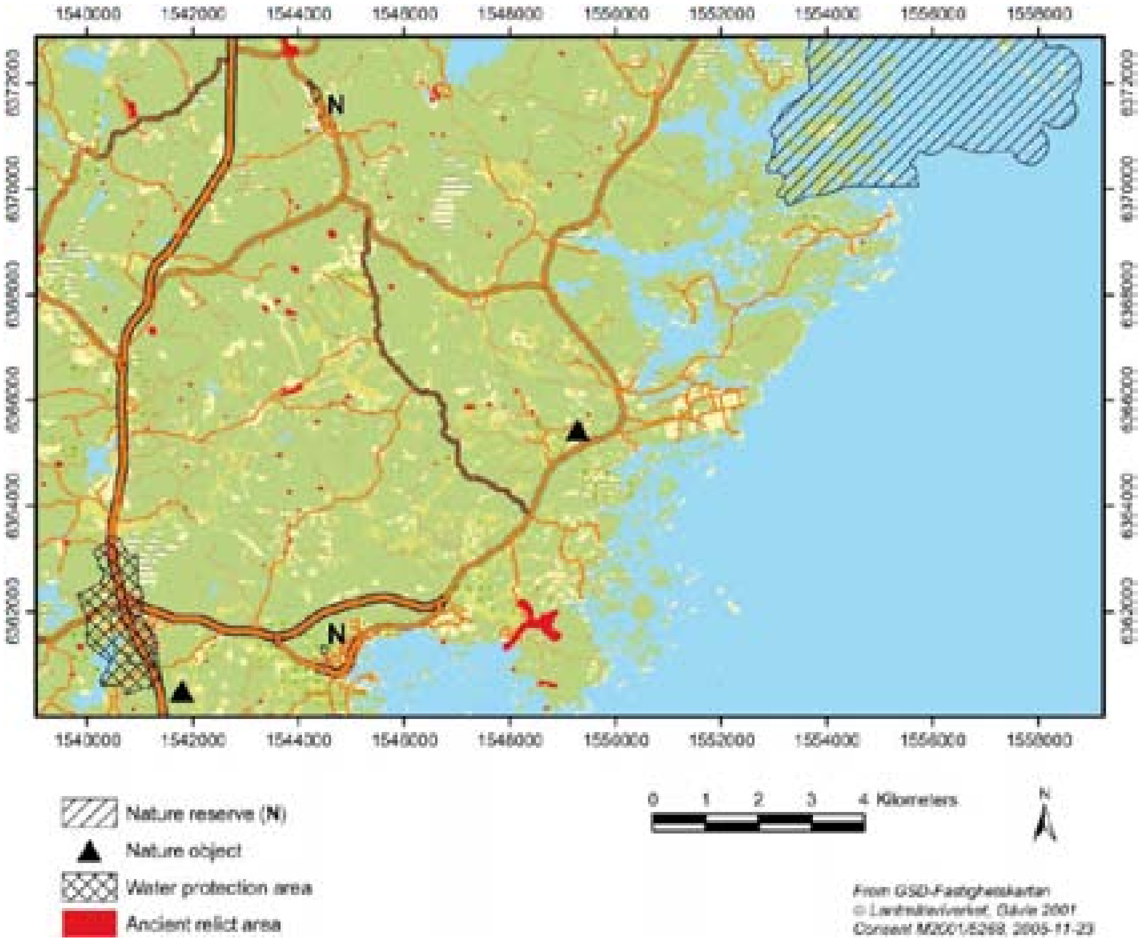

Figure 3-67. *Map illustrating areas of conservational interest in Simpevarp from /Kyläkorpi 2005/. N indicates the location of two small nature reserves (Figure 3-67, Table 3-31).*

Table 3-31. 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 (ädel-lövskog)	1	1.4
Nature reserve (Naturreservat)	Talldungen	Boulder ridge with old pine forest	1	4.6
Nature reserve (Naturreservat)	Misterhults skärgård	Archipelago with interesting cultural history and fauna	1	8,500
Nature object (Naturminne)	–	Single object or very small areas, protected by law	2	N/A
Ancient relict area (Fornlämnings-område)	–	Areas with ancient cultural remains	294	173
Water protection area (Vattenskyddsområde)	–	Fresh water reserves	2	269

Woodland 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. Forty six 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, is semi-natural grasslands with old pollarded (Sw: *hamlade*) deciduous trees in close proximity to old settlements (Table 3-32). Generally, the woodland key habitat is found in areas dominated by deciduous trees. These habitats are often a relict of an older and more open landscape created by intensive management.

Table 3-32. The woodland key habitats found in the Oskarshamn area after /Sturesson 2003/. Swedish names within brackets.

Habitat	No of objects	Total 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 are 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 3-68; Table 3-33).

Table 3-33. 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 contain the highest nature value.

Characteristics	No of objects	Total area (ha)
Class 2	4	169
Class 3	4	175
Class 4	2	60
Derived from the vegetation map	536	497

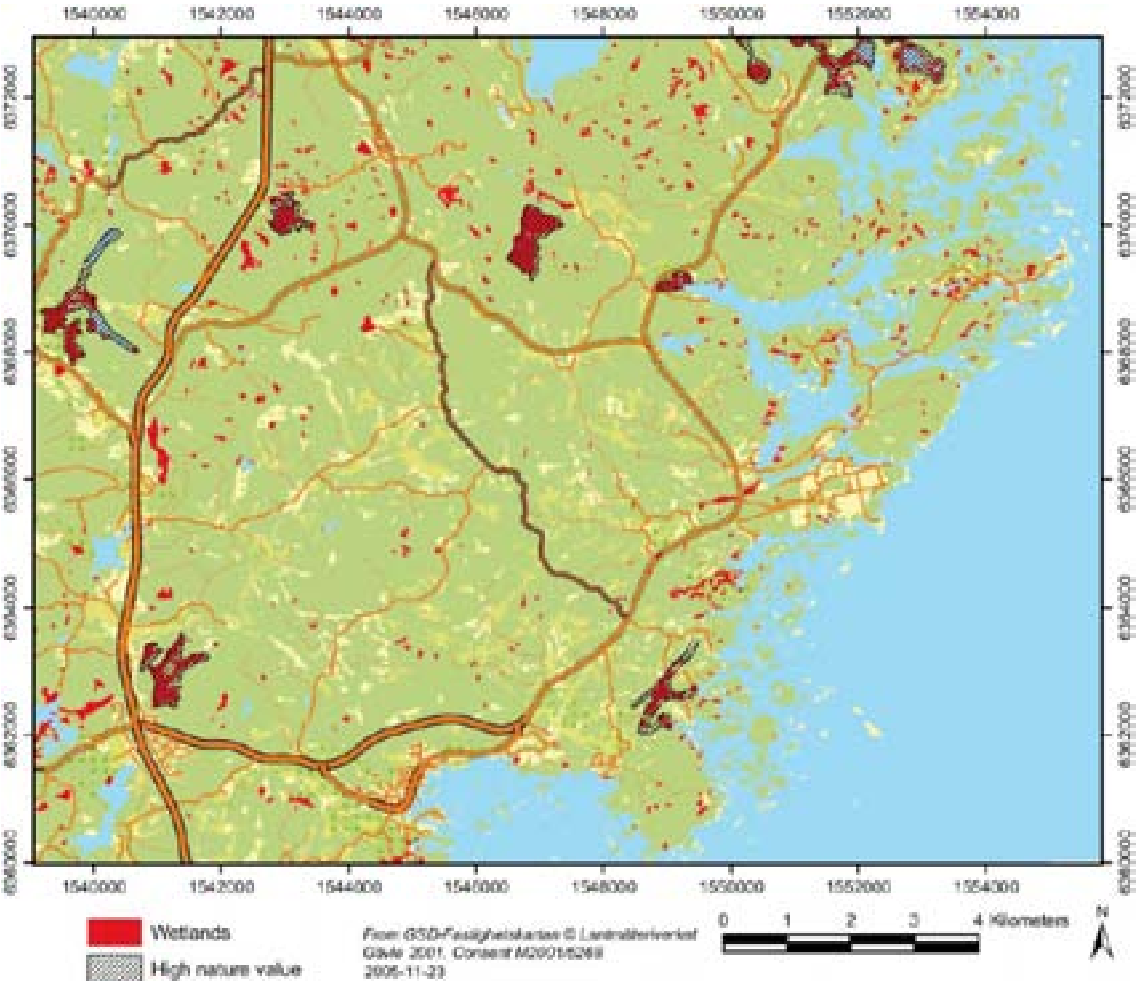

Figure 3-68. *Wetlands (in red) within the regional model area after /Kyläkorpi 2005/. Wetlands (striped) are classified by the Environmental Protection Agency.*

Descriptive biomass and NPP models – introduction

The vegetation constitutes to a major part the living biomass and is the 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 by their biomass, NPP and turnover, and are further used in the conceptual ecosystem model (see Section 4.1). This section describes the components, the data, the resolution and the methodology that is used to build the quantitative descriptive models of biomass and NPP that are further analysed in Section 4.1.

Biomass

The total plant biomass in an area consists of a number of different components that all have to be measured or estimated Figure 3-69, 3-70. Some of these components are well studied, while others are poorly investigated making 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 mycorrhizal fungi, 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 the 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 3-69). 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 equation:

$$NPP = \sum Pi + H \qquad (4)$$

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

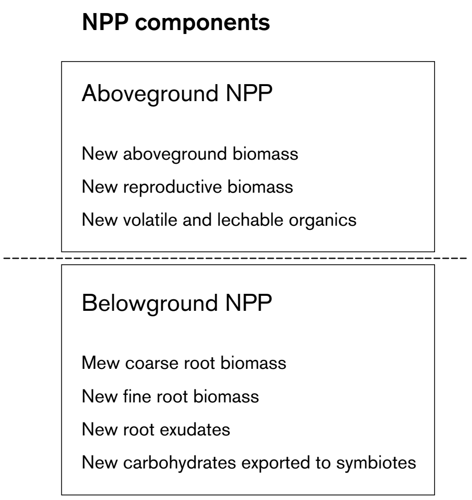

Figure 3-69. *The changes in biomass components that together constitutes the NPP during a specific time interval after /Clark et al. 2001/.*

A number of components, that so far are considered to be less important, have been omitted. 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 poorly studied fields, but some studies have shown that the loss may be significant at the individual level with up to 30% of the NPP /Chapin et al. 2002/. 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 review of herbivory showed that herbivores generally consume 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 (*P. 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 impact on total NPP in boreal systems, excluded from the calculations of NPP in equation (4). Herbivory by other animals is discussed in Section 3.7.3.

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. So far, we have no data of losses of coarse roots or mortality of living trees. No data are available of the ingrowth, which describes the continuous recruitment of new trees. However, the ingrowth is expected to have a low impact on the biomass and NPP estimations in managed forests.

The functional groups

In order to describe the ecosystem, a number of simplifications have to be made with regard to the descriptive units. This simplification is based on their ecosystem function, e.g. the different organisms in the ecosystem are lumped together into functional groups based on structural properties. The trees can be divided into different compartments e.g. stem, roots, branches and foliage. The green tissue is of particular importance as it continuously is replaced while the dead tissue, e.g. wood, will remain until the death of the entire tree. The trees are, if present, often the major component of the total biomass. 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, Scots pine, Birch, and other deciduous trees in the forest. This volume can be further partitioned into dead, green and non-green biomass /Marklund 1988/.

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 *B. pendula* on clear-cuts.

The field layer constitutes of herbs, grasses and dwarf shrubs (e.g. *Vaccinium vitis-idaea*). The significance of this layer in relation to the total plant biomass varies between habitats, from being the major constituent in some grasslands to being of low importance in some types of mires and forests.

The litter layer, the dead wood and the standing dead trees (mainly *P. sylvestris*) are the large pool of dead organic matter that is continuously being renewed due to the incoming fluxes from the vegetation and the outgoing fluxes as decomposition.

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 Scots pine forests, while 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 have the major function of absorbing water and nutrients from the surrounding soil, and the coarse roots may have multiple functions where the size often decides the function /Persson 2002/. There is no conventional definition of fine roots, but many studies of forest biomass have defined fine roots as having a diameter less than 5 mm /Vogt and Persson 1991/ and coarse roots having a diameter more than 5 cm in diameter. In this report, fine roots are defined as ≤ 10 mm. 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 using the above presented functional groups is presented in Figure 3-70.

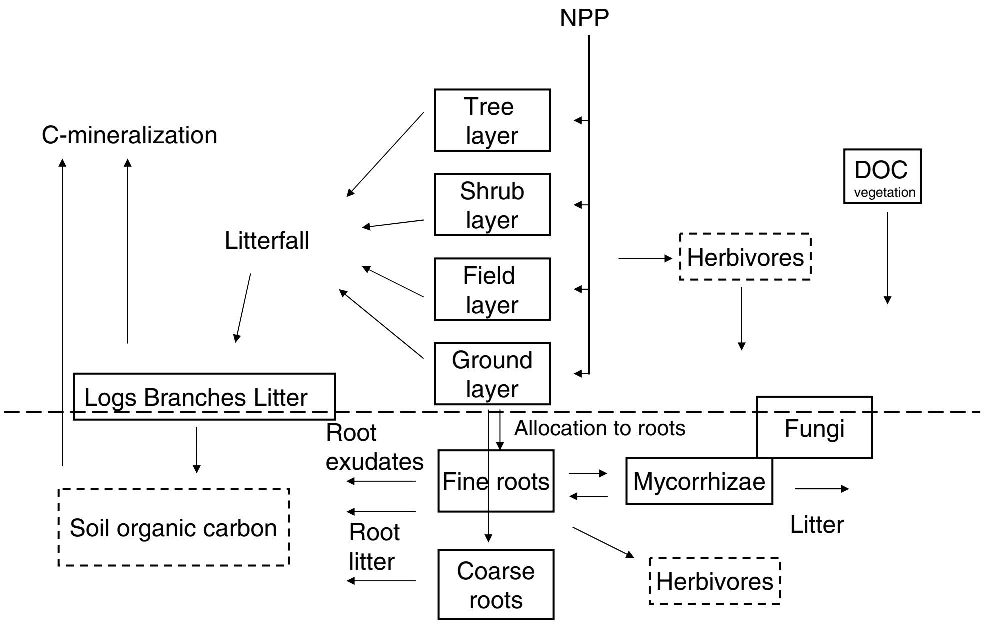

Figure 3-70. *An illustration of the different pools and fluxes of matter in a terrestrial ecosystem with the focus on the producers. Boxes with broken line are herbivores that are further described in Section 3.7.3.*

Descriptive biomass and NPP models – methodology

Input data

The descriptive model contains a large number of components that describe biomass (Table 3-34), NPP/net annual biomass increment (Table 3-35) and turnover of plant tissue (Table 3-36). 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, the NPP and the turnover are different. Sometimes the NPP and turnover are, as a simplification, set to equal meaning that there is no net accumulation of biomass between years.

All the results are presented in carbon per square metre ($g \cdot C \cdot m^{-2}$) for biomass components and in carbon per square metre and year ($g \cdot C \cdot m^{-2} \cdot y^{-1}$) for NPP and turnover components.

Table 3-34. The different functional units and their components that describe the biomass of the vegetation. All components are presented in $g \cdot C \cdot m^{-2}$. Data is taken from the three categories; Local/Regional/Generic (L/R/G). *Source* shows from where the data is taken. *Method* describes how the result in this report was calculated, e.g. a biomass expansion factor (BEF) is a factor describing a relationship between two biomass components, such as foliage and root biomass.

Functional unit	Component	Data L/R/G	Source	Method ref
Tree layer	Woody parts (AG)	L/R	NFI	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	L	/Alling et al. 2004a/	Allometric eq.
	Green parts	L	/Alling et al. 2004a/	Measured
	Coarse roots	L	/Alling et al. 2004a/	BEF
	Fine roots	L	/Alling et al. 2004a/	BEF
Field layer	Green parts	L	/Löfgren 2005/	Measured
	Non-green parts	L	/Löfgren 2005/	Measured
	Below ground	L	/Löfgren 2005/	Measured
Ground layer	Bryophytes	L	/Löfgren 2005/	Measured
	Lichens	L	/Löfgren 2005/	Measured
Fungi	Mycelia	G	/Vogt et al. 1982/	Measured
Dead organic material	Logs	L	/Andersson 2005/	Measured
	Branches	R	/Berggren et al. 2004/	Measured
	Litter layer	L	/Löfgren 2005/	Measured
Rootzon	Depth	L	/Lundin et al. 2005/	Measured

Table 3-35. The different functional units and their components that describe the NPP of the vegetation All components are presented in g·C·m^{-2}·y^{-1}. Data is taken from the three categories; Local/Regional/Generic (L/R/G). *Source* shows from where the data is taken. *Method* describes how the result in this report was calculated, e.g. a biomass expansion factor (BEF) is a factor describing a relationship between two biomass components, such as foliage and root biomass.

Functional unit	Component	Data L/R/G	Source	Method ref
Tree layer	Woody parts (AG)	L/R	NFI	Allometric eq.
	Needles/Foliage	L/R	NFI	BEF
	Coarse/fine roots	L/R	NFI	BEF
	Ingrowth	No data	–	–
Shrub layer	Woody parts	L	/Alling et al. 2004a/	Allometric eq.
	Green parts	L	/Alling et al. 2004a/	Measured
	Coarse roots	L	/Alling et al. 2004a/	BEF
	Fine roots	L	/Alling et al. 2004a/	BEF
Field layer	Green parts	L	/Löfgren 2005/	Measured
	Below ground	L	/Löfgren 2005/	BEF
Ground layer	Mosses	L	/Löfgren 2005/	Measured
	Lichens	L	/Löfgren 2005/	BEF
Fungi	Mycelia	G	/Vogt et al. 1982/	Measured

Table 3-36. The different functional units and their components that describe the turnover of the vegetation. All components are presented in g·C·m^{-2}·y^{-1}. Data is taken from the three categories; Local/Regional/Generic (L/R/G). *Source* shows from where the data is taken. *Method* describes how the result in this report was calculated, e.g. a biomass expansion factor (BEF) is a factor describing a relationship between two biomass components, such as foliage and root biomass.

Functional unit	Component	Data L/R/G	Source	Method ref
Tree layer	Needles/Foliage (litter fall)	L/R	/Berggren et al. 2004/	BEF
	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	Mycelia	G	/Vogt et al. 1982/	BEF
Dead organic material	Small branch, cones	R	/Berggren et al. 2004/	BEF
C-mineralisation	Decomposition in LFH	L	/Tagesson 2005a/	Measured
	Logs	G	/Næsser 1999/	Measured

Conversion factors

Net accumulation per year was presented for the stem volume in the data from The National Forest Inventory (NFI). It was converted into biomass using Table 3-37. When carbon content was not presented as a part of each study, it was calculated using the factors presented in Table 3-38, if not stated otherwise.

In the description of the field and ground layer by /Löfgren 2005/, biomass was presented as gram dry weight. These values were converted to carbon using Table 3-39.

Table 3-37. Biomass expansion factors for conversion from volume (m^3) to biomass (Ton dry matter after /Benediktsson et al. 2005/). Stem biomass refers to stem and bark biomass above stump height. One m^3 stem wood corresponds to the value in column 2 as ton dry matter.

Ton DM	Stem biomass
Pinus sylvestris	0.41
Picea abies	0.41
Broad-leaved	0.50
All trees	0.42
Dead trees	0.43

Table 3-38. Carbon content in some common tree species in percent of the dry weight /Skogsstyrelsen 2000/. Carbon content in roots is from /Alriksson and Eriksson 1998/.

Tree species	Stem	Branch	Needles	Root
Picea abies	48	59	49	48
Pinus sylvestris	49	51	51	48
Betula pendula	48	59	49	48
Other deciduous trees	49	49	49	*48

*Same value as *Betula pendula*.

Table 3-39. Carbon content in different functional groups in a Scots pine forest in Forsmark /Fridriksson and Öhr 2003/.

Component	N	Mean (SE), %
Field layer, green components	6	46.1 (0.2)
Field layer, brown components	6	45.7 (0.4)
Ground layer (Bryophytes)	6	43.9 (0.5)
Litter	6	46.2 (0.2)

Descriptive biomass and NPP models – results

This is a description of how the different functional groups, Table 3-34 to 3-36, are assigned values describing the different components of biomass, NPP and turnover, and how these are further transferred into a spatial context.

Tree layer

This layer was created using information from the vegetation map /Boresjö Bronge and Wester 2003/. The classification is presented in Table 3-40 and the spatial distribution in Figure 3-71. 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).

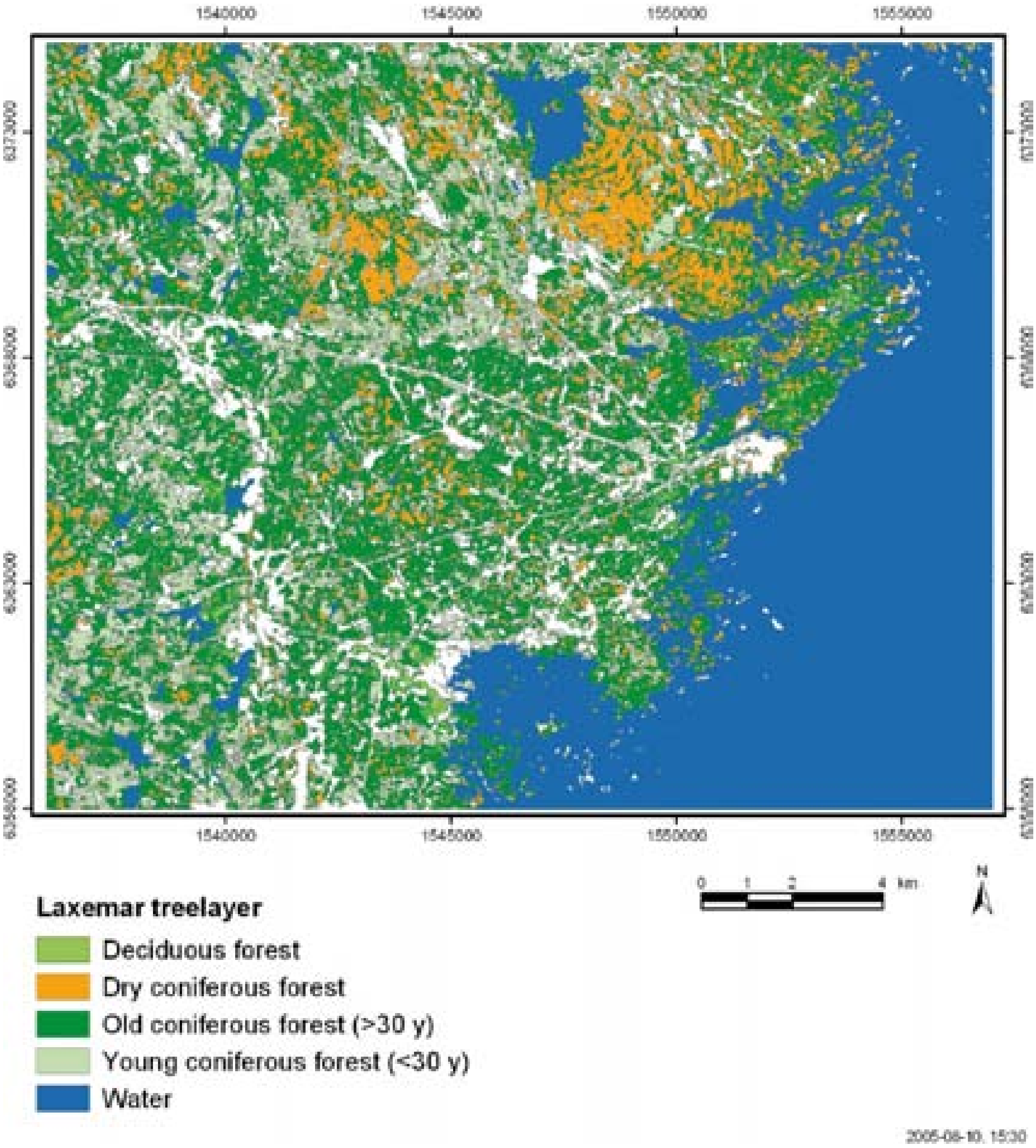

Figure 3-71. *The spatial distribution of the tree layer classes within the regional model area in Simpevarp.*

Table 3-40. The classes used to describe the tree layer from the vegetation map /Boresjö Bronge and Wester 2003/ 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	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	23, 24, 25, 63	73
Water	100	–

Data for the above ground (AG) biomass (except twigs) was extracted from The National Forest Inventory (NFI) (Table 3-40). 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 a nearby locality Asa (57°08'N 14°45'E) /Berggren et al. 2004/. /Berggren et al. 2004/ used Marklund's equations /Marklund 1988/ to calculate the biomasses for different fractions of the trees. The biomass of all branches (dead and alive) was 0.28 of the stem biomass and the coarse roots was 0.26 of stem biomass, averaged over 9 plots and three different localities of different moisture regimes /Berggren et al. 2004/. They also found that 0.08 of AG biomass was found as fine root biomass using a soil corer.

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 3-37. Annual biomass increment allocated to the different tree compartments was estimated using biomass expansion factors derived from /Berggren et al. 2004/. They measured the radial stem increment for two consecutive years and calculated the biomass increaments for the different compartments using Marklunds biomass functions /Marklund 1988/. Annual biomass increment allocated to branches, needles, roots were estimated to 0.18, 0.09 and 0.23 respectively of the stem increament based on three replicates from three different moisture regimes.

The data of stem biomass for deciduous forests was extracted from NFI, using the selective criteria of at least 70% broad leaved trees in the stand. Biomass of branches and twigs was 0.22 of the stem biomass using data from a study on *Fagus sylvatica* in five central European countries /Schulze 2000/. The green part is 0.02 of the total AG biomass (/Li et al. 2003/, using data from *F. sylvatica* in Sweden). BG biomass for deciduous trees was calculated using figures (0.15 of the above ground biomass is equal to the below ground biomass) from /Nihlgard et al. 1981/ presenting figures from four *F. sylvatica* stands in southern Sweden. The fraction fine roots of the total root biomass was taken from a study by /DeAngelis et al. 1981/ in a *F. sylvatica* stand in southern Sweden (0.12 of the root biomass is fine root biomass).

Table 3-41. Mean biomass of different fractions in dw g·C·m^{-2} of the trees in Oskarshamn.

Class	Number of NFI plots	Stem	Branches	Green parts	Coarse roots	Fine roots
Young coniferous forest (< 30 y) fresh-moist	69	1,340	375	136	348	118
Dry coniferous forest	46	2,423	678	150	630	206
Old coniferous forest (> 30 y) fresh-moist	151	5,332	1,493	356	1,386	455
Deciduous forests	16	6,142	1,351	150	1,124	135

Table 3-42. Annual biomass increment in g·C·m^{-2}·y^{-1} for different fractions of the tree.

Class	Number of NFI plots	Stem	Branches	Green parts	Coarse and fine roots
Young coniferous forest (< 30 y) fresh-moist	69	69	13	6	16
Dry coniferous forest	46	51	9	5	12
Old coniferous forest (> 30 y) fresh-moist	151	111	20	10	25
Deciduous forests	16	105	19	0	30

Table 3-43. Annual amount of litterfall and other falling components, such as cones and twigs (Ø ≤ 5 mm) ($g \cdot C \cdot m^{-2} \cdot y^{-1}$). These values are from /Berggren et al. 2004/ were three 40 years old *Picea abies* forests with different moisture regimes were investigated.

Class	Class in /Berggren et al. 2004/	Other comp	Litterfall	Root litter from trees
Young coniferous forest (< 30 y) mesic-moist	Mesic	10	34	118
Dry coniferous forest	Dry	6	30	206
Old coniferous forest (> 30 y) mesic-moist	Mesic	16	80	455
Deciduous forests	–	5	124*	135

*Is set equal to foliage biomass taken from Table 3-40.

The net annual increase of the green fraction of deciduous trees is assumed to be zero in lack of other estimates. Net annual increase of branches was estimated using the same BEF as for the conifers above, while the below ground increment was estimated using figures from /Gower et al. 2001/, who presented figures describing the relation between below and above ground mean annual increase for deciduous trees (N = 18, 0.24).

/Muukkonen and Lehtonen 2004/ estimated the yearly branch fall to be an average of 1.3% of the total branch biomass for *P. abies* and /Lehtonen et al. 2004a/ estimated it to be 2.7% for *P. sylvestris* in the southern part of Finland. This flux to the soil organic carbon pool is low, but may have a rather large contribution to the soil organic carbon pool due to the slow decomposition rate of large branches. This report does not contain any estimates of litter fall concerning the larger branches. /Viro 1955/ estimated the larger branches to represent 13% of the total litter weight. The smaller branches or twigs are usually included in the litter traps studies. Data for litter fall and larger components such as cones and small branches are from /Berggren et al. 2004/ that investigated the litter fall in *P. abies* stands at an inland location in southern Sweden. This data set was only covering a year in spite the fact that the variation between years may be large. A quotient was calculated using needle litter fall and total needle biomass. This was also done for the "other components" as smaller branches (Ø < 5 cm) and cones etc (Table 3-42). These quotients were then used along with the biomass estimates in Table 3-40 to generate litter fall estimates for the conifer classes. The litter fall in deciduous forests was assumed to equal the leaf biomass, while fall of other components was estimated using the same quotient as for old conifer forests.

Turnover of roots was set equal to the total biomass of the fine roots /Majdi 2001/.

Dead wood

The total amount of dead wood in the Oskarshamns area /Andersson 2005/ is divided by the total area inventoried for each class (Table 3-44). The transformation factor from volume to dry weight is taken from /Benediktsson et al. 2005/, (Table 3-37). 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 3-44. Biomass values of dead organic material as the total standing and laying logs in g·C·m^{-2}. Figures are medians and first and third quartiles recalculated from /Andersson 2005/, who investigated a specific area (in column 3) for a number of vegetation types. Gridcode from tree layer classification in /Boresjö Bronge and Wester 2003/.

Class	Gridcode	Total area (ha)	Dead wood	Q_1	Q_3
No tree layer within forest area	1	57	23	15	44
No tree layer outside forest area	2	66	0	0	0
Old spruce	11	53	51	31	78
Young spruce	12	5	15	8	21
Old pine	13	185	39	22	51
Young pine	14	15	22	22	25
Unspecified young conifer	17	7	25	17	34
Birch	21	4	36	27	38
Young birch (thicket on clear-cut)	22	3	21	18	28
Birch or oak mixed with spruce	24	30	41	32	85
Oak	25	3	82	48	106
Coastal birch/oak	27	4	35	22	48
Mixed forest	30	8	56	35	71

Shrub layer

This layer was described using information from the shrub layer and the vegetation map /Boresjö Bronge and Wester 2003/. The classification is presented in Table 3-45 and the spatial distribution in Figure 3-72.

A significant shrub layer is found within certain 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 some successional forests. Field inventories /Andersson 2004/ 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 /Alling et al. 2004a/. *Salix sp* can be abundant on mires and was identified by /Boresjö Bronge and Wester 2003/ in their shrub layer. Therefore, the focus in the shrub layer is on *Betula* and *Salix*. However, due to lack of biomass and NPP data for *Salix sp* the values for Birch are used. /Alling et al. 2004a/ estimated biomass and NPP for *B. pendula* on five different clear cuts. Their estimations were converted into g·C using Table 3-39 and are presented in Table 3-46 and 3-47. Turnover of leaves and fine roots per year were set equal to their biomass (Table 3-47).

Table 3-45. The classes used to describe the shrub layer classes and the GIS sources from where the information is obtained to construct the classes /Boresjö Bronge and Wester 2003/.

Class	Gridcode in vegetation map	Gridcode in shrub layer
Willow	–	12
Birch	44, 45	–
Water	100	–

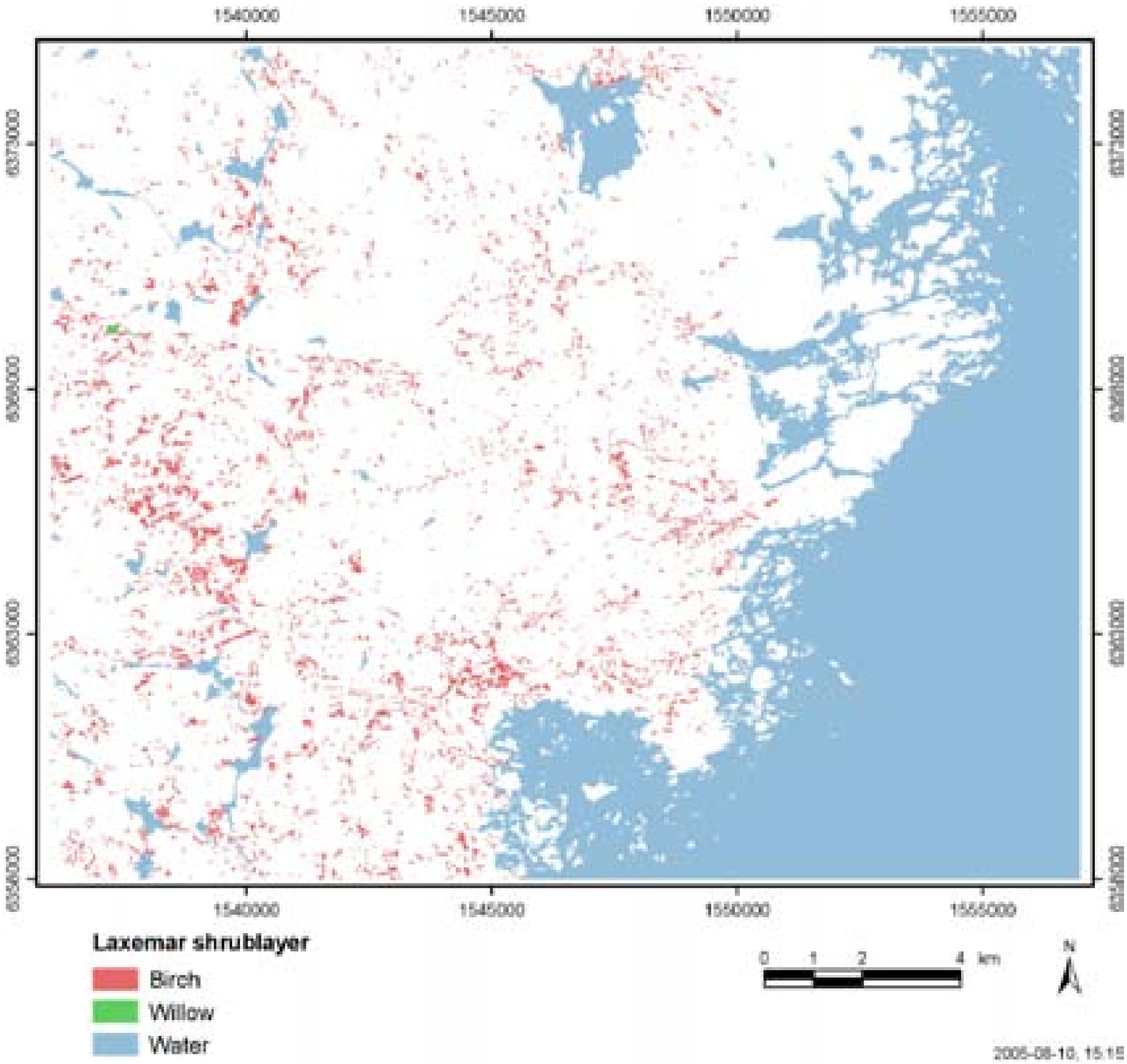

Figure 3-72. *The spatial distribution of the two shrub layer classes within the regional model area in Simpevarp.*

Table 3-46. Median values and range of biomass in g·C·m^{-2} after /Alling et al. 2004a/.

Class	Number of plots	Wood	Foliage	Coarse roots	Fine roots
Willow	5	368 (199–3,448)	148 (69–1,436)	38 (21–373)	5 (3–51)
Birch	5	368 (199–3,448)	148 (69–1,436)	38 (21–373)	5 (3–51)

Table 3-47. Median values and range of NPP and litter loss in g·C·m^{-2}·y^{-1} after /Alling et al. 2004a/. Net accumulation of biomass is NPP – litter production.

Class	Wood	Foliage	Coarse roots	Fine roots	Litter fall	Root litter
Willow	47 (22–330)	148 (69–1,436)	5 (3–38)	5 (3–51)	148 (69–1,436)	5 (3–51)
Birch	47 (22–330)	148 (69–1,436)	5 (3–38)	5 (3–51)	148 (69–1,436)	5 (3–51)

Field, ground and litter layer

This layer was described using information from the soil map constructed by /Lundin et al. 2005/ and the ground layer map /Boresjö Bronge and Wester 2003/. The classification is presented in Table 3-48 and spatial distribution in Figure 3-73. The woodland class measured in /Löfgren 2005/ was later renamed and transferred to the forested wetland class (HI-f) by /Lundin et al. 2005/. Nevertheless, this estimate of the woodland field and ground layer biomass and NPP is still based on the estimate from /Löfgren 2005/. One reason for keeping this is that the estimates for the different conifer forest field and ground layer classes were very similar /Löfgren 2005/.

The classes, mires and forested wetlands, were compared with the habitat classification in lakes by /Brunberg et al. 2004/, where their class "Littoral 1" was used as theme to exclude overlapping parts between the lake and the two "terrestrial" wetland classes. Some parts that were left in the open lake after this enclosure, were excluded.

Data describing the biomass and NPP for the different field layer types in Table 3-36 was taken from a study done in Simpevarp /Löfgren 2005/ (Table 3-49, 3-50) except for the seashore data taken from a study in Forsmark /Fridriksson and Öhr 2003/. The AG Production for the field layer is approximated using the standing biomass value of the green parts at late summer corrected for winter green species, such as *Vaccinium vitis-idaea* when present. The biomass was then translated to carbon content using Table 3-39.

BG biomass for the Seashore is calculated using the same relationship between above and below ground biomass as for the field layer in the forested wetland.

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/. The production above and below ground for arable land is set equal to the biomass due to the yearly harvest of crops. To the standard yield of 338 g oat m^{-2} /Berggren and Kyläkorpi 2002/ a generic values of treshing loss (x 1.05) and straw yield (x 1.4) was added. Data covering BG production for the field layer are scarce and thus a generic value taken from /Saugier et al. 2001/ was used for arable land (0.15) to calculate the BG production from the AG production. The total value was then translated to carbon content using Table 3-39.

Litter fall was estimated to equal the green fraction produced during the year. Dead plant parts attached to the plant were added to the litter fall component. 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.

Table 3-48. The classes that describe the field layer in Oskarshamn. The classes correspond to /Lundin et al. 2005/ describing the soil in Oskarshamn.

Class /Löfgren 2005/	Code in soil map
Mires	HI-w, HI-sp
Forested wetlands	HI-f
Herb dominated moist soils on fine texture parent material	UM/RG
Seminatural grasslands	UM/GL
Woodland, well drained, herbs, grasses and dwarf shrubs	PZ/RG, PZ/RG-e
Thin soils with lichen rich heath vegetation	LP
Shore line (bedrock excluded)	RG/HI
Arable land	UM/GL-a

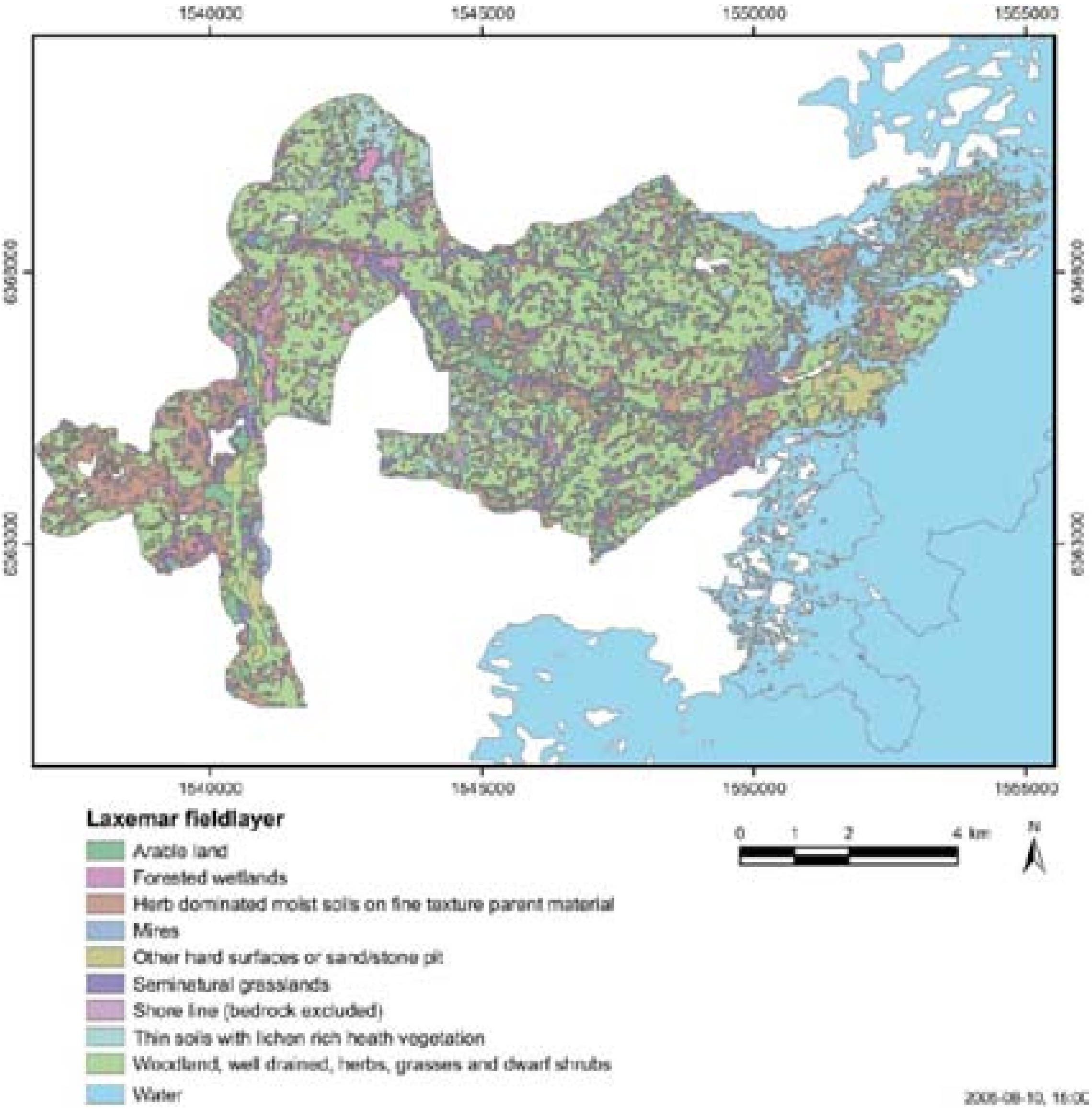

Figure 3-73. The spatial distribution of the field layer classes within the Laxemar model area.

Table 3-49. Assigning biomass values in g·C·m⁻² for the different field, ground and litter layer classes in the Oskarshamn area. Figures are means recalculated from /Löfgren 2005/ except for the seashore /Fridriksson and Öhr 2003/ and the arable land (see text).

Class	Litter layer	Ground layer	Field layer green	Field layer wood	Below ground
Mires	126	97	78	100	1,096
Forested wetlands	501	0	13	0	315
Herb dominated moist soils on fine texture parent material	226	23	41	0	127
Seminatural grasslands	225	20	72	0	367
Woodland, well drained, herbs, grasses and dwarf shrubs	737	54	4	0	257
Thin soils with lichen rich heath vegetation	562	187	19	6	70
Shore line (bedrock excluded)	140	0	28	0	682
Arable land	0	0	218	0	33

Table 3-50. Assigning NPP values and litter flux values in g·C·m^{-2}·y^{-1} for the different field and ground layer classes in the Oskarshamn area. Figures are means recalculated from /Löfgren 2005/ except for the seashore /Fridriksson and Öhr 2003/ and the arable land.

Class	Ground layer	Field layer AG	BG	Ground layer litter fall	Field layer litter fall	BG root litter
Mires	40	91	190	40	84	190
Forested wetlands	0	13	27	0	13	27
Herb dominated moist soils on fine texture parent material	6	41	84	6	41	84
Seminatural grasslands	33	72	150	33	72	150
Woodland, well drained, herbs, grasses and dwarf shrubs	34	4	8	34	4	8
Thin soils with lichen rich heath vegetation	18	8	17	18	8	17
Shore line (bedrock excluded)	0	28	59	0	28	59
Arable land	0	218	33	0	0	33

Fungi

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 /Fitter et al. 2000/. There are two dominating types of plant – mycorrhizal associations, the arbuscular mycorrhiza (AM) and the ectomycorrhiza (EM). A third type the ericoid mycorrhiza is exclusively formed by plants in the Ericales. In boreal and some temperate forests and in heatland ecosystems, the EM associations are dominating the root system of most plant species /Fitter et al. 2000, Read 1994/. We have no data covering biomass and NPP for the arbuscular and ericoid mycorrhiza.

Data for EM fungi, in Table 3-51, was extracted from an investigation made in USA, Washington State, estimating mycorrhizal fungal biomass and production at two *Abies amabilis* stands of different age (23 and 180 years old) /Vogt et al. 1982/. Fine roots of conifer (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 EM sheath, and was consequently subtracted (16% of total fungal component) from the total, to avoid accounting for that biomass twice. Similarly, that part was 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. Their result suggested that the fungi part was equal to 10.1% of the total root biomass (mycorrhizal sheath excluded) and that the NPP was 1.17 of the fungal biomass. A conversion factor of 0.5 was used to convert dry weight to carbon weight. The deciduous forest is given the same values as coniferous forest in lack of other data. Turnover of mycelia was calculated using an assumption of steady state in between years, which gives a turnover equal to NPP (Table 3-51).

These values can be compared with estimates of EM mycelia in the humus layer of a Norway spruce stand in SW Sweden, where the biomass of EM mycelia was estimated to 40 g·C·m^{-2} using biochemical markers, giving a similar value using the relationship from /Vogt et al. 1982/ for a young conifer forest (see Table 3-51). Production of mycelia was however estimated to only 9 g·C·m^{-2}·y^{-1} using sand-filled mesh bags and biochemical markers /Wallander et al. 2001/. These estimates are, however, uncertain due to the uncertainties accompanied with the use of conversion factors from biochemical markers and the extrapolated production estimates from sand-filled mesh bags to forest soil.

/Wiklund et al. 1994/ estimated the biomass of EM fruit bodies to 0.3 g·C·m^{-2}·y^{-1} at the same site as a mean of 5 years. In conclusion, the estimates by /Vogt et al. 1982/ is used in this version.

How the biomass of the EM mycelia correlates with stand age is poorly studied. /Vogt et al. 1982/ found that the EM mycelia (and sporocarps) constituted 10.1% and 2.4% of the total root biomass resp for a 23 and a 180 year old *Abies amabilis* stand. Nevertheless, the relationship between EM mycelia and rootbiomass for the 23 year old stand was used for the two age categories (< 30, > 30 year old).

Table 3-51. Biomass and NPP for fungi in forest habitats.

Class	Biomass (g·C·m^{-2})	NPP (g·C·m^{-2}·y^{-1})	Litter (g·C·m^{-2}·y^{-1})
Young coniferous forest (< 30 y) mesic-moist	47	55	55
Dry coniferous forest	84	99	99
Old coniferous forest (> 30 y) mesic-moist	186	218	218
Deciduous forests	127	149	149

Root zone depth

The root zone, which is the zone where fine roots (Ø < 5 mm) are found in a number of vegetation types. These vegetation types are the same used to describe the field and ground layer. The estimation of the fine root depth was done by /Lundin et al. 2005/ at two localities for each of the studied soil classes except for the mire and the rockpool types. Generally, the samples from the two replicates did correspond fairly well to each other and the largest variation was found between the different vegetation types (Figure 3-74). The largest deviation from that pattern was found between the two rockpool types (HI-s). The statistics presented in the Table 3-52 were made on all subsamples within the vegetation type.

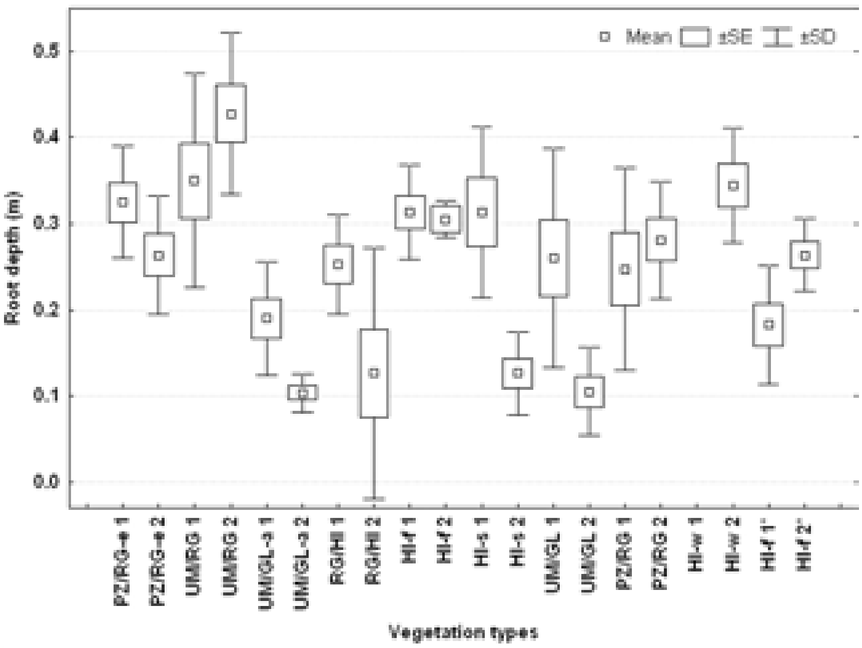

Figure 3-74. The fine root depth for a number of vegetation types. Codes correspond to the vegetation types in Table 3-40. Each vegetation type has two replicates except HI-w.

Table 3-52. Statistics describing the depth of the root zone for a number of vegetation types. The class LP was not estimated in /Lundin et al. 2005/.

Class	Code in /Lundin et al. 2005/	Mean (sd) (m)	Min–Max (m)	N
Mires	HI-w	0.34 (0.07)	0.30–0.47	7
Forested wetlands	HI-f	0.31 (0.05)	0.25–0.43	10
Herb dominated moist soils on fine texture parent material	UM/RG	0.39 (0.11)	0.20–0.60	16
Seminatural grasslands	UM/GL	0.18 (0.12)	0.60–0.54	16
Woodland, well drained, herbs, grasses and dwarf shrubs	PZ/RG	0.26 (0.09)	0.15–0.52	16
*	HI-f*	0.22 (0.07)	0.08–0.32	16
Esker	PZ/RG-e	0.29 (0.07)	0.18–0.43	16
Rockpool	HI-s	0.20 (0.12)	0.09–0.40	14
Thin soils with lichen rich heath vegetation	LP	–	–	–
Shore line (bedrock excluded)	RG/HI	0.19 (0.13)	0.00–0.35	15
Arable land	UM/GL-a	0.15 (0.07)	0.07–0.27	16

*Reclassified from "Woodland" to "Forested wetland" by /Lundin et al. 2005/, but is here not used for the calculation of root depth for either category.

Decomposition

During decomposition of dead plant, animal and microbial material, the organic matter is converted into inorganic nutrients and CO_2. The balance between decomposition and NPP strongly influences the carbon cycle at both ecosystem and global scales. The flux of carbon (CO_2) from the soil, i.e. the soil respiration, can be divided into autotrophic respiration, by roots and mycorrhiza, and heterotrophic respiration, by microbes and microfauna. It is the heterotrophic components that are the decomposition.

Soil respiration was measured during 2004 in the Simpevarp area in five different vegetation types /Tagesson 2005a/ (Table 3-53). The measurements were made from March 2004 to March 2005 at 14 occasions and covered nine permanent plots within each vegetation type. The measurements of CO_2 flux from the ground were done with a closed chamber technique along with measurements of air and soil temperature. The annual soil respiration was estimated using a regression approach where the relationship between the air temperature (logged every 30 minutes at the site), and the soil temperature and the measured soil respiration was used. In Table 3-53, the mean annual soil respiration for five vegetation types is presented.

Estimates of the contribution of root respiration to total soil respiration vary from 10% to 90% /Hanson et al. 2000/. However, /Högberg et al. 2001/ presented data from a boreal forest (*Pinus sylvestris*) in northern Sweden, suggesting that the contribution of root-mycorrhizal respiration was 52–56% of total soil respiration. This was for several reasons also considered to be a conservative estimate. They also showed that this relationship seemed to be fairly stable during the year. Accordingly, 50% of the measured mean annual soil respiration was considered to be caused by decomposition in the vegetation types having a tree layer (Table 3-51).

The water table is the principal factor affecting CO, fluxes from boreal wetlands /Silvola et al. 1996/, which have consistently shown a strong positive relationship between CO, fluxes and water-table depth. The forested wetland therefore has a lower C-mineralisation rate than the non-inundated forests. Here is measurements from an earlier peatland, now forested after drainage, used in lack of better estimates /Tagesson 2005a/. This value is lower than the other forest types except for the forest on bedrock (Table 3-53, LP).

The seminatural grassland vegetation was assigned a value of 50% in accordance with the review made by /Hanson et al. 2000/. There are no respiration measurements from the shore or the arable land. The shore was assigned the same C-mineralisation value as the meadow at the site. The estimate for the arable land has to be adapted to the fact that crops are only present during a part of the year. The input of organic carbon to the arable land is limited to the root fraction of the crop that is grown (and the lower part of the straw). The decomposition was therefore set to equal the input of roots as organic carbon.

Few figures have been published presenting the carbon mineralization in wetlands. /Moore et al. 2002/ presented the figure 245 $g \cdot Cm^{-2}y^{-1}$ from a boreal bog in Canada. This figure was used to describe the C-mineralization rate in the wetlands.

Table 3-53. Measured annual soil respiration and estimated C-mineralisation ($g \cdot C \cdot m^{-2} \cdot y^{-1}$) for six different vegetation types in Simpevarp from /Tagesson 2005a/.

Vegetation type	Classification in /Tagesson 2005a/	Classification in /Lundin et al. 2005/	Annual soil respiration	C-mineralisation
Mires	–	HI	–	245
Forested wetland	Spruce*	HI-f	851	425
Herb dominated moist soils on fine texture parent material	Deciduous 1 and 2 (mean)	UM/RG	980	490
Seminatural grasslands	Meadow	UM/GL	1,151	575
Woodland, well drained, grasses and dwarf shrubs	Pinus	PZ/RG, PZ/RG-e	1,173	586
Thin soils with lichen rich heath vegetation	Lichen	LP	750	375
Shore line (bedrock excluded)	Meadow	RG/HI	1,151	575
Arable land	–	UM/GL-a	–	33

*Reclassified as "Forested wetland" by /Lundin et al. 2005/.

Decomposition of logs and dead wood

Various amount of dead wood is found in the forests Table 3-44. The turnover rate of *Picea abies* logs was investigated by /Næsser 1999/ in southeastern Norway. He found that the decomposition of dead wood was significantly affected by cross-section diameter, ground contact, soil moisture and aspect. The overall average decomposition rate constant was 0.033 per year with a minimum of 0.017 and a maximum of 0.049 per year.

Confidence and uncertainties

There are mainly three types of errors that could be of importance, 1) estimations of different properties have errors due to large variation, low sample sizes or are poorly studied, 2) assigning these values to the different categories in the landscape assume that these categories have been correct identified, and 3) pools and fluxes not accounted for.

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 values would have a large effect on the overall confidence of the descriptive model. 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, however, a large spatial 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/. Nevertheless, 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 have 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. 2004b/ and here is the same BEF's used irrespective of age i.e. calculating below ground fractions from above ground fractions. This has most certainly lead to a slight overestimation of the actual biomass belowground and NPP belowground for older stands because the BEF's has been constructed from younger stands (~ 30 y /Berggren et al. 2004/). This approach will be modified in later versions.

Some pools and fluxes have not been treated within this version e.g. accumulation of biomass in the ground layer. These have been left out, so far, because of their relative small size in comparison to other pools and fluxes and therefore expected to have a small influence on the overall carbon budget. Interestingly, few or no single studies have been able, or chosen, to estimate all the properties that have been treated above.

Overall, the total estimations may be somewhat higher than expected because of an over-estimation of biomass and NPP for the root fractions of mature conifer forests. This also makes the estimations of EM mycelia high because they are a function of the belowground biomass.

3.7.2 Consumers

Descriptive biomass and production models for the terrestrial fauna have been calculated based on site-specific density data for mammals and birds. For amphibians and reptiles generic density data have been used. The biomass and production models with total carbon flows, that is production, consumption, respiration and egestion for each species, will provide the terrestrial ecosystem model with the necessary data to describe the consumers.

Input data

Site-specific data and generic data concerning the terrestrial fauna that have been obtained from different reports are shown in Table 3-54.

Description of consumers – methodology

Svensk Naturförvaltning AB has performed site investigations to estimate population densities for all the mammal species found in the Oskarshamn region. The mammals that have been included in the surveys are listed in Table 3-55. The chosen study area (approx. 120 km^2) was centred around the drilling activities in Simpevarp. A control area near Blankaholm, north of Simpevarp, was also used.

The large mammals were studied using pellet counts in 2003, while the small mammals where investigated using trapps during two consecutive seasons. Marten, Lynx and Red fox were only studied by snow tracking. The Moose population was also studied through aerial survey. More information about the methodology is found in /Cederlund et al. 2004/.

Table 3-54. List of input data.

Fauna family	Species	Data	Source
Mammals	Moose, Roe deer, Red deer, hare, small mammals, Marten, Wild boar	Densities (site specific), body masses, production, respiration, consumption, egestion	/Truvé and Cederlund 2005/
	Red fox	Density (generic)	/Svenska Jägareförbundet 2004(7), website/
		Body mass	/Truvé and Cederlund 2005/
Birds	Terrestrial birds	Breeding bird species that occur in the Simpevarp area	/Green 2004, 2005/
		Density and biomass	M Green pers. comm.
Amphibians and reptiles	–	Species that occur in the Simpevarp area	/Andrén 2004a/
	Snaks, newts, common toad, moor frog, lizards	Densities, body masses, consumption (generic)	/Andrén 2004b/
Soil fauna	–	Density in a deciduous forest, a moor pine and a grassland.	/Lohm and Persson 1979/

Table 3-55. Mammal species that have been selected for surveys by Svensk Naturförvaltning AB.

Species English	Species Swedish	Latin
Moose	Älg	*Alces alces*
Roe deer	Rådjur	*Capreolus capreolus*
Red deer	Kronhjort	*Cervus elaphus*
Fallow deer	Dovhjort	*Dama dama*
European (common) hare	Fälthare	*Lepus europaeus*
Mountain hare	Skogshare	*Lepus timidus*
Marten	Mård	*Martes martes*
Red fox	Rödräv	*Vulpes vulpes*
Lynx	Lo	*Lynx lynx*
Wild boar	Vildsvin	*Sus scrofa*
Bank Vole	Skogssork/Ängssork	*Cletrionomus glareolus*
Field vole	Åkersork	*Microtus agrestis*
Water vole	Vattensork	*Arvicola terrestris*
Yellow necked mouse	Större skogsmus	*Apodemus flavicollis*
Wood mouse	Mindre skogsmus	*Apodemus sylvaticus*
Common shrew	Vanlig näbbmus	*Sorex araneus*

For amphibians and reptiles a short field study was performed primarily to verify the presence of suitable habitats for the species. It was carried out mainly following the smaller roads in the area and checking surrounding areas with special interest. The aim was to confirm which species that do occur in the Simpevarp area /Andrén 2004a/.

A survey of breeding bird species has been carried out between 2002 and 2004, with a combination of line transects and point counts. In a few smaller areas around selected drilling sites, about 30 ha in size, all breeding birds were mapped with the territory mapping method. The aim with the survey was to evaluate the possible impacts from the ongoing site investigations in the area /Green 2005/.

Description of consumers – results

Moose

The aerial survey gave a mean density of approximately 0.8 Moose·km^{-2} in Simpevarp. The pellet counts indicate that the winter population is lower (approximately 0.6 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 low carcass weight (151 kg in average) and low age (1.8 years in average) of harvested bulls, reported from Ankarsrum close to Simpevarp, do also indicate a high hunting pressure on adult bulls /Svensk Viltförvaltning 2003/. The Moose feed mainly on deciduous trees and larger shrubs (approx. 45%). During summer the Moose also feed on herbs (26%) and low shrubs (13%) to a large extent, while coniferous browse (37%) is common during the winter /Truvé and Cederlund 2005/. The Moose 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(1), website/. 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). One can estimate the home range by calculating it from body mass with a specific formula. According to this formula, the Moose home range is 9.1 km^2. The median value among reported area sizes in literature is 13.3 km^2 /Truvé and Cederlund 2005/.

Roe deer

The density of Roe deer 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 no reason to believe that the densities found in this study are exceptional /Cederlund et al. 2004/. The summer diet of a Roe deer consists primarily of herbs (65%), while the winter diet is more diverse; deciduous browse (37%), low shrubs (26%), lichens (*Sw: lav*) (12%) and coniferous trees (10%) /Truvé and Cederlund 2005/. 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. A Roe deer lives at the most in 10–12 years /Svenska Jägareförbundet 2004(2), website/. The calculated home range for Roe deer is much smaller than for the Moose as its body mass is much smaller. The home range estimate is 0.7 km^2, while the median area from literature data is 0.46 km^2 /Truvé and Cederlund 2005/.

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/. The Red deer consumes primarily grasses and sedges (*Sw: halvgräs*) during the summer (62%) and partly also during the winter, besides low shrubs, deciduous browse and coniferous trees /Truvé and Cederlund 2005/. The Red deer population growth is slow. The females give birth to their first calves at the age of two, but never more than one calf and some years they do not reproduce at all /Svenska Jägareförbundet 2004(3), website/. The Red deer home range is, according to calculations from body mass, smaller than for the Moose and larger than for the Roe deer. It is calculated to 5.1 km^2, while the median value from the reported areas in the literature is 3.1 km^2 /Truvé and Cederlund 2005/.

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 /Cederlund et al. 2004/. Mountain hares feed mainly on grasses and herbs during summer, but in winter they browse on deciduous trees and occasionally on evergreen species. The European hare feeds to a large extent on agricultural crops and pasture vegetation all year around, and do not browse to the same extent as Mountain hares do /Truvé and Cederlund 2005/. 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(4), 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 hare home range is, according to calculations from body mass, estimated to 0.1 km^2, while the reported areas in literature is somewhat larger (median values of 1.1 km^2 for European hare and 0.6 km^2 for Mountain hare) /Truvé and Cederlund 2005/.

Small mammals

The small mammals occuring in the forest are Bank vole (*Sw: skogssork/ängssork*), a few Field voles (*Sw: åkersork*) and mice. The densities in Simpevarp forests are 445 Bank voles·km^{-2}, 30 Field voles·km^{-2} and 685 mice·km^{-2}. The mice included in the mammal survey are Yellow-necked mouse (*Sw: större skogsmus*) and Wood mouse (*Sw: mindre skogsmus*). The small mammals in field are mice (640 ind·km^{-2}) and the main part of the field voles (420 ind·km^{-2}). The density of Common shrew is 100 ind·km^{-2} and they are evenly spread over the forest and field area. The Water vole has a density of 570 ind·km^{-2} in the specific habitat of Water vole /Truvé and Cederlund 2005/. The Water vole inhabits the banks of ditches, rivers, streams and lakes. According to /BBC 2004, website/ the males have ranges of about 130 m along the riverbanks, whereas females have smaller ranges of about 70 m. The estimated home ranges for the small mammals are listed in Table 3-56.

All voles are herbivorous generalists and they consume green plants to a large extent during the summer. Seeds and fruits are also important food items, especially in winter. Voles collect hoards of food in the summer, which they consume during the winter. Mice are omnivores and feed on insects and larvae but, vegetable material is dominating the diet. Similar to voles they also store food when availability is high. The shrews are insectivores and feed mainly on small invertebrates like insects, spiders and earthworms, but also on carrion /Truvé and Cederlund 2005/. A mice produces in average 3.3 litters a year and the litter size is 6.1, and a voles reproduction is almost similar; 3.3 litters and a litter size of 5.9 /Truvé and Cederlund 2005/.

Table 3-56. The estimated home ranges for the small mammals.

Species	Allometric data (calculated based on body mass), (m^2)	Literature data (median value), (m^2)
Bank vole	578	8,900
Field vole	758	8,900
Water vole	1,904	8,900
Yellow necked mouse	681	9,650
Wood mouse	476	5,000
Common shrew	423	779

Cattle

As there are so few farms in the subareas within Laxemar model area, no data concerning the farms that do exist has been delivered by SCB /Miliander et al. 2004/. Therefore, there are no site-specific density data regarding the domestic animal population. However, for the quantitative model theoretical values for cattle are used.

Marten

The track indexes indicate that Marten is common in both Simpevarp and Blankaholm. The density was estimated to 0.13 Marten·km^{-2} in Simpevarp (and 0.05 in Blankaholm). The density estimates are relatively uncertain (large confidence intervals), but seems quite reasonable /Cederlund et al. 2004/. According to a study in Britain the diet of Martens mainly consists of mammals (47%), birds (14%), invertebrates (20%) and fruit and vegetables (10%) /Truvé and Cederlund 2005/. The Marten population growth rate is low. The first litter comes normally when the female is 2–3 years old and the litter size is 1–4 young /Svenska Jägareförbundet 2004(6), website/. The Marten home range is, according to calculations from body mass, estimated to 4.3 km^2, while the reported areas in literature is 1.9 (median values) /Truvé and Cederlund 2005/.

Red fox

The high frequency of tracks, in combination with long distances between end points and highly irregular movement patterns, made it too difficult and time consuming to estimate the Red fox density. There is therefore no site-specific density data for fox /Cederlund et al. 2004/. A generic density figure have been found on /Svenska Jägareförbundet 2004(7), website/. According to this source, the density in Sweden varies between 0.2 and 0.8 Red foxes per km^2. The highest density is found in agricultural areas in the southern parts of Sweden. The Red fox, has like the Marten, a mixed diet. Red foxes feed mainly on rodents (minimum 32%), hares (min 35%) and birds (min 18%) during the summer but several other animals as well as plants is consumed /Truvé and Cederlund 2005/. The female fox becomes fertile at 9–10 months of age and gives birth to in average five cubs, after a gestation period of approximately 52 days /Svenska Jägareförbundet 2004(8), website/. The fox home range is, according to calculations from body mass, estimated to 23.5 km^2, while the reported areas in literature is 3.1 (median values) /Truvé and Cederlund 2005/.

Lynx

No tracks of Lynx were found. However, since the Lynx move over large areas, it is reasonable to believe that they occasionally pass through the Oskarshamn area.

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/. A Wild boar is to 85% herbivorous (vegetation and mushrooms) and to 15% carnivorous /Lemel 1999/. 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(9), website/. The home range is, according to calculations from body size, estimated to 1.5 km^2, while the reported areas in literature is 5.3 (median values) /Truvé and Cederlund 2005/.

Birds

In total, 126 breeding species were found in the regional model area in 2003, and 28 of these are noted in the Red List as endangered bird species in Sweden /Green 2004/. Both the number of species and individuals/territories were similar (or even higher) in 2004 compared to the earlier years. The most common species on land in 2004 were Chaffinch and Willow Warbler (Table 3-57) /Green 2005/. A major part of the nesting species was small birds, associated with the open or semi-open landscape.

Table 3-57. The fifteen 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 2005/.

Species English (Swedish)	Latin	Total number (2004)	Abundance (n/km) 2004	Abundance (n/km) 2003	Abundance (n/km) 2002
Chaffinch (Bofink)	*Fringilla coelebs*	700	10.06	10.84	7.10
Willow Warbler (Lövsångare)	*Phylloscopus trochilus*	471	6.77	3.41	7.15
Robin (Rödhake)	*Erithacus rubecula*	388	5.57	7.42	2.22
Song Thrush (Taltrast)	*Turdus philomelos*	252	3.62	3.68	1.89
Blackbird (Koltrast)	*Turdus merula*	224	3.22	5.44	2.24
Great Tit (Talgoxe)	*Parus major*	192	2.76	7.77	1.55
Siskin (Grönsiska)	*Carduelis spinus*	170	2.44	1.89	0.81
Starling (Stare)	*Sturnus vulgaris*	163	2.34	0.40	0.49
Wood Pigeon (Ringduva)	*Columba palumbus*	157	2.26	2.62	1.63
Goldcrest (Kungsfågel)	*Regulus regulus*	131	1.88	1.44	0.38
Yellow hammer (Gulsparv)	*Emberiza citrinella*	106	1.52	1.59	0.87
Green finch (Grönfink)	*Carduelis chloris*	89	1.28	0.98	0.29
Blue tit (Bålmes)	*Parus caeruleus*	86	1.24	4.71	0.58
Tree pipit (Trädpiplärka)	*Anthus trivialis*	80	1.15	0.37	1.71
Wren (Gärdsmyg)	*Troglodytes troglodytes*	72	1.03	0.42	0.67

Reptiles and Amphibians

The information that was given in /Andrén 2004b/ is compiled in Table 3-58.

Soil fauna

The density and biomass in three different biotopes are listed in Table 3-59. 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 soil, 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 3-59. 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 3-58. Ecological data concerning amphibians and reptiles /Andrén 2004b/.

Species English (Swedish)	Weight (g)	Density (ind per km^2)	Diet	Energy needs (g dry weight per year)	Reproduction
Adder (huggorm)	150	100	Primarily mice and voles	0.33	In average 5 young/year
Grass snake (vanlig snok)	175	100 (200 in wetlands)	Frogs and toads, fish, newts	0.35	Approx. 13 eggs/year
Smooth snake (hasselsnok)	70	20	Other reptiles such as slowworm	0.14	In average 6 young/year
Slow-worm (kopparödla)	15	1,000	Earthworms and snails	0.06	8 young/year
Common lizard (skogsödla)	5	500	Spiders and insects	0.021	7 young/year
Sand lizard (sandödla)	8	15 (in Simpevarp)	Spiders and insects	0.027	10 eggs/year
Moor frog (åkergroda)	20	3,000 (0–100 m from pond) 1,000 (100–300 m from pond) 100–500 (300–500 m from pond)	Insects, spiders and worms	0.02	1,500 eggs/year
Common toad (vanlig padda)	60	4,000	Insects, spiders and worms	0.1232	4,000 eggs/year
Smooth newt (mindre vatten-salamander)	3	2 per m^2 water area, the population size can be up to 10,000 individuals. They stay within 300 m from the pond.	Larger zooplankton, waterinsects, water-spiders, earthworms, snails and larvae of insects	0.003	350 eggs/year
Great creasted newt (stor vatten-salamander)	9	1 per m^2 water area, the population is never larger than a few thousand individuals. They stay within 500 m from the pond.	Insects, earthworms, snails, waterinsects, waterspiders, larvae of frog and smooth newt.	0.0077	200 eggs/year

Table 3-59. Biomass and density in the soil fauna in three different biotopes /Lohm and Persson 1979/.

Species	Decidious forest (Uppland)			Pine moor (Gästrikland)			Grassland (Uppland)		
English or Latin (Swedish)	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	17	8	130	5,900	2,950
Enchytraeidae (småringmask)	3,800	370	185	17,000	420	210	24,000	850	425
Wood louse (gråsuggor)	2	9	5	<1	2	1	<1	4	2
Centipede (tusenfotingar)	1,200	70	35	25	3	2	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	1	40	1	0
Thrips (tripsar)	100	10	1,400	6	3	720	3	2	
Homoptera (växtsugare)	70	2	1	270	11	6	70	1	1
Hemipteron (skinnbaggar)	10	7	4	190	10	5	10	3	2
Beetles (skalbaggar)	600	480	240	500	170	85	1,400	2,800	1,400
Hymenoptera (steklar)	50	50	25	40	15	8	110	3	2
Wiggler (mygglarver)	1,300	50	25	700	20	10	4,400	320	160
Fly-maggot (fluglarver)	30	80	40	70	95	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	8,001	4,000	706,535	1,254	627	252,182	10,555	5,277

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 is instead of 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, 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 consume 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%).

Descriptive biomass and production models – Metodology

The ambition in this report has been to calculate the carbon pools and flows associated with the terrestrial consumers, expressed as $mgC \cdot m^{-2} \cdot y^{-1}$, as well as the total pools and flows ($gC \cdot y^{-1}$) in Simpevarp 6, Simpevarp 7, Simpevarp 8, Simpevarp 9 and part of Simpevarp 10 within Laxemar area (Figure 3-76). The values form input data for the terrestrial ecosystem model. Figure 3-75 illustrates the different flows of matter in a terrestrial ecosystem, with focus on the consumers. Estimated values for each box are found in Table 3-62 and 3-63.

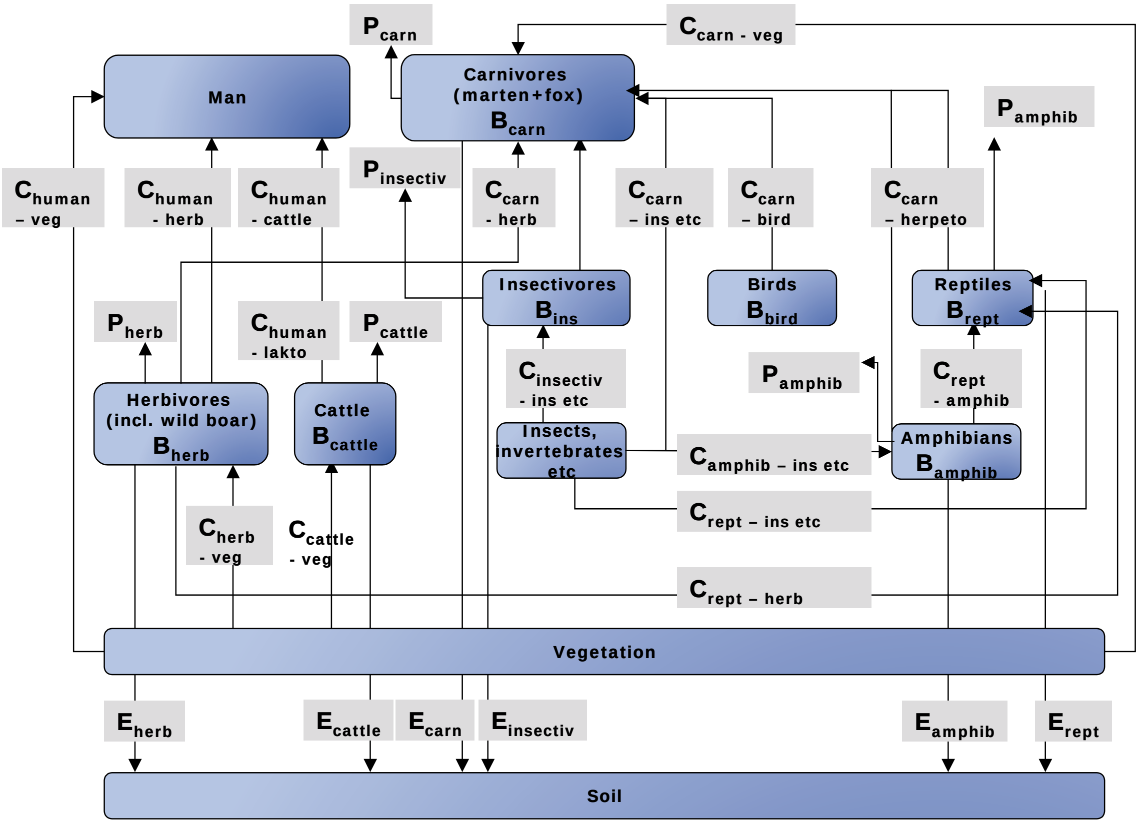

Figure 3-75. *An illustration of the pools and flows of carbon in a terrestrial ecosystem, with focus on the consumers.*

Mammals

The energy budget for different mammal species have been calculated by /Truvé and Cederlund 2005/ using different formulas and parameters. The standing stock (biomass) and the carbon flow, expressed as $mgC \cdot m^{-2} \cdot y^{-1}$, have been estimated based on density estimates from the site investigations made by Svensk Naturförvaltning AB. Estimates of population density is the only site-specific data used in the calculations. Svensk Naturförvaltning AB used the mean density of each species during the time period. For those rodents, that were surveyed on one occasion the first season, but on two occasions the second season, they used the mean value from the season with two trapping events.

The total energy budget for an organism can be estimated with the following formula /Baird and Ulanowicz 1989/:

The calculation of carbon flows where performed by Svensk Naturförvaltning AB in the following order:

1 The field metabolic rate (FMR) in *kJ/day* was calculated for different species using the formula FMR = ax^b, where *x* is body mass, *a* and *b* are known parameters for all eutherian mammals (mammals with placenta), herbivores and rodents /Nagy 1987/.

2 The production (P) and respiration (R) was estimated using the formula FMR = P+R. The production and respiration was separated by using an estimate of average production efficiency (P/A) /Humpreys 1979/.

3 The field metabolic rate in *g/day* was calculated for different species using FMR = ax^b, with other *a* and *b* parameters than in (1) /Nagy 1987/.

4 The consumption (C) was calculated by multiplying FMR (g/day) and the total energy content in different diets (kJ/g dry matter) /Golley 1961/, giving a consumption figure in kJ/day.

5 The egestion (E) was calculated by using the formula C = P+R+E.

6 The figures were finally converted to carbon content by equating 1 g carbon to 10.94 kcal = 45.8 kJ /Humpreys 1979/.

The total carbon budget in each subarea within Laxemar model area have been calculated based on the land use distribution within each area, obtained from the vegetation map /Boresjö Bronge and Wester 2003/. The habitat for each species is demonstrated in Table 3-62.

Carnivores

The carbon flow for Red fox was not estimated by Svensk Naturförvaltning AB, as there is no site-specific density data for fox. A generic density figure have been found on /Svenska Jägareförbundet 2004(7), website/. According to this source the density in Sweden varies between 0.2 and 0.8 Red foxes per km^2, where the highest density is found in agricultural areas in the southern parts of Sweden. A density of 0.2 Red foxes·km^{-2} has been used when calculating the carbon flow using the same procedure as Svensk Naturförvaltning AB. The normal body mass of an adult Red fox is demonstrated in /Truvé and Cederlund 2005/. The Red fox has a mixed diet. The Red fox consumption has been calculated based on the results from a diet survey in Finland /Truvé and Cederlund 2005/.

Table 3-60. Red fox summer diet in Finland.

Food item	Frequency of occurrence (min %)
Herbivores (rodents and hares)	70
Birds	18
Insects	5
Other plants	7
Sum	100

The Marten, as well as the Red fox, has a mixed diet. A study in Britain concerning the diet of Martens showed that the major food item is mammals, mainly small mammals /Truvé and Cederlund 2005/.

Table 3-61. Diet of Martens in Britain.

Food item	%
Mammals	47
Birds and eggs	15
Invertebrates and other	24
Fruits and vegetables	10
Hepetofauna (amphibians and reptiles)	4
Sum	100

The different carbon flows to the carnivores (Fox and Marten) have been calculated based on the figures in Table 3-60 and 3-61.

Wild boar

The Wild boar consumption has been included in the total herbivore consumption ($C_{herb\text{-}veg}$), even if a wild boar normally consumes animalia to 15% /Lemel 1999/.

Water vole

To be able to calculate the total biomass of Water voles in the subareas, the habitat area of the Water vole had to be defined and calculated in ArcGIS. The Water vole inhabit the banks of ditches, rivers, streams and lakes and the density investigations have been performed using traps along streams in the area. The home range is estimated to 1,904 m^2 in /Truvé and Cederlund 2005/. According to /BBC 2004, website/ the males have ranges of about 130 m along the river banks, whereas females have smaller ranges of about 70 m. If an average length of 100 m is assumed for the home range, the home range will cover a 10-metre wide zone along each side of the streams and around the lakes. The Water vole habitat is illustrated in Figure 3-76.

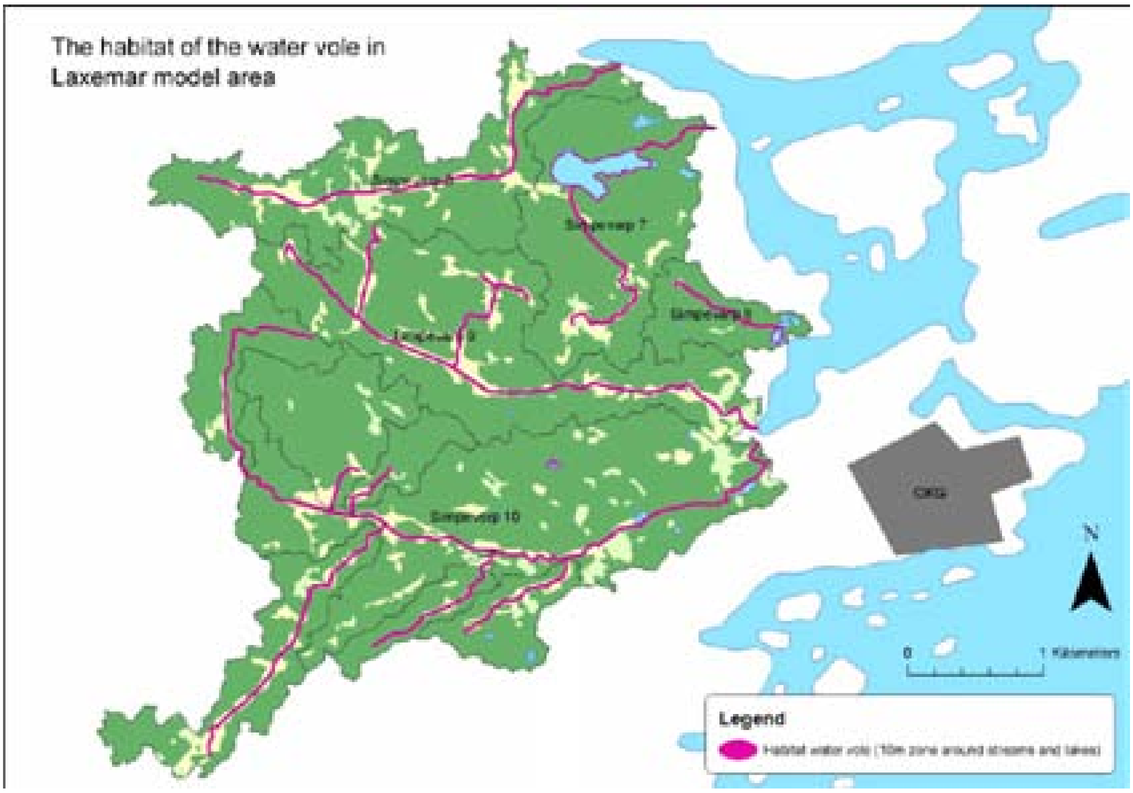

Figure 3-76. *The Water vole habitat, calculated and illustrated in ArcGIS, by using the hydrographical data in the topographic map.*

Cattle

As there are so few farms in the subareas within Laxemar model area no data concerning the farms that do exist has been delivered by SCB /Miliander et al. 2004/. Therefore, there are no site-specific density data for the domestic animals. However, for the terrestrial ecosystem model theoretical values for cattle are used. These values are based upon the field area (arable and pasture land) within each subarea and a figure given by /LivsmedelsSverige 2004(1), website/, suggesting that half of the agricultural area needed for humans to be self-sufficient, is used for fodder production and grazing. If we assume that half of the field area is used for livestock and that a cow needs in average 2.4 ha /Arnesson 2001/ for fodder production and grazing (41.7 cows per km^2), a theoretical standing stock of cattle in the subareas can be calculated. The cattle body mass is estimated by dividing the average weight of slaughtered cows (290 kg) /Miliander et al. 2004/ with 0.55, which is the conversion factor between live weight and carcass weight for game meat (G Cederlund 2004, pers. comm.). The calculations of the cattle production including milk production are demonstrated in Section 3.10. According to /LivsmedelsSverige 2004(2), website/ a diary cow consumes approximately 3,500 kg grass, 2,000 kg crops and 1,000 kg concentrated fodder. The carbon content in the diet is assumed to be 46.1% (mean value) of the dry weight as for the green field layer in /Fridriksson and Öhr 2003/. The dry weight in crop is 85% of the fresh weight according to /Jordbruksverket 2003a/. The dry weight in concentrated fodder is assumed to be equal to the dry weight in crop. The dry weight in grass is assumed to be 50% of the wet weight which is shown in /Belovsky 1986/, demonstrating a study concerning an arid grassland in Montana. The cattle faeces (egestion) has been calculated as 50% of the energy input (consumption), according to Table 2-4 in /Jerling et al. 2001/. The respiration was calculated by using the formula C = P+R+E. If the carbon flow is instead calculated according to the formulas presented in /Truvé and Cederlund 2005/ the consumption will be half as large, which means a smaller production, respiration and egestion. The consumption for a diary cow must on the other hand be larger than for a Moose, as the dairy cow is supposed to be very productive and therefore treated very supportive and facilitated.

Birds

A coarse density and biomass estimate of birds in the area has been given by (M Green 2005, pers. comm.). The terrestrial bird fauna make up 98% of the total bird fauna. In Laxemar area, this means a density of 637 pairs or 1,274 individuals per terrestrial square kilometre. The biomass is approximately 54 kg·km^{-2}. The figure is based upon the number of territories and the mean weight of each species. When calculating the standing stock, in mgC·m^{-2}, a carbon content of 22.9% of the total weight has been used as for mammals according to /Emsley 1998/. No carbon flows, that are production, consumption, respiration or egestion, have been possible to calculate for the bird fauna.

Amphibians and reptiles

Generic densities for the species that occur at Simpevarp area have been estimated by /Andrén 2004b/. Average body mass as well as feeding habits and the number of eggs/youngsters per individual are also included (see Table 3-5). No attempt has been made to calculate the production from the number of eggs/youngsters per female. Instead the production of the amphibians and the reptiles, as well as the egestion and respiration, 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), while the egestion represent 20% and the respiration 72%. The biomasses have been calculated with the assumption that the carbon content in amphibians and reptiles is 22.9%

as for mammals /Emsley 1998/. Reptiles are carnivores and their diet (small mammals, amphibians, other reptiles, insects and invertebrates) is assumed to contain 57% carbon of the dry weight, as for the mammals /Sterner and Elser 2002/. The different carbon flows to reptiles (C_{rept}) were differentiated based on the diet specification in Table 3-5. The Adder, for example, is the only reptile that consumes mammals and therefore the Adder consumption solely composes the flow $C_{rept\text{-}herbivores}$. Amphibians eat insects and invertebrates. To be able to calculate the total biomass of Moor frogs in the subareas, these areas had to be defined and calculated in ArcGIS. The Moor frog lives nearby small lakes, creeks, ponds and fens with slow running water, and its density varies with distance from a pond, see Table 3-5. The habitat size were calculated based on the lakes and open wetlands (fens or wetter wetlands) in the area, given by the vegetation map /Boresjö Bronge and Wester 2003/. The Moor frog habitats within Laxemar model area are illustrated in Figure 3-77.

Soil fauna

Three examples of soil fauna densities and biomass data are obtained. 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.

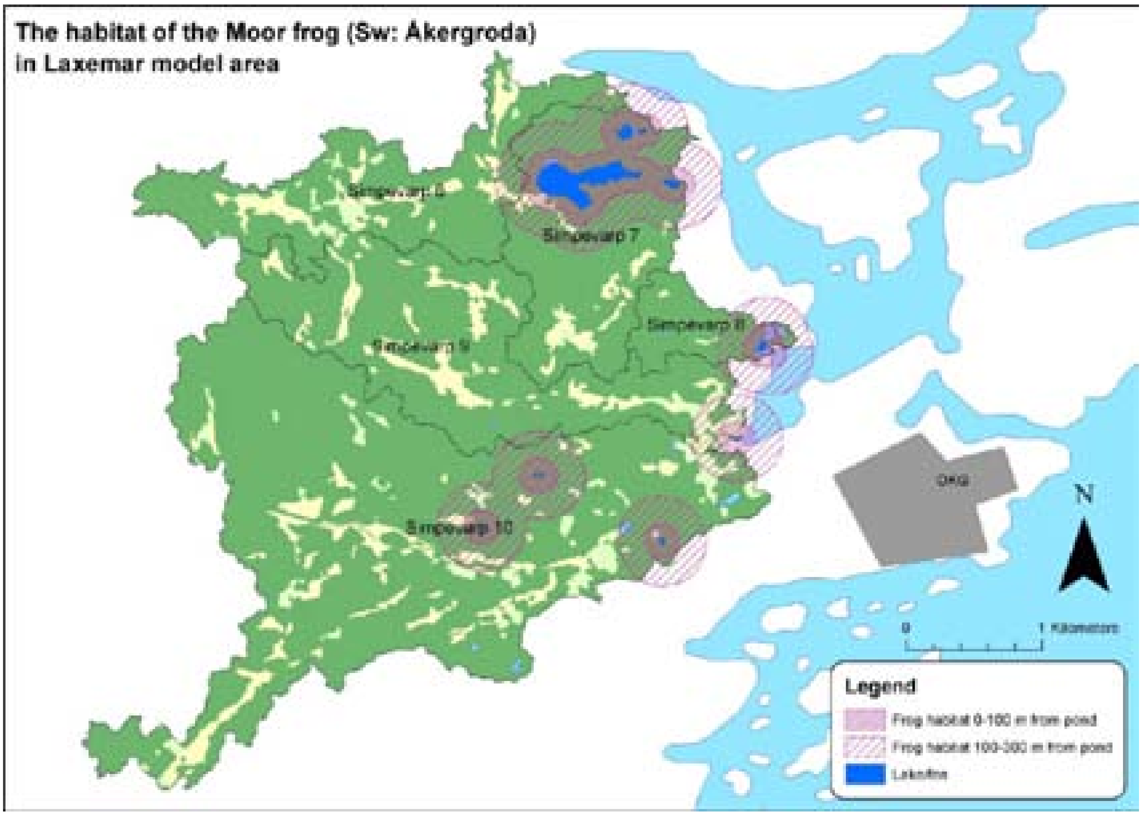

Figure 3-77. The Moor frog habitat, calculated and illustrated in ArcGIS based on the lakes and fens in the vegetation map /Boresjö Bronge and Wester 2003/.

Descriptive biomass and production models – Results

The calculations of biomass and carbon flows per unit area among the terrestrial consumers are compiled in Table 3-62. The total figures for the subareas are listed in Table 3-63.

Table 3-62. General figures per unit area concerning densities, biomass, production, consumption, egestion and respiration for the terrestrial consumers in Laxemar model area.

Species		Habitat	Density	Biomass (standing stock)		Produc-tion	Consump-tion	Egestion (Feaces)	Respira-tion
			Number per km^2	Body mass g/ind	Biomass C $mgC/m^2/y$	Prod C $mgC/m^2/y$	Consump C $mgC/m^2/y$	Faeces C $mgC/m^2/y$	Resp C $mgC/m^2/y$
Mammals – herbivores	Moose	Forest+Field	0.68	300,000	46	9.6	530	223	297
	Roe deer	Forest+Field	4.9	25,000	28	11	631	265	354
	Red deer	Forest+Field	0.030	170,000	1.2	0.28	16	6.6	8.7
	European hare	Field	3.5	3,800	3.1	2.1	115	48	65
	Mountaine hare	Forest	0.52	3,000	0.4	0.26	14	6.0	8.1
	Field vole	Field	420	30	2.9	3.0	252	55	194
	Mouse	Field	640	23	3.4	4.0	330	68	259
	Field vole	Forest	30	30	0.21	0.21	18	3.9	14
	Mouse	Forest	685	23	3.6	4.2	354	73	277
	Bank Vole	Forest	445	23	2.3	2.8	230	47	180
	Water vole	Around water[1]	570	74	9.7	6.4	569	146	416
	Cattle[2]	2.4 ha/cow	42	527,000	5,028	1,769	82,596	41,298	39,529
Mammal – omnivorous	Wild boar	Forest+Field	0.15	60,000	2.1	0.66	42	21	21
Mammals – carnivores	Marten	Forest+Field	0.13	1,250	0.040	0.040	1.9	0.71	1.1
	Red fox	Forest+Field	0.20	6,000	0.27	0.20	10.3	4.0	6.1
Mammal – insectivores	Common shrew	Forest+Field	100	8.5	0.19	0.13	24	9.2	15
Birds	Sum land birds[3]	Forest+Field	1,274	42	12				
Reptiles	Adder	Forest+Field	100	150	3.4	1.5	19	3.76	14
	Grass snake	Forest+Field	100	175	4.0	1.6	20	3.99	14
	Smooth snake	Forest+Field	20	70	0.32	0.13	1.6	0.32	1.1
	Slow worm	Forest+Field	1,000	15	3.4	2.7	34	6.84	25
	Common lizard	Forest+Field	500	5.0	0.57	0.48	6.0	1.20	4.3
	Sand lizard	Forest+Field	15	8.0	0.027	0.02	0.23	0.05	0.17
Amphibians	Common toad	Habitat amphibians	4,000	60	55	22	281	56	202
	Moor frog	0–100 m from pond	3,000	20	14	2.7	34	6.8	25
		100–300 m from pond	1,000	20	4.6	0.91	11	2.3	8.2
Soil fauna[4]		Field			5,277				
		Forest			627				

[1] A habitat zone of 10 m along each side of streams and lakes has been presumed.
[2] The cattle density is fictious and based on the fact that a cow need 2.4 ha for grazing and fodderproduction.
[3] A coarse estimate of the density before breeding has been used.
[4] Dry weight. The figure demonstrate the results from a pine moor in Gästrikland and a grass land in Uppland. Biomass (standing stock).

Table 3-63. The total carbon pools (biomass) and carbon flows for the terrestrial consumers in Simpevarp 6 to 10 within Laxemar model area.

Total gC per year	Simpevarp 6	Simpevarp 7	Simpevarp 8	Simpevarp 9	Simpevarp 10
Biomass					
B cattle	844,781	362,049	0	1,206,830	2,172,294
B herbivores	170,333	162,773	40,530	240,880	592,882
B carnivores	931	893	223	1,316	3,248
B insectivores	381	365	91	538	1,328
B bird	24,773	23,754	5,920	35,019	86,401
B reptiles	23,635	22,663	5,648	33,411	82,433
B amphibians	72,064	76,061	18,172	101,973	255,341
B soil fauna	2,833,096	1,868,295	333,342	3,960,372	8,338,893
Consumption					
C hum –cattle	297,196	127,370	0	424,566	764,219
C hum –herb	69,089	66,213	16,497	97,663	240,900
C hum –veg	22,466,815	9,292,947	937,491	30,173,150	55,035,250
C cattle –veg	13,876,100	5,946,900	0	19,823,000	35,681,400
C herb –veg	3,747,570	3,575,984	891,366	5,304,107	13,028,036
C carn –herb	16,212	15,545	3,874	22,917	56,542
C carn –birds	4,277	4,101	1,022	6,046	14,916
C carn –insects etc	1,923	1,844	460	2,718	6,707
C carn –veg	1,818	1,743	434	2,569	6,339
C carn –herpeto	148	142	35	210	517
C ins –insects	48,921	46,909	11,691	69,155	170,621
C rept –herb	37,683	36,132	9,005	53,268	131,425
C rept –insects etc	68,514	65,695	16,373	96,851	238,954
C rept –amphib	39,966	38,322	9,551	56,496	139,390
C rept –rept	3,197	3,066	764	4,520	11,151
C amphib –insects etc	367,009	369,240	90,071	519,062	1,289,981
Production					
P cattle	297,196	127,370	0	424,566	764,219
P herb	60,215	57,424	14,295	85,187	209,320
P carn	476	457	114	673	1,661
P ins	260	250	62	368	908
P rept	12,945	12,413	3,094	18,299	45,149
P amphib	29,361	29,539	7,206	41,525	103,198
Egestion					
E cattle	6,938,050	2,973,450	0	9,911,500	17,840,700
E herb	1,318,164	1,255,771	312,429	1,864,838	4,579,763
E carn	9,479	9,089	2,265	13,399	33,059
E ins	18,451	17,692	4,409	26,082	64,350
E rept	32,363	31,032	7,734	45,749	112,872
E amphib	73,402	73,848	18,014	103,812	257,996
Respiration					
R cattle	6,640,854	2,846,080	0	9,486,934	17,076,481
R herb	2,369,136	2,262,733	564,628	3,354,003	8,238,754
R carn	4,447	4,264	1,063	6,287	15,511
R ins	30,210	28,967	7,219	42,705	105,363
R rept	116,508	111,714	27,842	164,695	406,340
R amphib	264,247	265,853	64,851	373,725	928,786

Conclusions

The soil fauna represents the largest carbon pool in the terrestrial fauna. In the subareas where there might be agricultural activity, the domestic animals (cattle) will represent the second largest carbon pool. The uptake of vegetation by humans and herbivores (including cattle) represent the largest carbon flows.

Confidence and uncertainties

The herbivore production does not cover the consumption of herbivores, consumed by humans, carnivores (Marten and Fox) and reptiles. This incoherence might by a result of an overestimate of the density and/or consumption figure for Adder, as the production of voles and mice are much lower than the adder consumption (which is made up primarily by mice and voles). This is probably also a result of a too high estimate of the human consumption of Moose. When comparing human (see Table 3-99) 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 0.68 Moose·km^{-2}. All the same, the consumption is almost twice the production if a harvest of 0.35 is used instead. It should also be noted that the harvest values are recorded for *Oskarshamns Norra jaktvårdskrets,* an area of 714 km^2, while the population density figures have been estimated in a study area of approx. 120 km^2 /Cederlund et al. 2004/. The Moose is of course not evenly harvested within this area. Besides, the Moose does migrate within a large home range. The hunting figures for the Simpevarp area is in reality probable much lower than for *Oskarshamns Norra jaktvårdskrets* as a whole. Another explanation can of course be that the Moose density is underestimated. According to generic figures from /Svenska Jägareförbundet 2005, website/ the density is normally 1–1.5 Moose·km^{-2}, which is twice the estimation in Simpevarp (0.68 Moose·km^{-2}). The production in the populations of Hare and Roe deer are nearly balanced by the hunting activities. The Roe deer production is somewhat larger than the removal by hunting, while the hare production is clearly larger than the removal by hunting.

3.8 Limnic biota

3.8.1 Introduction

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. For some of the lakes there are also other biotic data collected, e.g. plankton, macrophytes, fish, and invertebrates. This report gives an account of data from four lakes; Lake Jämsen, Lake Frisksjön, Lake Söråmagasinet and Lake Plittorpsgöl.

Data have also been collected in streams, where a characterisation of the watercourses concerning vegetation, substrate, and encroachments has been performed. Moreover, invertebrate data have been collected in two of the streams.

3.8.2 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/. Macrophyte biomass has been investigated in Lake Frisksjön in August 2004 /Aquilonius 2005/, and macrophyte vegetation in watercourses have also been studied /Carlsson et al. 2005/.

Table 3-64. Data sources concerning primary producers in the limnic systems 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/
Macrophyte biomass	Lake Frisksjön	August 2004	/Aquilonius 2005/
Bottom vegetation (coverage and species)	Mederhultsån, Kåreviksån, Ekerumsån, Laxemarsån	2004	/Carlsson et al. 2005/

Metodology

The *lake characterisation* included identification of the 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 recorded using a DGPS and an 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 m. 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.

Macrophyte biomass was investigated along totally 7 transects in Lake Frisksjön in August 2004 /Aquilonius 2005/. Along these transects, frames with 0.5 m or 0.25 m sides were placed once in each 0.5 m depth interval, until the water depth and sight limited plants from growing. The water depth was measured for each frame. All plant individuals within the frames were identified and counted. Samples from each identified plant species were dried and weighed. The total dry weight of macrophyte biomass in each square was calculated from the number of individuals for each plant species and the dry weight/plant species. The calculations were often based only on one weighted sample of each plant species, and the result must therefore be considered as rough estimates of the total plant weight in each square.

A number of *stream parameters* were measured while walking along the stream, each of them estimated for every 10-metre section /Carlsson et al. 2005/. Notes were taken regarding morphometry, water velocity, shading, bottom substrate, vegetation and technical encroachments. For each investigated section, vegetation abundance was noted according to five abundance classes, together with up to five dominating plant species.

Description – lakes

The lakes in Oskarshamn have been divided into five different habitats according to /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 areas of the lakes without emergent or floating-leaved vegetation, but where the light penetration is enough to sustain photosynthetic primary production all the way 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 a permanent vegetation 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/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 characterisations for four of the investigated lakes, Lake Frisksjön, Lake Plittorpsgöl, Lake Jämsen and Lake Söråmagasinet, are presented.

Lake Frisksjön

All five major habitats are present in Lake Frisksjön (Table 3-65, Figure 3-78). Despite the relative shallowness of this lake (maximum depth 2.8 m), the brown colour of the water prevents light from penetrating down to the bottom in large 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.

Table 3-65. 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

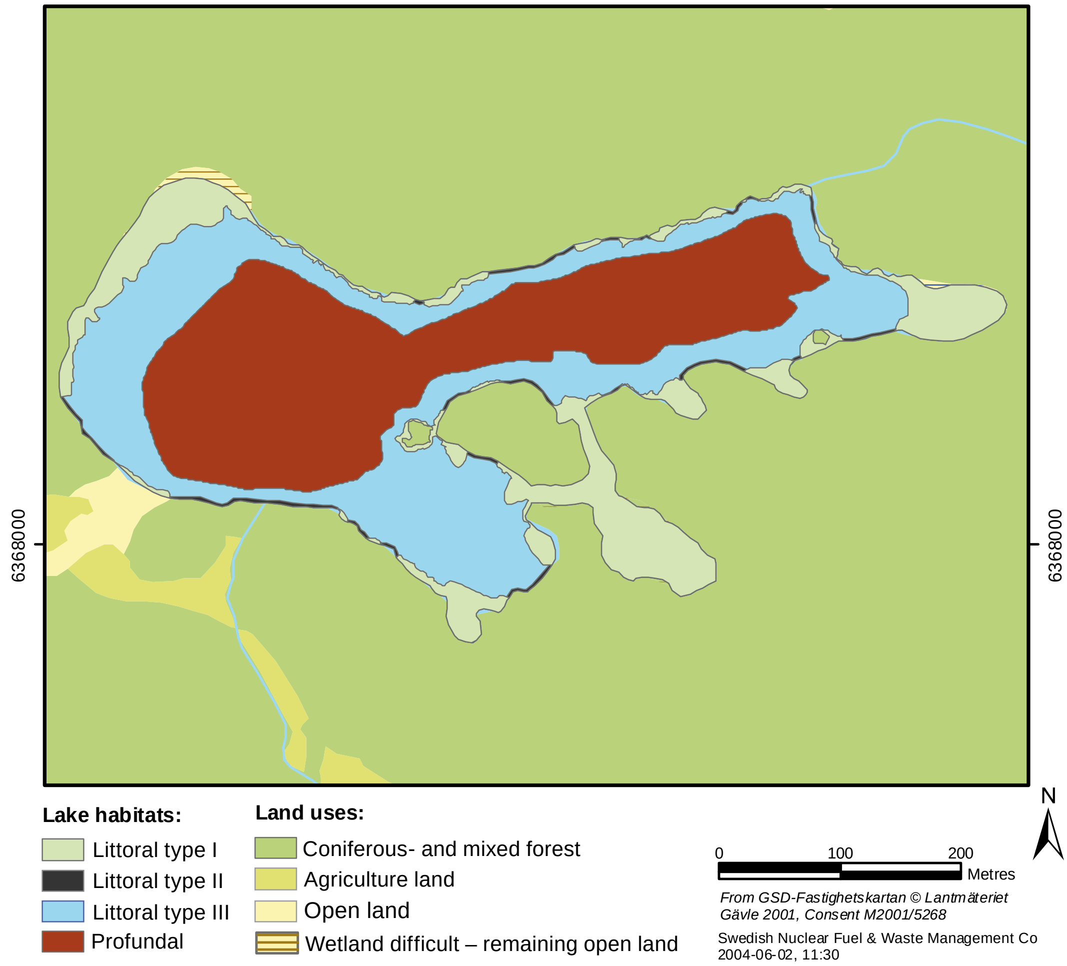

Figure 3-78. *Distribution of major habitats in Lake Frisksjön /Brunberg et al. 2004/.*

Macrophyte biomass in Lake Frisksjön was studied in August 2004, when the vegetation had reached its maximum biomass for the season. The calculations were often based only on one weight of each plant species and are therefore to be considered as rough estimates. In Littoral III, no vegetation was found. Littoral II hosted low vegetation biomass, whereas the biomass was higher in Littoral I (see Table 3-66). This indicates that the bottom area with light conditions below the compensation level, i.e. where it is too dark to enable primary production, is larger than the area classified as Profundal in /Brunberg et al. 2004/. In the ecosystem model for Lake Frisksjön presented below, we have therefore included the area of Littoral III in the Profundal.

Table 3-66. Biomass of macrophyte vegetation in Lake Frisksjön (data from /Aquilonius 2005/).

Habitat	Biomass (g DW m^{-2})
Littoral I	13.2
Littoral II	2.1
Littoral III	0

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 3-67). Dinophytes dominated phytoplankton biomass in July, whereas diatoms dominated in December 2003 and in April 2004 (Figure 3-79). *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 3-67. Phytoplankton biomass at three sampling occasions in the central part of Lake Frisksjön /Sundberg et al. 2004/.

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

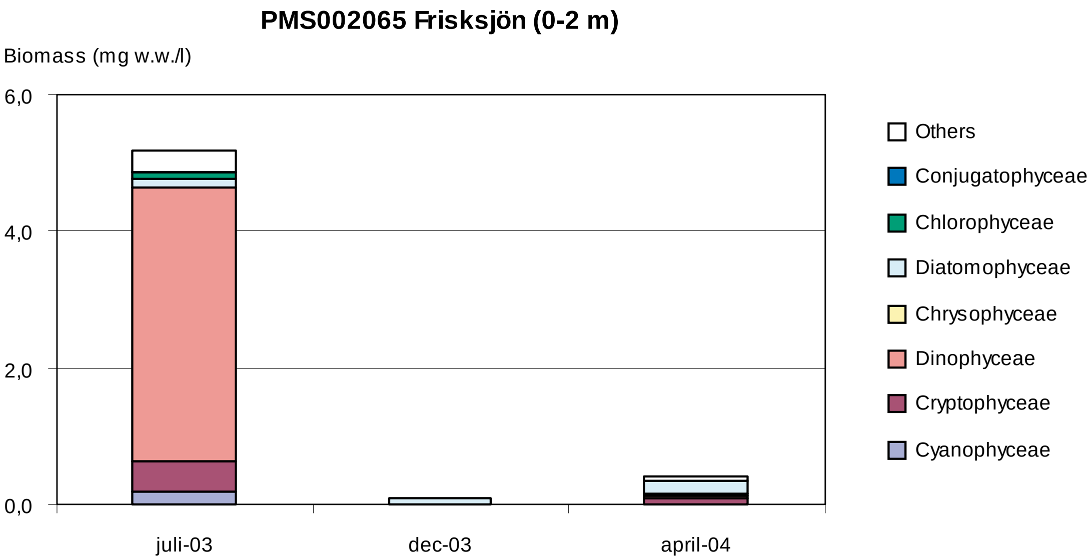

Figure 3-79. *Phytoplankton biomass in Lake Frisksjön (0–2 m), divided into different taxonomic classes /from Sundberg et al. 2004/.*

Lake Plittorpsgöl

All five major habitats are present in Lake Plittorpsgöl (Table 3-68, Figure 3-80). Due to the depth and the strong brown colour of the lake water, the profundal habitat is present at a major part of the bottom area. The littoral habitat with hard bottom is found through shorter parts around the shores.

Table 3-68. Distribution of major habitats in Lake Plittorpsgöl /Brunberg et al. 2004/.

Habitats	Area (%)	Area (m^2)
Littoral type I	20	6,630
Littoral type II	<1	290
Littoral type III	13	4,260
Pelagial	80	27,340
Profundal	67	22,800
Sum		33,980

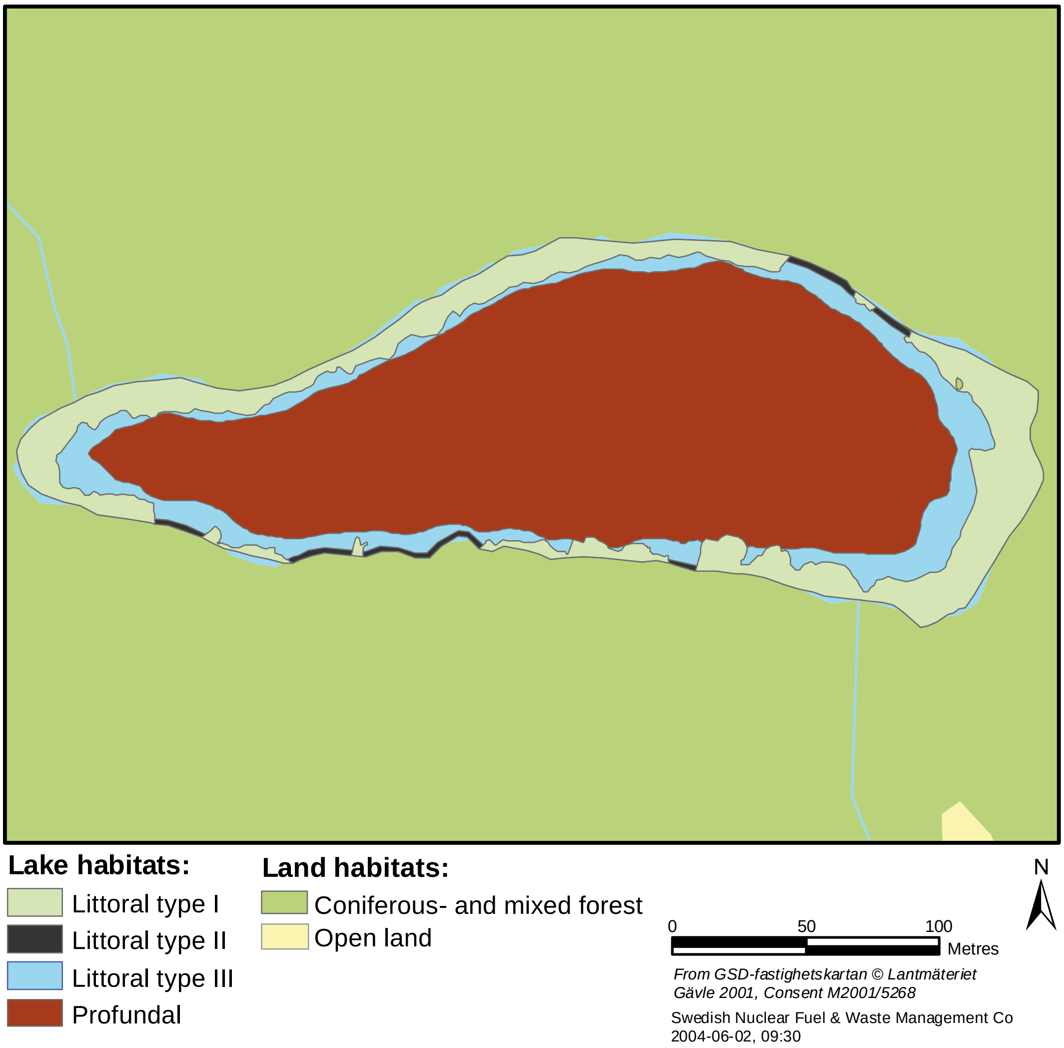

Figure 3-80. Distribution of major habitats in Lake Plittorpsgöl /Brunberg et al. 2004/.

Lake Jämsen

All five major habitats are present in Lake Jämsen (Table 3-69, Figure 3-81). Due to the brown water colour and relatively large depth of this lake, light does not reach large bottom areas and the littoral is restricted to the near-shore areas. Accordingly, the profundal habitat dominates the bottom areas of Lake Jämsen.

Table 3-69. Distribution of major habitats in Lake Jämsen /Brunberg et al. 2004/.

Habitats	Area (%)	Area (m²)
Littoral type I	21	48,500
Littoral type II	<1	1,550
Littoral type III	5	12,650
Pelagial	79	187,700
Profundal	75	177,300
Sum		240,000

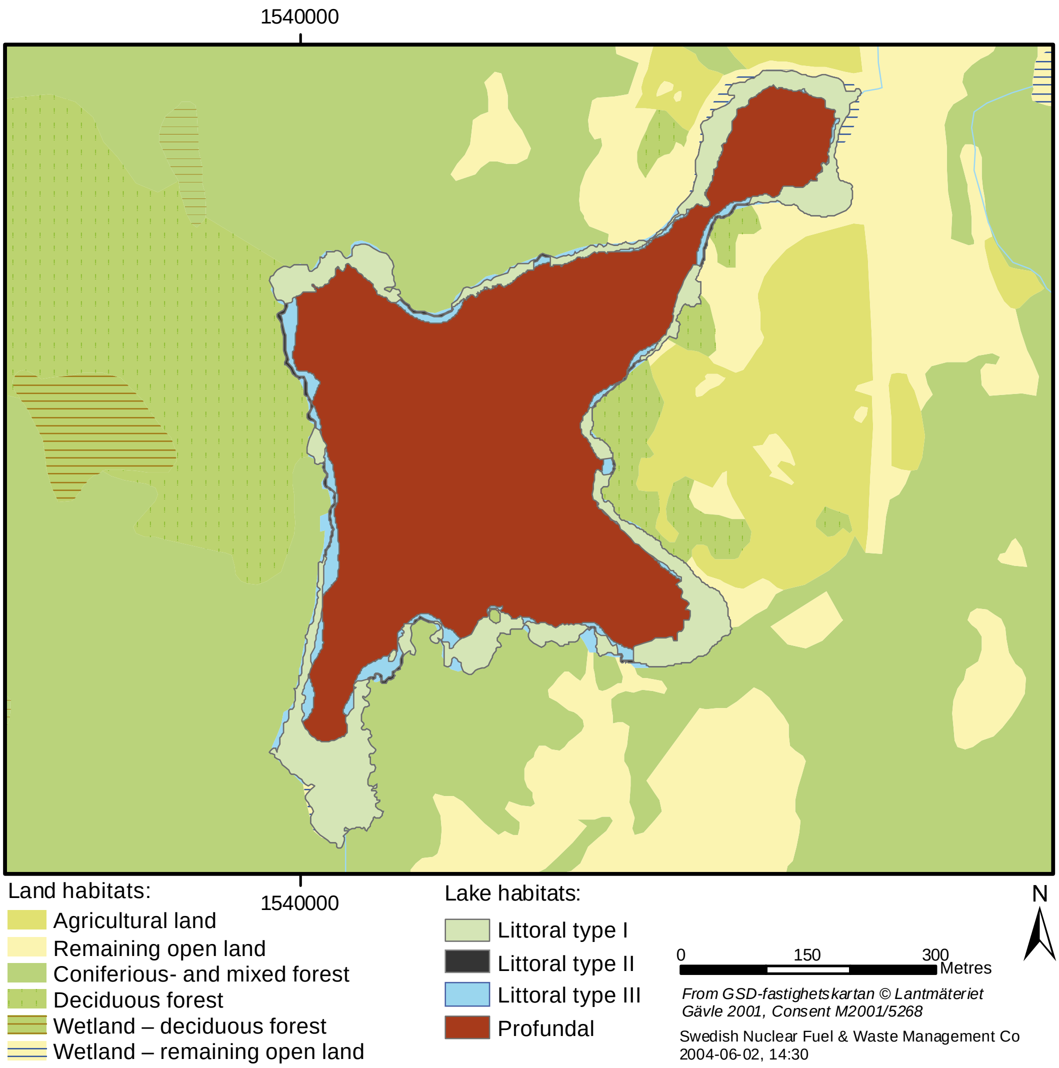

Figure 3-81. *Distribution of major habitats in Lake Jämsen /Brunberg et al. 2004/.*

Lake Söråmagasinet

All five major habitats are present in Lake Söråmagasinet (Table 3-70, Figure 3-82). This lake has a relatively small part of Littoral Type I compared to the other lakes in the Simpevarp area.

Table 3-70. Distribution of major habitats in Lake Söråmagasinet /Brunberg et al. 2004/.

Habitats	Area (%)	Area (m²)
Littoral type I	20	20,430
Littoral type II	<1	740
Littoral type III	40	39,690
Pelagial	80	82,330
Profundal	38	39,140
Sum		100,000

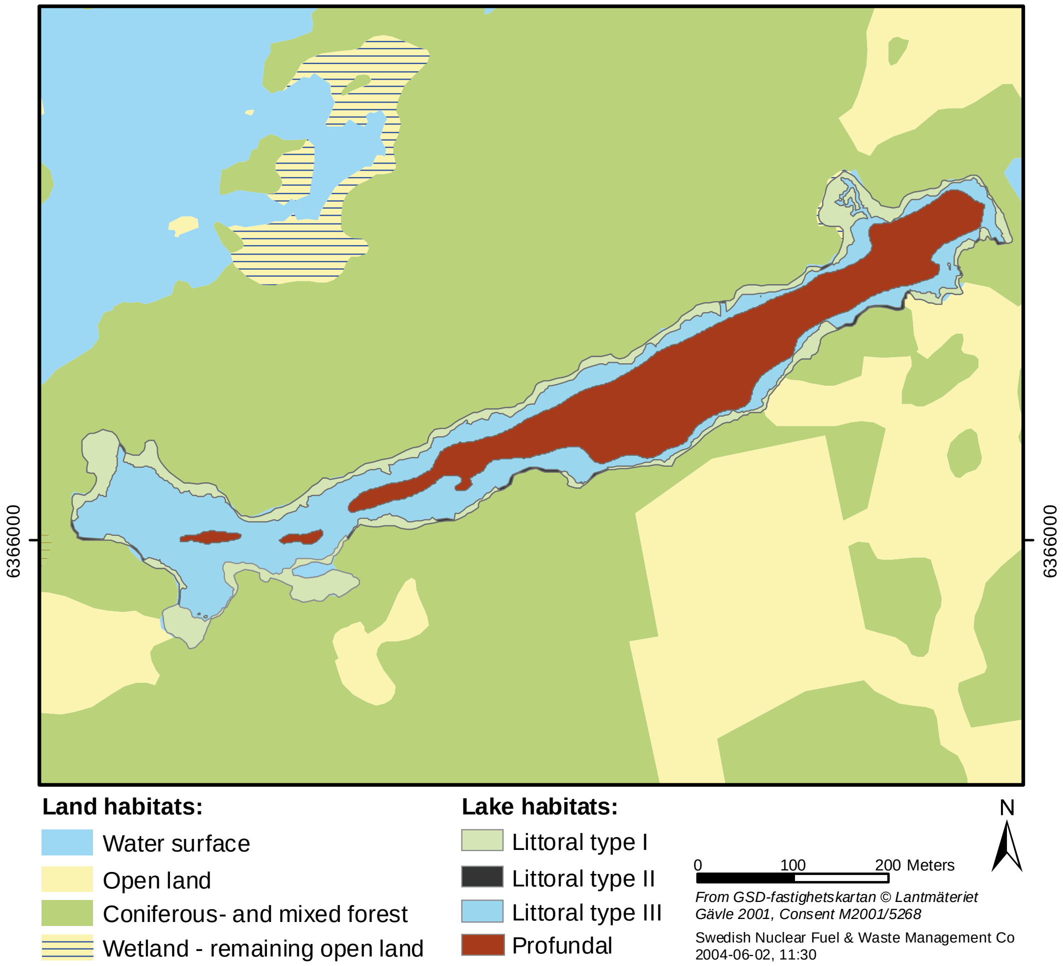

Figure 3-82. *Distribution of major habitats in Lake Söråmagasinet /Brunberg et al. 2004/.*

Description – watercourses

Mederhultsån

The investigated parts of the stream Mederhultsån were strongly dominated by slowly flowing water except for 160 m of dry sections, and a 130 m long section with slightly streaming water. Fine materials (fine organic material and clay) was the most common bottom substrate.

The vegetation cover was often 50% or more, the exception was in the downstream sections close to the outlet to the sea, where the growth was sparse or lacking (see Figure 3-83). The species that often dominated in upstream sections was *Lemna minor* (Common Duckweed, Sw. *Vanlig andmat*), which was found in substantial amounts. Further downstream, commonly dominating species were *Alisma plantago-aquatica* (Water plan-tain, Sw. *Svalting*), *Juncus effusus* (Soft-Rush, Sw. *Veketåg*), and *Sparganium sp* (Bur-reed, Sw. *Igelknopp*). The shading from terrestrial vegetation varied from zero to more than 50% along the investigated part of "Mederhultsån".

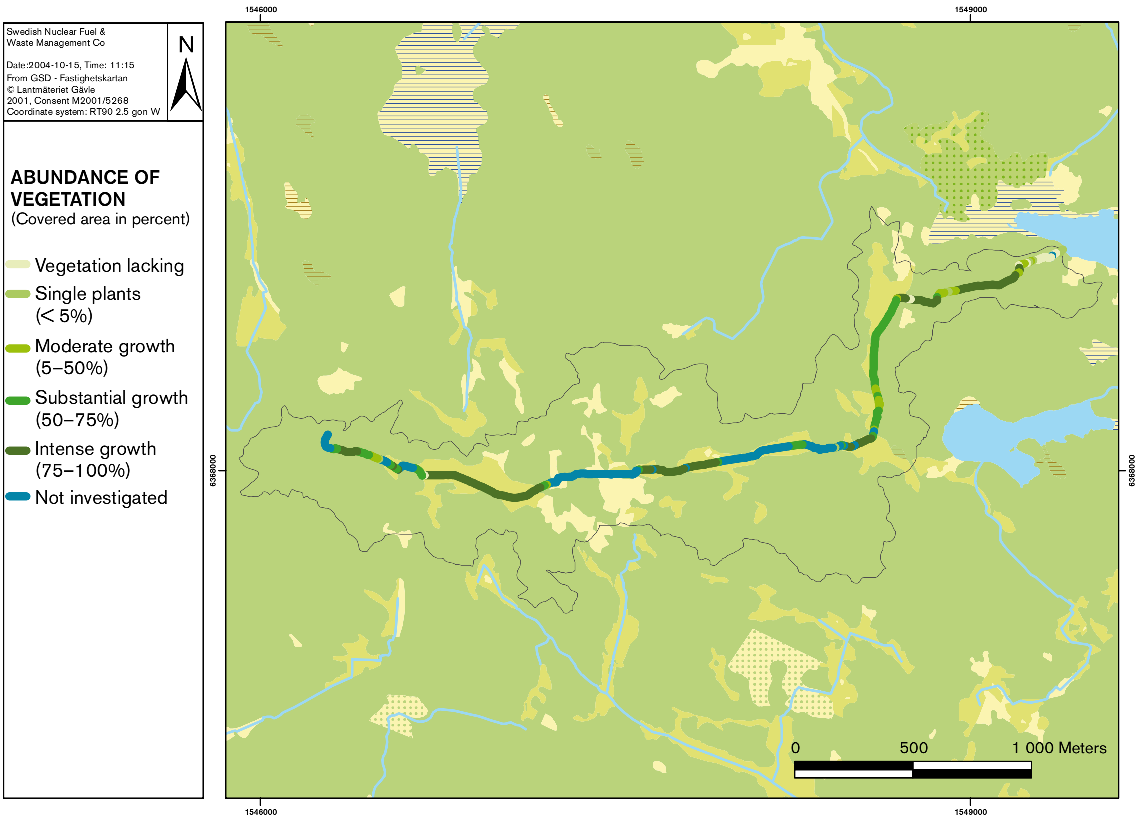

***Figure 3-83.** Vegetation in the stream Mederhultsån, in catchment Simpevarp 6 /Carlsson et al. 2005/.*

Kåreviksån

In all parts of the stream Kåreviksån where water was present, the water was slowly flowing (< 0.2 $m \cdot s^{-1}$). Dry sections dominated upstream of Lake Frisksjön, and these parts were not investigated regarding aquatic plants. Clay dominated the bottom substrate upstream of Lake Frisksjön, although sand was the most common substrate in the sections closest to the lake. Fine organic detritus dominated downstream of the lake.

In the most upstream part, where water was present, there were a few sections with dense growth of vegetation. Species that often dominated in this part of the stream were *Alisma plantago-aquatica*, but also sections with substantial amounts of *Lemna minor*. A substantial share of the uppermost part of the stream was not shaded at all. Downstream of Lake Frisksjön, where the channel was densely shaded, the vegetation was characterised by single plants, and in many of the sections vegetation was lacking (see Figure 3-84). Just as in the upstream parts, *A plantago-aquatica* was often among the dominating species, but also *Potamogeton polygonifolius* (Bog Pondweed, Sw. *Bäcknate*) and *Lysimachia thyrsiflora* (Tufted Loosestrife, Sw. *Topplösa*) dominated in some parts.

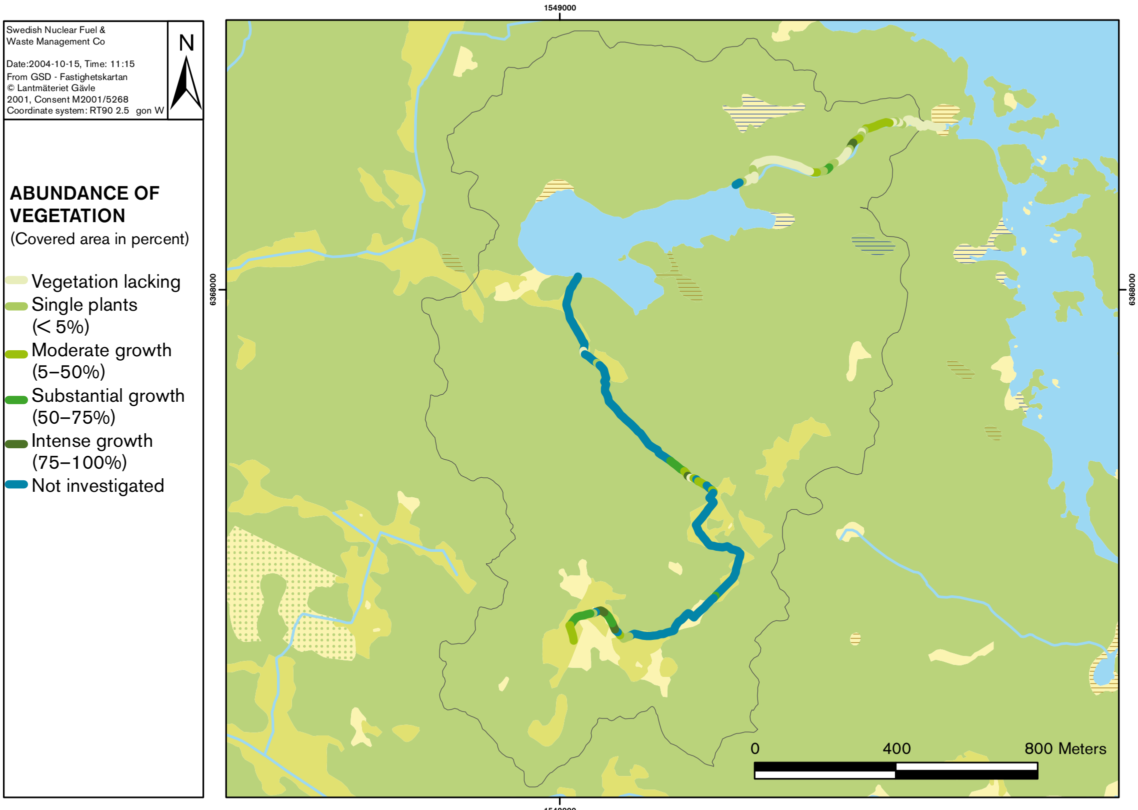

Figure 3-84. *Vegetation in the stream Kåreviksån, in catchment Simpevarp 7 /Carlsson et al. 2005/.*

Ekerumsån

The stream Ekerumsån was almost totally dominated by calm, slowly flowing water. Fine materials (fine organic material and clay) was the most common bottom substrate.There was a substantial and intense growth of vegetation in most parts (see Figure 3-85). Among the dominating species were *Alisma plantago-aquatica* and *Juncus effusus*. Large parts of the channel were not shaded at all.

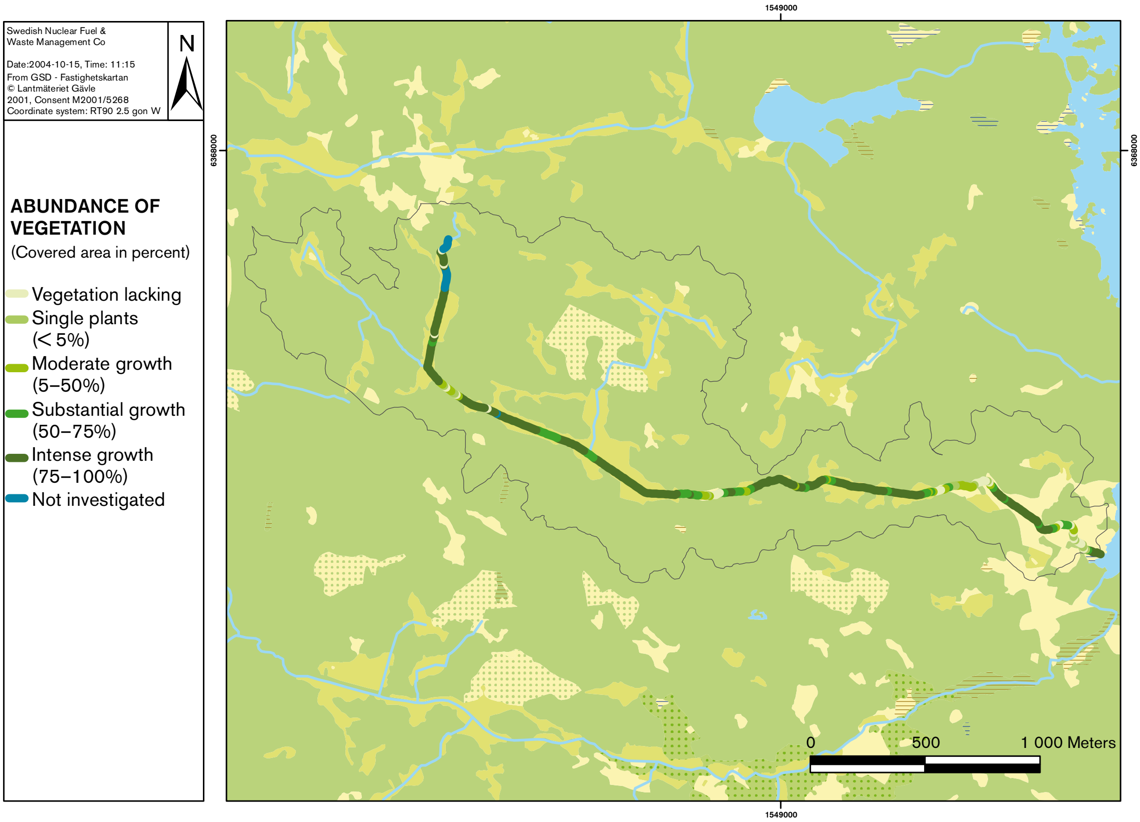

Figure 3-85. *Vegetation in the stream Ekerumsån, in the catchment Simpevarp 9 /Carlsson et al. 2005/.*

Laxemarsån

Investigations in the stream Laxemarsån has been performed in an upstream and a downstream section /see Carlsson et al. 2005/. In this report, only results from investigations in the downstream section are summarised.

The water velocity in the downstream section was mostly calm with slowly flowing water. Clay was most frequently the dominating bottom substrate whereas cobbles, sand and fine organic detritus also were dominating along some extended parts. The vegetation abundance fluctuated from “Lacking” to “Intense growth” (see Figure 3-86); however, “Lacking” was the most common abundance class. Species that frequently dominated the investigated sections were *Alisma plantago-aquatica* and *Nymphaeaceae* (Water lily, Sw. *näckros*). *Phragmites australis* (Common Reed, Sw. v*ass*) was commonly found in the most downstream part. Shading from terrestrial vegetation was more or less randomly distributed along the stream.

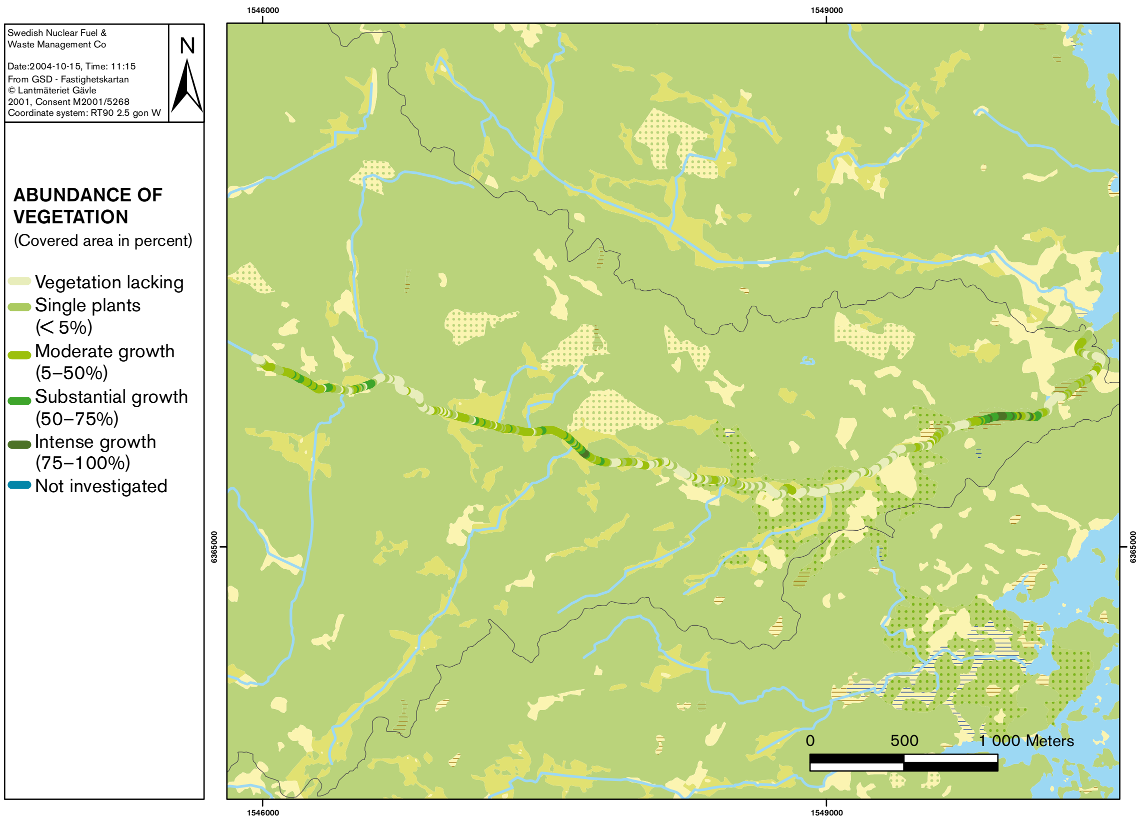

Figure 3-86. *Vegetation in the downstream investigated part of the stream Laxemarsån, in the catchment Simpevarp 10 /Carlsson et al. 2005/.*

3.8.3 Consumers

Input data

Data sources for limnic consumers in the Laxemar area are shown in Table 3-71. 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 (Lake Jämsen, Lake Söråmagasinet, Lake Frisksjön, Lake Plittorpsgöl, Laxemarsån and the stream from Lake Frisksjön) /Ericsson and Engdahl 2004c/. In the same four lakes have fish data been collected in August 2004 /Engdahl and Ericsson 2004/.

Table 3-71. 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 Lake Frisksjön, Laxemarsån	2004	/Ericsson and Engdahl 2004c/
Fish biomass	Lake Jämsen, Lake Söråmagasinet, Lake Frisksjön, Lake Plittorpsgöl	2004	/Engdahl and Ericsson 2004/

Methodology

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 was sampled in April 2004 from two streams and from different depth zones in four lakes. In the streams and 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 3-72).

Table 3-72. Classification of fish species into functional groups according to /Holmgren and Appelberg 2000/.

Functional group	Included species
Planktivorous fish	Bleak, 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 – lakes

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 3-87). 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 small 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.*

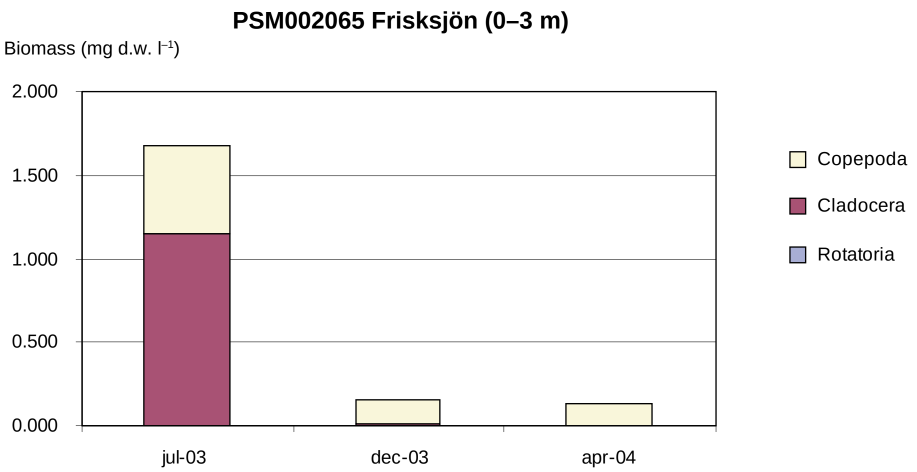

Figure 3-87. *Biomass of different zooplankton groups in the water column of Lake Frisksjön (0–3 m).*

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 3-73).

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 3-74). 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 3-75).

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 3-76.

Table 3-73. 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 m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	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	1.663	100

Table 3-74. 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 m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	27.9	1.5	179.86	97.3
Detritus feeders	1,534.9	83.3	1.37	0.7
Predators	260.5	14.1	3.64	2.0
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	18.6	1.0	0.0019	0.0010
Sum	1,841.9	100	184.87	100

Table 3-75. 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 m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	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

Table 3-76. Compiled results of fish data from Lake Frisksjön (8 gillnets), August 2004 /Engdahl and Ericsson 2004/.

Functional group	Species	Weight per Unit Effort (kg)	Biomass (kg/ha)	Total biomass (kg)	Total carbon biomass (kg C)
Z-fish	Perch	0.044			
	Z-fish total	0.044	1.5	15.7	1.5
M-fish	Bream	0.272			
	Ruffe	0.008			
	Perch	0.267			
	Roach	0.312			
	Rudd	0.032			
	M-fish total	0.891	29.4	315.3	31.0
F-fish	Perch	0.112			
	Pike	0.723			
	F-fish total	0.835	27.6	295.6	29.1
Total		1.77	58.4	626.6	61.7

Lake Plittorpsgöl

In the littoral the substrate was dominated by detritus. The site had some vegetation of above surface plants. Detritus feeders and predators were most abundant group among *benthic fauna* and dominated the biomass (Table 3-77).

In the sublittoral the substrate was dominated by detritus. Predators and detritus feeders were most abundant and they also dominated the biomass (Table 3-78).

In the profundal the predators were most abundant and they also dominated the biomass (Table 3-79).

Table 3-77. Abundance and biomass of different functional groups of benthic fauna in the littoral zone of Lake Plittorpsgöl (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m⁻²)	Abundance (%)	Biomass (g WW m⁻²)	Biomass (%)
Filter feeders	38.4	7.1	0.078	2.9
Detritus feeders	312.0	57.5	1.764	65.9
Predators	59.2	10.9	0.636	23.7
Scrapers	40.0	7.4	0.030	1.1
Shredders	1.6	0.3	0.113	4.2
Other/unknown	91.2	16.8	0.056	2.1
Sum	542.4	100	2.677	100

Table 3-78. Abundance and biomass of different functional groups of benthic fauna in the sublittoral zone of Lake Plittorpsgöl (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	18.6	0.6	0.142	1.6
Detritus feeders	1,162.8	38.7	3.676	41.6
Predators	1,665.1	55.4	5.014	56.7
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	158.1	5.3	0.0065	0.1
Sum	1,841.9	100	184.87	100

Table 3-79. Abundance and biomass of different functional groups of benthic fauna in the profundal zone of Lake Plittorpsgöl (mean value, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	288.4	13.4	0.622	7.2
Predators	2,195.3	86.6	7.977	92.8
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	0	0	0	0
Sum	2,483.7	100	8.599	100

The catch from the fish survey was dominated by perch in numbers, as well as in biomass, followed by roach /Engdahl and Ericsson 2004/. Data from the fish survey, divided into functional groups, is presented in Table 3-80.

Table 3-80. Compiled results of fish data from Lake Plittorpsgöl (4 gillnets), August 2004 /Engdahl and Ericsson 2004/.

Functional group	Species	Weight per Unit Effort (kg)	Biomass (kg/ha)	Total biomass (kg)	Total carbon biomass (kg C)
Z-fish	Perch	0.0088			
	Z-fish total	0.0088	0.3	0.8	0.1
M-fish	Perch	0.054			
	Roach	0.264			
	M-fish total	0.318	10.5	28.6	2.8
F-fish	Perch	0.344			
	Pike	0.134			
	F-fish total	0.477	15.7	43.0	4.2
Total		0.800	26.5	72.4	7.1

Lake Jämsen

In the upper littoral the substrate was dominated by detritus. The site had a rich vegetation of above surface plants. Detritus feeders and predators were most abundant but shredders and predators were the most dominant groups in relation to biomass (Table 3-81).

In the lower littoral the substrate was dominated of detritus and there was no vegetation. Predators and detritus feeders were the only functional groups present (Table 3-82). The site which was meant to represent a low littoral had more resemblance to a sublittoral.

In the sublittoral the substrate was dominated by detritus with some sand. Detritus feeders were most abundant and they also dominated the biomass (Table 3-83).

In the profundal predators were most abundant and they also dominated the biomass (Table 3-84).

Table 3-81. Abundance and biomass of different functional groups in the upper littoral zone of Jämsen (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	174.4	54.4	0.351	37.4
Predators	72.8	22.7	0.118	12.5
Scrapers	13.6	4.2	0.051	5.0
Shredders	3.2	1.0	0.325	35.0
Other/unknown	56.8	17.7	0.094	10.0
Sum	320.8	100	0.938	100

Table 3-82. Abundance and biomass of different functional groups in the lower littoral zone of Jämsen (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m⁻²)	Abundance (%)	Biomass (g WW m⁻²)	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	344.2	50.7	1.558	60.0
Predators	334.9	49.3	1.037	40.0
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	0	0	0	0
Sum	679.1	100	2.595	100

Table 3-83. Abundance and biomass of different functional groups in the sublittoral zone of Jämsen (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m⁻²)	Abundance (%)	Biomass (g WW m⁻²)	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	586.0	87.5	0.997	92.0
Predators	55.8	8.3	0.084	7.7
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	27.9	4.2	0.0028	0.3
Sum	669.8	100	1.084	100

Table 3-84. Abundance and biomass of different functional groups in the profundal zone of Jämsen (mean values, N = 8) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m⁻²)	Abundance (%)	Biomass (g WW m⁻²)	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	881.1	24.6	1.758	15.0
Predators	4,775.2	75.2	9.868	84.1
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	7.8	0.2	0.102	0.9
Sum	5,664.1	100	11.728	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 3-85.

Table 3-85. Compiled results of fish data from Lake Jämsen (16 gillnets), August 2004 /Engdahl and Ericsson 2004/.

Functional group	Species	Weight per Unit Effort (kg)	Biomass (kg/ha)	Total biomass (kg)	Total carbon biomass (kg C)
Z-fish	Perch	0.009			
	Bleak	0.028			
	Z-fish total	0.037	1.2	23.0	2.3
M-fish	Bream	0.138			
	Ruffe	0.010			
	Perch	0.084			
	Roach	0.068			
	Rudd	0.007			
	M-fish total	0.307	10.1	189.9	18.7
F-fish	Perch	0.203			
	Pike	0.109			
	F-fish total	0.312	10.3	193.1	19.0
Total		0.660	21.6	406.0	40.0

Lake Söråmagasinet

In the littoral, the substrate was dominated by detritus but some stones and boulders were present. The site had some above surface plants. Detritus feeders and predators were most abundant, but also scrapers were among the dominant groups in relation to biomass (Table 3-86). In the sublittoral, the substrate was dominated by detritus and there was no vegetation. Predators were most abundant, but also detritus feeders were an important group (Table 3-87). In the profundal, predators were most abundant and they also dominated the biomass (Table 3-88).

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 3-89.

Table 3-86. Abundance and biomass of different functional groups in the littoral zone of Söråmagasinet (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	4.8	0.6	0.134	6.1
Detritus feeders	280.8	335.0	0.791	36.2
Predators	235.2	29.3	0.885	40.5
Scrapers	166.4	20.8	0.320	14.6
Shredders	2.4	0.3	0.010	0.4
Other/unknown	112.0	14.0	0.045	2.1
Sum	801.6	100	2.184	100

Table 3-87. Abundance and biomass of different functional groups in the sublittoral zone of Söråmagasinet (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	353.5	22.4	0.69	19.3
Predators	1,227.9	77.6	2.87	80.7
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	0	0	0	0
Sum	1,581.4	100	3.56	100

Table 3-88. Abundance and biomass of different functional groups of benthic fauna in the profundal zone of Söråmagasinet (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	0	0	0	0
Detritus feeders	279.1	23.7	0.16	5.6
Predators	893.0	76.3	2.62	94.4
Scrapers	0	0	0	0
Shredders	0	0	0	0
Other/unknown	0	0	0	0
Sum	1,172.1	100	2.77	100

Table 3-89. Compiled results of fish data from Lake Söråmagasinet (8 gillnets), August 2004 /Engdahl and Ericsson 2004/.

Functional group	Species	Weight per Unit Effort (kg)	Biomass (kg/ha)	Total biomass (kg)	Total carbon biomass (kg C)
Z-fish	Perch	0.003			
	Z-fish total	0.003	0.1	0.7	0.1
M-fish	Bream	0.602			
	Ruffe	0.018			
	Perch	0.326			
	Roach	0.480			
	Rudd	0.015			
	M-fish total	1.440	47.5	391.0	38.5
F-fish	Perch	0.565			
	Pike	0.140			
	F-fish total	0.704	23.2	191.2	18.8
Total		2.146	70.8	582.9	57.4

Description – watercourses

Laxemarsån

Benthic fauna was investigated in April 2004 at one upstream and one downstream site in the stream Laxemarån /Ericsson and Engdahl 2004c/. At the downstream site, the substrate was dominated by stones and gravel and there was no vegetation. Detritus feeders and shredders were most abundant (Table 3-90). The biomass was dominated by detritus feeders, predators, and shredders.

At the upstream site the substrate was a mixture of gravel, stones, and boulders and there was no vegetation. Both abundance and biomass of benthic fauna was largely dominated by shredders (Table 3-91).

Table 3-90. Abundance and biomass of different functional groups of benthic fauna at the downstream site in Laxemarsån (near Lake Söråmagasinet) (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	116.8	15.1	0.265	10.3
Detritus feeders	236.0	30.5	1.186	46.1
Predators	47.2	6.1	0.506	19.7
Scrapers	32.0	4.1	0.056	2.2
Shredders	228.0	29.5	0.476	18.5
Other/unknown	112.8	14.6	0.086	3.3
Sum	772.8	100	2.575	100

Table 3-91. Abundance and biomass of different functional groups of benthic fauna at the upstream site in Laxemarsån (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	123.2	6.5	0.392	13.6
Detritus feeders	156.0	8.2	0.546	18.9
Predators	52.0	2.7	0.700	24.2
Scrapers	7.2	0.4	0.002	0.1
Shredders	1,513.6	79.3	1.222	42.3
Other/unknown	56.0	2.9	0.027	0.9
Sum	2,474.4	100	2.888	100

Stream from Lake Frisksjön

The samples were taken approximately 50 m downstream from the outlet of Lake Frisksjön. The substrate was dominated by sand and there was only little vegetation. Filter feeders and detritus feeders dominated the species composition, both the abundance and the biomass (Table 3-92). A dominance of filter feeders is normal close to lake outlets.

Table 3-92. Abundance and biomass of different functional groups at the site in the stream from Frisksjön (mean values, N = 5) /Ericsson and Engdahl 2004c/.

Functional groups	Abundance (number m^{-2})	Abundance (%)	Biomass (g WW m^{-2})	Biomass (%)
Filter feeders	1,732.0	56.6	4.072	55.2
Detritus feeders	802.4	26.2	1.759	23.9
Predators	103.2	3.4	0.353	4.8
Scrapers	172.8	5.6	0.077	1.0
Shredders	168.8	5.5	0.913	12.4
Other/unknown	83.2	2.7	0.195	2.7
Sum	3,062.4	100	7.370	100

Summary of characteristic of lakes and of watercourses in the regional model area

Lake Frisksjön, Lake Plittorpsgöl, and Lake Jämsen are all small, brown-water lakes, typical for this area of Sweden. Lake Söråmagasinet is a man-mad construction, created for water supply purposes to the nuclear power plant by cutting off of a narrow creek of the Baltic Sea. The watercourses in the area are generally small and to a large extent affected by human activities, i.e. straightening and ditching. In all of the investigated lakes, the profundal zone is the most common habitat, covering extended areas. The generally poor light condition, which is an effect of the brownish water colour, implies that macrophyte vegetation is restricted to shallow areas near the shoreline. Generally, a distinct thermal stratification develops during summer, and due to the high organic content in lake water, low oxygen conditions develop in the deeper parts of the lakes during stagnant periods, i.e. during summer and winter.

Concerning the fish community, Lake Frisksjön, Lake Jämsen, and Lake Söråmagasinet are all classified as “normal” lakes according to the Swedish fish index (FIX), published by the Swedish Environmental Protection Agency /Wiederholm 1999/. In these three lakes, seven different species were found. The smallest lake, Lake Plittorpsgöl, showed relatively low fish biomass as well as few individuals, and only three fish species were found in this lake. The relative fish abundance (CPUE in number as well as in weight) was highest in Lake Frisksjön and Lake Söråmagasinet, whereas the relative biomass was less than half in the other two lakes.

The benthic fauna showed similar species composition in all of the investigated lakes /Ericsson and Engdahl 2004c/. In the littoral, the diversity was moderately high or high, and many species groups were present. The dominant functional group in the littoral of most lakes was detritus feeders, but most functional groups were present. In the profundal zone of the investigated lakes, species richness was generally low. All species found were tolerant against low oxygen concentration, and most certainly the low species richness in the profundal of the investigated lakes was an effect of the low oxygen concentration /Ericsson and Engdahl 2004c/.

In this report we view watercourses 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. However, stream sections with low water velocity and fine organic bottom sediments indicate conditions where sedimentation may occur. The occurrence of such sections may affect the transport of matter and potentially retard radionuclide transport. The most obvious retardation process is through sedimentation of contaminated particles. Another possibility is uptake of radionuclides by vegetation, which brings the radionuclides into the food web.

In Table 3-93, we have compiled the share of sections where sedimentation may occur of the total number of investigated sections, and we have also calculated the share of sections with dense macrophyte vegetation of the total number potential sedimentation sections in each of the watercourses. The compilation shows that the watercourses Mederhultsån and Ekerumsån are similar in these characteristics, and that there may be a potential for sedimentation and retardation of radionuclide transport in these watercourses. The prerequisites for sedimentation is considerably lower in the other two investigated watercourses, and especially the downstream part of Laxemarsån, situated in the SurfaceNet model area, shows a small share of sections with sedimentation. which potentially may affect the transport of matter.

Table 3-93. Characteristics which potentially may affect the transport of matter in the investigated watercourses in the Laxemar area. Sections with sedimentation are those 10-metre sections classified as "Calm, slowly flowing water" in /Carlsson et al. 2005/, and sections with dense vegetation are those where the abundance of vegetation is classified as "Intense growth".

Watercourse	Sections with sedimentation (% of all investigated sections)	Sections with dense vegetation (% of all sections with sedimentation)
Mederhultsån	44	89
Kåreviksån	25	6
Ekerumsån	62	88
Laxemarsån*	27 (9)	55 (64)

*Figures within brackets shows % of the sections in the SurfaceNet model area

3.9 Marine biota

3.9.1 Introduction

The description of the marine ecosystems at Laxemar is 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 obtained in the site investigation programme /SKB 2002/.

In Section 4.3 biomasses and processes are distributed spatially in the area and summarized for 17 different basins. 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, 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). The basins characteristics are described below.

3.9.2 Overview

The Laxemar marine ecosystem has been divided in fourteen basins. The division is based on bathymetry and coincides with projected future drainage basins. Their characteristics are described below (see Figure 3-88) and in Section 4.3.

The marine system in Laxemar encompasses three major habitats; semi-enclosed bays 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

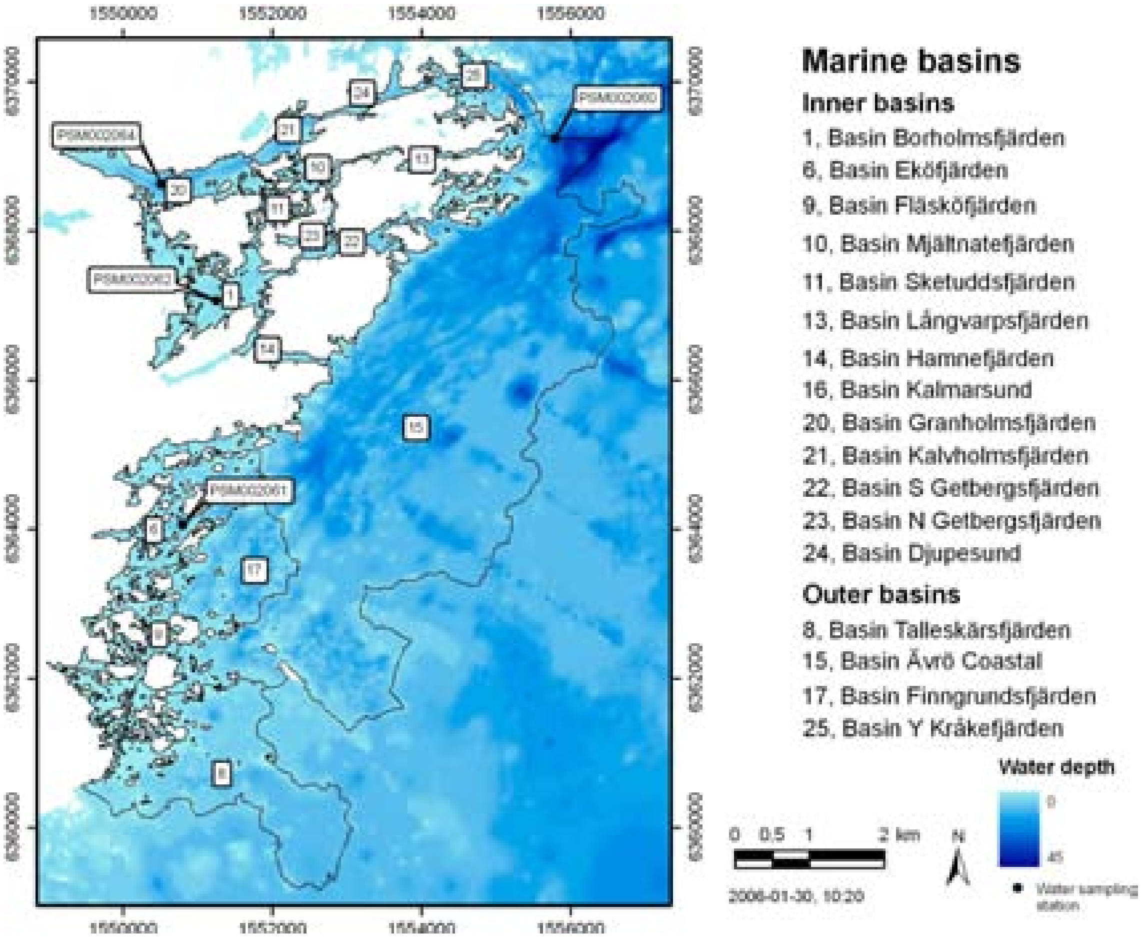

Figure 3-88. *The basins in the Laxemar area. The digital elevation model for the sea is displayed in increasing dark blue with depth.*

have a variable geometry, large shallow areas (less than 1 m) are found as well as depth down to 18 m. Area, volume and mean depth of the basins are found in Table 4-14. 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 inner soft bottom parts of the archipelago north of Laxemar (around Äspö) are dominated by *Chara sp* (Figure 3-89). West of Ävrö a large area is covered by Xanthophyceae *Vaucheria sp*. On corresponding bottoms in the southern area the vegetation is dominated by vascular plant communities, mostly *Potamogeton pectinatus* and *Zostera marina*. The sheltered inner coastal waters, particularly south of Laxemar, are dominated by *P. pectinatus*. 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 /Fredriksson and Tobiasson 2003/. *Fucus sp* in low abundance is recorded to approximatey 10 m depth and red algae down to approximately 30 m /Tobiasson 2003/. The benthic fauna is dominated by filter feeders (*Mytilus edulis*) and detritivores, often *Macoma baltica* or *Hydrobia sp*. In the coastal hard bottom areas filter feeders constitutes for up to 95% of the biomass /Fredriksson 2005/ and detritivores on the other hand constitutes for 50–80% of the biomass in the inner areas e.g. basin Borholmsfjärden. In total 45 animal species associated to the vegetation occurred in the area around Laxemar. The *Fucus sp* communities is the most

Table 3-94. Area, volume and mean depth of the basins in the Laxemar area.

Number	Name	Area (m^2)	Mean depth (m)	Volume (m^3)
1	Basin Borholmsfjärden	$1.37 \cdot 10^6$	1.6	$2.21 \cdot 10^6$
2	Basin Granholmsfjärden	$1.29 \cdot 10^6$	5.3	$6.88 \cdot 10^6$
3	Basin Getbergsfjärden	$3.61 \cdot 10^5$	3.2	$1.17 \cdot 10^6$
6	Basin Eköfjärden	$1.63 \cdot 10^6$	2.6	$4.30 \cdot 10^6$
8	Basin Talleskärsfjärden	$4.30 \cdot 10^6$	5.6	$2.40 \cdot 10^7$
9	Basin Fläsköfjärden	$1.03 \cdot 10^6$	0.6	$6.04 \cdot 10^5$
10	Basin Mjältnatefjärden	$2.85 \cdot 10^5$	0.7	$1.94 \cdot 10^5$
11	Basin Sketuddsfjärden	$1.56 \cdot 10^5$	0.9	$1.48 \cdot 10^5$
12	Basin Kråkefjärden	$8.99 \cdot 10^5$	5.7	$5.15 \cdot 10^6$
13	Basin Långvarpsfjärden	$8.91 \cdot 10^4$	estimated: 0.5	$4.58 \cdot 10^4$
14	Basin Hamnefjärden	$1.61 \cdot 10^5$	2.2	$3.58 \cdot 10^5$
15	Basin Ävrö Coastal	$2.02 \cdot 10^7$	11.9	$2.40 \cdot 10^8$
16	Basin Kalmarsund	$4.89 \cdot 10^8$	13.2	$6.44 \cdot 10^9$
17	Basin Finngrundsfjärden	$1.89 \cdot 10^6$	6.7	$1.27 \cdot 10^7$

diverse concerning associated fauna and harbour 31 species or higher taxa, while in the soft bottoms without vegetation only 14 species has been found.

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 is more abundant in the inner bays than in the coastal areas.

3.9.3 Producers

Four sources of site specific data have been used, all a part of the site investigation programme, Table 3-95. These studies are described below or in Section 4.3.

Table 3-95. Data sources concerning primary producers in the marine systems of Laxemar.

Parameter	Basin	Year	Reference
Water chemistry sampling; Chlorophyll, light penetration, temperature, carbon content	Basin 1, 2, 15, 6	2002–2004 2002–2004 2002–2004	/Ericsson and Engdahl 2004ab, field measurements in SICADA/
Macrophytes; Biomass, distribution	All basins	2002	/Fredriksson and Tobiasson 2003/
Reed (*Phragmites australis*); Biomass	Basin 1, 2, 14	2004	/Alling et al. 2004b/

Macrophytes

The vegetation map presented in /Fredriksson and Tobiasson 2003/ is based on three different data sets; the general survey of over 1,000 sites with recordings on dominant macrophytes and coverage, 20 diving transects and quantitative samples, 40 video recordings and bathymetrical data from the Swedish sea charts. The map was drawn by hand and the accuracy is dependant 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 nine different vegetation communities were defined on basis of dominating species or higher taxa (Figure 3-89). Figure 3-89 also presents the area covered by the different vegetation communities. Red algae community covered the largest area followed by *Potamogeton pectinatus*-community, *Chara sp* and *Fucus vesiculosus.* The vegetation communities consist of sub areas of different composition of species and coverage degree. Occurring species, species composition and methods are presented in more detail in /Fredriksson and Tobiasson 2003/.

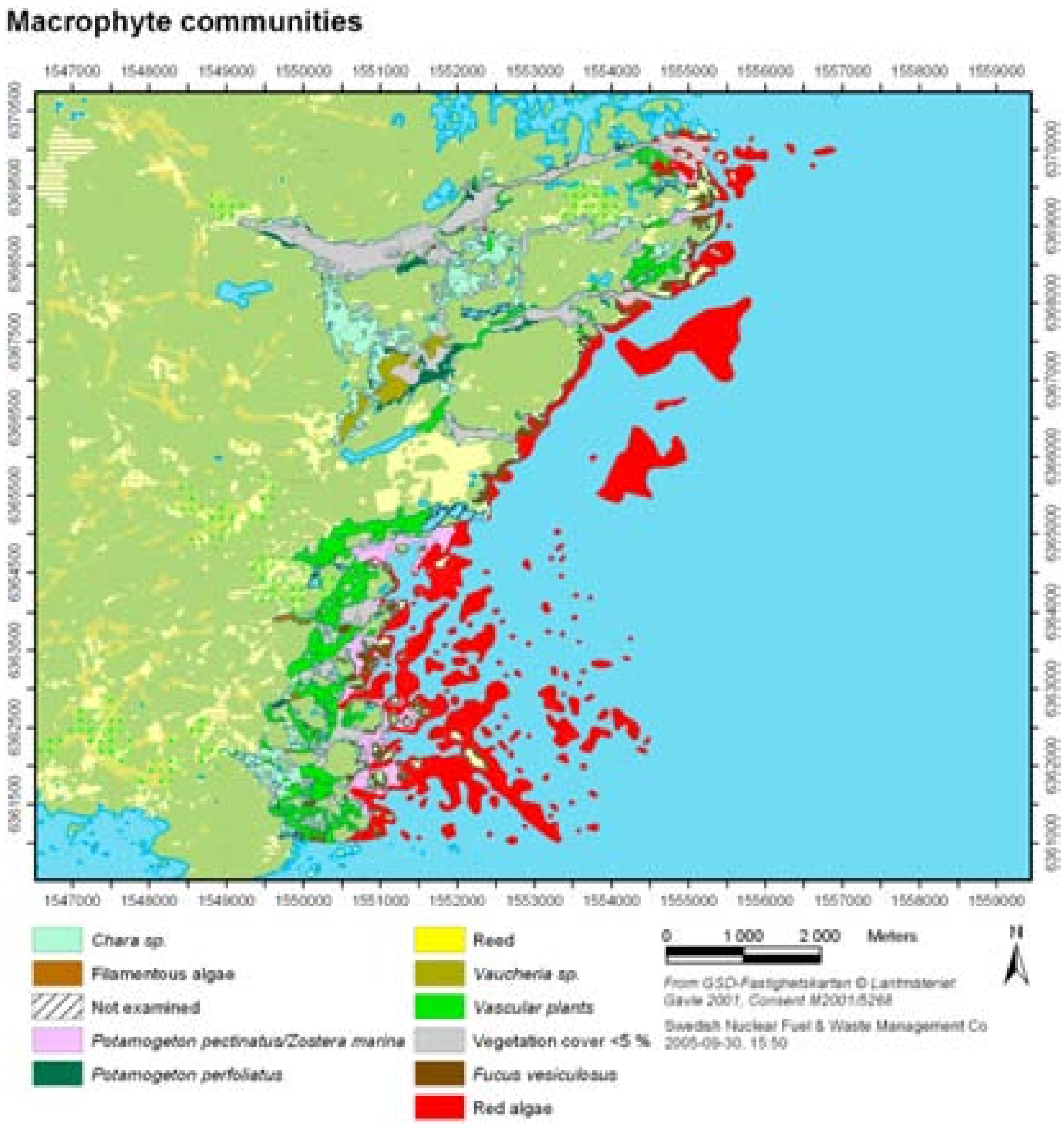

Figure 3-89. *Vegetation map over Laxemar. The map shows macrophyte communities identified by /Fredriksson and Tobiasson 2003/.*

Water chemistry

An extensive water sampling programme has been carried out in limnic and marine systems in the Laxemar area since 2002. The sample programme includes nutrients (N, P), carbon (DIC, DOC, POC), physical parameters (e.g. temperature, salinity) and other (e.g. chlorophyll). Sampling in lakes and the sea are performed in surface and bottom water and directly measured parameters are collected every half metre. Light penetration is logged continuously and correlated to depth once every sampling occasion. The programme has been performed 17 times a year and since 2005 once every month. Locations, complete set of parameters and results are found in /Tröjbom and Söderbäck 2006/.

3.9.4 Consumers

Four sources of site specific data have been used, all a part of the site investigation programme, Table 3-96.

Table 3-96. Data sources concerning consumers in the marine systems of Laxemar. Data is presented under each basin chapter.

Parameter	Basin	Year	Reference
Zooplankton; Biomass	Basin 1, 2, 15	2003–2004	/Sundberg et al. 2004/
Epifauna in macrophytes communities; species, biomass	All basins	2002	/Fredriksson and Tobiasson 2003/
Soft bottom infauna; species, biomass	All basins	2003	/Fredriksson 2004b/
Hard bottom fauna; species, biomass	Basin 6–9, 15, 17	2004	/Fredriksson 2005/
Bird; species, number of individuals	Basin 1, 2	2003	/Green 2004/

Zooplankton

A survey of zooplankton was performed along the water sampling programme. At three sites in the marine system, PSM002060, -2062 and -2064 (see Figure 3-88), zooplankton was sampled at three occasions during 2003–2004. The sampling included sections of the whole water column and result was presented as one to three sections or was integrated in the whole column. Total biomass varied between 80 and 350 mg dry weight·m^{-3} in the most secluded site and 5 and 50 mg dry weight·m^{-3} in the offshore site. The fauna was dominated by copepods except in July when the cladocerans or rotatifers dominated in the upper water column.

Epifauna

In the vegetation mapping study /Fredriksson and Tobiasson 2003/ also the fauna associated to vegetation was sampled. In each quantitative sample of macrophytes the attached fauna was sampled. The report presents biomass of all occurring fauna species in biomass related to biomass of vegetation, see Table 3-97. Red algae and the *F. vesiculosus* community comprised the largest number of taxa and also highest biomass per biomass macrophyte (g dry weight·gdw_{veg}^{-1}).

Table 3-97. Epifauna associated to macrophyte communities, compiled from /Fredriksson and Tobiasson 2003/.

Macrophyte community	Samples	Biomass ($gdw \cdot gdw_{veg}^{-1}$)		No taxa
		Mean	stdav	
Filamentous algae	10	61.7	16.5	21
Chara sp	8	4.59	2.59	19
Potamogeton pectinatus	6	24.1	5.90	21
Potamogeton perfoliatus	2	2.99	0.92	10
Vaucheria sp	2	3.60	2.30	11
Fucus vesiculosus	12	13.1	4.43	27
F vesiculosus undergrowth	6	298	132	23
Zostera marina	3	87.9	40.2	14
Red algae	8	387	114	28

Soft bottom fauna

In /Fredriksson 2004b/ the soft bottom fauna was sampled in 40 locations (Table 3-98) and occurring species and their biomass was presented per habitat; either vegetation community defined in /Fredriksson and Tobiasson 2003/ or in bare sediment in the inshore or offshore area. The offshore soft bottoms and bottoms vegetated by vascular plants had the highest number of taxa and biomass ($gdw \cdot m^{-2}$).

Table 3-98. Soft bottom fauna in different macrophyte communities or in bare sediment (in- or offshore), compiled from /Fredriksson 2004b/.

Macrophyte community or bottom type	Samples	Biomass ($gdw \cdot m^{-2}$)		No taxa
		Mean	stdav	
Bare sediment, inshore	10	5.9	1.97	14
Vaucheria sp	3	1.0	0.12	12
Chara sp	2	2.2	0.46	7
P pectinatus/Z. marina	15	17.5	5.33	35
Bare sediment, offshore	10	16.0	8.61	15

Hard bottom fauna

As a complementing study a survey of the hard substrate fauna in the exposed area was made. The study was performed at depths down to approximately 20 m /Fredriksson 2005/. In the study eight sites of hard substrates were surveyed and classified dependant on coverage of benthic fauna. In each class approximately ten quantitative samples were taken and a relationship between used hard substrate (cover) and biomass of fauna was found. This relationship was used to map the amount of fauna on known hard substrates. The cover (%) of benthic fauna below 3 m depth was found to be:

$$Cover = 103.3 + (D \cdot -6.15)$$

where D is depth in metres. The average biomass was found to be 14.6 $gdw \cdot unit\%^{-1}$. The benthic fauna was totally dominated by filterfeeders, especially *Mytilus edulis* that constituted for approximately 95% of the biomass.

Pelagic fish

At two occasions, early and late summer 2004, population estimates of pelagic fish was made using echo sounder and trawling. The echoes obtained were converted to biomass. At the same occasions as the echo sounding a trawling was performed. The species in the catch was used to relate to the estimated biomass. Results were presented as wet weight per hectare and the proportions between different species. The catch was fairly similar in the three hauls; three species sprat (*Sprattus sprattus)*, herring (*Clupea harengus*) and stickleback (*Gasterosteus aculeatus*) was common in all hauls. Biomass was found to be 21–57 kg/ha /Enderlein 2005/.

3.10 Human description

3.10.1 Introduction

The human description is based on the results presented in the report Human population and activities at 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 quantitative site-specific model (see Section 3.10.4), the numbers have been calculated based on data at the parish level.

3.10.2 Input data and methodology

Most of the data in /Miliander et al. 2004/ were obtained from Statistics Sweden (*Sw: Statistiska Centralbyrån (SCB)*). Other sources such as the National Board of Fisheries (*Sw: Fiskeriverket*), the County administrative board of Kalmar County (*Sw: Länsstyrelsen i Kalmar*) and The National Association of Huntsmen (*Sw: Svenska Jägareförbundet*) have also been used.

Wherever possible, the data have been collected for a time series of ten years. However, data for a time period of ten years have 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. $kg \cdot km^{-2}$). For more detailed information, see /Miliander et al. 2004/.

3.10.3 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 were 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 (20–64 years) 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 is 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.

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 year 1999.

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 (Å 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 County, 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 surveys of mammal populations /Truvé and Cederlund 2005/ the population density was estimated to be 4.9 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 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 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 land area is higher in Simpevarp area than in Oskarshamn 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 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 by the inhabitants in the Misterhult parish 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.

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 as well as four jogging tracks: Fårbo, Figeholm, Misterhult and Simpevarp. More than half of Ostkustleden is located within Misterhult parish.

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 3-99. A compilation of data from Misterhult parish – an overview.

Variable group A	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%
	≥ 65 y	22.7%
Properties and buildings		
Type of properties 2002		
farms	0.95 per km^2	
one-or two dwellings	2.48 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%

Variable group B	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	1,002	
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%	

[1] 1 Agriculture, forestry, hunting, fishing
2 Mining and manufacturing
3 Electricity-, gas- and water supply. Sewage and refuse disposal.
4 Construction
5 Trade and communication
6 Financial intermediation, business activities
7 Education and research
8 Health and social work
9 Personal and cultural activities
10 Public administration etc
11 Unknown

Variable group C	Results
Forestry	
Wood extraction	75 m^3 sk/yr/km^2
Agriculture (1999)	**kg/km^2**
Barley	1,331
Oats	286
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	3,762
Water supply (estimated)	**m^3**
Water use	
households	192,000
holiday houses	13,000
agriculture	52,000
industry	66,000
nuclear	175,000
other	134,000
Water withdrawal	
public supply	314,000
private supply	316,000
Water withdrawal	
ground water	91,000
surface water	515,000
Sea water or unknown	25,000
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.

3.10.4 Quantitative site specific model

In this section the quantitative ecosystem model for five areas within Laxemar model area is described. The carbon flow to humans through consumption of the terrestrial and limnic flora and fauna has been calculated as described below. The results are shown in Table 3-101 and Table 3-102.

Humans

The total number of inhabitants in Simpevarp 6, 7 and 9 are known and presented in /Miliander et al. 2004/. The number of inhabitants in the other subareas that are included in Laxemar model area are not presented in /Miliander et al. 2004/. The total population in Laxemar model area is 69 inhabitants (2002) given by the square net populationdata given by SCB (see Figure 3-90).

A potential population can be estimated based on a figure given by /LivsmedelsSverige 2004, website/, showing that each person needs 3,000 m^2 to be self-sufficient (see Table 3-100). This figure is based on the agricultural area in Sweden, needed for crop production, fodder production and grazing.

/Johansson 2005/ has made a doctoral thesis concerning the Swedish *foodprint*. Compared to the figure from LivsmedelsSverige, her calculations include the agricultural area used outside the national border and the result is an agricultural area of 0.45 ha per capita. According to the thesis 35% of our total agricultural area is located abroad. The thesis also include an ecosystem support area of 0.11 ha per capita that is needed to compensate for organic farming, which is a necessity for a sustainable development in the future.

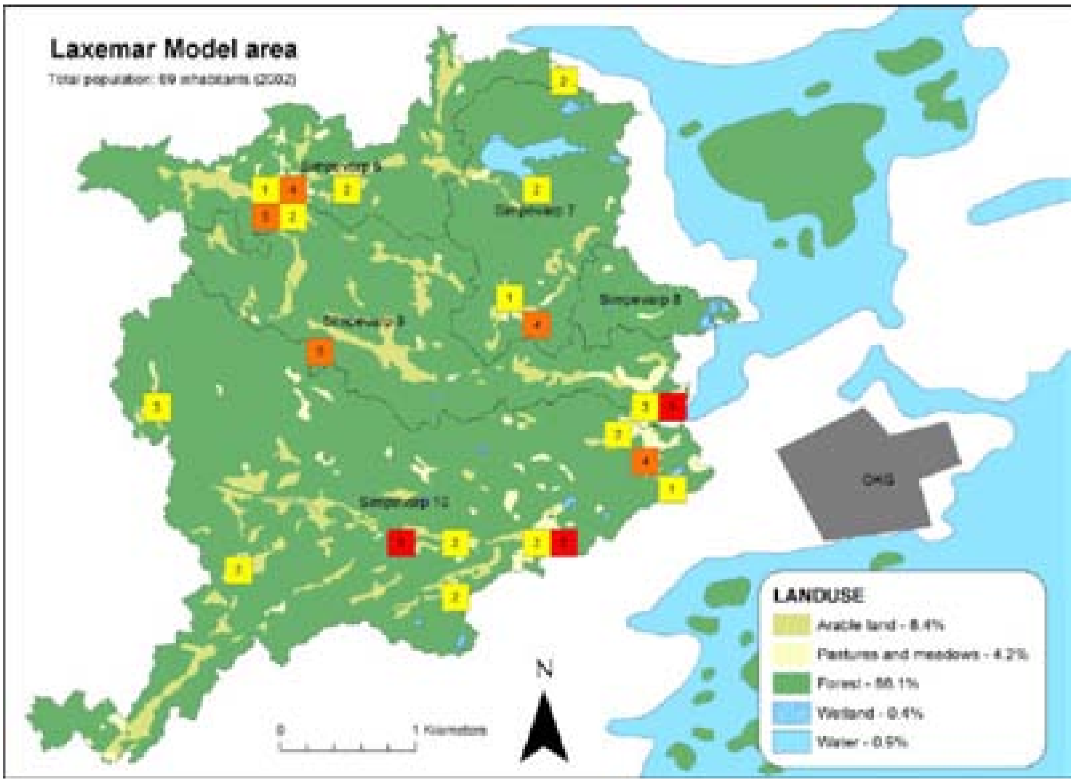

Figure 3-90. *The number of inhabitants within Laxemar model area and their location. The land use distribution has been calculated according to the vegetation map /Boresjö Bronge and Wester 2003/.*

Furthermore, the thesis includes the forest area needed to assimilate the carbon dioxide that is produced due to energy consumption in the food system. As there is mainly forest area in the Laxemar model area, this part is excluded when calculating a potential human population based on the field area (arable and pasture land) of today (see Table 3-100).

A third study concerning the ecological footprint tells us that 2 ha of arable and pasture land are used per capita in Sweden today, including global areas needed for our consumption /Lewan 2001/. Based on this figure the potential population does not differ so much from the actual population (see Table 3-100).

The field area in the subareas within Laxemar model area will of coarse change in the future. New cultivable areas will be created due to the elevation of the land, while some areas might be overgrown and thereby lost.

Table 3-100. The human population in Laxemar area today and a potential population calculated based on the field area in each area.

Human population	Simpevarp 6	Simpevarp 7	Simpevarp 8	Simpevarp 9	Simpevarp 10
Actual population (2002)	14	7	0	16	32
A potential human population					
3,000 m^2 field area per capita	113	48	2	157	284
5,600 m^2 field area per capita	61	25	1	84	152
20,000 m^2 field area per capita	17	7	0	23	43

Agriculture

As there are so few farms in the subareas within Laxemar model area no data concerning the farms that do exist has been delivered by SCB /Miliander et al. 2004/. Therefore, there are no site-specific density data for crop production and animal production. However, for the quantitative model theoretical values for cattle and crop production are used.

According to /LivsmedelsSverige 2004, website/ a good half of the area of 3,000 m^2 per capita is needed for fodder production and the rest for crop production. If we assume that half of the field area in each subarea is used for fodder production and half for crop production, theoretical values can be obtained.

Crop production

A theoretical crop production can be calculated based on the standard yield for barley in SKO-area 0814 in 2003 (3,350 kg per ha), in where Laxemar model area is located. Barley is the most dominating crop produced in Simpevarp today /Miliander et al. 2004/.

The amount of carbon in crop is estimated as 46.1% (mean value) of the dry weight, as for the green fieldlayer in /Fridriksson and Öhr 2003/. The dry weight is 85% of the fresh weight according to /Jordbruksverket 2003a/.

Meat and milk production

Based on the fact that a cow need 1.8–3.0 hectares (2.4 ha in average) for fodder production and grazing /Arnesson 2001/, we can estimate the cattle density and the number of diary cows within each area.

One dairy cow can produce 7,735 kg of milk per year (2002). The cow is inseminated by the age of 15–18 months and then gives birth to her first calf at the age of two years. Thereafter she has a calf each year and gives milk during ten months a year. 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, 0–5 years old, can together produce three calves per year. This means that three cows of five can produce milk.

The milk production per unit area has been estimated using the following formula:

$P_{milk} = \rho \cdot 3/5 \cdot 7{,}735$

where,

- ρ is the cattle density of 41.7 cows per km^2 /Arnesson 2001/.

The total milk production in each subarea can be estimated based on the field area.

A steady population of five cows, 0–5 years old, which produces three calves per year, would have to keep one calf per year for breeding, which leaves two for slaughter together with the oldest cow. 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 carcass weights is assumed to be 55% of the live weights as for the game meat (G Cederlund 2004, pers. comm.), which means that the biomass of a cow is approx. 527 kg and approx. 200 kg for a calf.

When calculating the theoretical meat production per unit area the following formula has been used:

$P_{meat} = 1/5 \cdot \rho \cdot X_{\text{cow}} + 2/5 \cdot \rho \cdot X_{\text{calf}}$

where,

- X is the biomass (live weight),
- ρ is the cattle density of 41.7 cows per km^2 /Arnesson 2001/.

The total meat production in each subarea can be estimated based on the field area.

The carbon content in mammals is 22.9% of the total weight according to /Emsley 1998/. The carbon content in milk can be estimated from the content of proteins, carbohydrates and lipids /Altman and Dittmer 1964, Dyson 1978, Rouwenhorst et al. 1991/:

$CC_i = 0.53 \cdot Proteins_i + 0.44 \cdot Carbohydrates_i + 0.66 \cdot Lipids_i$

where,

- CC_i is the carbon content in the i-th food type (kg C/kg fw),
- $Proteins_i$ is the protein content in the i-th food type (kg/kg fw),
- $Carbohydrates_i$ is the carbohydrate content in the i-th food type (kg/kg fw),
- $Lipids_i$ is the lipids content in the i-th food type (kg/kg fw).

The contents of proteins, carbohydrates and lipids have been found in the Nutrient Database from United States Department of Agriculture /USDA 2004/. The carbon content in Milk (reduced fat, fluid, 2% milkfat, with added vitamin A) is estimated as 5.1%.

Outdoor life

Berries

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 amount that is theoretically picked in each subarea can be calculated based on the figure above and the forest and wetland area in each subarea.

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 millions litres or 4,419 litres·km^{-2} as the total area of forest and mires in Sweden is 284,000 km^2 /SCB 1998/.

The carbon content in berries can, as demonstrated above, be estimated from the content of proteins, carbohydrates and lipids /Altman and Dittmer 1964, Dyson 1978, Rouwenhorst et al. 1991/. The contents of proteins, carbohydrates and lipids in blueberries have been found in the Nutrient Database from United States Department of Agriculture /USDA 2004/. The carbon content in blueberries is estimated as 7.0% of the fresh weight. The weight of one cup of blueberries is 145 gram according to USDA. Four cups are equal to 1 litre. 1 litre of berries is therefore assumed to be equal to 600 gram.

Mushrooms

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/. As the mushrooms are mainly found in the forests it is more correct to base the calculations upon the forest area solely, which gives a value of 65 litres·km^{-2}. The forest area in Sweden is 234,000 km^2 /SCB 1998/. The amount that is theoretically picked in each subarea can be calculated based on the figure above and the forest area in each subarea.

The total *available* amount of fungus that can be consumed is 40 kg·ha^{-1} (10,000 litres·km^{-2}), but only 1.5 kg·ha^{-1} (375 litres·km^{-2}) of the consumable mushrooms are to be considered as attractive mushrooms, according to /Berggren and Kyläkorpi 2002/.

The carbon content in mushrooms can, as demonstrated above, be estimated from the content of proteins, carbohydrates and lipids /Altman and Dittmer 1964, Dyson 1978, Rouwenhorst et al. 1991/. The contents of proteins, carbohydrates and lipids in raw mushrooms have been found in the Nutrient Database from United States Department of Agriculture /USDA 2004/. The carbon content in raw mushrooms is estimated as 3.3% of the fresh weight. The weight of one cup of blueberries is 96 gram according to USDA. Four cups are equal to 1 litre. 1 litre of mushrooms is therefore assumed to be equal to 400 gram.

Game meat

The species that are mainly hunted for consumption are moose, roe deer and hare. The average harvest of moose in Misterhult församling and the average harvest of roe deer and hare in *Oskarshamns Norra jaktvårdskrets* that are demonstrated in /Miliander et al. 2004/ are applied to the areas within Laxemar model area. The carcass weights are calculated according to /Miliander et al. 2004/. The carcass weight is 55% of the live weight and the utilized carcass weight is 80% of the carcass weight according to (G Cederlund 2004, pers comm.). The carbon content in mammals is 22.9% of the total weight according to /Emsley 1998/.

The birds that are hunted for consumption, mainly seabirds, are demonstrated in the table. The figures have been collected from *Oskarshamns Norra jaktvårdskrets*, an area almost twice as large as Misterhult församling. 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. The biomass data are based on that figure.

Fishing

The human fishing is either for recreation, for household requirements or for a livelihood (commercial fishing).

The fishing in limnic waters is most likely in Simpevarp 7 where there is a larger lake, Lake Frisksjön. The consumption of limnic fishes is basically only carnivorous fishes, such as pike, perch and pike-perch. Biomass of carnivorous fish has been measured in Lake Frisksjön. The respiration and consumption have been calculated based on the site-specific biomass and some conversion factors. The production can be calculated by the formula;
C (assimilated) = P+R /Heal and Maclean 1975, Baird and Ulanowicz 1989/.

The size of the coastal recreational or household fishing is unknown. A theoretical value of the annual catch 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.

The commercial fishing in EU-square 43G6, outside Laxemar, was in average 1,728 $kg \cdot km^{-2}$ between 1995 and 2002 /Miliander et al. 2004/. That corresponds to 173 $mgC \cdot m^{-2} \cdot y^{-1}$ if the carbon content is 0.1 gram per gram wet weight /Arrhenius and Hansson 1993/.

Table 3-101. The calculated production of consumable provisions within Laxemar model area. The meat production is also expressed in carcass weight and utilized carcass weight.

Production for human consumption		Number per km^2	Biomass $mgC \cdot m^{-2} \cdot y^{-1}$	Biomass $mgC \cdot m^{-2} \cdot y^{-1}$ carcass weight	Biomass $mgC \cdot m^{-2} \cdot y^{-1}$ utilized carcass weight
Agriculture[1]	Crop production –barley		131,270		
	Milk production		9,886		
	Meat production		1,769	973	555
Hunting[2]	Moose	0.49	24	13	11
	Roe deer	2.2	10	5.8	4.6
	European (common) hare	0.29	0.25	0.14	0.11
	Alpine (mountaine) hare	0.10	0.07	0.04	0.03
	Birds	2.3	0.65	0.43	
Fishing[3]			1,140		
Outdoor life	Picking of fungus (litre)	65	0.86		
	Picking of berries (litres)	81	3.4		
	Available amount of consumable fungus (litres)	10,000	132		
	Available amount of attractive consumable fungus (litres)	375	4.9		
	Available amount of berries (litres)	4,419	185		

[1] Theoretical values based on the standard yield of barley and a cow density of 41.7 cows per km2 (2.4 ha per cow).
[2] The hunting figures for Misterhults församling and Oskarshamns Norra jaktvårdskrets have been applied.
[3] A theoretical value based on the fishproduction in Lake Frisksjön.

Table 3-102. The total human consumption in Simpevarp 6 to 10 within Laxemar model area. The calculations are based on the figures in Table 3-101.

Total consumption per year in gC		Habitat	Simpevarp 6	Simpevarp 7	Simpevarp 8	Simpevarp 9	Simpevarp 10
C hum –cattle (utilized)	Cattle	Approx. half of the field area	93,171	39,930	0	133,101	239,583
C hum –cattle (carcass)	Cattle	Approx. half of the field area	163,458	70,053	0	233,511	420,320
C hum –cattle (live)	Cattle	Approx. half of the field area	297,196	127,370	0	424,566	764,219
C hum –herbiv.	Moose	Forest+Field	21,059	20,192	5,032	29,768	73,446
(utilized)	Roe deer	Forest+Field	9,253	8,872	2,211	13,080	32,270
	European (common) hare	Field	38	16	1	52	94
	Mountaine (Alpine) hare	Forest	50	54	14	71	185
	Total		**30,399**	**29,134**	**7,259**	**42,972**	**105,996**
C hum –herbiv. (carcass)	Moose	Forest+Field	26,323	25,240	6,291	37,211	91,807
	Roe deer	Forest+Field	11,566	11,090	2,764	16,349	40,338
	European (common) hare	Field	47	20	1	65	118
	Mountaine (Alpine) hare	Forest	63	67	18	89	232
	Total		**37,999**	**36,417**	**9,073**	**53,714**	**132,495**
C hum –herbiv. (live)	Moose	Forest+Field	47,861	45,892	11,437	67,656	166,922
	Roe deer	Forest+Field	21,029	20,164	5,025	29,726	73,341
	European (common) hare	Field	86	36	2	119	215
	Mountaine (Alpine) hare	Forest	114	122	32	162	422
	Total		**69,089**	**66,213**	**16,497**	**97,663**	**240,900**
C hum –birds (carcass)	Birds	Land, lake, coast	868	894	216	1,229	3,039
C hum –birds (live)	Birds	Land, lake, coast	1,296	1,334	323	1,834	4,536
C hum –fish	Carnivorous fish	Lake Frisksjön	0	135,095	0	0	0
C hum –veg	Crop (barley)	Approx. half of the field area	22,459,729	9,285,300	935,428	30,163,084	55,009,048
	Fungus (picked)	Forest	1,436	1,534	407	2,038	5,293
	Berries (picked)	Forest+mire	5,650	6,113	1,656	8,028	20,909
	Total		**22,466,815**	**9,292,947**	**937,491**	**30,173,150**	**55,035,250**
C hum –lakto	Milk	Approx. half of the field area	1,660,894	711,812	0	2,372,705	4,270,869

Conclusions

The main transport (flow) of organic recourses from the terrestrial ecosystem to the human population is through crop consumption, as long as there is an agricultural activity within the area. The milk consumption represents the second largest flow, and again, as long as there is an agricultural activity with dairy cows within the area.

3.10.5 Confidence and uncertainties

According to the hunting figures in Table 3-101, the moose consumption is 24 $mg \cdot m^{-2} \cdot y^{-1}$, which is more than twice the moose production according to /Truvé and Cederlund 2005/ (see Table 3-99). This incoherence can be a result of the fact that the hunting figures are recorded for *Oskarshamns Norra jaktvårdskrets*, an area of 714 km^2, while the population density figures have been estimated in a study area of approx. 120 km^2 /Cederlund et al. 2004/. The moose is not evenly harvested within Oskarshamns Norra jaktvårdskrets, and it migrates within a large home range. The hunting figures for the Simpevarp area is in reality probably much lower than for Oskarshamns Norra jaktvårdskrets as a whole.

The total meat consumption is in average 40 kg per person and year (including game meat but excluding cured meat and delicatessen, such as sausage) and 112 kg with meat delicatessen /Jordbruksverket 2003b/. 40 kg meat is equivalent to 9,160 gC. The production of game meat and beef in e.g. Simpevarp 7 is approx. 70,000 gC (utilized biomass). This amount can feed almost 8 persons. If we calculate with a consumption of 112 kg, the production in Simpevarp 7 can only feed 2.7 persons. The cured meat and delicatessen are not always made up of 100% meat, so it is an overstatement to assume that we consume 112 kg fresh meat per year. However, these calculations are not coherent with the potential population calculations telling us that 7–48 people can live in Simpevarp 7 (see Table 3-100).

If we assume that 5,600 m^2 per capita is needed to be self-sufficient and half of the area is used for fodder-production and grazing, we would only be able to produce 1,550 gC (6.8 kg) utilized beef meat per year, based on the production estimate of 555 $mgC \cdot m^{-2} \cdot y^{-1}$ (utilized meat). Moreover, 20,000 m^2 per capita gives a production of 5,550 gC (24 kg). According to the figures above from Jordbruksverket this is not enough for one person. This indicates that the beef production is estimated too low. According to /Lewan 2001/ the Swedish yield of beef is 245 $kg \cdot ha^{-1} \cdot y^{-1}$ (approx. 5,600 $mgC \cdot m^{-2} \cdot y^{-1}$), which is much more than the estimation in Table 3-100.

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 types of abiotic and biotic parameters with the aim of describing the organisms, the physical environment and their interactions in a certain area. The ecosystem approach is here used with the purpose of describing accumulation and flow of matter in a temporal and a spatial context. A budget of organic matter is described by estimating the different pools of matter and the fluxes between these pools. The foundation of 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. With a numerical model it is possible to simulate all the pools and fluxes in the ecosystem or it may use site-specific input data setting starting conditions. This approach requires running the model to equilibrium and adapting parameters accordingly. By using a numerical model it will be possible to estimate factors that are difficult to measure in field. In brief, this chapter is devoted to:

1. presenting a conceptual model describing the terrestrial ecosystem,
2. combining estimates of the different carbon pools and fluxes in the conceptual model for a number of vegetation types,
3. constructing carbon budgets for a number of discharge areas,
4. presenting 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 the land above sea level that is not part of a lake (delimited by firm ground). The terrestrial ecosystem extends one metre 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 3.4.5). The terrestrial system also includes wetlands, such as wetland forests and mires.

4.1.2 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 fluxes 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 are elaborated within the chapter covering the specific field. Below follows a description of the principal functioning of pools and fluxes within the conceptual model (Figure 4-1).

Biota and functional groups

The biota is divided into three main groups according to their ecosystem functioning, so-called functional groups.

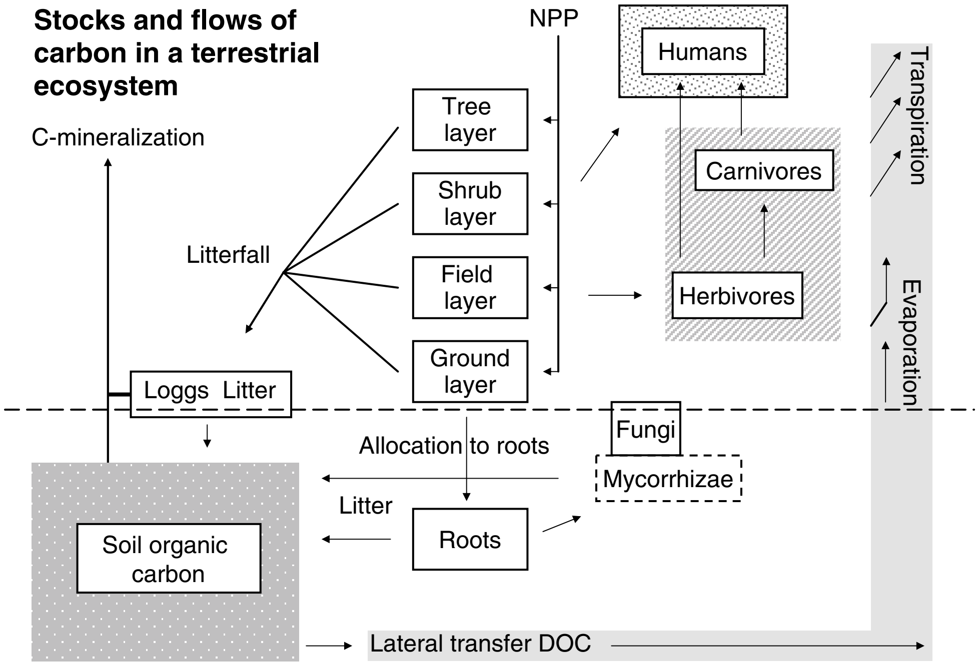

Figure 4-1. The conceptual terrestrial ecosystem model. The boxes/fluxes that are outside the grey boxes are treated within the section describing terrestrial producers. Boxes indicate carbon pools while arrows indicate fluxes of carbon. Respiratory fluxes have been omitted in the figure. Arrows in the grey box to the right indicate water flow.

Primary producers

The vegetation is the primary producers binding carbon dioxide in the photosynthesis. This group is further divided into the functional layers, tree, shrub, field and ground layer. These layers are divided, if possible, into woody and green parts above ground, and coarse and fine roots below ground. Fungi are also treated within this group although they function as consumers and decomposers. The main reason for this is the tight linkage with plants via mycorrhizal fungi. Producers are presented more exhaustively in 3.7.1.

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 accumulation of substances similar to carbon potentially large. Soil microbes are left out of the following calculations, because lack of site-specific data and the fact that the total carbon content in the soil includes the carbon from the microbial biomass. Consumers are presented more exhaustively in 3.7.2.

Decomposers

Decomposers is an important functional group responsible for the carbon mineralization process in the carbon cycle. The decomposers are found in the soil, mainly in the topmost layer and involve a wide array of different taxa (e.g. Table 3-6). They are small and numerous, and constitute a considerable part of the carbon in the soil. Fungi are also an important decomposer, but are mainly considered in the earlier part of the decomposition stage e.g. litter, logs and branches.

Soil

The soil is an important factor for abiotic conditions both with regard to 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, the soil carbon pool is 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 goes. High carbon content in the mineral soil layer are often an indication of 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 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 consists 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 a near surface water table. Peat-forming wetlands are carbon sinks, where a thick layer might be accumulated over time.

Hydrology

Water movements control transport of matter in plants, on the ground and in the soil. There are three main flows of water (see Section 3.4); 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 majority 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). Humic substances are tied up in soil sorption processes during the downward transport /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 hydraulic lift /Caldwell et al. 1998/ and to the actual plant uptake of substances dissolved in water. It is, however, of minor importance for transportation of DOC.

The lateral flow of water (3) is large enough to cause transport of substances, mainly DOC but also particulate organic carbon /Canhem et al. 2004/, from terrestrial to limnic and marine ecosystems. This water flow originates from precipitation that infiltrates the surface and reaches the satured zone (see Section 4.4), and is further transported into streams and lakes. The unsatured overland flow is assumed to be negligible in the quantitative hydrological modelling. Moreover, 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 of significance for accumulation of allochtonous matter.

4.1.3 Quantitative descriptive model

This section describes how estimates of carbon pools and fluxes, representing the Laxemar area, are introduced into the conceptual model. Firstly, there is an overview of the assumptions. Secondly, the methodology behind the construction of the carbon budgets is presented. Thirdly, the results extracted from a number of vegetation types are discussed and compared with other studies. Fourthly, the stocks and flows of carbon for a number of subcatchment areas in Laxemar are presented and discussed.

Modelling assumptions

The assumptions underlying the estimates of specific pools and fluxes are presented within Section 3.7. Some of the assumptions covering specific data not presented elsewhere are presented below.

Wetlands

The wetlands in Laxemar are characterised by nutrient poor mires /Rühling 1997, SNV 1984/. Bogs are not yet so numerous in this area, partly depending on the areas' young age. 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. CH_4 in two boreal bogs, 1–2 $g{\cdot}C{\cdot}m^{-2}{\cdot}y^{-1}$ /Alm et al. 1999/ and 4 $g{\cdot}C{\cdot}m^{-2}{\cdot}y^{-1}$ /Waddington and Roulet 2000/) and is not accounted for in the descriptive model.

Secondary, tertiary consumers and humans

The carnivore group cover a number of different functional groups, such as insectivores, amphibians and reptiles.

The human consumption of herbivores, such as cattle and wild game, is the actual utilized meat after slaughter. In this consumption also milk consumption is included. Consumption of vegetation covers crop, fungi and berries.

Carbon content and turnover in the soil

The average carbon content in the soil Laxemar area is presented in Table 4-1. The soil microbial biomass is included in this carbon pool, and there is no site specific data describing the microbial biomass and turnover separately. However, some generic data describing biomass for soil fauna is presented in Table 3-59.

Table 4-1. Carbon stocks for the soil map classes, corresponding to the classes in Figure 3-73, in the Oskarshamn area /Lundin et al. 2005/.

Map class	Soil class	C tot ($kg \cdot m^{-2}$)
HI-f	Histosol, (forested peatland)	44.2
HI-sp	Histosol (small peatland)	37.5
HI-w	Histosol (open wetland)	15.6
PZ/RG	Podzol/Regosol (woodland)	19.1
PZ/RG-e	Podzol/Regosol (on glaciofluvial material)	14.6
RG/HI	Regosol/Histosol (shoreline areas)	15.8
UM/GL	Umbrisol/Gleysol (seminatural grassland)	39.4
UM/GL-a	Umbrisol/Gleysol (arable land)	34.8
UM/RG	Umbrisol/Regosol (Herb dominated moist soil)	9.5

Dissolved Organic Carbon (DOC)

The transport of carbon at the landscape level may be treated as,

- Downward flow in soil,
- Upward flow in soil,
- Transport and retention within the terrestrial ecosystem, and
- Transport from the terrestrial ecosystem

The downward flow of carbon originates from leaching of DOC from the litter layer. This leakage may be as high as 10% of the litter fall /Persson and Nilsson 2001/. The DOC becomes less mobile in lower soil horizons /Neff and Ashner 2001, Berggren et al. 2003/, (see also 4.1.1). This fraction is probably a substantial part of the carbon that is retained over time in woodland soils. There is no estimation of this fraction in this version of the descriptive model.

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).

The lateral transport between neighbouring terrestrial ecosystems is, in lack of data, assumed to be of minor importance (e.g. 4 $g \cdot C \cdot m^{-2} \cdot y^{-1}$ was transported from conifer forests to lakes in a large catchment area in Canada /Canhem et al. 2004/). Transport to wetlands may be larger due to a discharge area that concentrates water flow to a smaller area. In /Brydsten 2004b/, data from six investigated lakes in the Forsmark area suggested that sediments had a high degree of material of autochtonous origin. This was also supported by other factors, such as small topographic variation (small watersheds), low current velocities and low abundance of fine-grained sediments. An example was calculated to illustrate how much the carbon dynamics within the wetland may be influenced by input of carbon from the local discharge area /Lindborg 2005b/. This was based on literature data from /Canhem et al. 2004/ who estimated leaching of DOC from conifer forests to 3.5 $g \cdot C \cdot m^{-2} \cdot y^{-1}$. The size of the drainage area was multiplied with this figure to get a measure of the DOC loading to the wetland. Output from emergent marshes was estimated by /Canhem et al. 2004/ to 13 g·C·m^{-2}·y^{-1}. The results suggested that the average accumulation of external DOC is 4% of the total input from the local wetland to the soil organic carbon (SOC) pool as litter (field layer and roots). Consequently, the external input of DOC from the drainage area is low in relation to the local flux of carbon to the SOC. In lack of better data, it is therefore assumed that the majority of the carbon deposited in wetlands is from the production within the wetland.

Studies of DOC loading to lakes in a drainage area, as a function of vegetation types, 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 18 g·C·m^{-2}·y^{-1}, 13 g·C·m^{-2}·y^{-1} and 4 g·C·m^{-2}·y^{-1} respectively, using a predictive model based on 2,750 lakes and their drainage areas in Canada. /Waddington and Roulet 2000/ estimated the lateral transport from a boreal bog in Sweden to be 4.2 g·C·m^{-2} and 6.7 g·C·m^{-2} in two consecutive years. These figures are small in comparison to the local carbon budgets, but their impact on the recipient may be large depending on the size of the drainage area. The lateral flow of carbon as DOC was calculated for each subcatchment area, using the estimates by /Canhem et al. 2004/ for "emergent marches" and forests, with the aim of providing lake Frisksjön and the coastal basins with input data.

Methodology

Spatial distribution of data

The quantitative descriptive model is the quantification of the components in the conceptual model (Figure 4-1) and further transferred into GIS, thereby giving the data a spatial distribution. The data that was used to turn the conceptual model into a quantitative descriptive model was taken from sources in accordance with Table 4-2, and from tables presented within this section. The spatial resolution of data is different depending on the property and is presented in detail within the section of relevance in accordance with Table 4-2. Generally, the aim is to have a resolution that is a trade-off between what is possible to identify using digitalised maps (e.g. the vegetation map) and what is biologically relevant in relation to the overall aim. In many cases, this is equivalent to a resolution that is based on the vegetation map (Figure 4-1). However, there are still much data that are under preparation or being sampled and therefore have a poor resolution today. The results presented is a GIS database that consists of spatially distributed information describing each property listed in the different sections presented in Table 4-2.

Table 4-2. Presentation of the properties that were used to characterise the entities in the quantitative descriptive ecosystem model and where they are more thoroughly treated.

Entity	Section	Table no	Property
Regolith	3.3	4-1	Soil organic carbon
Hydrology	3.4	–	Evaporation, transpiration, specific runoff
Producers	3.7.1	4-6, 4-7, 4-8	Biomass, NPP and turnover
Consumers	3.7.2	7-28	Biomass and consumption
Humans	3.10	10-1	Hunting, utilized berries and fungi

Results

Carbon budget within some vegetation types

The large amount of information describing pools and fluxes, and the various 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 complete catchment areas. A number of vegetation types, representative for the area, were therefore exemplified by extracting data for the different functional groups from the GIS (Table 4-3, 4-4). However, it is important to notice that these examples are some of the possible combinations that may be found in the Laxemar area. Moreover, data describing some of the water fluxes was extracted for these habitats (Table 4-5).

Table 4-3. The major pools ($g \cdot C \cdot m^{-2}$) and fluxes of carbon ($g \cdot C \cdot m^{-2} \cdot y^{-1}$) presented for eight different vegetation types in the Laxemar area. These figures are combined into an estimate of the net ecosystem production (NEP), which is a measure of how much carbon that is retained (positive value) or lost (negative value) from the ecosystem. Negative values are fluxes of carbon leaving the ecosystem.

Property		Vegetation type							
		Mire	Conifer wetland	Old conifer forest	Young conifer forest	Pine forest on bedrock	Seminatural grassland	Arable land	Clear-cut with birch
Pools	Biomass	1,497	10,037	10,260	3,416	5,015	684	251	1,611
	Litter	126	552	788	752	601	225	0	788
	SOC	15,600	34,200	19,100	19,100	0	39,400	34,800	19,100
Fluxes	NPP	321	975	981	367	461	255	251	251
	Litter	314	617	623	175	312	255	33	199
	C-mineralisation	–245	–425	–586	–586	–375	–575	–33	–586
	Run-off	–13	–13	–4	–4	–4	–4	–4	–4
Net accumulation (soil)		56	371	225	–327	5	–324	–4	–391
Net ecosystem production		63	537	391	–223	82	–324	0	–339

Table 4-4. Pools ($g \cdot C \cdot m^{-2}$) and fluxes ($g \cdot C \cdot m^{-2} \cdot y^{-1}$) related to the fauna in the Laxemar area. Herbivory is considered as the input of carbon to animals from the vegetation. These fluxes are more thoroughly presented in Section 3.7.3.

Functional group	Property	Vegetation type							
		Mire	Conifer wetland	Old conifer forest	Young conifer forest	Pine forest on bedrock	Seminatural grassland	Arable land	Clear-cut with birch
Herbivores Incl. Cattle	Biomass	0.09	0.08	0.08	0.08	0.08	5.12	5.12	0.08
	Consumption (vegetation)	1.92	1.83	1.83	1.83	1.83	84.51	84.51	1.83
	Production	0.03	0.03	0.03	0.03	0.03	1.80	1.80	0.03
Carnivores insectivores, amphibians, reptiles	Biomass	0.09	0.09	0.02	0.02	0.02	0.02	0.02	0.02
	Consumption (herbivores)	0.43	0.43	0.12	0.12	0.12	0.12	0.12	0.12
	Production	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01

Table 4-5. Estimates of different water flows in the three exemplified vegetation types in the Laxemar area. See Section 3.4 for a description of how the estimates were obtained.

Properties	Water fluxes in ($m^{-3} \cdot y^{-1}$)		
	Forest	Wetland	Arable land
Transpiration	73 mm	–	–
Evaporation (intercept.)	203 mm	–	–
Lateral flow	6.5 $lm^{-2}s^{-1}$	–	–

Wetlands

Peatlands in Sweden contain on average 260 $kg \cdot m^{-2}$ /Olsson 2000/. This figure is higher than the figure from Laxemar. This can be an effect of the comparatively young soils in Oskarshamn. The Laxemar value does also only cover the first metre of the regolith, which therefore is an underestimation if the peat layer is deeper. For four wetlands in Forsmark, there is data describing the accumulation of carbon using the age of the site and the thickness of the peat layer (Table 4-6). The net accumulation of carbon in the wetland peat (Table 4-3) fit these rates well.

There is a high accumulation of carbon in the forested wetland (Table 4-3), where most of the carbon is accumulated in the SOC pool. We have today no field estimations of the C-mineralisation from this vegetation type and have therefore used estimation from a forested ditched peatland, where C-mineralisation is expected to be higher due to the lowered water table and the beginning of oxidisation processes in the peat, e.g. /von Arnold et al. 2005/. However, the tree layer production is taken from woodland localities (NFI-plots in the region), where production is expected to be higher than the production in the forested wetland due to the periodically water inundated soils. In conclusion, the high decomposition is balanced by a high input of litter but the accumulation of carbon is probably overestimated. Unfortunately, there are few references describing carbon cycling from forested wetland, especially fen-like wetlands.

Table 4-6. 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} y^{-1}	Reference
Stenrösmossen	43.2	/Fredriksson 2004a/
Lersättermyran	66.3	/Fredriksson 2004a/
T1	58.3	/Lundin et al. 2004b/
T2	73.8	/Lundin et al. 2004b/
Mean	60.4	

Forests

The carbon pool of productive forests in Sweden, including soil carbon down to 1 m depth, have approximately 8,000 $g \cdot C \cdot m^{-2}$ /Olsson 2000/. The corresponding values for Laxemar are more than twice as high and are difficult to explain. The figures from Skogaby /Persson and Nilsson 2001/, where they had a carbon content in the humus layer of 2,200 $g \cdot C \cdot m^{-2}$ and 10,000 $g \cdot C \cdot m^{-2}$ in 0.5·m of the mineral soil, is higher but is still much lower than the Oskarshamn estimates. The C-mineralisation estimations from the Skogaby plots of 266 $g \cdot C \cdot m^{-2} \cdot y^{-1}$ /Persson and Nilsson 2001/ is lower than the estimates from Laxemar. They also found that the accumulation of carbon in the SOC pool was 160 $g \cdot C \cdot m^{-2} \cdot y^{-1}$ while the accumulation in the vegetation was 190 $g \cdot C^{-2} \cdot y^{-1}$. The modelled respiration using the COUP-model gives an estimate of C-mineralisation of 250 $g \cdot C \cdot m^{-2} \cdot y^{-1}$ for an old conifer forest in the Laxemar region /Gustavsson et al. 2006/, which is more than two times lower than the field estimates from Simpevarp. The COUP-model estimated the NEP to 84 $g \cdot C \cdot m^{-2} \cdot y^{-1}$ for an old conifer forest in the Laxemar region /Gustavsson et al. 2006/, and the SOC accumulation to 3 $g \cdot C \cdot m^{-2} \cdot y^{-1}$. These figures do suggest that the present descriptive model overestimates the net accumulation in the SOC pool in this vegetation type. However, the COUP-model makes the estimates using long-term average climatic parameters (Section 4.1.4), while e.g. soil respiration in Laxemar was measured during one year.

Young conifer forests (< 30 years old) are a large source of carbon, partly because they have been assigned the same high soil respiration (C-mineralisation+root respiration, see Section 3.7.1) as the older forests, which have a higher input of litter to the SOC pool and a larger root biomass.

The pine forest on bedrock, a fairly common vegetation type in this region, has been assigned a zero SOC pool. This fits badly with the C-mineralisation that result in a net emission of carbon dioxide that has to come from decomposition of the litter pool, which is decomposed within a few years. The bedrock vegetation types do, however, often have a thin soil layer intermingled with bare bedrock. Moreover, variation between years can be substantial /Lindroth et al. 1998/.

The young clear-cut is most certainly a large carbon source due to the large sudden input of below-ground root litter from the cut trees that eventually is decomposed. However, in this calculation the clear-cut has been assigned the same C-mineralisation as the woodland before harvest. Exactly how the C-mineralisation is affected and how fast the heterotrophic respiration and the SOC are declining is poorly studied. Measurements of soil respiration from 5–8 years old clear cuts during two consecutive years was compared to their uncut vegetation types and they had a similar soil respiration /Euskirchen et al. 2003/. How autotrophic and heterotrophic respiration was partioned within the total soil respiration at the sites is unknown. Consequently, the soil respiration for uncut forests will in this version serve as a fairly good approximation for recently cut forests. The run-off from recent clear-cuts is expected to increase during a period, however, this has not been accounted for in this version.

Seminatural grassland

The seminatural grassland is a comparatively large net source of carbon (–324 $g \cdot C \cdot m^{-2} \cdot y^{-1}$ CO_2-C). /Tagesson 2005b/ estimated the NEE of the same meadow to a loss of CO_2-C varying between 400 and 630 $g \cdot C \cdot m^{-2} \cdot y^{-1}$. These figures fit reasonably well but the discrepancy would increase if the descriptive model took the mycorrhizal fungi into account, which would increase the litter input thereby balancing the NEP in Table 4-3. The measurements of the soil respiration was made on a ditched seminatural grassland that imply the presence of oxidising peat soils causing the high negative net ecosystem exchange of CO_2.

Arable 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. It is assumed that everything above ground is removed, which is a simplification because a small part of the straw is left after harvest. Fungi are also present in this vegetation type and are known to form mycorrhiza with fertilized crop /Chapin et al. 2002, van der Heijden and Sanders 2002/, but it has not been accounted for here. The C-mineralisation rate that was chosen to balance the input of root litter is therefore most certainly too low.

NEP

There is a large variation in the net ecosystem production (NEP) between the exemplified vegetation types, with the largest accumulation within forested wetland and the largest net emission of carbon in the clear-cut (Table 4-3). Periodically water inundated soils and soils with a mature conifer forest stand are the only soils having a net accumulation of carbon. The SOC pool for all the other vegetation types are large sources of carbon emitted to the atmosphere. This may be a consequence of high organic carbon content in the soils that are continuously being decomposed. It may also be an effect of too high soil respiration estimates from the area that is not representative for the different vegetation types, see also discussion in /Tagesson 2005b/. However, it should be remembered that the soil respiration was only measured during one year and in a study of soil respiration covering six vegetation types, there was an overall difference of 37% between two consecutive years in soil respiration, which was associated to changes in soil temperature /Euskirchen et al. 2003/. The other vegetation types that have a positive NEP are all having a large net accumulation of biomass balancing the large emission of carbon from the SOC. These calculations show how the C-mineralisation values are crucial for the carbon budget and further investigations will reveal the representativity of those estimations.

Fauna

The pools and fluxes within the fauna (Table 4-5) are small compared to those describing the primary producers (Table 4-4) and contribute little to the calculation of vegetation type NEP. The secondary production estimate is highest on the mire and the forested wetland, which mainly is explained by the high abundance of amphibians close to these wetter habitats.

Carbon budgets for subcatchment areas

The descriptive ecosystem model is applied at the landscape level covering 14 subcatchment areas within the larger drainage area Laxemar. Pools and fluxes for all functional groups are summed using GIS (earlier described). The budgets are here presented in a reduced version, where all the separate pools and fluxes, in accordance with the conceptual model, are used to quantify a number of ecosystem properties.

The modelled Laxemar drainage area is situated in the Simpevarp region (Figure 4-2). The dominating vegetation types are forests, primarily pine forest on acid rocks and pine forest of mesic-moist type (Table 4-7).

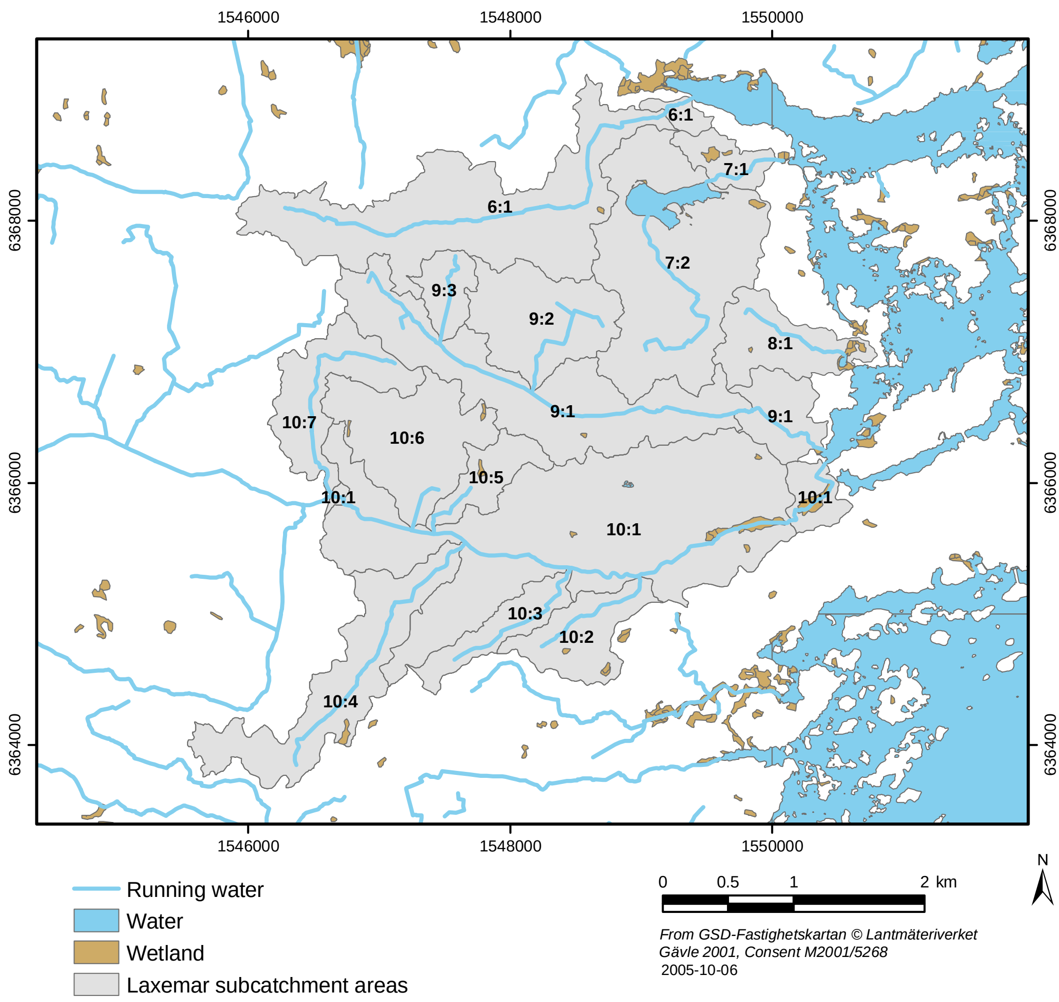

Figure 4-2. *The subcatchment areas with the lake, wetlands and running water in Laxemar on which the descriptive ecosystem model was applied in order to construct large scale carbon budgets.*

Table 4-7. The subcatchment areas within the Laxemar drainage area charcterised by their size (km²) and some land types coverage in fraction of total subcatchment area.

	Subcatchment area													
	6.1	**7.1**	**7.2**	**8.1**	**9.1**	**9.2**	**9.3**	**10.1**	**10.2**	**10.3**	**10.4**	**10.5**	**10.6**	**10.7**
Land area (km²)	2.00	0.21	1.73	0.50	1.85	0.77	0.22	3.44	0.46	0.32	1.00	0.29	0.89	0.61
Wetlands	0	0.05	0	0.03	0	0	0	0.01	0.02	0	0.01	0.01	0	0
Conifer forest	0.52	0.27	0.58	0.85	0.56	0.53	0.68	0.49	0.46	0.71	0.57	0.22	0.49	0.57
Agriculture land	0.12	0	0.06	0	0.11	0.15	0.17	0.05	0.11	0.07	0.15	0.04	0.04	0.03
Young conifer forest	0.21	0.44	0.22	0.08	0.16	0.21	0.09	0.22	0.18	0.13	0.14	0.28	0.24	0.3
Clear cuts	0.06	0.11	0.03	0	0.08	0.1	0.02	0.09	0.14	0.05	0.04	0.39	0.14	0.09

Net Ecosystem Production

The NEP, which is the net accumulation of carbon in the discharge area during a time step (see equation (1)), was highly variable between subcatchments (Table 4-8). Area specific NEP ranged from –60 to 379 $g \cdot C \cdot m^{-2} \cdot y^{-1}$. The NEP for the whole area was positive suggesting that there is a net yearly accumulation of carbon within the Laxemar area. The accumulation is largest in living biomass, approximately six times higher than the accumulation in the SOC-pool, averaged for the Laxemar area (Table 4-3).

The variation in NEP is explained by the land type coverages in the specific subcatchment area (Table 4-7). A comparison using information about land type coverage and data for some specific vegetation types in Table 4-2, suggests that the low NEP in subcatchment 10.5 is explained by the substantial coverage of clear-cuts, while the large NEP in subcatchments 8.1, 9.3 and 10.3 is explained by the large coverage of mature conifer forests (> 30 years old), where most of the carbon is stored in the SOC pool.

Secondary and tertiary producers

The consumption of herbivores and carnivores is very similar over the landscape, which is an effect of low resolution of their defined feeding habitats. Some are divided into field or forest feeding, but the majority is evenly feeding in the landscape. A more precise definition of feeding habitat is only available for amphibians and cattle; wetlands are rather scarce in the modelled area. Otherwise it is the presence of arable land that increase the secondary production due to the possibility to sustain cattle.

Humans

The human consumption of products derived from the vegetation is of the same order as the herbivore consumption when the subcatchment area contain agriculture land thereby being able to sustain cattle according to the premises presented in Section 3.7.3. The human consumption of meat and milk is one order of magnitude lower than the consumption of vegetation and is similarly dependent on the subcatchment area's possibility to sustain cattle.

Flow of matter

There is, so far, no site-specific data that can be used to confirm the estimated transport of carbon from the subcatchment areas. Calculations of the carbon budget for lake Frisksjön in subcatchment 7.2, where the transport of DOC from land is used as input, do not indicate that the estimates are unrealistic. However, observations from the lake indicate that the input of particulate organic carbon (POC) should be fairly large and the estimates of input from land should therefore be somewhat low.

Table 4-8. Major pools (g·C) and fluxes ($g \cdot C \cdot y^{-1}$) of carbon for 14 subcatchment areas within the larger catchment area Laxemar. Negative values are fluxes of carbon leaving the subcatchment area. The figures are combined into an estimate of the net ecosystem production (NEP), which is a measure of how much carbon that is retained (positive value) or lost (negative value) from the ecosystem. The carnivore group contains also insectivores, birds, amphibians and reptiles. The human consumption includes crop, fungi, berries, cattle, milk and wild game using certain assumptions about their availability within the subcatchment area (see 3.7.2).

Functional groups	**Property**	**Subcatchment area**														**Total**
		6.1	**7.1**	**7.2**	**8.1**	**9.1**	**9.2**	**9.3**	**10.1**	**10.2**	**10.3**	**10.4**	**10.5**	**10.6**	**10.7**	
Autotrophs																
Vegetation	Biomass	1.20E+10	1.01E+09	1.15E+10	4.23E+09	1.16E+10	4.39E+09	1.51E+09	2.02E+10	2.75E+09	2.42E+09	6.49E+09	1.19E+09	5.56E+09	3.99E+09	8.89E+10
	NPP	1.29E+09	1.09E+08	1.19E+09	4.18E+08	1.24E+09	4.81E+08	1.64E+08	2.20E+09	2.88E+08	2.50E+08	7.05E+08	1.29E+08	5.96E+08	4.08E+08	9.48E+09
	Litter flux	1.02E+09	8.63E+07	9.58E+08	3.48E+08	9.92E+08	3.75E+08	1.29E+08	1.78E+09	2.27E+08	2.02E+08	5.59E+08	1.02E+08	4.85E+08	3.31E+08	7.59E+09
Soil	Litter pool	1.11E+09	1.33E+08	1.07E+09	3.37E+08	9.86E+08	4.26E+08	1.15E+08	1.70E+09	2.41E+08	1.94E+08	5.01E+08	1.78E+08	5.00E+08	3.80E+08	7.87E+09
	SOC pool	4.35E+10	4.24E+09	3.40E+10	9.43E+09	3.98E+10	1.69E+10	5.33E+09	7.35E+10	9.77E+09	6.67E+09	2.29E+10	5.84E+09	1.85E+10	1.21E+10	3.02E+11
	C-mineralisation	–9.87E+08	–1.15E+08	–8.92E+08	–2.72E+08	–9.19E+08	–3.66E+08	–1.02E+08	–1.78E+09	–2.24E+08	–1.67E+08	–4.78E+08	–1.58E+08	–4.80E+08	–3.24E+08	–7.26E+09
	Run off	–8.01E+06	–9.49E+05	–6.93E+06	–2.13E+06	–7.38E+06	–3.07E+06	–8.88E+05	–1.41E+07	–1.92E+06	–1.28E+06	–4.09E+06	–1.19E+06	–3.56E+06	–2.44E+06	5.72E+07
	Net acc. soil	2.85E+07	–2.93E+07	5.91E+07	7.35E+07	6.60E+07	5.72E+06	2.67E+07	–1.33E+07	1.34E+06	3.42E+07	7.69E+07	–5.66E+07	1.48E+06	5.00E+06	3.37E+08
	Net acc. soil (m^{-2})	14	–138	34	147	36	7	120	–4	3	107	77	–195	2	8	24
Heterotrophs	Biomass	1.02E+06	1.70E+04	5.40E+05	4.35E+04	1.04E+06	3.06E+05	1.39E+05	1.50E+06	1.59E+05	1.48E+05	5.68E+05	2.45E+04	1.96E+05	1.72E+05	5.86E+06
Herbivorer	Consump. (veg)	1.76E+07	3.77E+05	9.15E+06	8.91E+05	1.73E+07	5.40E+06	2.40E+06	2.62E+07	2.83E+06	2.59E+06	9.81E+06	5.40E+05	3.62E+06	3.12E+06	1.02E+08
	Production	3.57E+05	6.03E+03	1.79E+05	1.43E+04	3.53E+05	1.08E+05	4.92E+04	5.27E+05	5.61E+04	5.21E+04	2.00E+05	8.67E+03	6.89E+04	6.07E+04	2.04E+06
Carnivorer	Biomass	1.23E+05	1.06E+04	4.32E+04	2.89E+04	4.55E+04	2.46E+04	5.47E+03	8.45E+04	1.12E+04	7.88E+03	2.47E+04	7.16E+03	2.19E+04	1.50E+04	4.54E+05
	Consump. (herb.)	6.05E+05	3.76E+04	2.04E+05	1.44E+05	2.16E+05	1.04E+05	2.60E+04	4.02E+05	5.33E+04	3.75E+04	1.17E+05	3.41E+04	1.04E+05	7.15E+04	2.16E+06
	Production	4.33E+04	2.49E+03	1.19E+04	1.03E+04	1.26E+04	6.38E+03	1.52E+03	2.34E+04	3.10E+03	2.18E+03	6.84E+03	1.98E+03	6.08E+03	4.16E+03	1.36E+05
Humans	Consump. (veg.)	2.25E+07	8.57E+02	9.14E+06	9.37E+05	1.86E+07	8.67E+06	2.86E+06	2.82E+07	5.66E+06	1.02E+06	1.17E+07	2.50E+06	4.74E+06	1.14E+06	1.18E+08
	Consump. (fauna)	1.96E+06	6.09E+00	8.41E+05	1.23E+02	1.96E+06	5.61E+05	2.80E+05	2.80E+06	2.81E+05	2.80E+05	1.12E+06	2.98E+02	2.81E+05	2.80E+05	1.07E+07
NEP		3.00E+08	–7.10E+06	2.93E+08	1.44E+08	3.15E+08	1.12E+08	6.17E+07	4.12E+08	6.28E+07	8.15E+07	2.23E+08	–2.97E+07	1.13E+08	8.20E+07	2.16E+09
NEP (m^{-2})		150	–33	169	288	171	146	278	120	137	255	223	–102	127	135	151

Confidence and uncertainties

The importance of the different pools and fluxes for the overall carbon budget is dependent on their relative sizes. Thus, large variations or uncertainties in relative large pools/fluxes overshadow the influence of relative smaller pools/fluxes. This has 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 forestry management. Tree biomass and stem increment are probably the data that have the best estimations in this carbon budget, since it 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 /Svensson 1984, see also Banfield et al. 2002/. Therefore, calculations of the carbon budget should get less sensitive to spatial variation when the area of interest is larger. Accordingly, the carbon budget for the discharge area should be more robust (relative deviance from the actual pools and fluxes) than the carbon budgets for a square metre forest, mire or seminatural grassland presented earlier. See also the discussion under Section 3.7.2.

The presented results suggest that the accumulation in the SOC pool in older coniferous forests and forested wetlands are overestimated. This might be an effect of a high input of AG and BG litter input. The AG litter fall was estimated using BEF's originating from one year of litter fall, which may vary a lot between years. The BG litter fall is built upon the assumption of a complete turnover of fine roots during a year, which may be an overestimation. Both these litter fluxes are being studied more thoroughly at the site and these studies will be included in later versions of this descriptive model. The C-mineralisation was generally somewhat higher than expected from literature. However, soil respiration is sensitive to soil temperature /Widén and Majdi 2001/ and may vary between years /Euskirchen et al. 2003/. Further measurements are in progress and willThe net accumulation in trees is probably slightly overestimated because of lack of age correlated biomass expansion factors (see discussion in Section 3.7.2).

4.1.4 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/. The results and more detailed description of the applications to Simpevarp and Forsmark is found in /Gustafsson et al. 2006/. Below follows a short presentation of the CoupModel and some of the input data to the modelling approach.

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 (Figure 4-3). It is an integration of the SOIL and SOILN 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

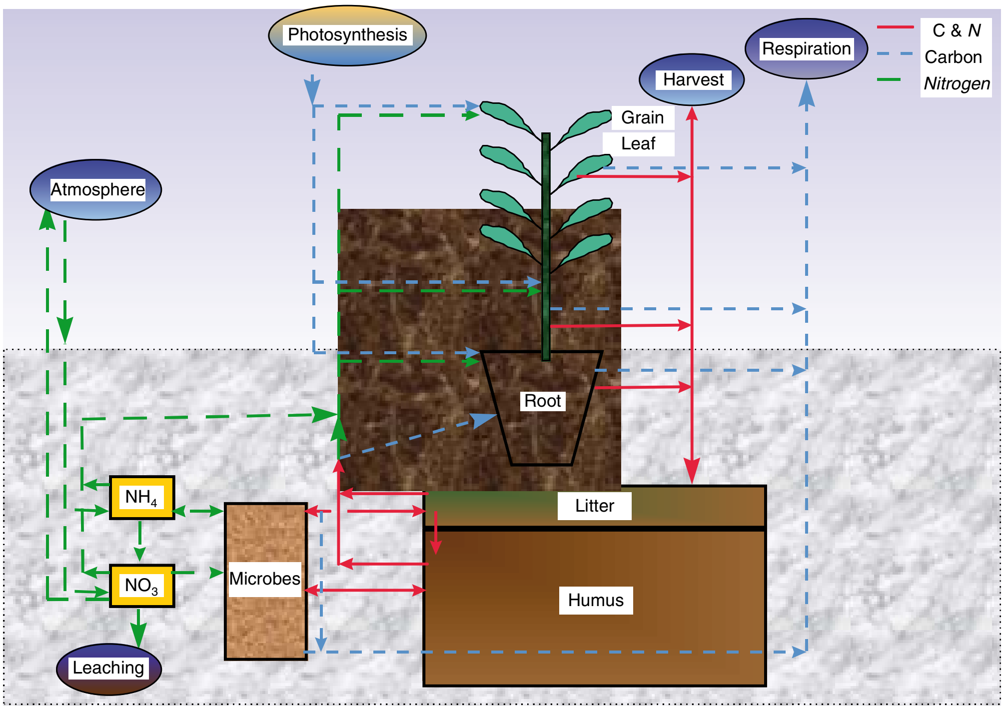

Figure 4-3. *Schematic model of carbon, nitrogen and biomass flows (in one dimension) and storages. The soil is further divided into layers and plant biomass is divided into pools of annual and perennial tissues.*

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. 2005/, 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 /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/. 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.

Results

See /Gustavsson et al. 2006/ for a presentation and a discussion of the results.

Conclusion

We have identified the crucial role of some key processes that need to be carefully considered when transient long-term development of ecosystem are to be described. For time scales up to 100 years, nitrogen transformations and nitrogen uptake have been demonstrated as very crucial and also complicated to parameterize. To enable a realistic representations for time scales of 1,000 years or longer, we suggest more focus on soil formation processes and transitions between different plant species, feedback between soil organic storage and physical properties of the soils, etc. We believe that the present model is well adapted to represent periods of up to 100-year but for the longer periods we will also suggest new model developments /Gustafsson et al. 2005/.

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 view of the stream ecosystem may be too simplified, especially for large, slowly flowing water courses with extended areas of periodically flooded stream banks. However, the running waters within the Laxemar model area are rather small and their importance for production of food to humans is regarded as insignificant.

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 has 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, which are described in detail in Section 4.10. In short, the bottom of the lake basin is separated from the free open water, *the pelagial zone*. *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 between 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 3.8.2). 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.

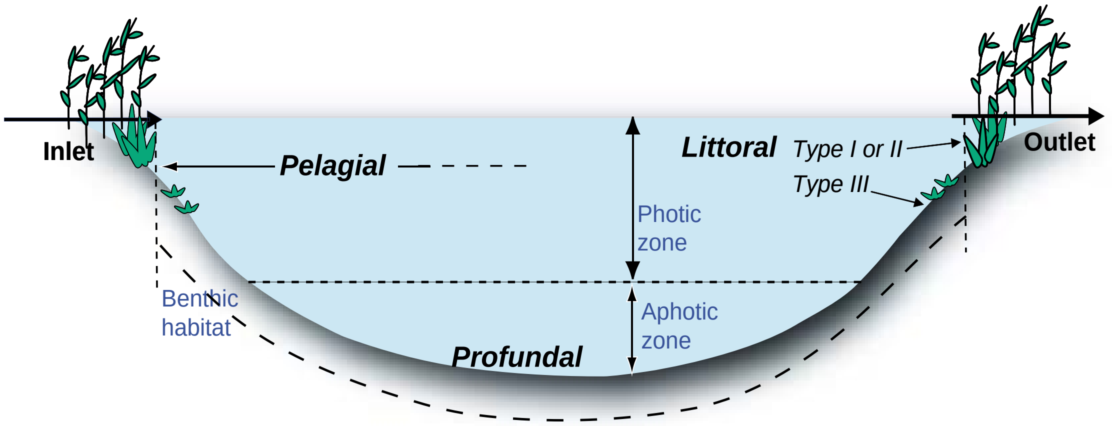

Figure 4-4. *Conceptual illustration of a lake ecosystem with the conventional division into littoral, pelagial and profundal habitats. In the budget calculations, the bottom areas of the Littoral type III and the profundal zone has been combined to the benthic habitat.*

Functional groups – Primary producers

The major groups among primary producers in most lakes 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**. Also in the Littoral II (hard bottoms), some macrophytes are present though the biomass is much lower. The vegetation biomass is dominated by Common reed (*Phragmites australis*) and Bulrush (*Typha latifolia*). Water lilies (*Nuphar lutea, Nymphea alba*) also make up an essential part of the biomass.

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 benthic habitat (Littoral III) contains no bottom vegetation. It may be reasoned that since there are no submerged macrophytes, this zone should instead be classified as profundal. 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 group of *phytoplankton* in Lake Frisksjön in July was dinophytes, while diatoms dominated in December and April /Sundberg et al. 2004/. Generally, both biomass and taxonomic composition of phytoplankton varies greatly during the year. In the budget calculations, total biomass of all taxonomic groups was used. Regardless of seasonal variation 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. 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 consumed at different rates. The bacteria have been divided into three groups; bacterioplankton, benthic bacteria and epiphytic bacteria.

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 considered necessary for the carbon budget calculations, and therefore no further division has been used for these groups.

The functional group *fish* is also very heterogeneous, especially concerning food choice, and fish data from Lake Frisksjön was therefore divided into the functional groups zooplanktivore fish (Z-fish), bentivore fish (M-fish) and piscivore fish (F-fish), according to /Holmgren and Appelberg 2000/ (cf Section 4.10).

Food web relationships

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.

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 biomass is 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 are 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 the M-fish are assumed to eat in proportion to the availability of benthic fauna, epiphytic bacteria, epiphytic algae and epiphytic fauna, respectively.

Piscivore fish (F-fish) do, by definition, consume fish. The transition of food preferences into piscivori are for some species (e.g. perch) neither distinct nor complete. Each individual eat the kind of food that is available, which means that if the amount of fish is low it will eat other food items instead. Piscivore fish are therefore assumed to consume also benthic fauna. Moreover, it is assumed that there are no preferences for specific prey species or sizes, and the consumption is assumed to be in proportion to what is available in biomass of Z-, M-, F-fish and benthic fauna.

Thus, zooplankton, benthic fauna and F-fish consume to some extent organisms belonging to their own taxonomic group. As can be seen above, 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.

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 are assumed to occur in the whole area of Littoral I (mainly represented by reed) and Littoral II (other species). Epiphytic algae, epiphytic bacteria and epiphytic fauna are assumed to be present in the reed belt on straws of *P. australis* 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 2005/. Fish are assumed to be distributed in the pelagic.

Biomass

Phytoplankton biomass was calculated from site data on Chlorophyll *a*. Direct measurements of phytoplankton biomass are available from three different occasions, but biomass estimates based on Chlorophyll *a* were chosen because of the much larger amount of data (28 values from the time period December 2002–May 2004). Macrophyte biomass in Littoral I was estimated from a study of reed belts in a coastal area nearby Lake Frisksjön /Alling et al. 2004b/. In that study, the reed biomass (including rhizomes) showed large spatial variation (500–7,000 g $DW \cdot m^{-2}$). A value of 1,150 g $DW \cdot m^{-2}$ (25^{th} percentile of the data presented in /Alling et al. 2004b/) was chosen as most accurate for Lake Frisksjön, since the coastal sediments are assumed to be thicker and more nutrient rich than the lake sediments. Biomass of macrophytes in Littoral II was estimated using data from /Aquilonius 2005/.

Bacterioplankton biomass was taken from the coloured Lake Tvigölingen in Uppland /Lindström 1998/ and biomass of benthic bacteria from Lake Erken in Uppland /Goedkoop and Törnblom 1996/. Zooplankton biomass in Lake Frisksjön has been investigated at three occassions; July and December 2003 and April 2004 /Sundberg et al. 2004/. In the budget calculations, the mean biomass from the December and April samplings was used for the period November–May. The July value was very high and is not judged as representative summer value for Lake Frisksjön. Instead, median zooplankton biomass in a humic lake, included in the Swedish national monitoring programme (Lake Älgsjön; /SLU 2005 (www)/), was used for the period June–September, and the mean of these two values for October.

Biomasses of benthic fauna and fish are estimated from site data. In one sample of benthic macroinvertebrates in the sublittoral, a single mussel made up almost the entire biomass. This mussel was excluded before calculating a mean biomass to be used in budget calculations. Literature values were used for biomasses of epiphytic algae /Meulemanns 1988 (oligo-mesotrophic 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.

Primary production

No direct measurements of primary production in Lake Frisksjön are available. Instead, phytoplankton production was estimated using literature data /Nürnberg and Shaw 1999/, based on investigations in a number of humic lakes. Data for epiphytic algae was taken from an oligo-mesotrophic lake /Meulemanns 1988/. The reed biomass (excluding rhizomes) measured in August in coastal areas near Lake Frisksjön /Alling et al. 2004b/ was assumed to correspond to the annual primary production in the Littoral I. Macrophytes in Littoral II (e.g. Water lilies) are assumed to loose part of the yearly production during the growing season, and it was therefore assumed that the August biomass made up 80% of the total yearly production. 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. The DOC release from macrophytes during primary production is assumed to be negligible.

Consumption, respiration and secondary production

In the budget calculations, secondary production for a given heterotrophic organism group was generally assumed to equal the difference between the amount of carbon consumed and the amount respired. No site data describing these heterotrophic processes are available from Lake Frisksjön, and therefore literature values from lakes as similar to Lake Frisksjön as possible were used.

Bacterial respiration was assumed to be 3 times the bacterial production. Based on literature values on bacterioplankton production in humic lakes with DOC concentration similar to Lake Frisksjön /Nürnberg and Shaw 1999/, bacterioplankton production was assumed to be 20 mgC m^{-3} d^{-1}. For benthic bacteria, data on bacterial production in the top sediments of the mesotrophic Lake Erken /Goedkoop and Törnblom 1996/ was used, and for epiphytic bacteria, bacterial production on reed from /Haines et al. 1987/ was used. Respiration estimates for zooplankton, benthic fauna and fish were calculated from site specific data on biomass, using conversion factors from /Kautsky 1995/ (Table 1-2) and measured temperature in Lake Frisksjön.

Bacterial consumption was assumed to be the sum of respiration and bacterial production. For consumers other than bacteria, consumption was assumed to be 3 times the respiration, except for fish where the consumption was assumed to be 1.73 times the respiration.

Conversion factors

Data on biomass and respiration given in other units than gC were converted with the aid of conversion factors from /Kautsky 1995/ (see Table 4-9).

Table 4-9. 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 data from Lake Frisksjön (measured at samplings for water chemistry, 20 times per year) to calculate the respiration, assuming a direct linear relationship between respiration and temperature. DW = dry weight, WW = wet weight.

Functional group	Biomass $gDW \cdot gWW^{-1}$	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

Particulate and dissolved organic carbon

Particulate and dissolved organic carbon (POC and DOC) are important food resources for several functional groups (see Table 4-3). The mean annual concentration of POC and DOC can be calculated from site data. However, the turnover of these carbon pools (at least the easy degradable parts) is likely much shorter than a year, and the mean concentrations are therefore poor estimates of the total available annual carbon pools. On an annual basis, most organism groups in the carbon budget show a carbon excess when subtracting losses by grazing/predation from net primary/secondary production (see Table 4-12). Since there is no increase in biomass over time, this excess carbon is assumed to contribute equally to the POC and DOC pools (in reality there is of course a dynamic exchange of carbon among biota and the POC and DOC pools, but this is not possible to handle in a static model). Beside this, 40% of the primary production by phytoplankton and algae was assumed to be released to the water and thereby contribute to the DOC pool (see above)

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 4. Where site specific data on biomass is missing, generic data available in the literature has been used. Since no site data on production or respiration is available, these processes have either been estimated from generic data, or calculated from biomass and temperature data with the aid of conversion factors as described above. The data sources for the different parameters in the model are compiled in Table 4-10.

Table 4-10. 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		Estimated from Chlorophyll *a* values (SICADA)
Bacterioplankton		X	/Lindström 1998/
Zooplankton	X	X	/Sundberg et al. 2004, SLU 2005 (www)/
Z-fish (zooplanktivore)	X		/Engdahl and Ericsson 2004/
M-fish (benthivore)	X		/Engdahl and Ericsson 2004/
F-fish (piscivore)	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	X	/Aquilonius 2005, Alling et al. 2004b/
Epiphytic algae		X	/Meulemanns 1988/
Epiphytic bacteria		X	Assumed to have the same biomass as epiphytic algae
Epiphytic fauna		X	/Ahlkrona et al. 1998/
Abiotic carbon pools	X		SICADA; /Nilsson 2004/
Surface and volume info	X		/Brunberg et al. 2004/

Food web matrix

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). The food web relationships, together with the availability of different food sources, were used to calculate the estimated proportions of different food sources for the functional groups in Lake Frisksjön (Table 4-11).

Table 4-11. Food web matrix, including estimated food proportions (based on the availability of different food sources) for Lake Frisksjön. Numbers in the matrix denote the estimated proportion of different food sources (columns) consumed by a given organism group (row).

	Phytoplankton	Macrophytes	Epiphytic algae	Epiphytic bacteria	Epiphytic fauna	Bacterioplankton	Zooplankton	Planktivore fish	Benthivore fish	Piscivore -fish	Benthic bacteria	Benthic fauna	DOC	POC	DIC
Phytoplankton						0.45					0.05				0.50
Macrophytes															0.00*
Epiphytic algae															1.00
Epiphytic bacteria													0.58	0.42	
Epiphytic fauna			0.50	0.50											
Bacterioplankton													0.58	0.42	
Zooplankton	0.59					0.21	0.19								
Planktivore fish							1.00								
Benthivore fish			0.03	0.03	0.00							0.94			
Piscivore -fish								0.01	0.11	0.10		0.79			
Benthic bacteria														1.00	
Benthic fauna	0.01					0.01	0.01				0.03	0.04		0.91	

*Macrophytes use carbon from the atmosphere.

Carbon budget for the limnic ecosystem

The biomass in Lake Frisksjön is totally dominated by macrophytes (reed), comprising more than 98% of total biomass in the lake (Table 4-12, Figure 4-5). Also primary production is dominated by macrophytes, but phytoplankton contributes with a substantial part of total primary production, despite the low biomass of this functional group. The primary production by other producers in the lake (i.e. epiphytic algae) can be neglected. This means that about 2/3 of total primary production in the lake occur within the littoral and 1/3 in the pelagial. Reed utilises carbon from the air and not from the water, and does accordingly not influence the inorganic carbon (DIC) compartment in the water. On the other hand, when decomposing, a substantial part of the reed will be released to the pelagial as particulate or dissolved carbon /Gessner et al. 1996/, thereby contributing to the bacterial production and, accordingly, strongly influencing the overall carbon budget.

The estimated total annual primary production in the lake (about 12,000 kg C) corresponds to half of the total biomass, and is in the same order of magnitude as total lake respiration (Figure 4-3). Almost 80% of the secondary production occurs in the pelagial, with mixotrophic phytoplankton, bacterioplankton and zooplankton are the most important contributors. Most of the remaining secondary production can be attributed benthic fauna and bacteria (Table 4-12, Figure 4-5). In the previous version of the carbon budget for Lake Frisksjön, presented in /Lindborg 2005a/, the magnitude of bacterial respiration was exaggerated, partly due to a miscalculation in the biomass of benthic bacteria, and partly due to unrealistically high respiration rates for both benthic and pelagic bacteria.

Table 4-12. Total average biomass (gC), annual primary and secondary production (gC year^{-1}), and annual excess of functional organism groups in Lake Frisksjön, according to the carbon budget. Excess for a functional group denotes the difference between estimated annual supply (net primary/secondary production) and demand (grazing/predation). Note that phytoplankton includes both autotrophic and mixotrophic species and hence this group shows primary as well as secondary production.

Functional group	Biomass		Net primary prod.		Secondary prod.		Excess
	gC	%	gC y^{-1}	%	gC y^{-1}	%	gC y^{-1}
Pelagic habitat	1.4E+5	0.5	4.3E+6	36.3	6.0E+6	78.8	
Phytoplankton	3.8E+4	0.1	4.3E+6	36.3	2.5E+6	33.3	5.6E+6
Bacterioplankton	1.4E+4	0.0			1.6E+6	21.3	–3.0E+6
Zooplankton	2.5E+4	0.1			1.3E+6	17.1	8.8E+5
Planktivore fish	1.5E+3	0.0			1.3E+4	0.2	1.0E+4
Benthivore fish	3.1E+4	0.1			2.7E+5	3.6	2.1E+5
Piscivore fish	2.9E+4	0.1			2.5E+5	3.3	1.9E+5
Benthic habitat	3.9E+5	1.4	0	0	1.5E+6	19.6	
Benthic bacteria	1.7E+5	0.6			4.5E+5	5.8	–1.4E+5
Benthic fauna	2.3E+5	0.8			1.0E+6	13.7	–1.4E+5
Littoral habitat	2.8E+7	98.1	7.5E+6	63.7	1.2E+5	1.6	
Macrophytes	2.8E+7	98.1	7.2E+6	60.8	0.0E+00		7.2E+6
Epiphytic algae	7.5E+3	0.0	3.4E+5	2.9	0.0E+00		1.8E+5
Epiphytic bacteria	7.5E+3	0.0			1.2E+5	1.6	9.8E+4
Epiphytic fauna	2.4E+2	0.0			2.3E+3	0.0	1.7E+3
Lake total	2.8E+7		1.2E+7		7.6E+6		

Carbon is transported to the top predator, piscivore fish, through two main pathways. One is through POC to benthic fauna, to benthivore fish, and further to piscivore fish. The other pathway is through bacterioplankton to zooplankton (or through mixotrophic phytoplankton to zooplankton), to planktivore fish and further to piscivore fish. The main part of carbon reaching piscivore fish goes through the first benthic pathway (Figure 4-5).

Carbon pools in Lake Frisksjön

As described above, most organism groups show a carbon excess when subtracting losses by grazing/predation from net primary/secondary production, and this excess is assumed to contribute to the POC and DOC pools. This makes it possible to calculate rough estimates of the annual POC and DOC pools in lake water. When sediment carbon is excluded, these abiotic pools comprise together about 1/3, and the biotic pools about 2/3, of the total carbon pool in the lake (Table 4-13). However, when sediment carbon is included in the comparison it is totally dominating, with 99.8% of the total carbon pool bound into the sediment.

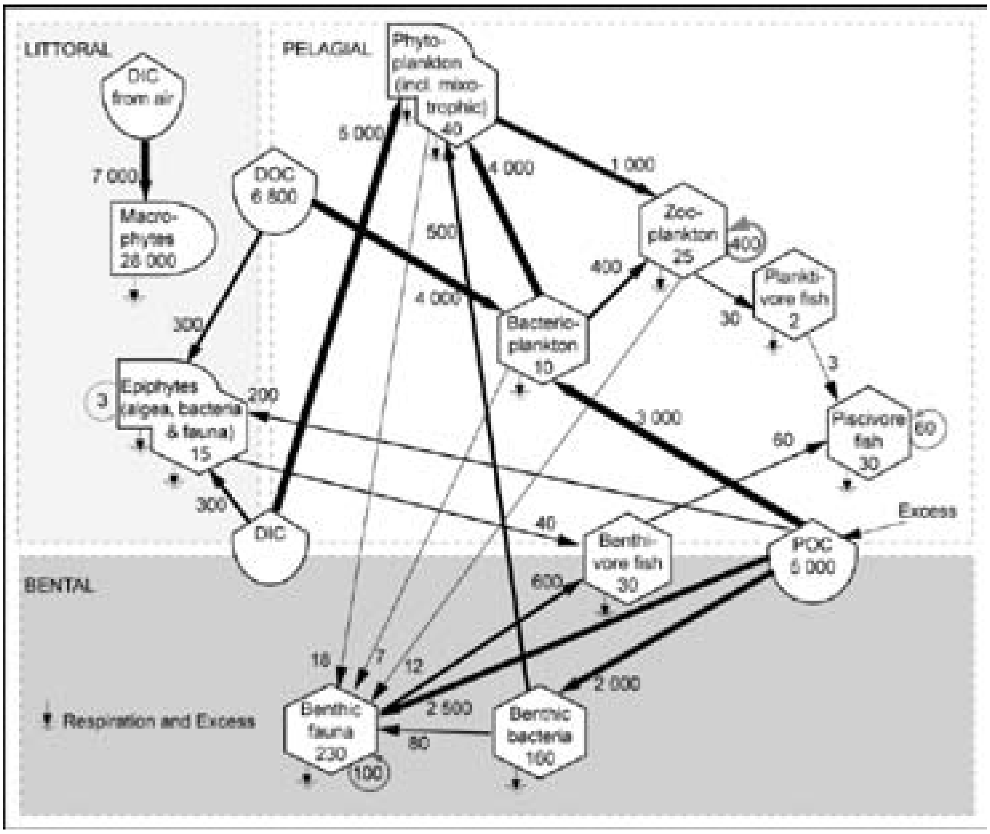

Figure 4-5. Carbon budget for Lake Frisksjön. Values within symbols denote the carbon pool (kgC) and values beside arrows denote annual carbon flow (kgC·y^{-1}). Arrow sizes indicate the magnitude of carbon flow between different functional groups. Since the biomasses of all epiphytic groups (algae, bacteria and fauna) are so small, they have been treated as a single epiphyte group in the figure.

Table 4-13. Estimated carbon pools in biota, water, and sediment in Lake Frisksjön, and the relative amount of carbon in the different pools when sediment carbon is excluded and when it is included.

	C pool (kg)	% of total C pool excluding sediment C	% of total C pool including sediment C
Biota	28,500	70	0.32
Producers	28,000	68	
Consumers	500	1	
Water	11,800	30	0.14
POC	5,000	12	
DOC	6,850	17	
Sediment	8,775,000	–	99.5

Overall carbon budget for Lake Frisksjön

The ecosystem model presented above indicates that the annual respiration in Lake Frisksjön is at the same level as the annual primary production, about 12 metric tonnes per year. Annual carbon input from the catchment area is estimated in the terrestrial ecosystem model (see Section 4.1) to 6.9 tonnes. A rough estimate of carbon outflow, based on measured total organic carbon (TOC) in lake surface water and modelled discharge, indicates that the annual transport of organic carbon out of the lake is approximately 5 tonnes. Annual sedimentation has been estimated from the sedimentation rate (1.2 $mm \cdot y^{-1}$) and sediment carbon content given in /Nilsson 2004/, to 1.9 tonnes carbon per year. Taken together, this gives an almost balanced overall carbon budget for Lake Frisksjön; the carbon deficit is c 300 kg per year, which correspond to about 1% of the total annual carbon turnover in the lake (Figure 4-6).

Confidence and uncertainties

This ecosystem model for Lake Frisksjön is an updated version of the model earlier presented in the site characterisation of the Simpevarp area /Lindborg 2005a/. Compared to the previous model version, some of the assumptions on which the model is based have been reconsidered, and a direct miscalculation concerning bacterial biomass has been corrected. As a result, the previously completely dominating role of bacteria in the lake ecosystem is reduced in the present model. In addition to the carbon budget for the limnic ecosystem, estimated inputs of carbon to the lake from external sources, as well as carbon outflow from the lake, have been used to produce an overall carbon budget for Lake Frisksjön.

The estimate of phytoplankton primary production is based on literature values from 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 this introduces some uncertainty into the estimated phytoplankton biomass.

Zooplankton biomass generally shows high seasonal variation, with the highest biomass during summer. The only site data on zooplankton biomass from the summer period was extremely high, and the value was not judged as representative for summer conditions in Lake Frisksjön. Instead, summer data from another humic lake in central Sweden was used in the model, but this use of generic data may add uncertainty to the model. Moreover, a potentially important component of the zooplankton community, the ciliates, has not

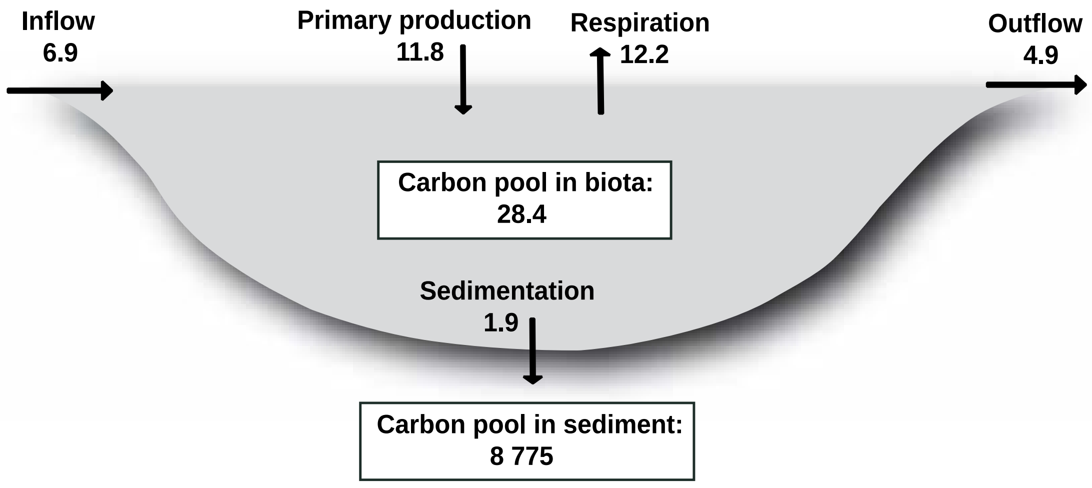

***Figure 4-6**. Major in- and output pathways for carbon in Lake Frisksjön. Numbers denote annual carbon flow (metric tonnes of carbon per year). For comparison, the major carbon pools in the lake are shown within boxes (tonnes of carbon).*

been included in the model, mainly because of lack of quantitative data describing the role of ciliates in the limnic ecosystem. However, even if it is not possible to quantify the uncertainties connected to the zooplankton estimates, it seems not likely that these uncertainties should be critical for the confidence of the carbon budget for Lake Frisksjön.

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. There is no study which can be used to validate any conversion factor, and the proposed conversion factor used in this study may be regarded as an “expert guess”.

In conclusion, despite the fact that many of the parameters in the model are not measured in the lake, the carbon budget presented here can 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 major uncertainties in the carbon budget are associated with assumptions concerning microbial organisms and processes, e.g. bacterial biomass and metabolism in all of the lake habitats, and the degree of heterotrophy in the phytoplankton community. These uncertainties are reflected in the carbon budget, in that both bacterio-plankton and benthic bacteria show a carbon deficit on an annual basis, but this deficit is more than balanced by the annual carbon excess for phytoplankton.

4.3 The marine ecosystem

4.3.1 Introduction

In this chapter, a marine ecosystem model for the Laxemar study area is calculated on a spatial domain consisting of 1,200×1,400 grid-cells each with a 10×10 m size. This grid was used in modelling the fluxes of carbon between functional groups and the surrounded environment. The system is assumed to be in a steady, non-seasonal, state and all input data are based on yearly averages. The parameters used in the calculations have been interpolated to the 10 m grid by using a number of different methods which are described below. As a principle all biomasses and production values are considered to be fixed and independent to each other. No fluxes between the grid-cells or to and from the system are quantified and the pool of particulate organic carbon in the sediment is not included. The results are presented as per square metre or per basin. The basins are presented in Figure 4-7, below together with the digital elevation model for the marine area.

4.3.2 Conceptual model of the marine ecosystem

The organisms represented in the research area were divided into different functional groups, which then were connected into a food-web. This classification scheme of which groups to use and how to divide the organisms among them was based on work by /Kumblad et al. 2003/.

Primary producers

Primary producers are normally divided into large benthic algae and plants- macrophytes, unicellular benthic algae- microphytobenthos and pelagic “free-swimming plankton”-phytoplankton. In the Laxemar area, macrophytes are abundant in the phytobenthic habitat, particularly the brown algae *Fucus vesiculosus*, the soft bottom living *Chara sp*, and red

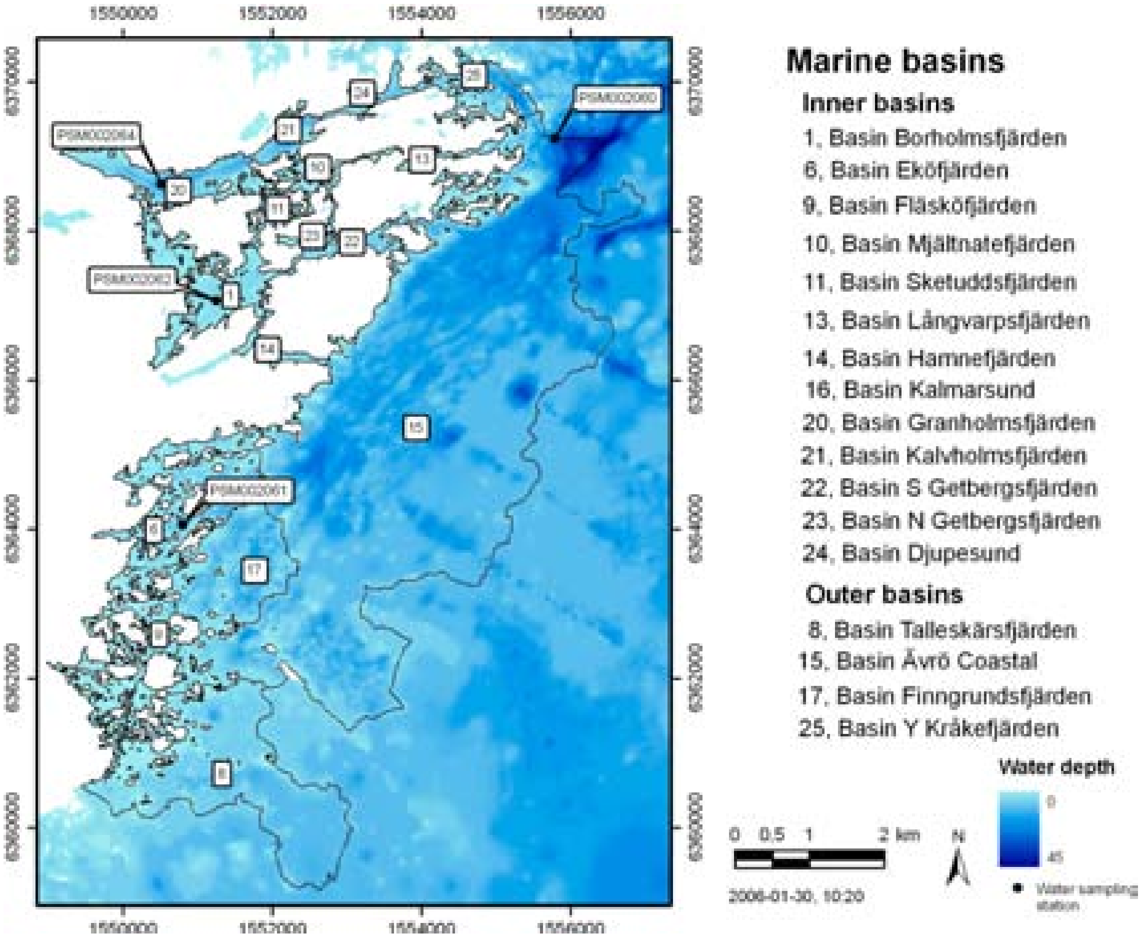

Figure 4-7. The coastal basins in the Laxemar area. The digital elevation model for the sea is displayed in increasing dark blue with depth. PSM-number show water chemistry sampling stations.

algae (e.g. *Polysiphonia sp*) each in different habitats. (This is described in more detail in Section 3.9) Any epiphytic primary producers are assumed to be included in the estimations of primary production and biomass of the macro algae. Reed, *Phragmites australis*, is included in macrophytes.

Also microphytobenthos is present in the benthic system, and is often important in coastal Baltic systems. There are no site-specific data of microphytobenthos available for the Laxemar area.

Phytoplankton is in the Laxemar area dominated by diatoms, cryptophytes and dinoflagellates. The biomass varies greatly both intra- and inter-annually /Sundberg et al. 2004/.

Consumers

Consumers are defined as all heterotrophic organisms in the ecosystem, i.e. herbivores, carnivores and detrivores. In the quantitative model, these organisms are divided into 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 in recirculation of nutrients. The species composition is not known but is assumed to be non-significant for the budget calculations. Because bacteria on different substrate are assumed to assimilate carbon from different pools and to be eaten at different rates, they have been divided into two groups; bacterioplankton and benthic bacteria. None of these have been studied in the Laxemar area and data from other regions have been used. Pelagic bacteria, have been estimated using data from /Kuparinen 1987/ and benthic bacteria by data from /Mohammadi et al. 1993/.

Zooplankton is a heterogeneous group with respect to organism size, life cycle and food choice. However, in this budget, that level of detail has been omitted as it was assumed to not be of importance for the carbon budget calculations.

Fish was divided into the functional groups zooplanktivore fish, bentivore fish and piscivore fish.

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* and gobides. 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, was used in the calculations /Ankar and Elmgren 1978/.

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 implies an underestimation.

Habitats

The marine environment was divided into three major habitat. A conceptual illustration is shown in Figure 4-8, where the “phytobenthic habitat” is defined as the benthic habitat in the photic zone, “benthic” as the benthic habitat in the aphotic zone, and the “pelagic habitat” as the open water habitat, both photic and aphotic.

Temperature, respiration, consumption and secondary production

To calculate respiration, established conversion factors on specific respiration ($gC \cdot gC^{-1} \cdot day^{-1}$) were used together with a “degree day” concept, which was calculated by the equation

$$Degreedays = meantemp \cdot \frac{365}{20}$$

where *meantemp* was the yearly mean of temperature (of surface and bottom water) during the period 2002 to 2004.

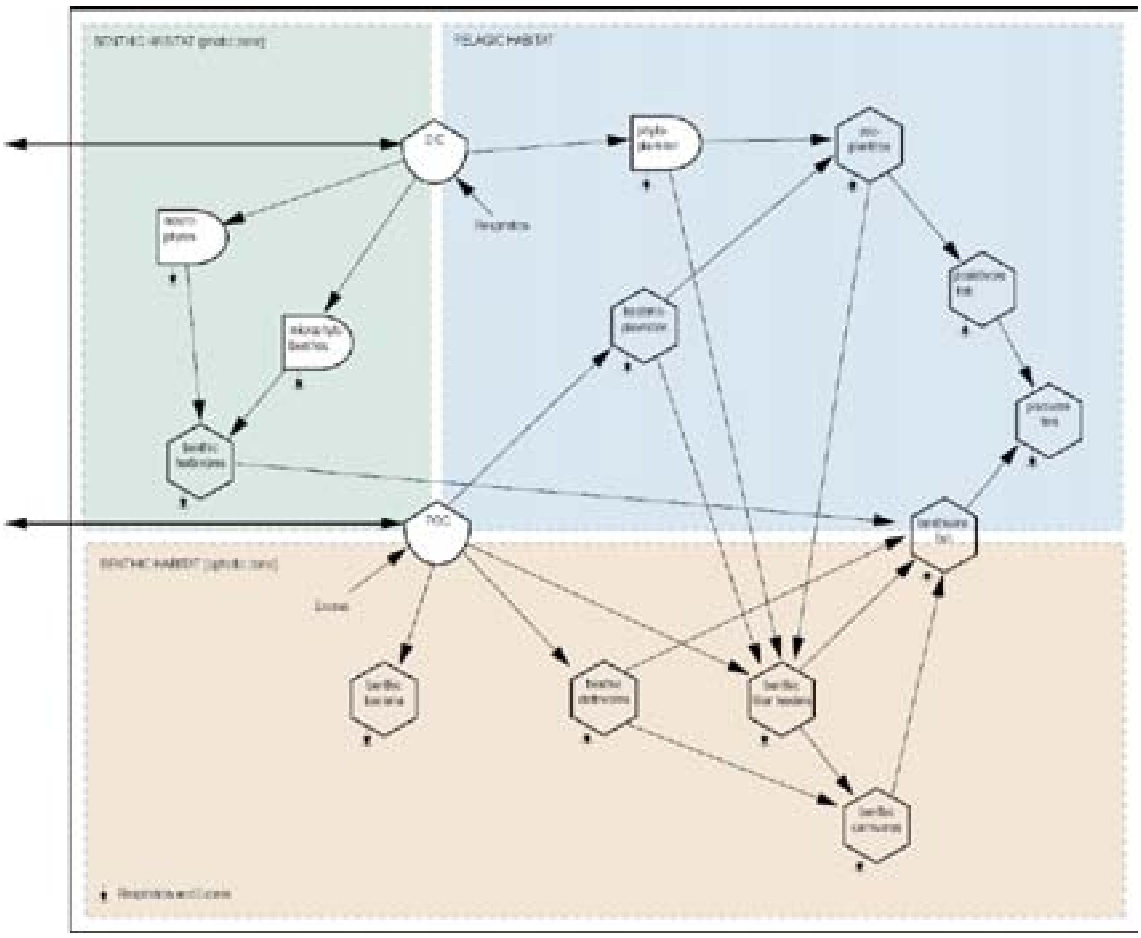

***Figure 4-8.** Conceptual illustration of the marine coastal ecosystem in the Laxemar area including illustrations of the habitats (phytobenthic, soft benthic and pelagic).*

Consumption was assumed to be three times the respiration rate except bacterial consumption that was assumed to be two times the respiration. Secondary Production (heterotroph production) is defined as consumption minus respiration, and is later in this chapter, together with Primary Production (autotroph production), included in the term Production. Heterotrophic organisms are supposed to consume their food in proportion to the production or available biomass of the specific food (see "Excess" below).

Excess

Excess is defined as the overshoot of primary or secondary production subtracting the demand from consumers. Excess is calculated from:

$$E_{food1} = P_{food1} - \left[C_{pred1} \cdot \left(\frac{P_{food1}}{P_{food1} + P_{food2}} \right) + C_{pred2} \cdot \left(\frac{P_{food1}}{P_{food1} + P_{food2} + P_{food3}} \right) + \right.$$

$$\left. \ldots + C_{predn} \cdot \left(\frac{P_{foodn}}{P_{foodn} + P_{foodn} + \ldots + P_{foodn}} \right) \right]$$

where E_{food1} is excess of a functional group being consumed of other organisms (*Pred1, 2, 3*). P_{food1} is its production, $C_{pred,. 2, 3}$ is the total consumption of the consumer and $P_{food2,3}$ is the production of the predators other source of food.

Food web relationships

The distribution of the consumption pattern for various functional groups is shown in Table 4-17. 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 (in biomass).

All primary producers (except Reed), i.e. macrophytes, microphytobenthos and phytoplankton, were assumed to assimilate 100% of their carbon demand 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.

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.

Fish feeding on zooplankton (planktivore fish) were assumed to consume zooplankton but not POC, phytoplankton or bacterioplankton, while these groups are assumed to be too small to be ingested. Fish feeding on benthic fauna (benthic fauna feeding fish) are most probably feeding selective. Of this we have no detailed information, therefore the benthivore fish were assumed to consume in proportion to what's available of the benthic fauna (benthic herbivores, filter feeders, detrivores and carnivores). Piscivore 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 birds feeding on fish consume fish in proportion to their abundance.

4.3.3 Quantitative site specific model

Indata

Substrate

A grid with bottom substrate classified as hard bottom and soft bottom, Figure 4-9, was created by using surveys from SGU and Marin Mätteknik /Ingvarsssson et al. 2004/ in which the latter have priority when overlaps occurred. Clay, sand and gyttja were classified as "soft" and bedrock and moraine were classified as "hard". To fill gaps in the dataset, an interpolation technique with the aim to preserve the distribution and patch size of the existing data was developed. Each basin was evaluated separately, column by column. A vector containing available data for the column was created and each empty cell was assigned the next value in the vector. If the end of the vector was reached, the first value was used again etc. If a column for a certain basin did not contain any data, a vector consisting of data from the entire grid was instead used**.**

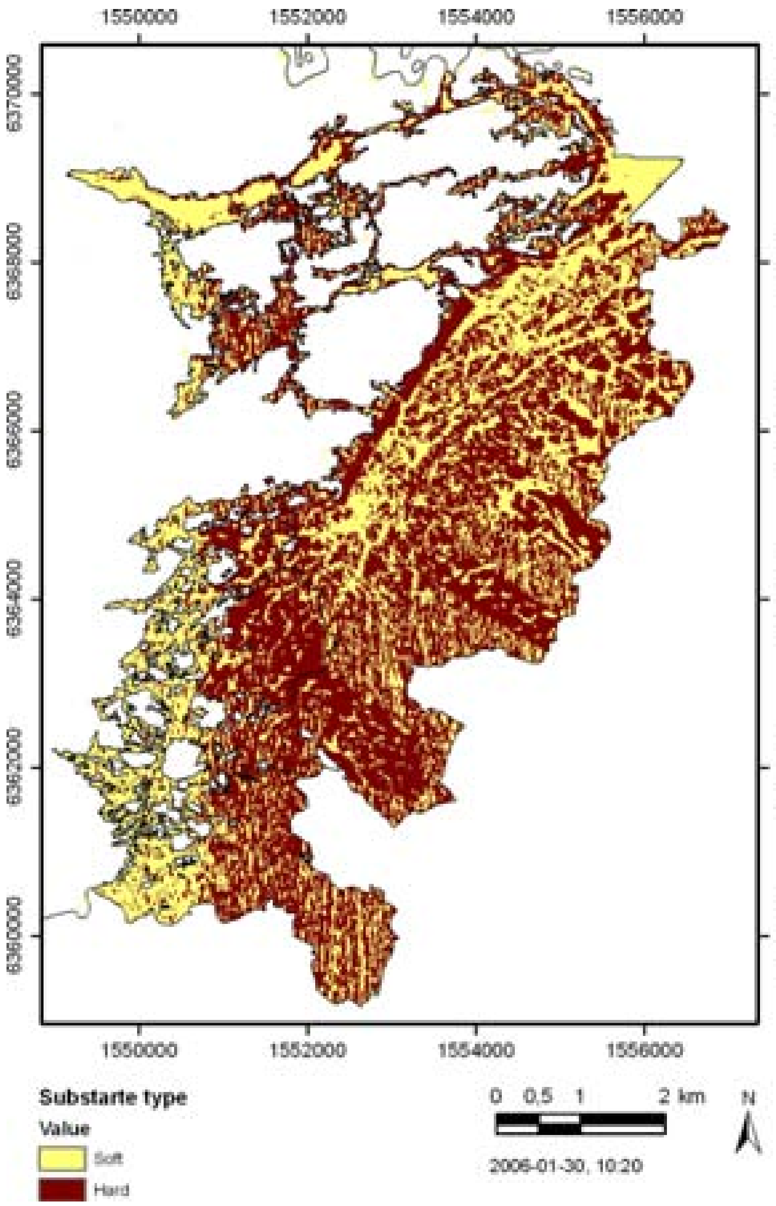

Figure 4-9. *Classifications of the bottoms in the Laxemar area in hard- and soft substrate.*

Light

To calculate incoming light and production of benthic primary producers on the sea floor an average light-attenuating grid was produced based on the light penetration of photosynthetic active radiation (PAR) and the digital elevation model (DEM, cf Section 3.2). Light penetration measurements during 2003 to 2005 in four sites were correlated to depth by the relationship:

$$I = I_{surface} \cdot e^{-\alpha \cdot D}$$

where I is PAR at a given depth, I_{surface} is PAR above water, α a constant depending on water transparency, and D is water depth (m). Four different sets of attenuation grids (for basins represented by the four different measuring sites) were calculated (using the equation above and setting D = DEM) and merged.

To be able to convert daily production to yearly production, a “light-day” grid was constructed. The grid presents the annual number of light days defined as a day where radiation exceeds 5 $MJ \cdot m^{-2}$ /Kautsky 1995/ at the actual depth. The light day grid is presented in Figure 4-10. Solar irradiance was obtained from /Lärke et al. 2005/.

Phytoplankton

Phytoplankton biomass was estimated by using chlorophyll (Chl) values from the water chemistry sampling sites PSM002060–64 (cf Section 3.3). Different basins were represented by different sites according to the information in Table 4-14.

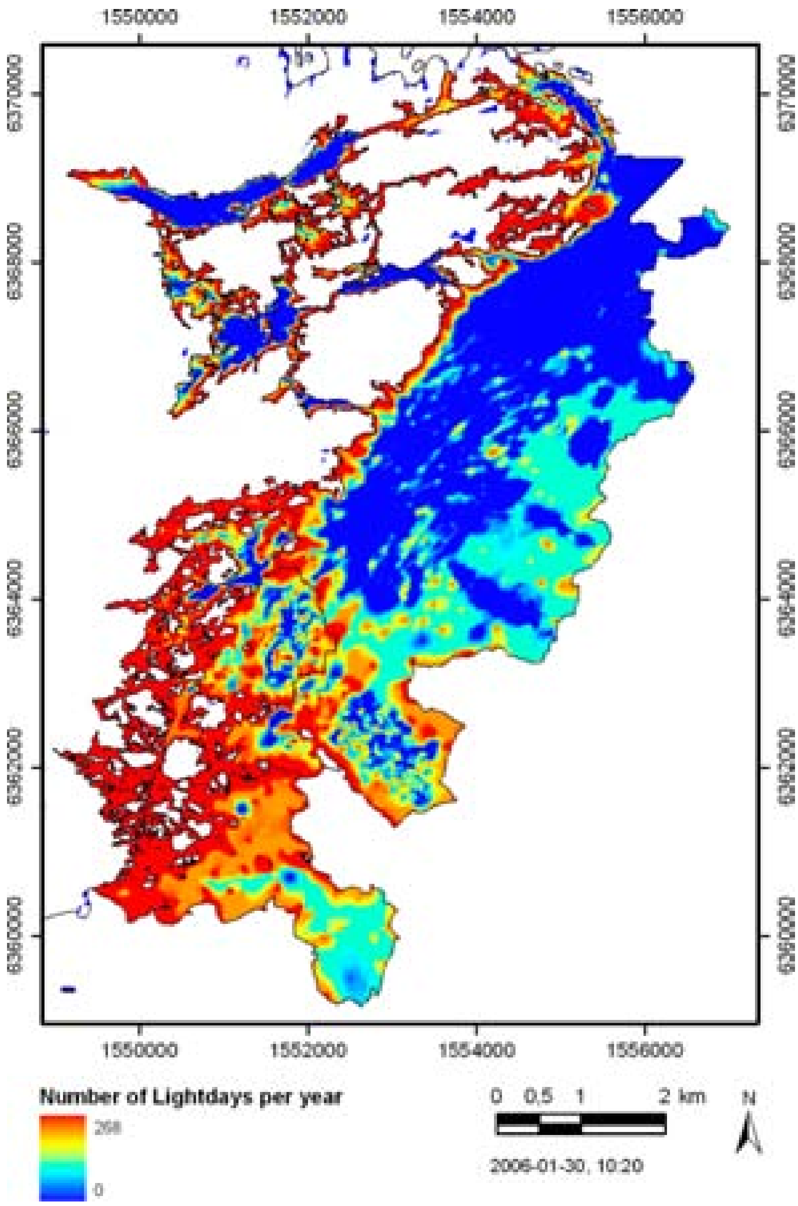

***Figure 4-10.** The light-day grid used to calculate macrophyte production in the Laxemar area. Number of light days is the number of days per year in that receives radiation that exceeds 5 $MJ \cdot m^{-2}$. Black areas are assumed aphotic, where less than 1% of incoming light reaches the sea floor.*

Table 4-14. Water chemistry sampling sites and the basins represented by the different samoling sites. The basins and sampling sites are presented in Figure 4-7.

Site	PSM002060	PSM002061	PSM002062	PSM002063	PSM002064
Basin numbers	1, 7	9, 14	2, 3	10, 11, 12, 3	4, 5, 6, 8

The measured values of gChl were then converted to gC by using a conversion factor of gC m^{-3} = 41 gChl m^{-3} for inner basins, and gC·m^{-3} = 35 gChl m^{-3} for outer basins (10–13) respectively. These factors have been established for the conditions in the southern Baltic by /Renk and Ochocki 1999/. Finally, a depth integrated grid was achieved by using the earlier described DEM. This method do not take the difference between photic depth and real depth into account explicitly, but rather implicitly in the conversion-factors between Chl and C and the fact that the measured Chl is based on depth averaged values.

Phytoplankton Primary Production was calculated using the same chlorophyll estimates as with biomass, together with yearly averaged sea surface PAR from the Äspö meteorological field station. A conversion methodology adapted from /Renk and Ochocki 1999/ was used to convert the measured Chl data to Primary Production via the algorithm

$$\int_{-\lambda/2}^{\lambda/2}\int_{0}^{H} AN \cdot Chl \frac{\eta_d \exp(-kz)\left(1+\cos\frac{2\pi t}{\lambda}\right)}{\lambda E_s} \exp\left(1-\frac{n_d \exp(-kz)\left(1+\cos\frac{2\pi t}{\lambda}\right)}{\lambda E_s}\right) dz dt$$

where λ is the length of day, H photic depth, η_d daily irradiation dose in PAR, diffuse attenuation coefficient, AN is maximum photosynthetic rate, and E_s irradiance in PAR where saturation of photosynthesis occur. AN, Es, and η_d are estimated from /Renk and Ochocki 1999/ as 1.81, 358.22, and 0.3 respectively. These values are based on averages for a number of sites in the southern Baltic. Finally, the results were combined with the bathymetry grid to calculate Primary Production (gC m^{-2}), see Figure 4-11.

Microphytes

The amount of benthic microalgae has not been measured in field in Laxemar, instead generic data from two set were used; /Meyercordt and Meyer-Reil 1999/ and /Snoeijs 1985, 1986/. The former was used to estimate the production in soft substrates and the latter for hard substrates. Production on soft substrate was given by:

$$P = P\max \cdot \left[1 - e^{\left(\frac{-\alpha \cdot E}{P\max}\right)}\right] \quad \text{from /Meyercordt and Meyer-Reil 1999/}$$

where P is production, P_{max} is production at light saturation, E is radiation, and α is a constant. α was set to 0.175 and P_{max} to 22.195 as a yearly average for the location "Rassower strom", a location assumed similar in abiotic characteristics to the semi enclosed basins in Laxemar /Meyercordt and Meyer-Reil 1999/. Net production was obtained by subtracting the average respiration of 54 gC m^{-2}·$year^{-1}$. Measurements of radiation from Äspö in 2004

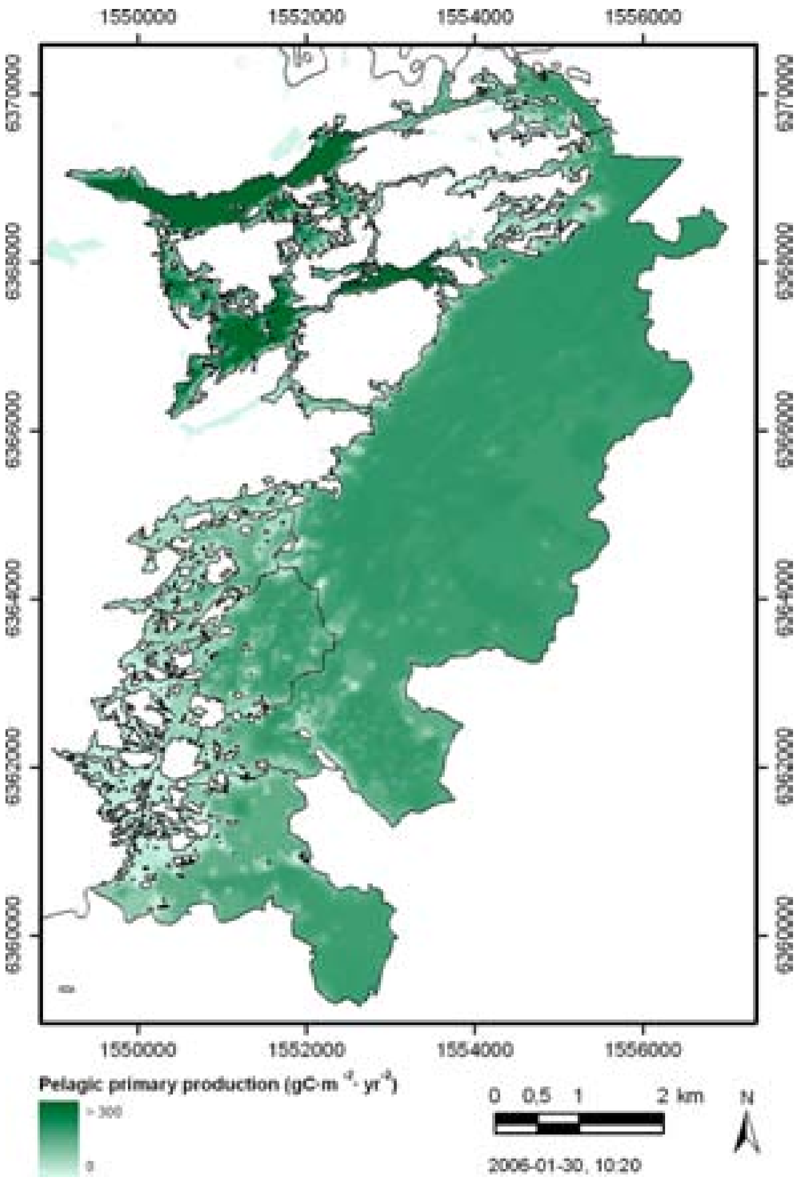

Figure 4-11. *Phytoplankton primary production (gC·m^{-2}·year^{-1}) in the Laxemar area.*

was used and transformed to PAR by multiplying with 0.45 /Tagesson 2005b/, and from W m^{-2} to μEm^{-2}·s^{-1} by multiplying with 5.6 /Licor, 2006/. PAR at a certain location and depth was obtained by multiplying measured radiation with the light attenuation grid. Light was further reduced in areas with macrophytes. In these areas incoming light was reduced by half of the coverage of macrophyte vegetation.

Data on biomass and net production of microphytobenthos on hard substrates were based on /Snoeijs 1985, 1986/. The average value ash free dry weight (g·m^{-1}·year^{-1}) was converted to dry weight assuming a factor 4 /Snoeijs 1985/ and 0.11 /Kautsky 1995/ to obtain gC. Microphytes were assumed to be equally distributed in all photic hard substrates, but reduced by half of the macrophyte coverage. The depth of the photic zone was assumed to correspond to the depth where more than 1% of incoming light reaches the sea floor (cf Figure 4-10).

Macrophytes

Macrophyte biomass was calculated from relative coverage in the vegetation communities (presented as a GIS-project) /Fredriksson and Tobiasson 2003/ multiplied with a specific conversion factor for each community. Recalculations from dry weight (g dry weight) to carbon (gC) was made using species-specific conversion factors /Kautsky 1995/ for each vegetation community. The conversion was weighted for relative abundance in each vegetation community.

Net primary production was calculated by multiplying biomass with estimates of species specific production ($gC \cdot gC^{-1} \cdot day^{-1}$) presented in /Kautsky 1995/ and annual insolation during 2004 using the light day grid (see "Light" above). Net primary production is expressed as $gC \cdot m^{-2} \cdot year^{-1}$. The biomass was assumed to be constant during the year.

Bacterioplankton

Biomass of bacterioplankton was calculated from estimates of density made for the pelagic habitat in Tvärminne, Finland (11–36 $mgC \cdot m^{-3}$) /Kuparinen 1987/ and the DEM. Respiration was calculated using specific daily respiration /Kautsky 1995/. Consumption was calculated from respiration, by multiplying the respiration by a factor two. Bacterioplankton were assumed to be evenly distributed in the pelagic habitat.

Zooplankton

Zooplankton biomass was measured at three sites during 2003 to 2004 /Sundberg et al. 2004/. The average biomass for each site was used for the different basins as presented in Table 4-15 in the same fashion as the Phytoplankton biomass. Biomass was multiplied with the DEM to obtain biomass ($g \cdot m^{-2}$).

Table 4-15. Sampling sites for zooplankton and calculated biomass values for the different basins. Basins are presented in Figure 4-7.

Site	PSM002060	PSM002062	PSM002064
Biomass ($g \cdot m^{-3}$)	0.00456	0.0780	0.0195
Basins number	1, 7, 9–14	2, 3	4, 5, 6, 8

The Zooplankton respiration was calculated using an empirically determined conversion factor between respiration and biomass of 13.8 yr^{-1} /Kumblad and Kautsky 2004/. The consumption was analogously calculated using a conversion factor of 3 between consumption and respiration.

Fish

Fish are divided in three functional groups; planktivore fish, benthivore fish and piscivore fish. Three sets of data were used to calculate fish biomass: The study on pelagic fish populations in Laxemar /Enderlein 2005/, a study of benthic fish in the Askö area /Jansson et al. 1985/ and a summary of catch by the National Board of Fisheries (*Sw: Fiskeriverket*) in Figeholm. The biomass presented by /Enderlein 2005/ was assumed to be evenly distributed in basin 8, 15, 16 and 17. Benthic fish /Jansson et al. 1985/ was assumed to be present in all, and biomass was distributed according to, the distribution of the phytobenthic communities (see "Macrophytes"), mapped by /Fredriksson and Tobiasson 2003/. Proportions of the functional groups of the catches by the National Board of Fisheries in the semi-enclosed bays and in the sea (pelagic) around 0.5 nautical mile around Laxemar are summarized in Table 4-16. Carnivorous and planktivore fish in the inner basins and piscivore fish in the pelagic habitat were calculated by a factor obtained by the proportions in Table 4-16.

Conversion from biomass wet weight to carbon was made using a factor of 0.1 /Arrhenius and Hansson 1993/. Consumption was assumed to be three times respiration, estimated from specific respiration /Kautsky 1995/.

Table 4-16. Proportions of biomass of catches of different functional groups fish.

	Semi-enclosed bays	Pelagic
Planktivore fish	0.26	0.96
Benthic fish	0.47	0.01
Piscivore fish	0.27	0.03

Benthic fauna

The benthic fauna was divided in four functional groups; benthic herbivore, benthic filter feeders, benthic detrivores and benthic carnivores.

Four sources of data on biomass have been used; the vegetation mapping study /Fredriksson and Tobiasson 2003/, also in which associated epi-fauna was also sampled, a study on soft bottom fauna /Fredriksson 2004/ and a study on hard bottom fauna /Fredriksson 2005/, and a study on meiofauna by /Ankar 1977/. From theses sources separate grids for each functional group was created. The gris was created in several steps, representing the different investigations, and added t form grids covering all basins and all benthic habitats. In Figure 4-12 the functional groups are added to present the sum of biomass of all benthic fauna. The quantitative data was recalculated into carbon (gC) using the species specific conversion factors presented in /Kautsky 1995/.

In areas with macrophytes, quantitative data from both the study on epifauna and hard or soft bottom fauna have been added. Epifauna biomass was obtained by using biomass of each vegetation community and a relative biomass value /Fredriksson and Tobiasson 2003/.

Soft bottom fauna was assumed to be present in soft bottoms classified by the substrate grid (Figure 4-7) and in habitats in basin 1, 2, 3, 10, 11, 13 as suggested by /Fredriksson 2004b/ cf Section 3.9.4. Soft bottom fauna biomass was assumed to be evenly distributed in the habitats according to the findings by /Fredriksson 2004b/.

Hard bottom fauna data was based on the substrate grid and DEM for basins 6, 8, 9, 12, 15 and biomass was calculated from the relationships found by /Fredriksson 2005/ between depth, hard substrate and covereage, and cover and biomass in this area. The biomass (*B*) at a certain depth (*D*) was calculated by:

$$\begin{cases} B = (103.3 - 6.15D) \cdot 14.6k, \; D > 3 \\ B = 14.6k \cdot 5, \; D < 3 \end{cases}$$

compiled from /Fredriksson 2005/

where *k* is a constant, specific for each functional group /Kautsky 1995/ representing the relationship between g dry weight and g carbon. Cover was set to be 5% between the surface and 3 m depth /Fredriksson 2005/.

Data on biomass of meiofauna found in the northern Baltic proper (Askö) presented by /Ankar 1977/ was assumed to be present and evenly distributed in the soft seabed in the entire area and was added to the functional group benthic detritivores.

The respiration and consumption of the benthic fauna was calculated using species specific (or higher taxa specific) data presented in /Kautsky 1995/ and adjusted for relative abundance in each habitat type (vegetation type or bare sediment).

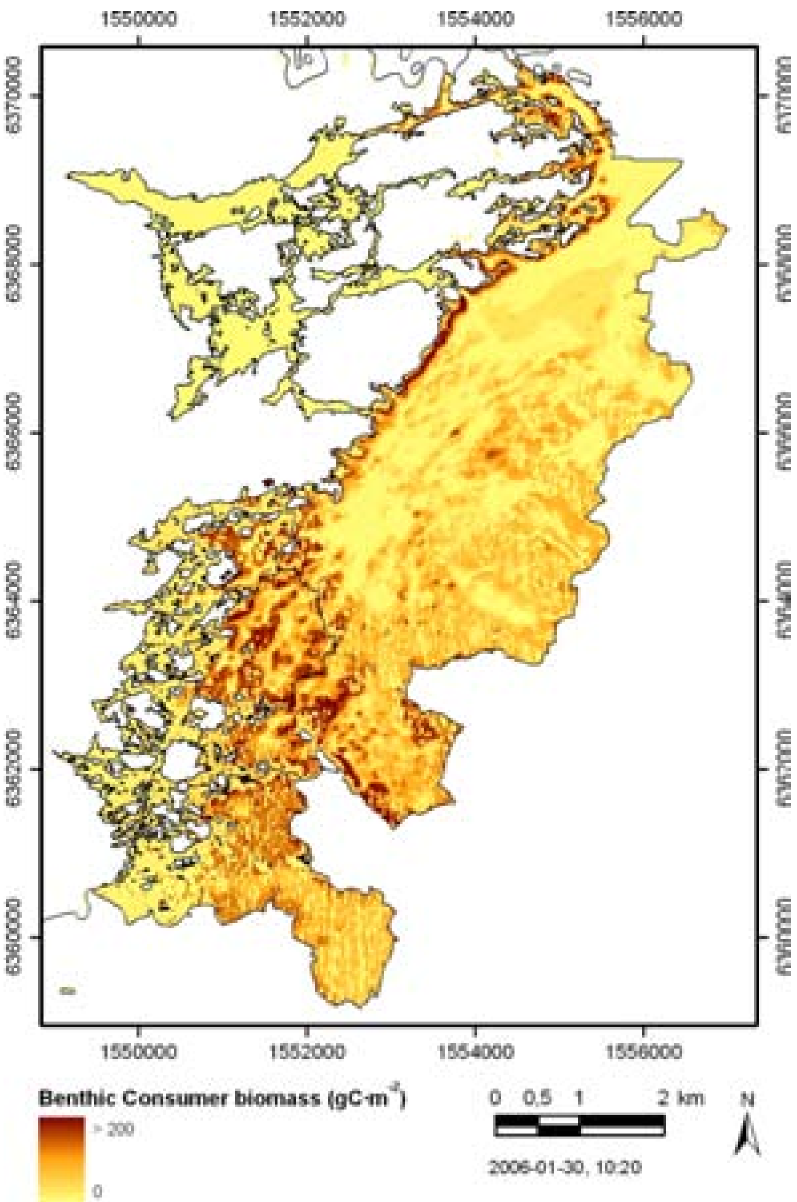

Figure 4-12. *Biomass ($gC{\cdot}m^{-2}$) of benthic fauna (sum of all functional groups) in the Laxemar area.*

Benthic bacteria

Biomass was calculated by using an average of 21.1 μgC·ml sediment^{-1} in the bothnian Sea presented by /Mohammadi et al. 1993/, then converted to an average 1.06 gC·m^{-2} which was assumed to represent soft substrate. A tenth of this was assumed to be present on hard substrate.

Birds

Birds were classified into benthic feeding birds (feeding on benthic macrophytes and fauna) and fish feeding birds. A study on nesting pairs of birds in the inner archipelago of Laxemar region /Green 2004/ has been used to estimate biomass density. Biomass and consumption of some species were compiled from different sources (e.g. Solbreck C pers. comm.). For species which are present in the area, but with unknown biomass and consumption, an average value was used. Birds were assumed to be evenly distributed in all basins with the same density as in the basin Borholmsfjärden. Specific consumption was estimated to be 87 and 32 gC·gC^{-1}·year^{-1} for benthic feeding and fish feeding birds respectively.

Seals

Consumption of fish by seals was estimated by assuming that one seal consume about 5 kg fish per day and that there are about 20 seals in the pelagic basins (8, 12, 15, 17). The biomass was based on an estimated individual weight of 200 kg wet weight.

Humans

The human consumption of fish was calculated using two different data-sets. Commercial fishing were estimated using catch data provided by the National Board of Fisheries (*Sw: Fiskeriverket*) from a 0.5°·0.5° area outside Laxemar. Total catch in kg yr^{-1} were then converted to g m^{-2} yr^{-1} with the resulting flux of 2 gm^{-2} yr^{-1}. Total catch from recreational fishing in southern Sweden have been surveyed by National Board of Fisheries using a questionnaire survey. The resulting numbers were recalculated as catch per m^{-2} in all basins except 15 and 17. Total outtake were finally calculated by assuming that commercial fishery is taking place in basin 15 and 17 and recreational fishing in all basins.

Results

Consumption proportions

The food matrix presented in Table 4-17, shows the proportions of consumption of one functional group (vertical) on another functional group (horizontal). The proportions of food choice are similar to those calculated and assumed in the earlier study in the area /Lindborg 2005b/. A large difference is found in benthic feeding organism. Due to the dominance of filter feeders this group contributes to a large share of the food source of benthivore fishes and birds. The matrix is an average of the whole area and there are large differences between and within the basins, due to the difference in composition of functional groups. This difference is explained by variations in abiotic factors (e.g. hypsography, light penetration, substrate type etc). Macrophytes and benthic fauna (especially filter feeders) dominates the biomass in all basins, but as can be seen in Table 4-21 and Table 4-22 differences between the basins are large. In basin Borholmsfjärden, macrophytes contribute to the total biomass with over 80% whereas in Ävrö coastal filter feeders contribute with approximately 75% of the total biomass. Due to its large size, the latter basin, have a large impact on the average food web of the whole area integrated.

Table 4-17. Food web matrix (mean values) including food proportions (estimated from the identified available biomass/production of their respective food source) in average of all basins in the Laxemar area.

	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	0.64			0.36											
6. Planktivore fish					1.00										
7. Benthivore fish									0.05	0.78	0.16	0.01			
8. Piscivore fish						0.69	0.21	0.10							
9. Benthic herbivores		0.16	0.84												
10. Benthic filter feeders	0.22			0.12	0.03										0.63
11. Benthic detrivores													0.32		0.68
12. Benthic carnivores									0.05	0.78	0.16				
13. Benthic bacteria															1.00
14. Fish feeding birds						0.69	0.21	0.10							
15. Benthic feeding birds			0.21						0.04	0.61	0.13	0.01			
16. Seals						0.69	0.21	0.10							
17. Humans						0.69	0.21	0.10							

Primary producers

Primary production varies greatly both between and within the basins. In some parts of the inner shallow areas, the calculated production exceeds 1,000 $gC \cdot m^{-2} \cdot year^{-1}$, whereas in pelagic areas with low or no benthic production the production ranges between 50 to 100 $gC \cdot m^{-2} \cdot year^{-1}$ (see Figure 4-13). On average for the whole area, the primary producing biomass and primary production is dominated by macrophytes and phytoplankton (see Table 4-19). Most of the phytoplankton production is consumed (by zooplankton and filter feeders) in contrast to macrophytes, which in all areas is greater than the part being consumed, resulting in a positive excess and a potential source of POC to the phytobenthic community or to be exported to surrounding POC consuming areas. In the inner, shallow areas (e.g. Basin Borholmsfjärden, Table 4-21) the biomass and production of primary producers are dominated by macrophytes, while vast areas in e.g. Basin Ävrö coastal (Table 4-22) lack benthic macrophytes, and hence are dominated by phytoplankton production.

Consumers

Filter feeders dominate both biomass, and secondary production among consumers. As with primary producers there is a large variation within and between the basins. , the largest biomass of benthic filter feeders (up to 200 $gC \cdot m^{-2}$) are found in the lower part of the phytobenthic community and in the more exposed areas. In the soft bottom habitats in the inner basins there is a more modest benthic fauna biomass, not exceeding 25 $gC \cdot m^{-2}$ in total (se Figure 4-12). This is difference between inner and outer basins is obvious when comparing Basin Borholmsfjärden and Ävrö coastal (Table 4-20 and 4-21); the biomass of the shallow Basin Borholmsfjärden is dominated by detritivores, whereas the biomass Basin Ävrö coastal is dominated by filter feeders (*Mytilus edulis*) and the biomass of consumers is approximately tenfold that of Basin Borholmsfjärden. The great variance within the basins is reflected by the standard deviation of the mean of grid cells.

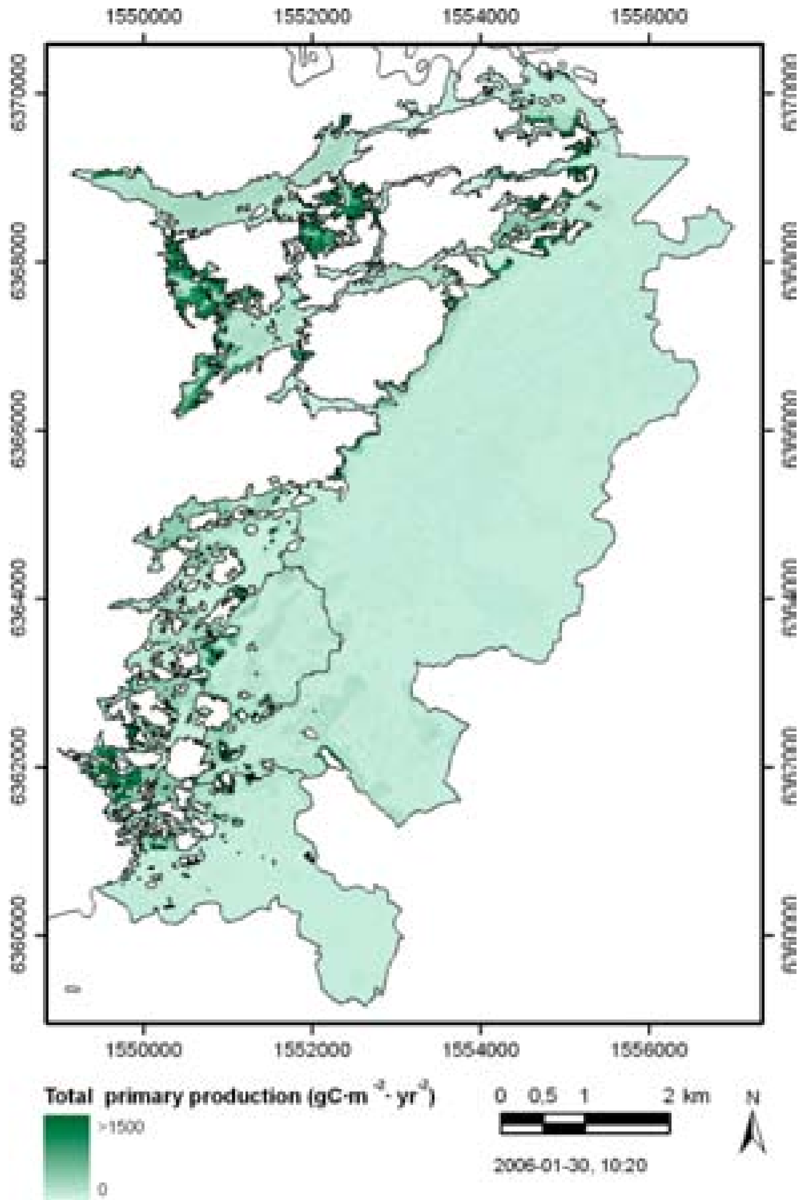

Figure 4-13. *Total net primary production i.e. sum of phytoplankton, benthic micro- and macrophyte net production (gC·m^{-2}·year^{-1}) in the Laxemar area.*

Carbon balance

All functional groups, except zooplankton and benthic bacteria, are in excess on a yearly basis (Table 4-18), i.e. the primary and secondary production of biomass from each group is higher than the consumption of their predators. This excess can either result in an accumulation of biomass or, as we assume in this steady state model, formation of POC (excretion from consumers and dead material from all functional groups). The fate of POC is either consumption, sedimentation (likely for some inner basins), or export to other basins via water movement.

Table 4-18. Average biomass ($gC \cdot m^{-2}$), primary or secondary production and excess ($gC \cdot m^{-2} \cdot year^{-1}$) for the functional groups in all basins in the Laxemar area.

	Biomass	Production	Excess
Phytoplankton	0.37	82.1	4.60
Microphytes	1.23	17.6	3.53
Macrophytes	11.9	94.01	81.6
Bacterioplankton	0.21	74.4	29.7
Zooplankton	0.05	1.49	–13.6
Planktivore fish	0.39	3.25	2.67
Benthivore fish	0.12	1.00	0.74
Piscivore fish	0.06	0.48	0.27
Benthic herbivores	2.46	18.2	18.0
Benthic filter feeders	37.9	270	269.6
Benthic detrivores. meiofauna	6.91	56.4	55.0
Benthic carnivores	0.40	3.25	3.18
Benthic bacteria	0.52	4.54	–21.8
Fish feeding birds	0.008		
Benthic feeding birds	0.003		
Seals	0.006		
DIC	135		–58.3
POC	1.09		–463
Sum Biota	61.3	627	433

A possible explanation for benthic bacteria having a deficit in the budget is that the predation by the large group benthic detritivores is overestimated. It might also be due to an underestimation of the importance of POC as food source for benthic detrivores. Table 4-18 also present an deficit of POC (negative excess) which is due to the fact that influx of POC from terrestrial runoff or water have not been included. Taking the POC inflow from these sources along with net production organic material and faeces into account would lead to a higher proportion of the consumption of POC by benthic detrivores and consequently a decrease in predation pressure on benthic bacteria. The data on bacteria are, furthermore, not site-specific which might contribute to an underestimated standing stock, and accordingly bacterial secondary production, in the area. The reason for the estimated deficit for the zooplankton compartment is possibly due to an underestimation of zooplankton consumption, and in consequence secondary production, or an overestimation of consumption of filter feeders. Filter feeders dominate the biomass and consumption of particulate organic matter (plankton and POC) in the whole area and in many of the basins separately. The feeding proportions of filter feeders (see Table 4-17) are calculated from concentration of POC and the biomass of plankton. Analogous to the reasoning in benthic bacteria, an underestimation of POC production can be the reason for filter feeders consuming relatively more zooplankton.

There are four sources of DIC to the basins; run-off from land, respiration, exchange with surrounding basins, and diffusion from the air. Diffusion and exchange with surrounding water were not calculated here, the run-off of DIC contributes with only a small part (see Table 4-19). Respiration, however, contributes with a significant amount and supplies, integrated over all basins, more carbon than is needed for primary production. On a basin scale however, there is a large net demand in all basins except basin 8, 15 and 17 which are net sources of inorganic carbon – i.e. they are net respiring. This pattern reflects the

Table 4-19. Net primary production, respiration, drainage area and annual inflow of carbon (POC, DOC and DIC) for each basin.

Basin		PP	$Resp_{cons}$	Drainage area	Annual inflow of carbon		
	Name				POC	DOC	DIC
		10^6 gC	10^6 gC	10^6 m^2	10^6 gC	10^6 gC	10^6 gC
1	Basin Borholmsfjärden	757	54.2	46.3	14.3	153	26.7
2	Basin Granholmsfjärden	311	93.8	32.7	10.3	129	17.6
3	Basin Getbergsfjärden	80.0	21.0	1.26	0.39	4.42	0.69
6	Basin Eköfjärden	390	337	4.38	1.34	15.4	2.41
8	Basin Talleskärsfjärden	603	1192	0.28	0.09	1.00	0.16
9	Basin Fläsköfjärden	495	108	4.28	1.31	15.0	2.35
10	Basin Mjältnatefjärden	197	8.56	0.98	0.30	3.46	0.54
11	Basin Sketuddsfjärden	147	5.05	0.17	0.05	0.63	0.10
12	Basin Kråkefjärden	188	264	1.46	0.45	5.14	0.81
13	Basin Långvarpsfjärden	23.5	1.94	0.25	0.08	0.88	0.14
14	Basin Hamnefjärden	20.6	7.43	0.47	0.14	1.65	0.26
15	Basin Ävrö Coastal	2,900	5,750	2.19	0.67	7.67	1.20
16	Basin Kalmarsund	–	–	*639*	*195*	*2,240*	*351*
17	Basin Finngrundsfjärden	422	775.28	0.49	0.15	1.73	0.27
	Sum (excl. basin 16)	6,530	8,613	95.4	29.5	339	53.1

large amount of benthic fauna in these basins (e.g. Basin Ävrö coastal, see Table 4-21 and Figure 4-12), and the large primary production in some of the shallow basins (e.g. basin 1, 9, 10, 11, see Table 4-21 and Figure 4-13). The major flux of inorganic carbon, however, comes probably from exchange with the atmosphere; this is also the most likely fate for the inorganic surplus in the net respiring outer basins 8, 15 and 17.

In Figure 4-14 the net primary production subtracted by heterotroph respiration is shown. This is a rough measure of the amount of inorganic carbon being added to, or released from the system. There is a clear pattern with net ecosystem production in all the inner shallow bays and the very shallow coastal zones. At depths well above the aphotic zone (cf Figure 4-10), the ecosystem is net respiring in the coastal areas.

The total amount of POC consumed (by bacteria and benthic filter feeders) in all basins is 15,600 tonnes of carbon, the majority consumed by filter feeders in the outer basins. There are three sources of POC to the basins; run-off from land, excess from organisms and via exchange with surrounding basins. Exchange with surrounding water is not calculated and the run-off of POC contributes with only a small part (see Table 4-19). Only in basin Borholmsfjärden and Granholmsfjärden, the run-off is of any significance, supplying 20% and 6% of the demand for POC, respectively. As reasoned earlier, some of the excess (secondary and primary production minus consumption) is in fact POC (dead organic matter, faeces etc). This excess contributes in some of the basins with more POC than what is needed and is probably exported to the outer basins. Some of the demand of POC is the result of consumption by bacteria, and they, in reality, also consume DOC. The consumption of DOC is not included in these calculations, and would if included, lessen the demand of POC.

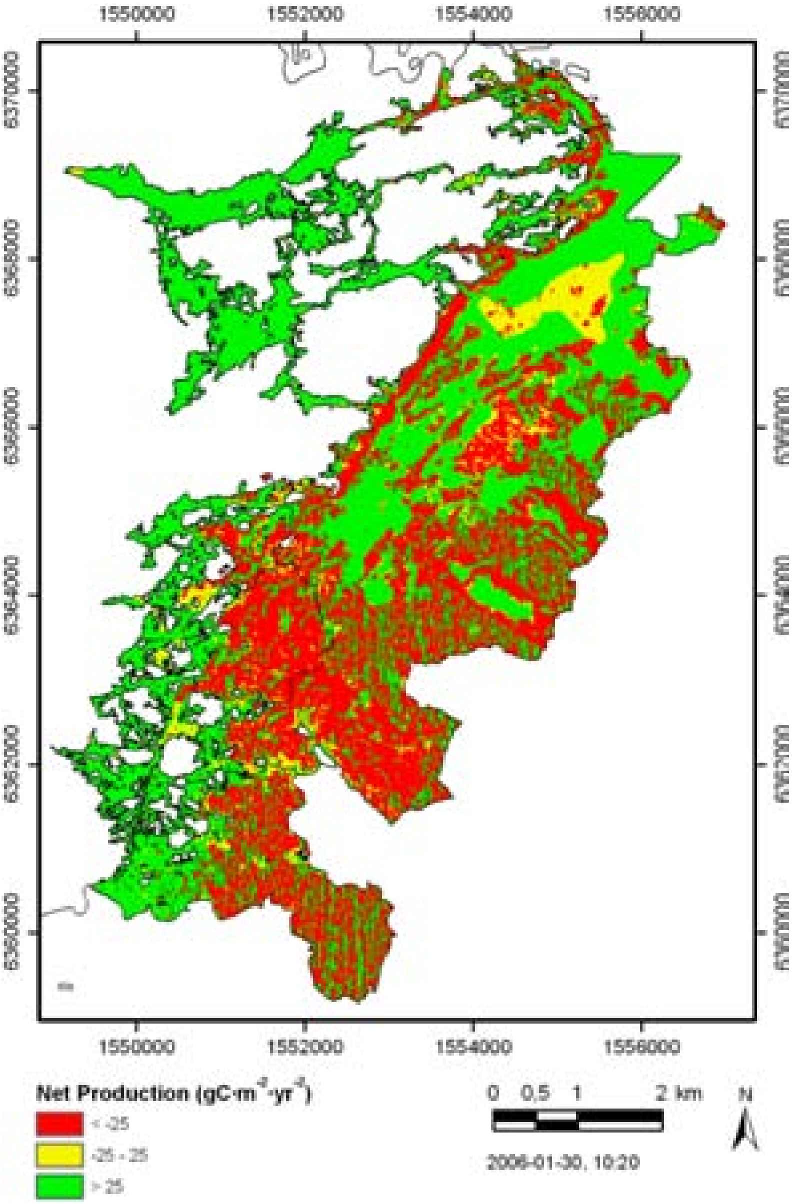

Figure 4-14. *Net ecosystem production i.e. sum of net primary production (see Figure 4-13, gC·m^{-2}·year^{-1}) and heterotroph respiration in the Laxemar area. Green scale indicates positive values and red negative.*

Basin Borholmsfjärden

Basin Borholmsfjärden has a surface area of 1.37 km^2 and a mean depth of 1.6 m (see Table 3-94 in Section 3). The bottom of most of the basin area is estimated to be photic (Figure 4-8) and it is characterized by macrophytes and *Characae* in the shallow parts and Vaucheria in deeper areas. The fauna is dominated by detritivores. All functional groups except benthic bacteria are in excess. As earlier discussed, this can be explained by an underestimation of benthic bacteria biomass (and consequently secondary production). There is a large excess from macrophytes (Table 4-20) available for consumption, sedimentation or export to other basins.

Table 4-20. Mean and standard deviation of biomass, secondary and primary production and excess ($gC \cdot m^{-2} \cdot year^{-1}$) for the functional groups in basin Borholmsfjärden. Standard deviation is based on all grid cells a measure of estimated variance in the grid.

All basins	Biomass		Production		Excess	
	mean	sd	mean	sd	mean	Sd
Phytoplankton	0.30	0.25	100	63.8	96.69	59.15
Microphytes		0.00	15.69	23.8	14.73	23.78
Macrophytes	41.5	79.0	434	556	430	553
Bacterioplankton	0.04	0.03	13.3	11.2	12.7	10.5
Zooplankton	0.12	0.10	3.66	3.04	0.48	3.06
Planktivore fish	0.23	0.05	1.97	0.38	1.08	0.29
Benthivore fish	0.42	0.15	3.53	1.27	2.10	0.89
Piscivore fish	0.24	0.05	2.05	0.39	1.12	0.31
Benthic herbivores	0.43	0.30	3.17	2.24	2.39	1.82
Benthic filter feeders	0.21	0.20	1.48	1.40	1.16	1.18
Benthic detrivores. Meiofauna	2.38	0.95	19.5	7.78	14.0	7.85
Benthic carnivores	0.97	0.45	1.97	0.38	5.99	3.08
Benthic bacteria	0.55	0.48	4.80	4.18	–9.55	10.91
Fish feeding birds	0.003	0				
Benthic feeding birds	0.008	0				
Seals	0	0				
DIC	18.1	15.2	0.00	0.00	–530	541
POC	0.84	0.71	0.00	0.00	–51.4	28.1
Sum Biota	47.4	–	605	–	573	–

Basin Ävrö coastal

Basin Ävrö coastal differs greatly from Basin Borholmsfjärden. It has a surface area of 20 km^2 and a mean depth of 11.9 m (see Table 3-94 in Section 3). Due to the comparably clear water, it has a light penetration that allows most of the sea floor to be photic (se Figure 4-8). The primary production is dominated by phytoplankton, but the functional group generating the largest carbon flow is filter feeders (Table 4-21). Filter feeders alone are estimated to have a secondary production double the primary production. As in Basin Borholmsfjärden, benthic bacteria have a negative excess, but also microphytes. The deficit in microphytes is probably due to large photic areas where only microphytes are present and an overestimation in herbivores there. On basin scale however, there is a much larger excess of macrophytes than the deficit of microphytes. The negative excess, or deficit, of zoo- and phytoplankton is probably due to the consumption by the large groups of filter feeders. According to the budget, filter feeders feed to a large extent of POC. This results in a great demand for POC that must be imported from the phytobenthic zone or from the pelagic as the runoff to this basin is negligible.

Summary

Basin Borholmsfjärden, an example of shallow basin, produce a net excess organic carbon, primarily as a result from high primary production. The deeper phytobenthic areas, exemplified by Basin Ävrö coastal are net consumers of organic material, i.e. they consume the

Table 4-21. Mean and standard deviation of biomass ($gC \cdot m^{-2}$), secondary and primary production and excess ($gC \cdot m^{-2} \cdot year^{-1}$) for the functional groups in basin Ävrö coastal.

All basins	Biomass		Production		Excess	
	mean	stdav	mean	Stdav	mean	stdav
Phytoplankton	0.48	0.24	88.6	21.2	–6.14	113
Microphytes		0.00	11.4	13.2	–3.36	19.0
Macrophytes	7.35	28.9	43.2	189	32.8	171
Bacterioplankton	0.28	0.14	99.9	51.01	44.1	97.2
Zooplankton	0.05	0.03	1.59	0.81	–14.4	12.5
Planktivore fish	0.42	0.03	3.55	0.22	3.06	0.20
Benthivore fish	0.05	0.11	0.46	0.91	0.42	0.84
Piscivore fish	0.01	0.00	0.11	0.02	0.10	0.01
Benthic herbivores	2.34	2.80	17.3	20.7	17.2	20.6
Benthic filter feeders	39.	44.7	279	319	278	318
Benthic detrivores. meio-fauna	6.86	4.30	55.9	35.1	55.5	35.1
Benthic carnivores	0.25	0.30	3.55	0.22	2.13	2.50
Benthic bacteria	0.48	0.47	4.24	4.10	–17.5	24.9
Fish feeding birds	0.008	0				
Benthic feeding birds	0.003	0				
Seals	0.007	0.0004				
DIC	183	93.6	0.00	0.00	40.2	229
POC	1.26	0.64	0.00	0.00	–516	287
Sum Biota	57.8	–	609	–	392	–

excess from more shallow, highly productive areas and runoff from land. The demand from the outer deeper parts of the benthos is much larger than the supply. This implies a large flow of organic matter from shallow coast but also from the pelagic habitat.

4.3.4 Confidence and uncertainties

The quality of data and how well data represents the site is estimated and summarized in Table 4-22. Each functional group is assessed and given a number from low (1) quality to high (4). The reasoning for the judgements is discussed below.

General

The digital elevation model (DEM) that was used to estimate e.g. areas, volumes, depth, light penetration originate from a combination of recent site-specific measurements and existing digital sea charts and has a very high quality (cf Section 3.2).

The estimation of solar radiation is based on the DEM (above) and averages of light penetration over several years for individual sites. The differences between different areas have been taken into account and the result can hence be regarded as reliable. Solar radiation is determining primary production in the system and is therefore of great importance.

Table 4-22. Estimations of the quality of input data and how representative the data is for the basins in Oskarshamn. Higher figures indicate higher quality of data.

Functional group	Quality of data (1–4)	Representativeness of data (1–4)
Areas and volumes	4	4
Light penetration	4	4
Bottom type (hard, soft)	3	4
Carbon transport from runoff	3	3
Concentration of carbon	3	4
Phytoplankton	3	4
Microphytes	2	1
Macrophytes	3	4
Bacterioplankton	3	2
Zooplankton	2	4
Planktivore fish	3	1
Benthivore fish	3	1
Piscivore fish	3	1
Benthic herbivores	3	4
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	3	4

Primary production was estimated from actual radiation (PAR) during one year (2004) and conversion factors. 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 an underestimation in biomass but above all primary production. Currently site specific measurements of benthic production are in progress and will validate these calculations.

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. But as 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 reported by /Elmgren 1984/ is a general relationship. Of this reason is likely to underestimate some and overestimate some functional groups. The relationship for bacteria (1:2) is estimated based on that their metabolism has a higher rate.

Calculations of the modelled runoff from land are described in Section 3.4. Concentrations of DIC, DOC and POC were based on a 3 year monitoring sampling programme with samples every week, or every second week, and an average run-off value (cf Section 4.2). The estimation of total carbon flow is probably of sufficient quality due to the long monitoring. As seen in Table 4-19, the run-off is of limited importance for the carbon budget in the basins.

Phytoplankton

Estimations of biomass were made from several site measurements of chlorophyll during two years time. Quality of the calculated specific net primary production and respiration is good but neither species nor site specific, which probably affects the quality of the estimates used 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 should be good enough.

Microphytes

Neither microphyte biomass nor primary production has been measured at the site. The microphyte data used originate from two different studies performed in the northern and southern Baltic Sea. The measurements of irradiance are used to calculate production on soft bottom, has high resolution and is site specific. However, production relationship is not site specific. Production on hard bottoms has no site specific component and should therefore be regarded with some scepticism.

Macrophytes

Field measurements of biomass and distribution are of high quality due to the large number of sampling sites (> 1,000), but the quality of the extrapolations made (from point and line data to area data) has not been quantified. The biomass is probably overestimated as we have assumed a constant biomass (sampled in autumn) during the year.

Bacterioplankton

Measurement of neither bacterioplankton biomass nor respiration has not been at the site. The data was used obtained from a study performed in Tvärminne, Finland /Kuparinen 1987/. That study was also used to estimate the bacterioplankton respiration and consumption. The Tvärminne data is of high quality, but the representativeness for this area has not been evaluated.

Zooplankton

Estimations of biomass were made from three samples, one in three different basins. 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.

Fish

Data on fish biomass and species distribution of fish have been obtained from the area and from an area of similar characteristics, which implies that the data is reliable. Data have been distributed according to habitat and resulting biomass are similar to other studies /Heibo and Karås 2005, Jansson et al. 1985/. A recent study, not yet published, performed in Basin 1 also support the calculated biomass values /Adill and Andersson 2006/.

Benthic fauna

The benthic fauna was sampled at the site in a several investigations relying on over 100 samples all together and thus can the biomass data for these functional groups be considered to have high quality and be 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. Also, the high biomass of hard bottom fauna has not been verified with other studies.

The meiofauna has not been studied in this area and data used originate from Askö /Ankar 1977/. The representativeness of this study for the Simevarp area is not known but could probably be considered to be low.

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 representativeness for this area has not been evaluated.

Birds

The estimated number of birds is probably underestimated as only nesting birds are included.

Humans

Catch-data were obtained from a compilation from the National board of Fisheries (*Sw: Fiskeriverket*) where commercial catch is based on data from a larger area north of Öland. This estimation should be rather reliable as long as no local fishing habits are present in the direct proximity to Laxemar. Recreational fishing was estimated from telephone interviews conducted by National board of Fisheries, probably giving results with rather low quality.

4.4 Integrated ecosystem model

4.4.1 Introduction

In order to describe and compare the stocks and flows of water and carbon beyond the boundaries of the previous described ecosystems, the three ecosystems are here connected, using information from the terrestrial parts of the Laxemar area, the lake and the marine basins. Few comparisons have to our knowledge been done covering fluxes and pools of matter across terrestrial, limnic and marine environments, but see /Cebrian 1999/. The comparison of stocks and flows of matter beyond the boundaries of specific ecosystems generate insights, e.g. of their relative importance as sources and sinks for matter, or their relative turnover rate of matter. An even more intriguing task is to compare pools and fluxes among different ecosystems within a limited geographical context, where fluxes of water and matter connect the different ecosystems.

Descriptions of pools and fluxes of matter in a landscape mosaic are of increasing interest to Environmental Impact Assessments describing flow and accumulation of bioavailable contaminants, e.g. radionuclides, in a landscape context /Kumblad and Kautsky 2004, Lindborg and Löfgren 2005/. A number of ecosystem properties may be useful to under-stand and quantify accumulation and transfer of bioavialable contaminants, with similar behaviour as carbon or macro nutrients, using stoichiometric relationships /Sterner and Elser 2002/. In this model version there is a focus on carbon that in the future will include nitrogen and phosphorous as well. The detailed description of the pools and fluxes of these substances will serve as a base on which predictions of pools and fluxes for other substances will be made using stoikiometric relationships e.g. /Elser and Urabe 1999, Elser et al. 2000, Hessen et al. 2004/.

Here we use a descriptive model covering terrestrial, limnic and marine ecosystems within a discharge area. Water is the principal media for transport and accumulation of elements and matter in the landscape hence the first step to an integrated model is to describe the hydrology. The carbon budgets are built upon ground-based estimates of pools and fluxes within the ecosystems and horisontal transfer is based on hydrologically driven fluxes. The main aims of this section are to compare;

1) the two major pools of carbon, biomass and soil organic carbon, among the terrestrial, limnic and marine ecosystems,
2) the largest fluxes of carbon; net primary production, heterotrophic respiration, import and export of carbon, among ecosystems,
3) estimates of detrital accumulation among ecosystems,
4) the turnover of organic carbon among ecosystems.

This knowledge will provide a safety assessment with estimates of a potential release of bioavialable contaminants in an area, with an important tool to identify the relative importance of sinks and sources of matter beyond the boundaries of the specific ecosystem, and also help to identify potential hot spots for contaminant accumulation.

4.4.2 Conceptual description of an integrated ecosystem model

The integrated model allows comparisons of transport, accumulation and residence time of carbon among the ecosystems. The input data to the integrated model comes from the separate ecosystem models describing the terrestrial, limnic and marine environments.

The conceptual model for water

The transport of matter is mediated by water flow, and is at the landscape scale the focus of the horizontal flow between the ecosystems, from the terrestrial discharge areas into streams, lakes and marine basins, and further out into the Baltic Sea. These flows are driven by a number of hydrological processes that have been quantified using the MIKE SHE model, and for each catchment area the following parameters have been quantified:

- Precipitation.
- Evaporation.
- Transpiration.
- Water flow in the upper part of the Quaternary deposits.
- Runoff in water courses.
- Direct runoff to the sea (only for near-coastal areas).
- Water residence time.

A detailed description of the MIKE SHE model is presented in the Section 3-4.

The conceptual model for organic matter

The ecosystem

The focus of the conceptual linked ecosystem model is on pools and fluxes which are regarded as important in describing sinks and sources of matter for the terrestrial, limnic and marine environments at a landscape level. Two large carbon pools are identified; the carbon included in living organisms and the soil organic carbon pool (Figure 4-15). The autotrophs are producing organic matter entering the biomass carbon pool as net primary production, which may serve as an estimate of the amount of inorganic substances turned into organic matter. The annual mean biomass pools in the aquatic environments are assumed to be fairly constant over time. In contrast, the terrestrial ecosystem of today shows an accumulation of organic matter in the biomass pool due to the fairly young age of the forests, which is a consequence of an intensive forest management. The biomass pool is constantly producing matter that is entering the soil (including sediment) organic carbon (SOC) pool (Figure 4-15). The heterotrophic respiration is, at least on land, dominated by decomposition of the SOC pool, and this is balancing the large litter input from the biomass pool. However, over longer time periods carbon is constantly accumulating in the SOC carbon pool, both in aquatic and terrestrial environments /Schlesinger 1997/.

The fate of these different carbon pools are rather different, with turnover times ranging from hours in bacteria /Schoener 2002/ to thousands of years or more in sediments /Schlesinger 1997/. The SOC pool can, at least in a simplified conceptual model, be divided into a "fast", easily degradable, and a "slow", more refractory, pool /Schlesinger 1997, Cebrian 1999/. Most of the organic matter is decomposed in the fast pool, whereas a minor part is entering the slow SOC pool. The relative fractions entering these pools may vary between ecosystems and also between years within ecosystems.

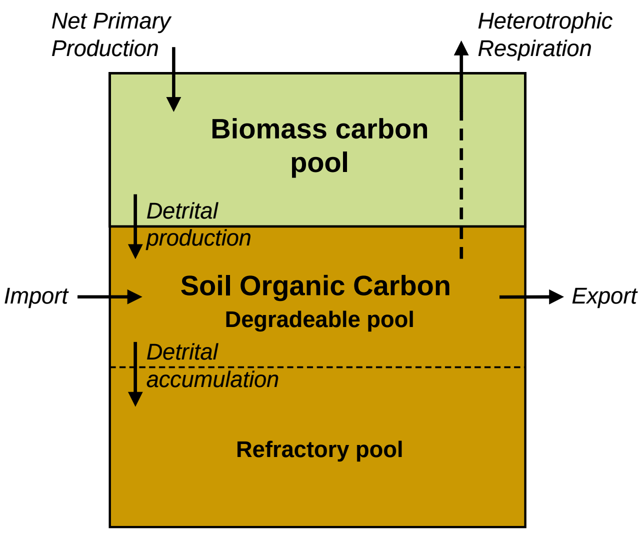

Figure 4-15. *The conceptual model describing the major pools and fluxes which are compared across the landscape.*

Import and export – linking ecosystems across the landscape

Three separate models, describing the terrestrial (Section 4.2), limnic (Section 4.3) and marine ecosystems (Section 4.4) are linked together using exchange of water between the three separate ecosystems. Water is the principal media for transport of elements and matter in the landscape, and carbon is mainly transported as dissolved organic carbon. The import and export of carbon between terrestrial ecosystem units can be regarded as overall small compared to other fluxes within the terrestrial ecosystem, whereas the aquatic ecosystems both may have a considerable import from land and a considerable flux to and from adjacent aquatic systems. Although the export of carbon from land is small, it is important with regard to fluxes of bioavailable contaminants from land into aquatic environments and is therefore crucial in the linking of terrestrial and aquatic environments.

Carbon residence time

The turnover of carbon in different pools is an estimate of how long the carbon may remain in a carbon pool before it leaves the pool again (residence time). Here we have calculated a Carbon Residence Time (CRT) of the total carbon pool, including biomass and SOC, on one hand as a function of heterotrophic respiration and export from the ecosystem, and on the other only as export from the ecosystem. The first is an estimate of how fast the total carbon pool may be replaced irrespective of whether the fluxes are internal or external of the system. The second is an estimate of how fast the total carbon pool, including any associated bioavailable contaminant, is exported from the ecosystem.

Assumptions

The estimations are based on a number of premises that in this version of the model are more or less realistic; SOC below one metre soil/sediment depth is not included, there is no accumulation in biomass over time in the aquatic systems, there is no accumulation of degradable detrial matter, which means that all long term accumulation in the SOC pool is occurring in the refractory pool, the estimations of pools and fluxes are in many cases based on a snapshot in time, which implies that the results may not be valid in a longer time perspective. Some part of the biomass pools and the SOC pools may be more easily retained, while others have a higher turnover, but this is not accounted for in this model.

4.4.3 Quantitative descriptive model

The pools and fluxes of water and carbon in the conceptual model (Figure 4-15) were populated with hydrology data from the MIKE SHE model (Section 3.4), and with data on carbon pools and fluxes from the terrestrial, limnic and marine descriptive ecosystem models (Section 4.1–4.3). The terrestrial and the marine model were divided into catchments and basins, respectively, according to Figure 4-17. The limnic model was a description of the only lake in the Laxemar area, Lake Frisksön. Both the terrestrial and the marine model used GIS to distribute data spatially among functional groups. Below follows a brief description of how the pools and fluxes have been estimated. A more detailed description is available within the separate sections covering the terrestrial, limnic and marine systems. The terrestrial catchments, the lake and the marine basins are more or less connected to each other by fluxes of water, mainly surface runoff (land and lake) or water currents (marine basins). These connections are shown in Figure 4-17.

Hydrology

The hydrological data used in the integrated ecosystem model is calculated with MIKE SHE, a processed based hydrological modelling tool. The conceptual and descriptive model which is the base for the quantitative modelling is described in Section 3.4. The input data, the modelling process and the results from the MIKE SHE modelling are also described here. The annual average water balance for the whole model area for the simulated year, 2004, is used in the integrated ecosystem model, the water balance is presented in Figure 3-37, Section 3.4. The following values are used in the modelling:

- Precipitation: 655 $mm \cdot y^{-1}$ (Section 3.4) (Input data to the MIKE SHE model, local meteorological data from the meteorological station at Äspö, 2004).
- Total runoff: 6 $l \cdot s^{-1} \cdot km^{-2}$ (Section 3.4).
- Evapotranspiration: 466 $mm \cdot y^{-1}$ (Section 3.4).
- Transpiration: 200 $mm \cdot y^{-1}$ (see Figure 4-2).

The total turnover of water in each catchment was calculated using the field controlled area for each sub-catchment.

The terrestrial ecosystem

Biota

The biomass pool in the terrestrial environment is mainly comprised of primary producers, divided into the functional groups; tree, field and ground layer covering both above- and belowground biomass. A detailed account on how biomass, production and respiration is calculated is given in Section 4.1. The total biomass of herbivores and carnivores in the catchments is small in comparison to that of primary producers (Section 4.1) and it was therefore disregarded in these calculations.

Soil organic carbon

The soil organic carbon pool (SOC) is the largest carbon pool in the terrestrial environment. SOC was estimated down to approximately 1 m below ground surface, including litter and humus horizons and mineral soil. The much smaller pool of logs was also added to this pool (see Section 4.1). Detrital accumulation was calculated as the difference between litterfall and the sum of respiration and horizontal transport of dissolved organic carbon (DOC).

Import and export

Mean TOC export from terrestrial areas was taken from /Canhem et al. 2004/. An estimate of 4 $gC \cdot m^{-2} \cdot y^{-1}$ was used for all vegetation types, except for wetlands and forested wetlands, where an estimate of 13 $gC \cdot m^{-2} \cdot y^{-1}$ for "emergent marshes" was used /Canhem et al. 2004/.

The limnic ecosystem

Biota

Biomasses, as well as production and respiration, of different taxonomical groups in Lake Frisksjön were, as far as possible, estimated from site data. These include studies on macrophytes, phytoplankton and zooplankton, benthic fauna and fish (see Section 4.2).

Site data on bacteria in the water and in the sediments were not available, and therefore we used data on bacterial biomass, production and respiration from lakes as similar to Lake Frisksjön as possible.

Sediment organic carbon

The total carbon pool in the upper metre of the lake sediments was calculated from data given in /Nilsson 2004/ by multiplying carbon content in post-glacial sediments with the estimated sediment volume in the lake. The accumulation rate of carbon into the refractory pool in lake sediments was calculated using an estimated sedimentation rate of 2 mm per year (L Brydsten, Umeå univ, personal communication).

Import and export

The estimated export of carbon from the terrestrial discharge area (as calculated above) was used as an estimate of the annual import of carbon to the lake. The transport of carbon by runoff was calculated from measured monthly TOC concentrations in lake surface water (n = 34) and modelled monthly discharge from the lake /Werner et al. 2005a/.

The marine ecosystem

Biota

The biomass, production and respiration of both autotrophs and heterotrophs were as far as possible estimated from site specific investigations, performed during 2002–2005. Benthic microphytes, and benthic and pelagic bacteria, were not studied in the area, and carbon pools and fluxes associated to these groups were therefore estimated from literature (see Section 4.3).

Sediment organic carbon

The total carbon pool in the upper metre of the sediments in each basin was calculated from data given in /Nilsson 2004/ by multiplying carbon content in post-glacial sediments with the estimated sediment volume in the basin. The sediment volume was calculated as seafloor surface of the substrate multiplied with average thickness of the substrate. Data on carbon content in sediments from basins 1 and 14 were used for all basins.

The density of carbon in the sediment was estimated as the product of the density of dry substance (gdw·m^{-3}) in the sediment and the relative amount dry substance in the sediment /Nilsson 2004/. The site specific data from basin 1 and 14 was used for all basins. The density of dry substance was estimated to be 183 to 700 gdw·m^{-3} (calculated from water content) in the glacial clay and gyttja in the different basins /Nilsson 2004/. The carbon content of the dry substance was assumed to be less than 1% in glacial clay and 13–14% in gyttja.

Import and export

The total transport of water and carbon to the 13 basins from terrestrial runoff was estimated by using the hydrological model described in Section 3.4 and annual means for organic carbon (TOC), calculated for downstream stream sites in the Laxemar area from data given in /Engdahl and Ericsson 2004/ (Table 4-23). The direct runoff to the sea in near-coastal areas was calculated in the same way as the terrestrial carbon export above.

Table 4-23. Carbon concentrations in surface water at different locations in the Laxemar area, used to calculate carbon content in water fluxes to the marine basins.

Catchment area	Name	Total Organic Carbon (gC m^{-3})
6	Mederhultsån	20.2
7:1	Kåreviksån	16.5
7:1	Frisksjön/Kåreviksån	16.5
9:1	Ekerumsån	20.1
9:2	Ekerumsån	20.1
9:3	Ekerumsån	20.1
10:1 inside the model area for the integrated ecosytem model	Laxemarån	19.4
10:1–32	Laxemarån	19.4

Water exchange among the basins and the open Baltic Sea plays an important role in water and carbon transport to and from the basins. This is pronounced in the outer basins, e.g. Basins 15, 6, 9 and 14 (see Figure 4-17 and 4-18 where a simplified illustration of the net water and carbon flow to and from the basins is presented). The water flows were estimated in the oceanographic model (Section 3.5), and the resulting carbon transport was estimated using median values of organic carbon (TOC) from sampling sites in the basins /Engdahl and Ericsson 2004/. Carbon content in basins lacking TOC data were approximated from adjacent basins, from basins having similar characteristics (e.g. basin location in relation to the open sea), or from median values between adjacent basins (basin 24 situated between basin 21 and 25).

The processes contributing with carbon to the basins are primary production and runoff from the terrestrial environment, whereas respiration and sedimentation remove carbon from the system. Water exchange between basins is both a contributing and a removing process, depending on net flow direction of water. Water mediated carbon flow varies from 98% (Basin 22) to 42% (Basin 1), depending on the extent of water exchange.

The net flow of the contributing and removing processes was expected to be zero. However, on an annual basis there is a calculated net contribution of carbon from most basins and a deficit of carbon in four of the basins. The deviation from the expected balanced budget is in most cases around 1% of the total carbon content, however, in the large coastal basin the deficit is around 30%.

4.4.4 Results and discussion of the landscape budgets

Water budget

For water it is assumed that there is no annual storage. The runoff from the watersheds contribute with only a small amount to the water budgets of the marine basins; about 5% and 2% of the total water flow into the most affected basins Borholmsfjärden (Basin 1) and Granholmsfjärden (Basin 20), respectively (Figure 4-17). Thus, any inflow of matter from the terrestrial and limnic systems to the marine basins will be highly diluted due to the large flows and fast water turnover in the coastal area. The highest fluxes are found in the coastal area, where it is driven by the exchange of water between the marine basins and between the basins and the open Baltic Sea.

The theoretical residence time for water (water volume divided by flow) was estimated to days in the coastal area, whereas it was approximately half a year for the lake. The longest water residence time, almost 3 years, was found in the terrestrial parts of the watersheds Figure 4-17.

Carbon budget

Carbon pools

The calculated area-specific total carbon pool, i.e. all carbon included in biota and in the soil organic carbon (SOC) pool, is somewhat higher in Lake Frisksjön (34 $kgC \cdot m^{-2}$) than in the terrestrial ecosystem (range between 25 and 31 $kgC \cdot m^{-2}$ in the different catchments), whereas it is lower and much more variable in the marine ecosystem, varying between 3 and 23 $kgC \cdot m^{-2}$ in the different basins (Table 4-24).

Although there are no dramatic differences in total carbon pool between the different ecosystems, there is a clear difference between the terrestrial and the aquatic ecosystems in the distribution of carbon between the biomass pool and the SOC pool. The average ratio between SOC and biota carbon in the terrestrial ecosystem is < 4 (range 2.3–5.0), whereas it is considerably larger (mean 330) and highly variable (range 4–1,075) in the limnic and marine ecosystems. This difference is mainly caused by the accumulation of carbon in terrestrial vegetation, in contrast to the aquatic systems where accumulation of carbon over years in vegetation (including algae) is insignificant.

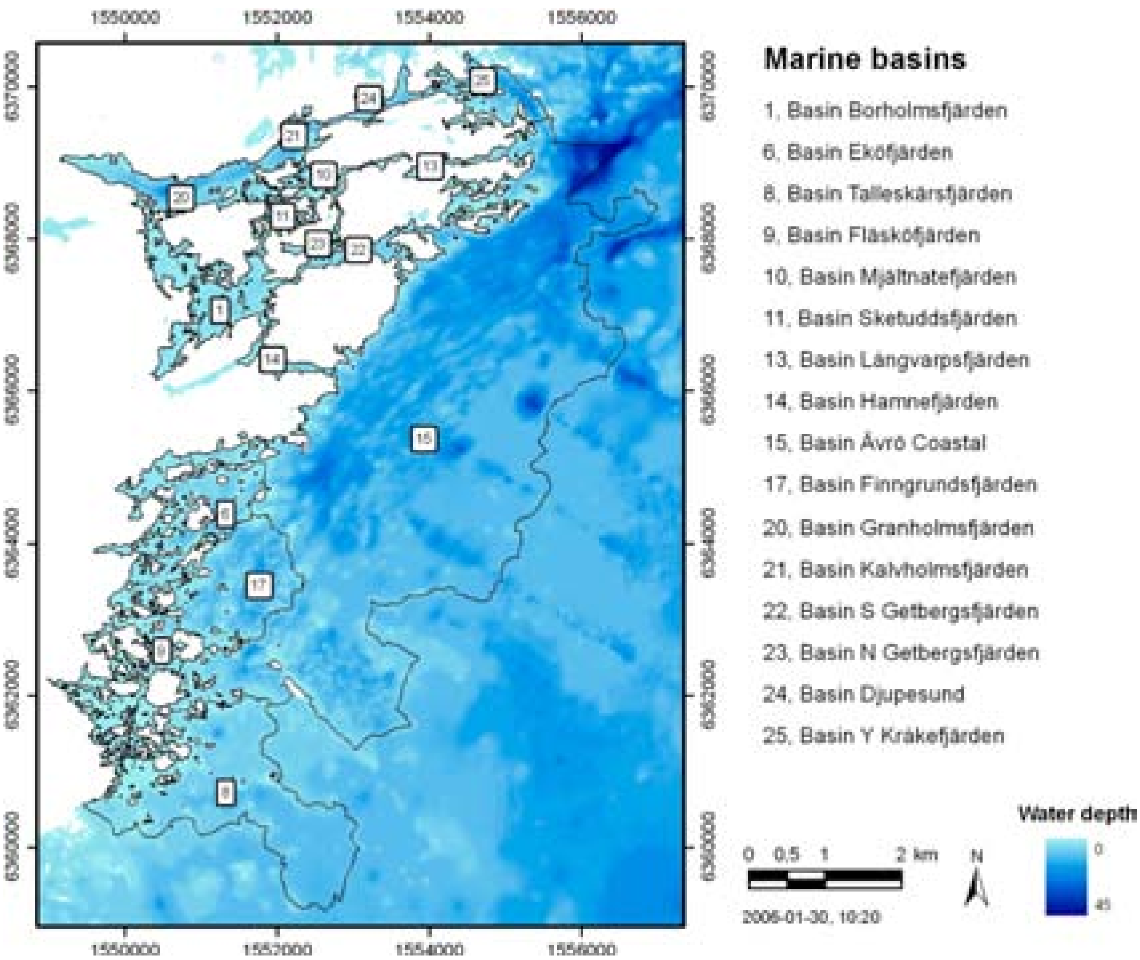

Figure 4-16. Map describing the basins used in the integrated ecosystem model.

The largest carbon pools in the area in absolute numbers are found in the largest terrestrial catchments, and the smallest pools in the smallest coastal basins. This is largely an effect of object size. However, some of the outer coastal basins have disproportional small carbon pools in relation to their area due to relatively small areas of vegetation and accumulation bottoms, and the inner basins, e.g. Borholmsfjärden and Granholmsfjärden, together with Lake Frisksjön have disproportional large carbon pools due to large areas of accumulation bottom.

Table 4-24. Area specific pools and fluxes of carbon for the terrestrial catchments (brown), the lake (blue) and the marine basins (blue-green) in the Laxemar area. Pools are in kgC m^{-2} and fluxes are in gC m^{-2} y^{-2}. Carbon residence time is calculated in two ways, CRT 1 = (Total Organic Carbon pool/(Heterotrophic respiration+Export)) and CRT 2 = (Total Organic Carbon pool/Export). Heterotrophic respiration and Detrital accumulation is abbreviated in the table head.

Objekt	Area km^2	SOC pool	Biomass pool	NPP	Het. Resp	Import	Export	Detr acc	CRT 1	CRT 2
10:2	0.46	21.8	5.98	627	487	0	4	3	56	6,636
10:3	0.32	21.5	7.60	783	524	0	4	107	55	7,272
10:4	1.00	23.4	6.49	704	478	0	4	77	62	7,306
10:5	0.29	20.7	4.11	445	545	0	4	–195	45	6,071
10:6	0.89	21.3	6.24	670	539	0	4	2	51	6,893
10:7	0.61	20.4	6.55	670	532	0	4	8	50	6,740
10:1	3.44	21.9	5.88	640	517	0	4	–4	53	6,776
9:2	0.77	22.5	5.72	627	477	0	4	59	59	7,061
9:3	0.22	24.5	6.81	739	459	0	4	120	68	7,836
9:1	1.85	22.1	6.28	672	498	0	4	36	57	7,100
8:1	0.50	19.6	8.48	838	545	0	4	147	51	6,568
7:2	1.85	19.0	6.24	645	483	0	4	32	52	6,730
7:1	0.21	20.5	4.75	509	540	0	4	–138	46	5,671
6:1	2.00	22.2	5.98	646	493	0	4	14	57	7,057
Median terrestrial	0.69	21.6	6.24	658	508	0	4	23	54	6,835
Lake	0.13	33.4	0.22	91	94	53	38	12	255	885
1	1.37	12.9	0.06	507	40	456	416	508	28	31
20	0.96	22.8	0.02	210	74	774	658	251	31	35
11	0.16	14.1	0.04	906	33	621	659	835	20	22
10	0.29	14.1	0.05	658	31	1,621	1,579	668	9	9
21	0.34	16.1	0.01	242	72	2,940	3,015	94	5	5
24	0.20	5.2	0.08	86	298	4,816	5,078	–475	1	1
25	0.70	2.9	0.10	235	301	24,862	24,710	85	0	0
23	0.07	14.1	0.04	114	19	1,181	1,202	74	12	12
22	0.29	13.0	0.02	208	70	3,287	4,186	–761	3	3
6	1.63	2.8	0.08	229	209	7,039	7,224	–165	0	0
9	1.03	2.8	0.08	472	108	832	835	361	3	3
8+15+17	21.26	0.3	0.08	180	364	89	94	–189	1	4
Median marine	0.52	13.0	0.05	232	73	1,401	1,391	90	4	5

Carbon fluxes

The largest carbon flux per square metre is the NPP that range between 86 and 906 $gC \cdot m^{-2} \cdot y^{-1}$ depending on ecosystem (Table 4-24). The terrestrial ecosystem has a higher and more evenly distributed NPP among the different catchments than the marine ecosystem has among the basins. A similar pattern is found for the heterotrophic respiration. Interestingly, there seems to be no correspondence between high production and high heterotrophic respiration in the marine system. The lake shows a similar pattern as the marine ecosystem with regard to the low fluxes.

A carbon flux that is rather small in comparison to the NPP in the terrestrial ecosystem but large in the aquatic systems is the lateral transport of carbon via water fluxes into and out of the lake and the coastal basins. This carbon flux is in the marine system of the same magnitude as the NPP in the marine basins, which suggest that carbon transported between basins is a large contribute to the carbon budget as a whole. This is not the case in the terrestrial ecosystem, where lateral transport in most cases is small, even for wetlands /Lindborg 2005b/. This large exchange in marine basins is hydrologically driven by water movements between basins and between basins and the Baltic Sea. The lake falls somewhere in between the terrestrial and the marine ecosystem with regard to the lateral transport of carbon in relation to NPP. The runoff from the watersheds contributes with only a small amount to the carbon budget for the marine basins. Thus, any inflow of matter from the terrestrial and limnic systems to the marine basins will be highly diluted due to the large flows and fast water turnover in the coastal area.

The detrital accumulation is larger in the sea basins than in the lake and the terrestrial catchments. The variation between basins and catchments are large, and several of them are negative suggesting that, during periods, there are no overall detrital accumulation within some of the basins and catchments. This flux has been calculated as the difference between a number of large fluxes, in some cases originating from measurements during a single year e.g. soil respiration (Section 3.7), so it is intresting that the values are fairly consistent within ecosystems. This accumulation could be assigned different fate depending on wheather the system is aquatic or terrestrial. In the aquatic system the organic material is trapped in the sediments /Kautsky 1995 and references therein/, while in the terrestrial system the carbon is entering the lower horizons as DOC and humins becoming less mobile due to sorption process /Neff and Ashner 2001, Berggren et al. 2003/.

The largest absolute fluxes in the modelled area is NPP within the terrestrial catchment 10.2, closely followed by the heterotrophic respiration (in 10.2) and the lateral carbon fluxes into and out of the basin 21 and 24. Catchment 10.2 is the largest modelled catchment on land while the two basins have a high exchange of water with other basins.

Carbon residence times

The first estimate of carbon residence time (CRT 1), as a function of respiration and horizontal export, among terrestrial catchments is fairly constant, ranging between 45 and 68 years (Table 4-24). The turnover of carbon in the lake is 430 years, while the turnover of the sea carbon pool range between < 1 and 31 years. There are large differences between the different marine basins in regard to turnover, where some of the innermost basins with long water residence times have a much longer carbon residence time than some of the outer basins, which have a shorter water residence time.

The second estimate of carbon residence time, as a function of horizontal export, is considerably longer for the terrestrial ecosystem (5,671–7,836 y) than for the lake (885 y) and for the marine basins (< 1–35 y), Table 4-24. This is explained by the small lateral transport of DOC among terrestrial vegetation types. The opposite is valid for the marine basins, where the horizontal transport is the major route for carbon transport.

Elements sorbing to or incorporated into organic matter will also be accumulated on land and in the lake due to long carbon residence times, where heterotrophic respiration more or less dominates the turnover of carbon. This turnover will however have an insignificant effect for other elements than carbon with regard to lateral transport, although it will make them more mobile. When these elements finally enter the coastal basins they are quickly transported out of the area into the Baltic Sea. 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), the accumulation can be at most in the order of 10,000 years in this area.

The pools may also be regarded as fairly constant depending on the successional stage, e.g. there may be large difference between the accumulation in a young forest and in a lake, both in a shorter perspective such as one year or in a somewhat longer period of 100 years. However, it may be rather similar in a longer perspective, where the effects of regular disturbances in the forest, such as logging or fires, get less prominent. The pools are also more or less different with regard to turnover. The biomass pool will eventually end up in the SOC, but the time span is rather wide depending on the type of organism e.g. the turnover for bacteria may be counted in hours while trees may survive for hundreds of years. Similarly, the turnover of the fast SOC pool is somewhere in the same interval. The slowly decomposing SOC pool is more problematic because this pool is accumulating organic matter over longer time spans that are not balanced by decomposition. This accumulation is highest in water-inundated environments on land and in lakes and certain marine environments, such as shallow bays. These environments may later be sources for organic matter because they are often used as agriculture land when ditching or land up-heaval has made them accessible.

Conclusions

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.

Different residence times for carbon in the three ecosystems suggest where we have the largest potential for accumulation. By combining this knowledge with the potential of incorporation of different elements into biomass (NPP) and the SOC pool we are able to set an uppermost limit to how large quantities of elements, behaving as carbon, may be accumulated in the three ecosystems. 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, whereas elements sorbing to or incorporated into 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 10,000 years in this area.

When the separate ecosystem models are connected to each other it is apparent that the magnitude of estimated fluxes of carbon over system borders are roughly consistent, even though they have been estimated independently with different models or with measured fluxes or concentrations. The water and carbon budgets describing the different ecosystems are more or less well balanced, partly due to 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 and partly for the terrestrial catchments. These errors can be estimated and in some cases minimised by further use of collected data of e.g. other elements than carbon. Unbalanced budgets may also be a consequence of low spatial resolution in the measurements of e.g. TOC contents in 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.

The amount of resources in the area that humans can utilise is described in Section 3.10. In the next version of the site description, 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 attempt to obtain an overall carbon budget for the different connected ecosystems in the Laxemar area has given a platform to build dose models, to obtain data for biosphere objects and to build a landscape model. There are still 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.

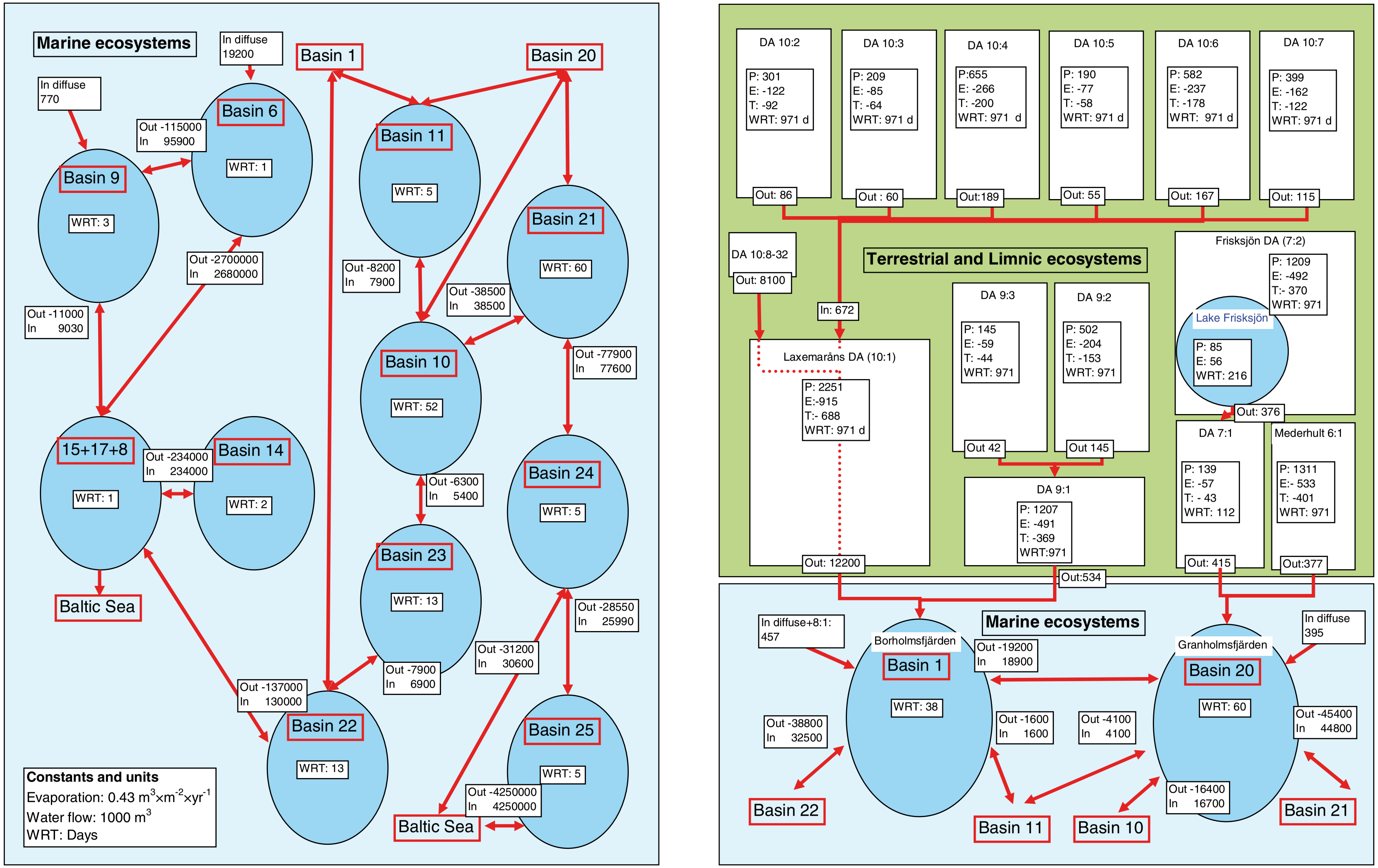

Figure 4-17. *An annual water budget for the discharge area Laxemar and adjacent coastal basins, where land, lakes and the coastal basins have been interconnected. Negative sign indicates a flux that is leaving the specific subsystem, e.g. evapotranspiration or water transport from the lake or a specific basin. P = Precipitation, E = Evaporation, T = Transpiration, WRT = Water Residence Time in days for the specific subsystem, DA = Drainage area. Sub catchment 8.1 is not in the figure but do contribute to the inflow of water to the basin Borholmsfjärden.*

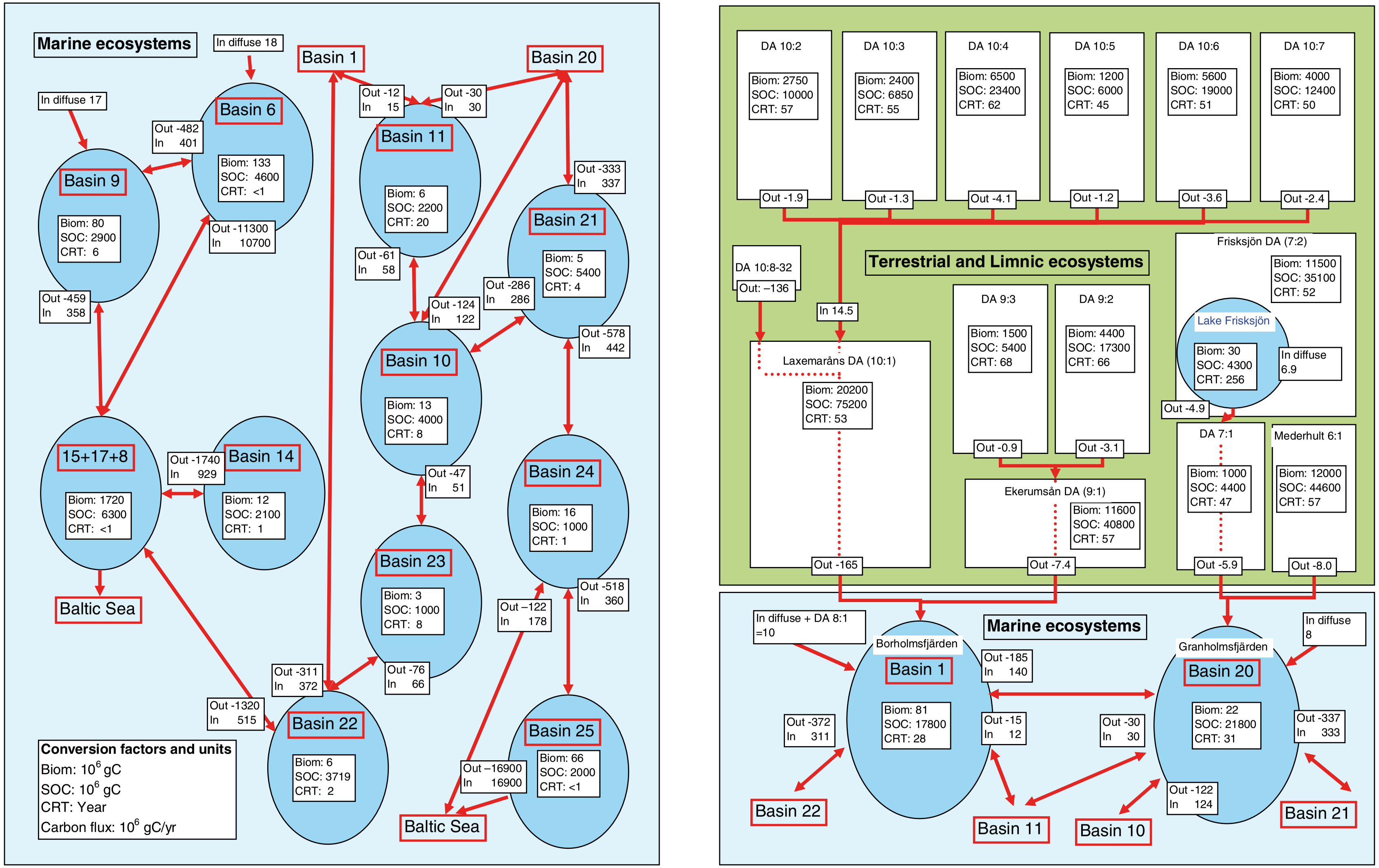

Figure 4-18. *An annual carbon budget for the discharge area Laxemar and adjacent coastal basins, where land, lakes and the coastal basins have been interconnected. (MgC in units denotes 10^6 gC). Negative sign indicates a flux that is leaving the specific subsystem, e.g. respiration. Biom = Biomass, SOC = Soil/Sediment Organic Carbon, CRT = Carbon Residence Time (theoretical) for all organic carbon in the specific subsystem, DA = Drainage area. Sub catchment 8.1 is not in the figure but do contribute to the inflow of DOC to the basin Borholmsfjärden.*

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Appendix 1

Description of biosphere object in Simpevarp

Introduction – A biosphere object

In the safety assessment are so-called biosphere objects used to build a landscape model with the purpose of describing transport and accumulation of radionuclides in space and time. A biosphere object is a delimited ecosystem in the landscape that is exposed to a radionuclide release from a deep-sited repository. The present biosphere objects may be used for modelling radionuclide accumulation and transport between objects in a future landscape, whose properties are difficult to measure. Therefore, descriptive statistics for the biosphere objects in the present landscape are used to characterize the future biosphere objects. A number of ecosystems are found in the Laxemar area, such as forest, agriculture land, mire, running water, lake and sea. Moreover, is the well considered here, due to its importance as a potential source for radionuclides.

A general description of the methods

Data in GIS has been used to identify, construct and assign properties to the biosphere objects. The main source for identifying the terrestrial objects within the regional model area has been a vegetation map /Boresjö Bronge and Wester 2003/ Table A1-1. The different sources of information used to characterise the biosphere objects are presented in Table A1-2. All work in GIS has been done using the ESRI Inc. software ArcView 3, ArcGIS 8.3 and 9.1 with extensions /ESRI 2005ab/, and all statistics has been calculated using Statistica 6.0 /StatSoft Inc 2001/.

Table A1-1. Data sources used to describe the spatial distribution of the biosphere objects in Simpevarp.

Biosphere object	Source for construction
Woodland	Vegetation map /Boresjö Bronge and Wester 2003/, following grid codes: 11–14, 15, 23, 24, 25, 30, 41–45, 50, 62, 63
Wetland	Vegetation map, following grid codes: 62, 63, 71–79
Agriculture land (including seminatural grassland)	Vegetation map, following grid codes: 81, 82
Lake	All lakes from the lake characterization /Brunberg et al. 2004/
Well	From the SGU well archive and inventories by SKB /SGU 2004/
Running water	All objects from the water course mapping /Carlsson et al. 2005/

Table A1-2. GIS data that have been used to characterise the biosphere objects in Simpevarp.

GIS data	Name in SKB's GIS database	Date	Report reference
DEM	SDEADM.UMEU_SM_HOJ_2102	2004-09-21	/Brydsten 2004a/
Regolith	SDEADM.POS_SM_GEO_2653	2005-06-29	/Rudmark et al. 2005/
Boulderness	SDEADM.SGU_SM_GEO_2501	2005-03-01	/Rudmark et al. 2005/
Soil	SDEADM.SLU_LX_GEO_2497	2005-01-20	/Lundin et al. 2004b/
Regolith depth	SDEAM.POS_SM_FM_GEO_2655	2005-07-08	/Nyman 2005/
Groundwater depth	G:\skb\modellering\mikeshe\L1.2\Resultatbearbetning\Basecase\Grundvattenyta\grvyta_esri	2005-09-14	This report
Hydrological model	G:\p\pa\Platsbeskrivande modeller\GIS\Simpevarp\Hydromodell_Simp_050207	2005-02-07	This report
Biomass	SIMONE version Laxemar 1.2	2004-12	This report
Production	SIMONE version Laxemar 1.2	2004-12	This report
Vegetation map	SDEADM.SWP_OSK_BIO_1251	2002-09-02	/Boresjö Bronge and Wester 2003/
Historic map	http://www.humangeo.su.se/kartburken/	2005-03-29	/Jansson et al. 2004/
Well	SDEADM.SFGL_OH_GEO_1016	2002-03-12	–
	SDEADM.SGU_SVE_GEO_2056	2004-05-28	/SGU 2004/
Lake characterization	SDEADM.UMEU_OH_VTN_2268	2004-09-28	/Brunberg et al. 2004/
Water course	SDEADM.UPU_OH_VTN_2293	2004-10-26	/Carlsson et al. 2005/
Land use (Fastighetskartan © Lantmäteriverket)	SDEADM.LMV_FM_FK_MY_324	2003-09-25	–

Statistics

Each property is described using number of observations, mean, median, min, max, lower and upper quartile, and standard deviation. Finally, is a distribution curve presented for the parameter data, where the red line indicates the form of a dataset with normal distribution. No transformation of the data has been performed before calculating the descriptive statistics.

The agriculture objects

Construction

The agriculture objects were constructed from the vegetation map /Boresjö Bronge and Wester 2003/. The grid codes specified in Table A1-1 were used to identify the agriculture objects within the regional model area. In total 1,175 agriculture objects are identified in the Simpevarp regional model area, Figure A1-1. The semi-natural grasslands in the area are also included, because many of these are former agriculture land.

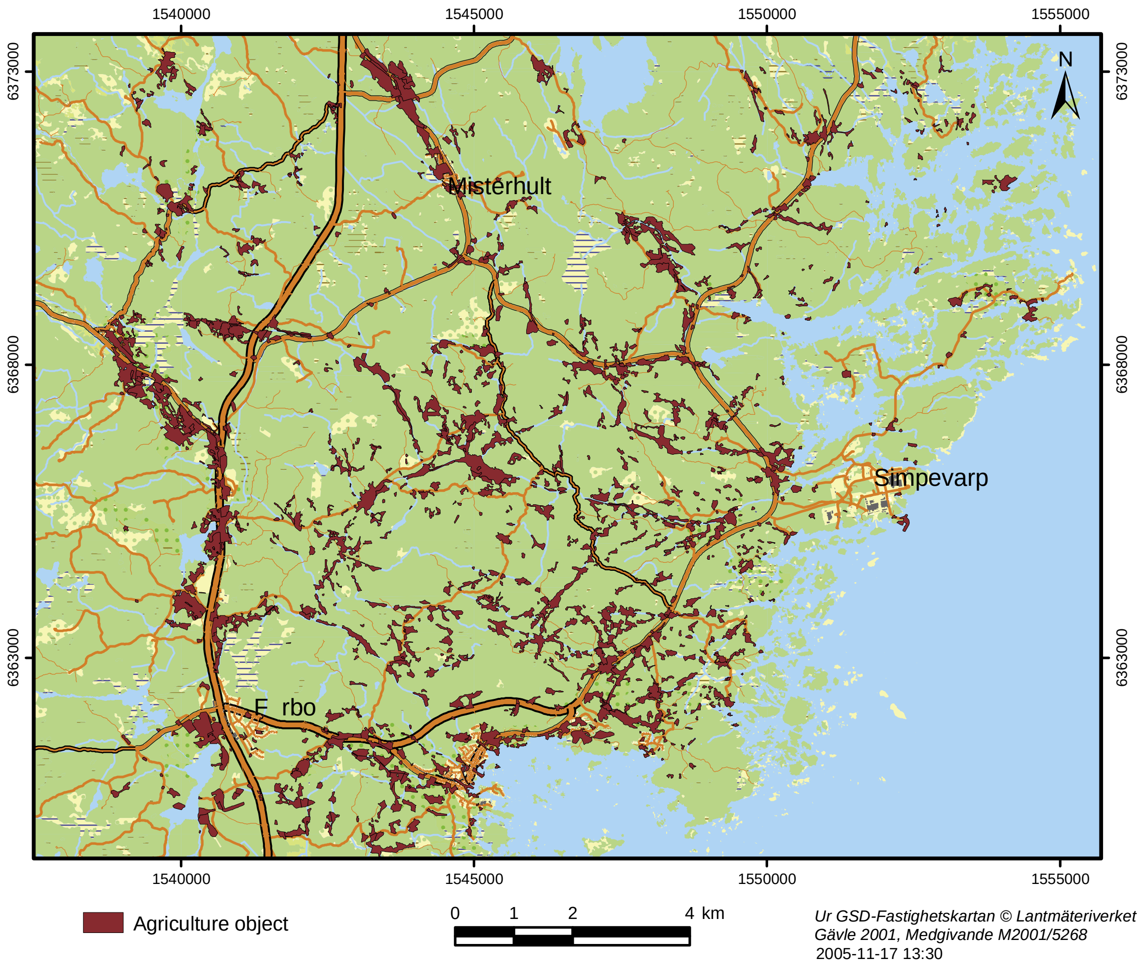


Figure A1-1. *Agriculture objects in the Simpevarp regional model area.*

Parameters

All properties in Table A1-3 are available as shapes (GIS data format) and were assigned to the agriculture objects using the tool "join" in ArcGIS 8.3/9.1. Raster data was added using "zonal statistics". The function "union" was used when data of several categories were assigned to polygons e.g. regolith classes, to be able to describe the distribution of different classes within each biosphere object.

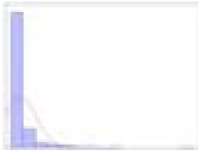
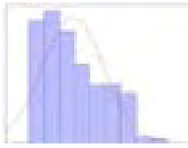
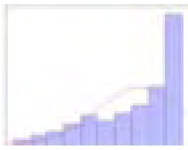
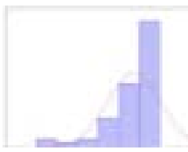
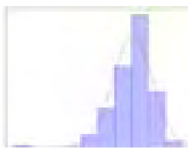
- Catchment area

This parameter was calculated using the maximum "flow accumulation" value in each agriculture land object. This estimate could be an underestimate of the actual catchment area, if the object has a water divider crossing. However, a subsample of the objects did not generate any agriculture lands with such a water divider, indicating that most of the agriculture land objects have one catchment.

- Potential agriculture land

Objects covered by any type of boulderness /Rudmark et al. 2005/ are categorized as not potential agriculture land, while objects covered by areas classified as "lacking a boulder frequency" are categorized as potential future agriculture land. Objects outside boulderness mapped area are not categorized at all.

Table A1-3. Statistics describing the agriculture objects identified within the Simpevarp regional model area.

Property	N	Mean	Median	Min	Max	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Area (m^2)	1,175	12,200	4,900	50	242,000	2,300	12,500	21,600	
Catchment area (m^2)	1,175	$1.52 \cdot 10^6$	56,000	0	$92{,}45 \cdot 10^6$	11,000	$0.32 \cdot 10^6$	$6.38 \cdot 10^6$	
DEM (m.a.s.l.)	1,175	14.4	12.3	–0.2	43.1	6.1	21.8	9.9	
Regolith depth (m)	1,174	4.9	5.4	0.0	15.0	2.0	6.7	2.7	
Coverage of dominating soil type (%)	1,175	80	86	25	100	67	97	19	
Boulderness freq. (%)	523	15	0	0	100	0	0	32	
Ground water table (m below surface) [1)]	60	–0.6	–0.5	–3.0	–0.0	–0.9	–0.1	0.6	
Wetness index (TWI, mean)	1,174	9.4	9.7	0.0	13.4	8.6	10.5	1.5	

[1)] Contained 22 positive values, which were removed.

- Wetness Index (TWI)

The wetness conditions in a certain location relates to its specific catchment area, i.e. the upslope area draining through that location, and the slope. This relation is used to calculate a topographical wetness index (TWI) from a DEM in the TOPMODEL hydrological model /Beven and Kirkby 1979, Seibert et al. 1997/. The index describes the spatial distribution of the groundwater table, which reflects the soil moisture in the upper part of the soil. The index is valid as long as the groundwater surface varies according to the topography and the soil transmissivity is constant. When the accumulated flow reaches a certain threshold the flow becomes saturated and a stream is formed, which discharges the surface water. The index (TWI) for a grid cell is a non-linear function of the upslope area (α) and slope (β):

$$TWI = \ln (\alpha / \tan \beta)$$

A large index indicates wet soil conditions as opposed to low index, which indicates dry conditions. Before it was used further, the calculated TWI values for were smoothened by calculating a local mean value in a three by three cell neighbourhood (30 by 30 m).

Topographical information was a high-resolution digital elevation model (DEM) with 10 m raster cell size /Wiklund 2002/. The elevation data was used to calculate a topographical index of soil moisture, which could be used to outline down slope areas with moist conditions.

- Calculating area proportion for properties

For properties that have been mapped in just a part of the regional model area, the calculated area proportion of the biosphere object can be misleading. For instance, boulderness and groundwater depth is just mapped in a part of the model area so biosphere object laying on the border of the mapped area may be assigned an incorrect proportion of boulderness. The same phenomenon comes up for objects lying on the border of the regional model area.

Results

A large number of agriculture objects were identified and many of these were relatively small, Table A1-3. The median is less than half a hectare, which is questionable to use from an economic point of view. 75% (N=543) was regarded as potential agriculture land in regard of boulder frequency. The groundwater table is high, which also is indicated by the average wetness index value for agriculture objects. Till, peat and clay is the dominating soil types in the area Figure A1-2. Peat has been inventoried with different methods within the area and in some parts peat has been separated into fen and bog peat. Interestingly, no agriculture objects with bog peat have been identified indicating that many of the agriculture objects have a former stage as a fen.

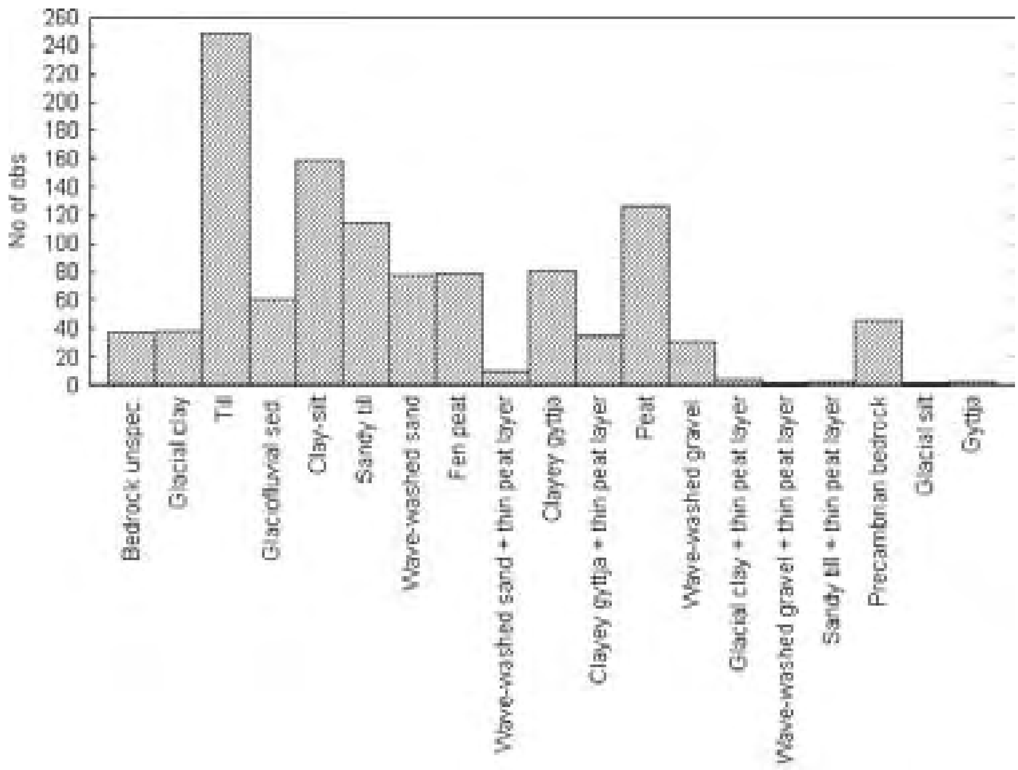


Figure A1-2. *Dominating soil types of the agriculture objects identified within the Simpevarp regional model area. Some of the peat areas were unclassified in regard of fen or bog peat. These were only identified as peat.*

The woodland objects

Construction

To describe the spatial distribution of the woodland objects the vegetation type categories in Table A1-1 were used. These categories were merged together to one category and 1,000 points were randomly distributed within the spatial extension of this woodland category with the nearest minimum distance set to 50 m between each point, Figure A1-3.

Parameters

All properties in Table A1-4 are available as shapes (GIS data format) and were assigned to the woodland objects using the tool "join" in ArcGIS 8.3/9.1. Raster data was added by assigning the woodland objects the grid value from the pixel it corresponds to.

- Catchment area

Describes the catchment area above the point representing the woodland biosphere object. A zero value indicates that the point is situated high in the terrain, while a high value indicates that the point is situated low in the terrain and thereby having a large catchment area.

- Distance to next Biosphere object

This is a description of the closest distance to the nearest biosphere object downstream, as the distance from the woodland object to the next biosphere object downstream (lake, stream, wetland, agriculture land, sea basin). For 124 randomly chosen woodland objects, the distance to the next biosphere object has been calculated along with the type

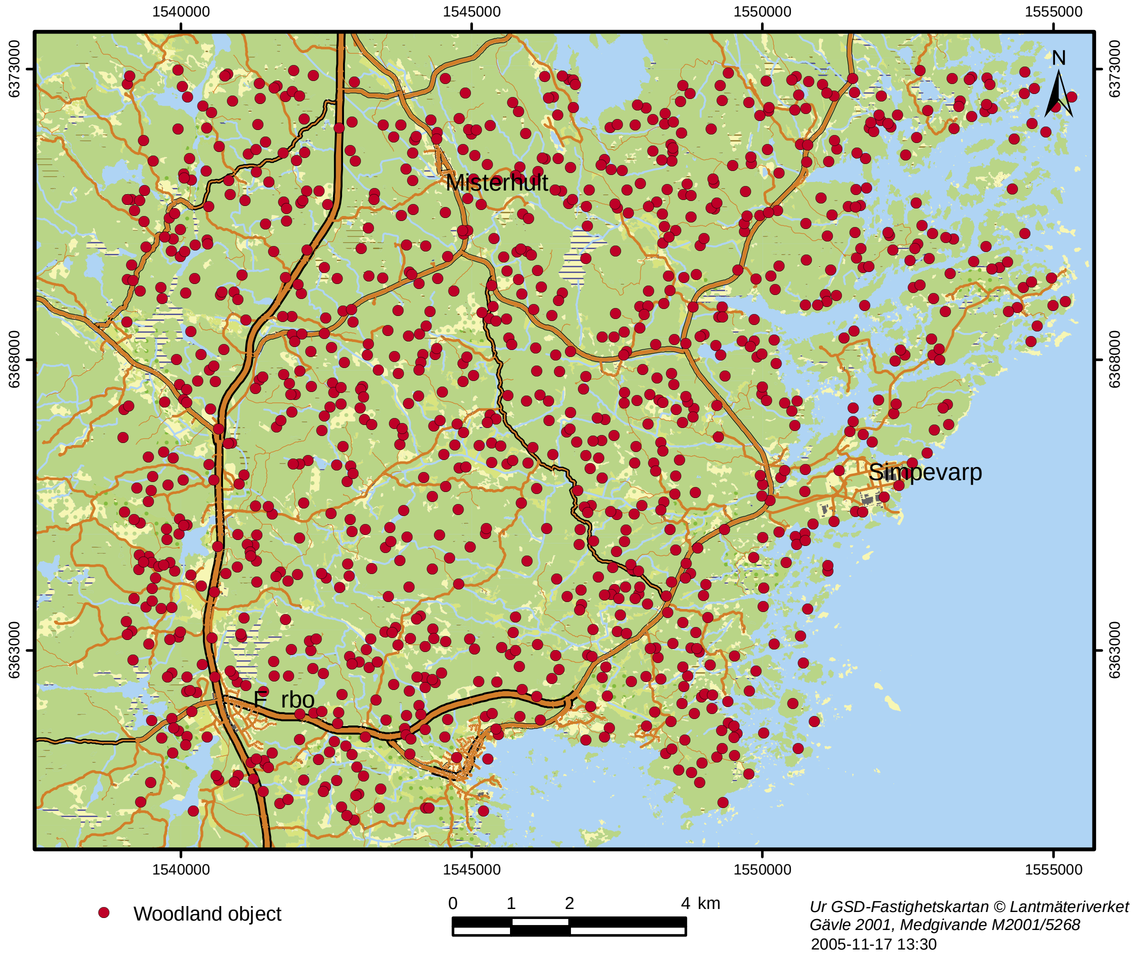


Figure A1-3. *Woodland objects in the Simpevarp regional model area.*

Table A1-4. Properties assigned to the woodland objects.

Properties	Unit	Comment
Distance to next Biosphere object	m	Only calculated for 124 of the 1,000 objects
Elevation	m.a.s.l.	
Regolith	Category	
Boulderness	Category	
Soil	Category	
Regolith depth	m	
Groundwater depth	m	
Catchment area	m^2	
Vegetation type	Category	
Historic landuse	Category	
Wetness index (TWI)	Index	

of biosphere object. The Hydro extension in ArcGIS 8.3 was used to release a rain drop from the selected woodland biosphere points. The length to the point, where this drop entered another biosphere object, was measured. Also the type of biosphere object was denoted. Not only the lake biosphere objects was used, but all lakes in the Fastighetskartan (©Lantmäteriverket) to match a distance to next biosphere object.

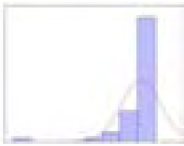
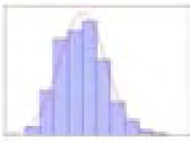
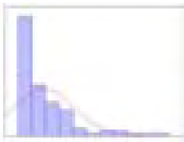
- Historical land use

Maps of historical land use are available from the years 1689, 1793, 1813 and 1872 /Jansson et al. 2004/.The maps are local and are not covering the whole area and they show agriculture land, meadow, marsh and outlying land.

Results

The Woodland biosphere object is most often an old Scots Pine forest on fresh to moist ground, situated on approximately 2 m of till, with the ground water surface 0.5 m below surface (this is, however, most certainly an underestimation of the actual depth to the groundwater, due to a number of small ditches that not had been considered in the descriptive groundwater level model, (Bosson unpubl.). The median distance to next biosphere object is 220 m (Table A1-5) and it is most often agriculture land, Figure A1-7. The historical landuse map from 1840 have 60 of the woodland biosphere objects marked as arable land.

Table A1-5. Statistics describing the woodland objects identified within the Simpevarp regional model area.

Property	N	Mean	Median	Min	Max	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Catchment area	1,000	110,400	200	0	45,303,500	0	600	1,964,200	
DEM (m.a.s.l.)	1,000	18.1	17.0	–0.9	49.1	8.7	27.0	11.2	
Regolith depth (m)	1,000	1.9	2.0	0.1	15.0	0.1	2.0	2.5	
Ground water table (m below surface)	56	–0.9	–0.5	–7.1	–0.1	–1.1	–0.2	1.1	
Wetness index (TWI, mean)	999	8.0	8.0	4.3	13.6	6.8	9.0	1.6	
Distance to next BO (m)	124	370	220	1	2,100	70	540	440	

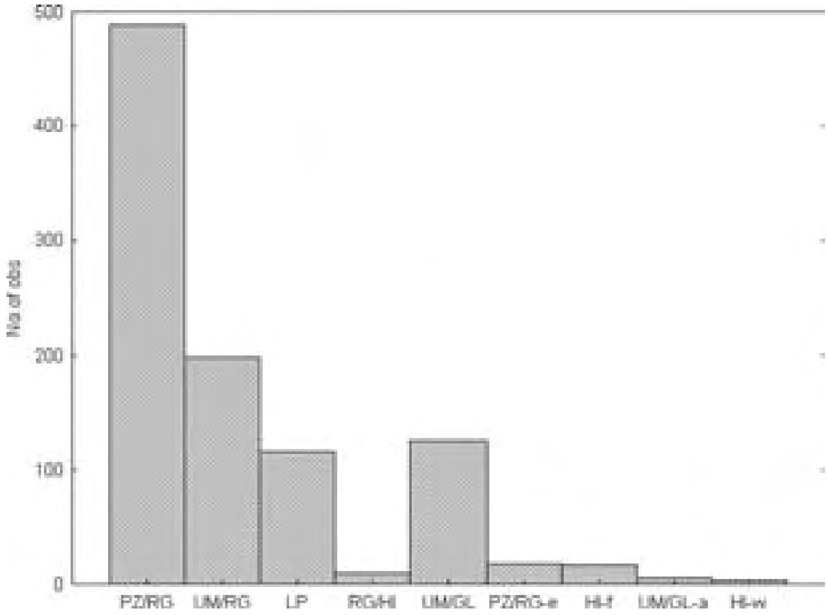


Figure A1-4. *Dominating soils of the woodland objects in the Simpevarp regional model area. PZ/RG: Podzol/Regosol (thin forested soil), UM/RG: Umbrisol-Regosol (drained forest soil), LP: Leptosol (bedrock), RG/HI: Regosol/Histosol (shoreline area), UM/GL: Umbrisol-Gleysol (open, partly forested moist soils), PZ/RG-e: Podzol/Regosol (esker soil), HI-f: Histosol, (forested peatland), UM/GL-a: Umbrisol-Gleysol-a (arable land), HI-w: Histosol (open wetland).*

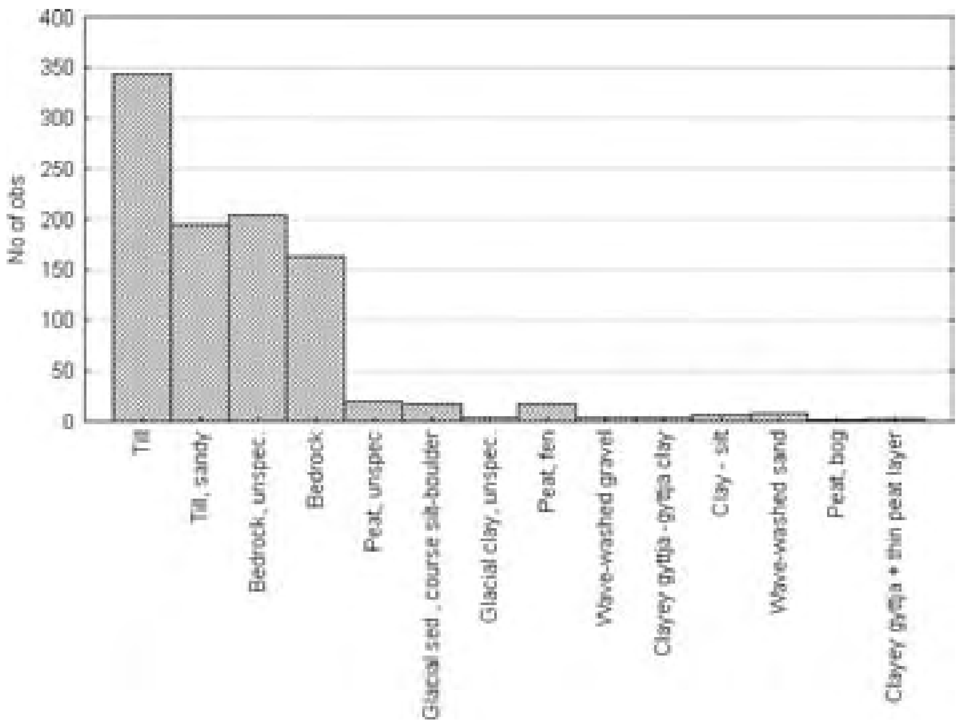


Figure A1-5. *Soil types of the woodland objects in the Simpevarp regional model area. Some of the peat areas were unclassified in regard of fen or bog peat. These were only identified as peat.*

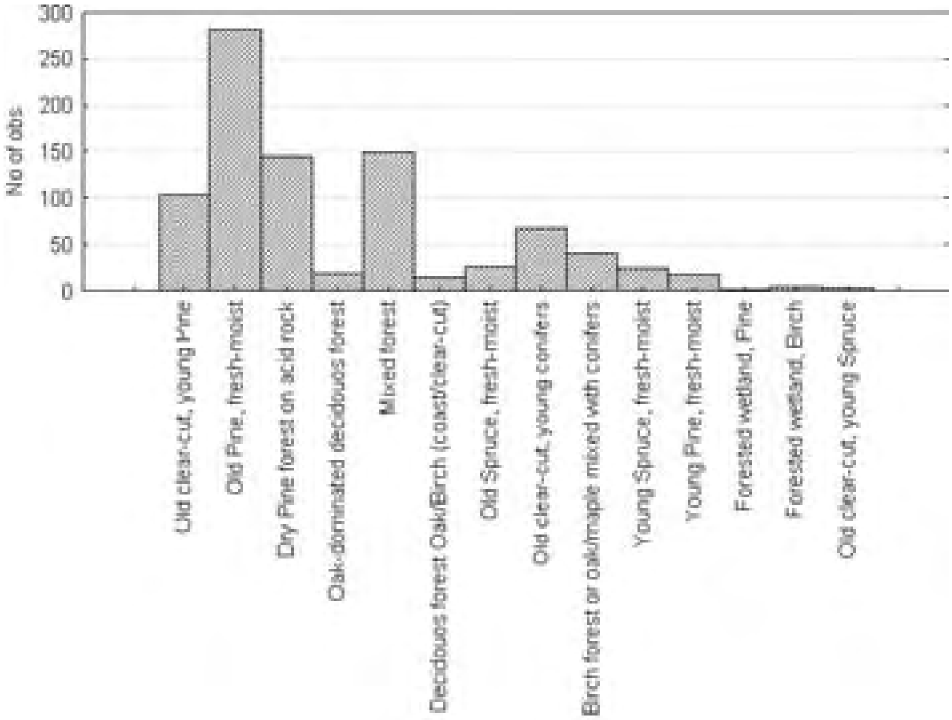


Figure A1-6. *Vegetation types within the woodland objects in the Simpevarp regional model area.*

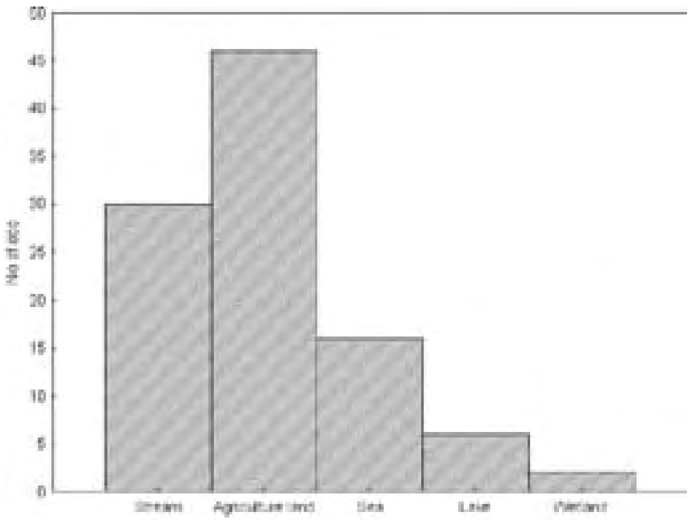


Figure A1-7. *Closest biosphere object to the woodland biosphere object as a function of the water flow direction.*

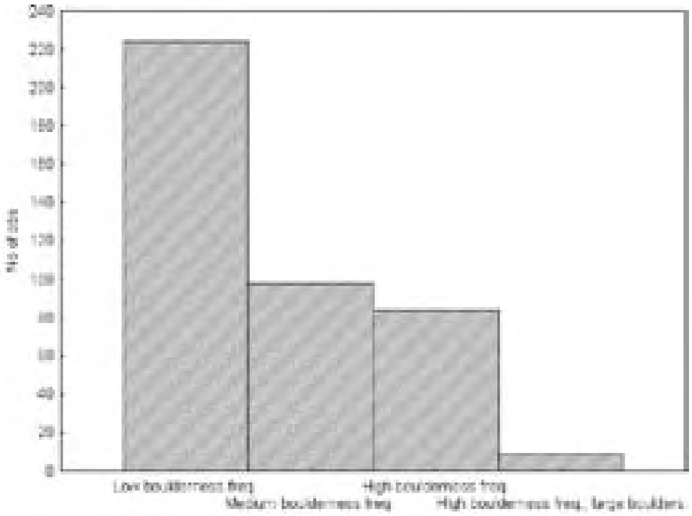


Figure A1-8. *Boulderness frequency within the woodland biosphere objects. All biosphere objects were not situated within the area that had been investigated with regard to boulderness.*

The wetland objects

Construction

The wetlands categories from the vegetation map were used (Table A1-1) to identify the spatial distribution of the wetland objects. These were divided into three subclasses:

1) Sea classes (in contact with the sea).
2) Lake mires (the longest half in contact with the lake).
3) Stand alone mires, but can in one end be in contact with a lake.

Clusters of mire types were given a single id when situated together.

The lake objects /Brunberg et al. 2004/ were delimited from other vegetation types using a DGPS. Their class "Littoral 1" defined as "habitat with emergent and floating-leaved vegetation often developed in wind-sheltered, shallow areas" is often bordered on other mire types as defined in the vegetation map /Boresjö Bronge and Wester 2003/. However, the lake objects should end as more solid ground is reached. It is therefore here assumed that the littoral 1 is more a part of the lake. Consequently, the lake objects were used to remove intersecting areas from the wetland objects.

In total 536 wetland objects are identified in the Simpevarp regional model area, Figure A1-9.

Parameters

All properties in Table A1-6 are available as shapes (GIS data format) and were assigned to the agriculture objects using the tool "join" in ArcGIS 8.3/9.1. Raster data was added using "zonal statistics". The function "union" was used when data of several categories was assigned to polygons e.g. regolith classes, to be able to describe the distribution of different classes within each biosphere object.

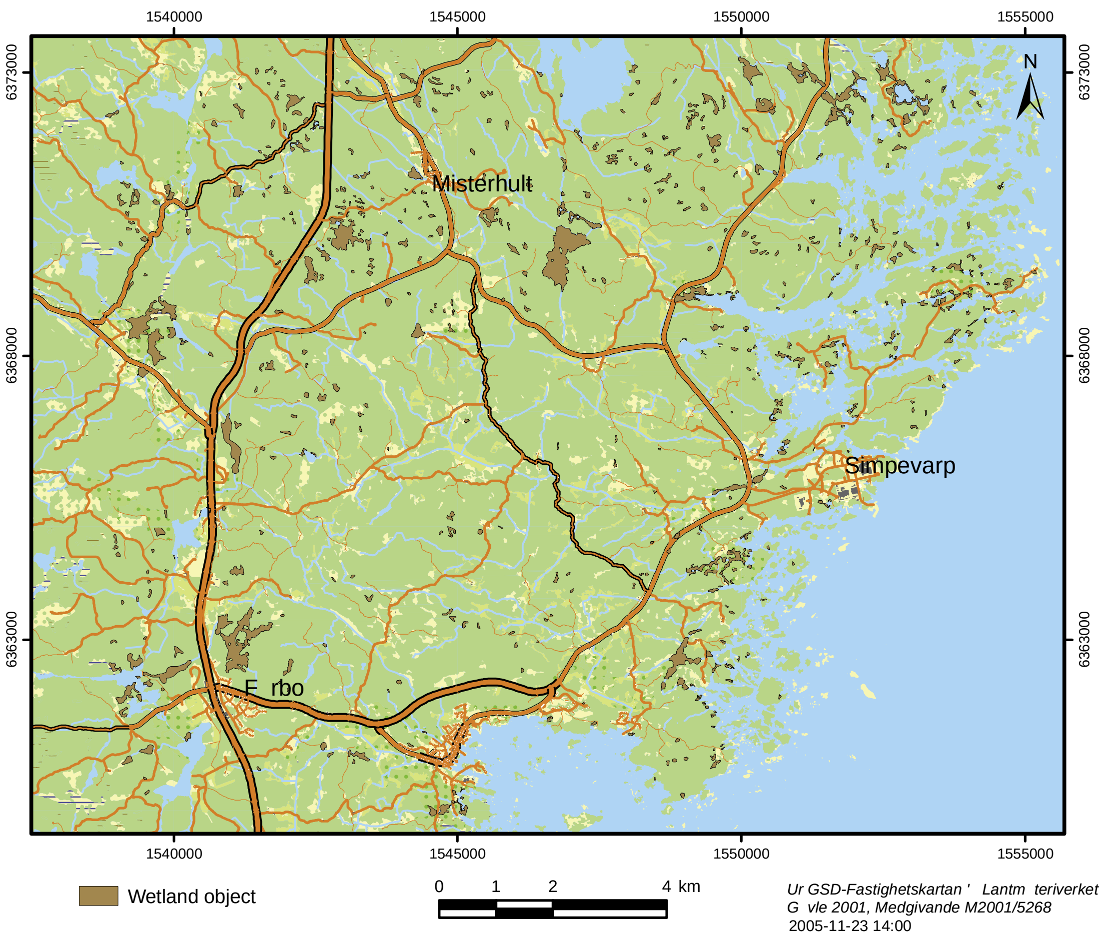


Figure A1-9. *Wetland objects in the Simpevarp regional model area.*

Table A1-6. Properties assigned to the wetland objects.

Properties	Unit
Area of Biosphere object	m^2
Elevation	m.a.s.l.
Regolith	Category
Boulderness	Category
Soil	Category
Regolith depth	m
Groundwater depth	m
Water flow through point	m^3
Potential agriculture land	Yes/No
Wetness index (TWI)	Index
Wetland vegetation type	Category
Tree layer type (if present)	Category

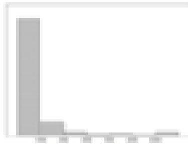
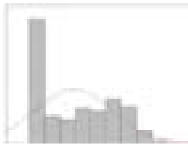
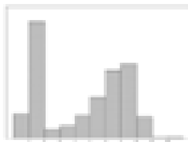
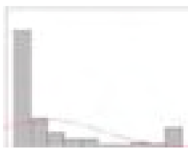
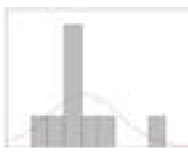
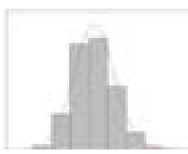
- Calculating area share for properties

For properties that have been mapped in just a part of the regional model area, the calculated area share of the biosphere object can be misleading. For instance, boulderness and groundwater depth is mapped only in a part of the model area so biosphere object lying on the border of the mapped area then may get an incorrect share of boulderness calculated. The same phenomenon comes up for objects lying on the border of the regional model area.

Results

A large number of wetlands are found in the area, where most are small, well below a hectare, Table A1-7. Scots pine dominated wetlands on histosols over layering peat seems to be the most abundant wetland type in this area, at least in regard to number of wetlands, Figure A1-10–13. This type is closely followed by the open pore lawn mire. Few bogs are present in the area. A large number of wetlands are situated on till. Approximately, 25% of the wetlands can be regarded as potential agriculture land if we suppose that a boulderness categorised as above normal is too stony to be utilised for agriculture purposes, Table A1-7.

Table A1-7. Statistics describing the Wetland objects identified within the Simpevarp regional model area.

Property	N	Mean	Median	Min	Max	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Area (m^2)	536	9,600	3,400	20	391,700	2,100	6,800	28,800	
Catchment area (m^2)	534	1,326,000	30,100	0	81,210,300	10,300	127,500	7,987,500	
DEM (m.a.s.l.)	536	14.5	13.8	0	42.1	1.2	26.1	12.4	
Regolith depth (m)	536	4.7	5.3	0	35.5	2.0	7.0	3.1	
Coverage of dominating soil type (%)	536	78	82	3	100	68	93	20	
Boulderness freq. (%)	206	20	6	0	100	0	24	30	
Ground water table (m below surface) [1)]	18	0.03	–0.03	–0.6	1	–0.1	0.04	0.4	
Wetness index (TWI, mean)	534	9.3	9.2	6.5	13.2	8.5	10.0	1.1	

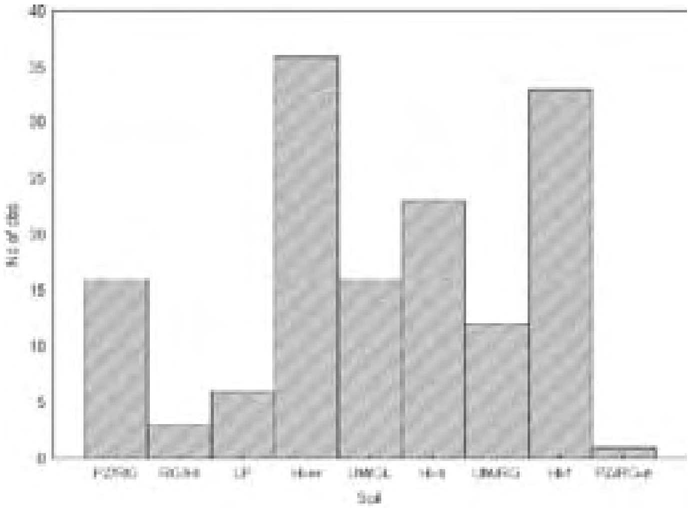


***Figure A1-10.** Dominating soils of the wetland objects in the Simpevarp regional model area.*

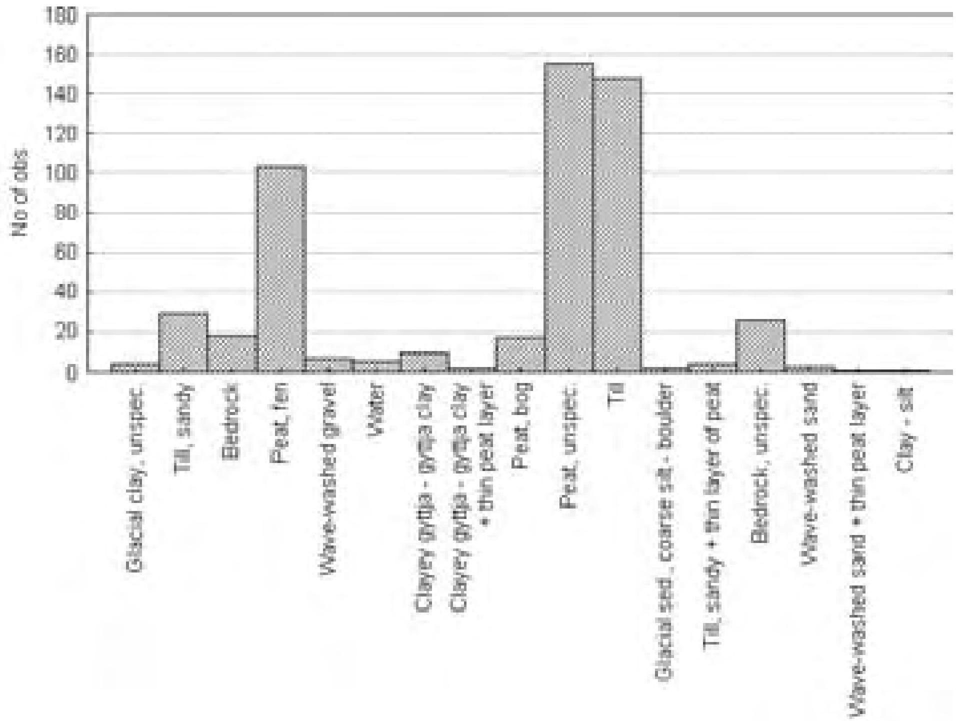


***Figure A1-11.** Soil types of the wetland objects in the Simpevarp regional model area. Some of the peat areas were unclassified in regard of fen or bog peat. These were only identified as peat.*

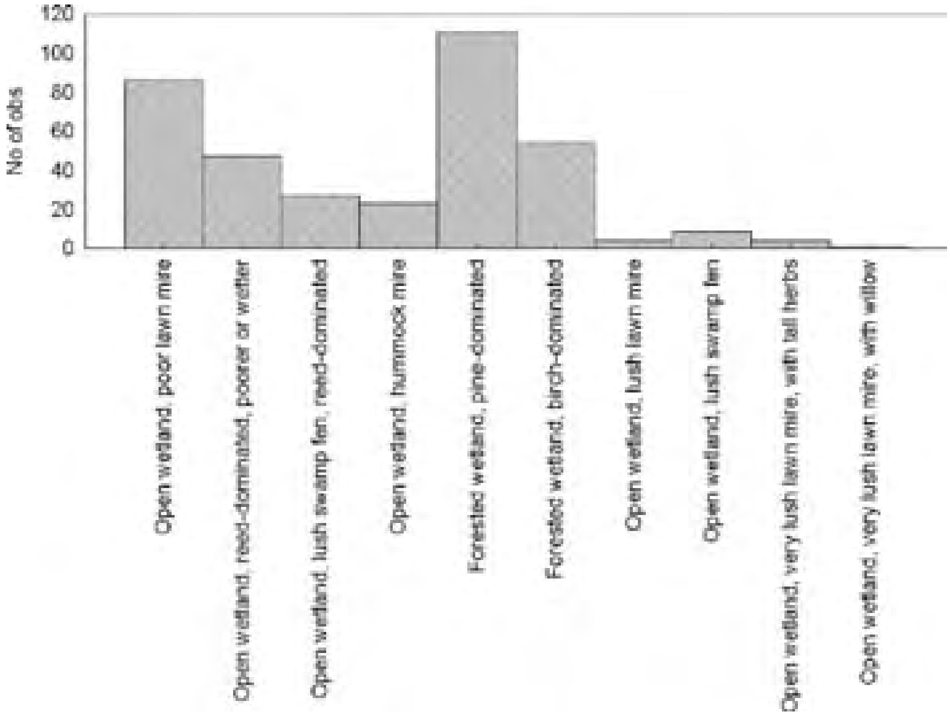


Figure A1-12. *Wetland type according to the vegetation map. The larger wetlands with multiple-vegetation types are excluded.*

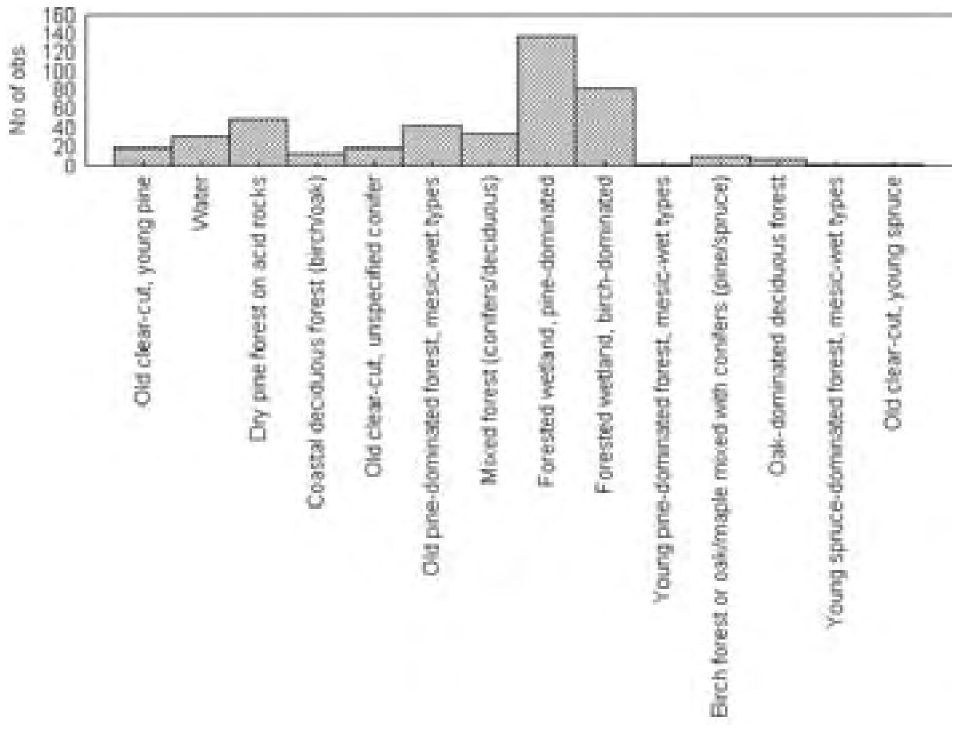


Figure A1-13. *Tree layer types within the wetland objects in the Simpevarp regional model area.*

The lake objects

Construction

The five lakes from the lake characterization /Brunberg et al. 2004/ have been used to define the spatial limitation of these objects, Figure A1-14.

Results

Only five lakes are present in the area. These vary considerable in size and properties and a full description of each of the objects is found in /Brunberg et al. 2004/.

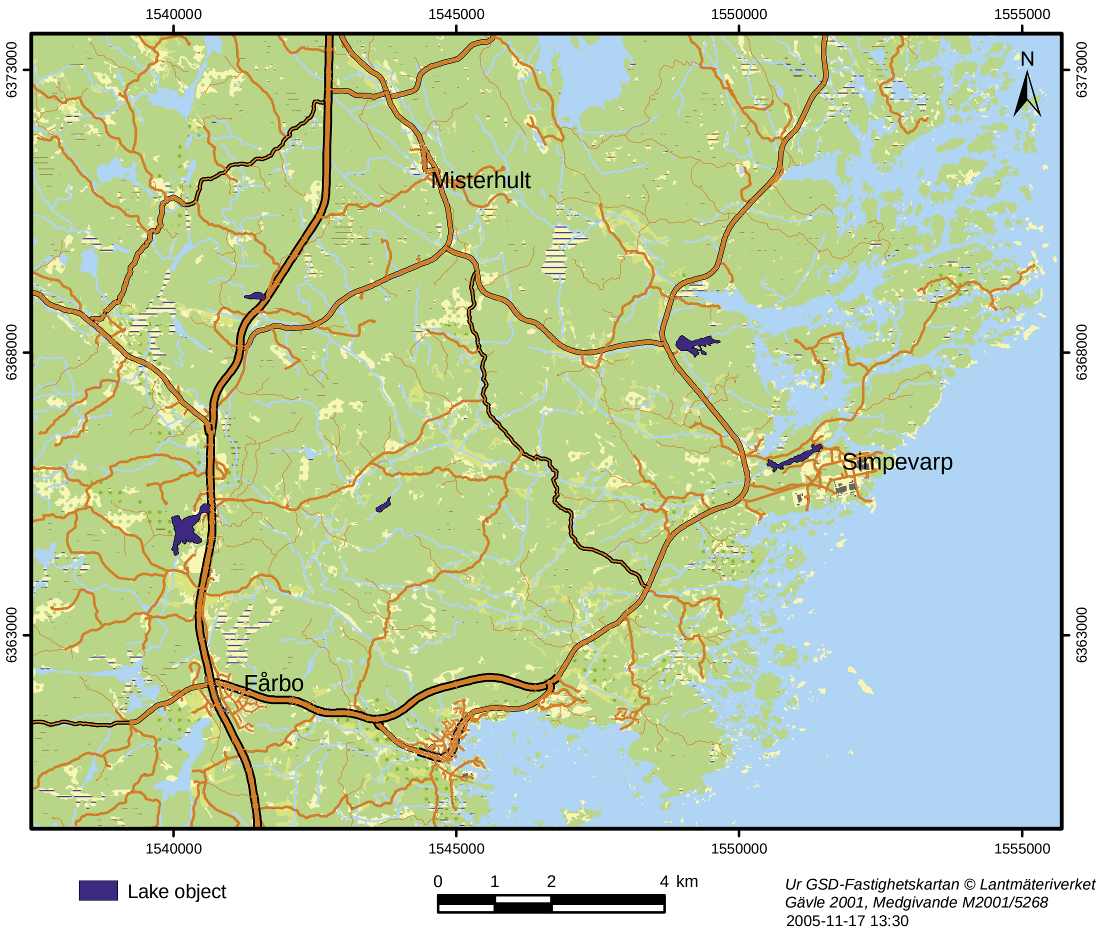


Figure A1-14. *Lakes in the Simpevarp regional model area.*

The running water objects

Construction

All objects from the water course characterization /Carlsson et al. 2005/ have been used. Two files have been constructed, one with the 10 m sections along all water courses preserved and one where each water course represent one object. The first more detailed file contains 2,107 objects and has been supplied with more parameters than the other one, containing only nine objects (Table Z and Z respectively). The sections for each water course are turned into one object by using the "dissolve" tool in ArcGIS. The objects are shown in Figure A1-15.

The water courses were categorised according to the size of their catchment area; 1) 0.13–0.30 km^2, 2) 2–3 km^2 and 3) 10 km^2, see Table A1-8.

Parameters

All properties in Table A1-9 are available as shapes (GIS data format) and were assigned to the running water objects. The slope was calculated with the ArcView 3 extension LineSlope Analyst.

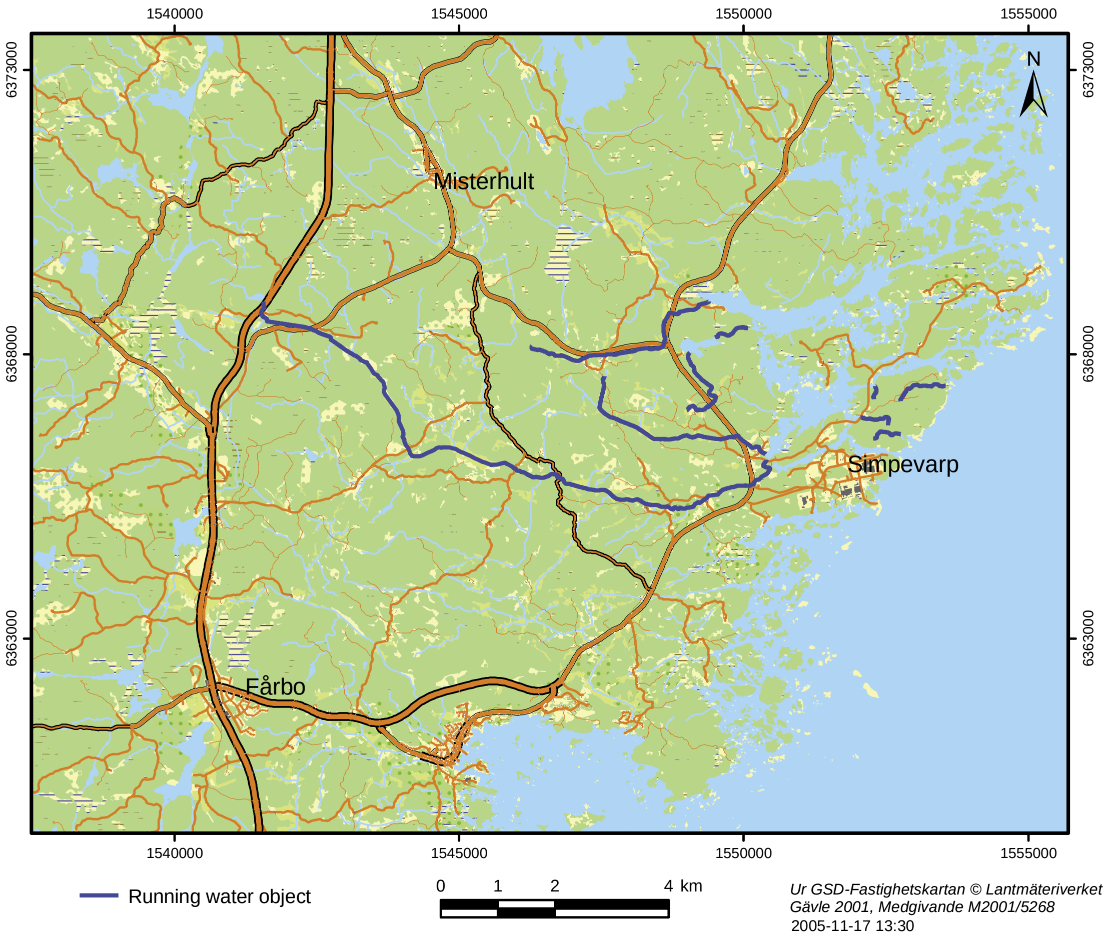


Figure A1-15. Running water objects in the Simpevarp regional model area.

Table A1-8. Number of sections and the lengths of the investigated parts of the streams in the Simpevarp area after /Carlsson et al. 2005/.

Categorisation	Stream	Number of sections	Length (m)
1	Catchment 23: "Vadvikebäcken"	102	1,000
1	Catchment 24: "Lindströmmebäcken"	27	260
1	Catchment 25: "Gloebäcken"	66	670
1	Catchment 26: "Skölkebäcken"	62	610
2	Catchment 6: "Mederhultsån"	402	3,950
2	Catchment 7: "Kåreviksån"	258	2,530
2	Catchment 9: "Ekerumsån"	399	3,920
3	Catchment 10: "Laxemarån"	791	7,710
Total		2,107	20,650

Table A1-9. Properties assigned to the running water objects, sections preserved.

Property	Unit
Depth	m
Width	m
Regolith depth	m
Current velocity	ms^{-1}
Bottom vegetation abundance	Categories, coverage
Proportion of dry sections	

Results

The geometric parameters describing the three running water categories, in the Simpevarp area, all seem to increase as the catchment area increases, Table A1-10–12. The vegetation abundance seems to peak in the intermediate sized running waters, while the proportion of dry sections in the running water decreases with catchment area.

Table A1-10. Statistics describing the running water objects category 1 within the Simpevarp regional model area.

Property	N	Mean	Median	Min	Max	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Depth (m^2)	257	0.02	0.0	0.0	0.2	0.0	0.0	0.05	
Width (m)	257	0.4	0.0	0.0	2.5	0.0	0.0	0.7	
Regolith depth (m)	257	4.1	4.1	0.1	8.3	2.0	6.2	2.8	
Current velocity (ms^{-1})	257	0.2	0.0	0.0	1.0	0.0	0.0	0.4	
Vegetation abundance	257	0.6	0.0	0.0	5.0	0.0	0.0	1.3	
Proportion of dry sections	257	0.76	–	–	–	–	–	–	

Table A1-11. Statistics describing the running water objects category 2 within the Simpevarp regional model area.

Property	N	Mean	Median	Min	Max	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Depth (m^2)	1059	0.1	0.1	0.0	0.9	0.0	0.2	0.1	
Width (m)	1059	0.8	0.6	0.0	3.5	0.0	1.3	0.8	
Regolith depth (m)	1059	5.7	6.2	0.1	11.2	2.0	8.3	2.6	
Current velocity (ms^{-1})	1059	1.2	1.0	0.0	4.0	1.0	1.0	1.1	
Vegetation abundance	1059	2.9	4.0	0.0	5.0	0.0	5.0	2.1	
Proportion of dry sections	1059	0.15	–	–	–	–	–	–	

Table A1-12. Statistics describing the running water objects category 3 within the Simpevarp regional model area.

Property	N	Mean	Median	Min	Max	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Depth (m^2)	792	0.5	0.4	0.0	3.0	0.3	0.5	0.4	
Width (m)	792	2.4	2.	0.0	8.0	2.0	2.5	0.9	
Regolith depth (m)	792	6.4	7.4	0.1	8.3	5.1	8.3	2.6	
Current velocity (m/s)	792	1.1	1.0	0.0	4.0	1.0	1.0	0.5	
Vegetation abundance	792	2.5	3.0	0.0	5.0	1.0	3.0	1.3	
Proportion of dry sections	792	0.02	–	–	–	–	–	–	

Appendix 2

Species list

Latin	**English**	**Swedish**
Fish		
Perca fluviatilis	Perch	Abborre
Abramis brama	Bream	Braxen
Gymnocephalus cernuus	Ruffe	Gers
Esox lucius	Pike	Gädda
Alburnus alburnus	Bleak	Löja
Rutilus rutilus	Roach	Mört
Scardinius erythrophtalmus	Rudd	Sarv
Sprattus sprattus	Sprat	Skarpsill
Clupea harengus	Herring	Strömming
Gasterosteus aculeatus	Three spined stickelback	Storspigg
Gobidae	Gobide	Gobid
Macrophytes		
Lemna minor	Common Duckweed	Vanlig andmat
Alisma plantago-aquatica	Water plan-tain	Svalting
Juncus effusus	Soft-Rush	Veketåg
Sparganium sp	Bur-reed	Igelknopp
Potamogeton polygonifolius	Bog Pondweed	Bäcknate
Lysimachia thyrsiflora	Tufted Loosestrife	Topplösa
Nuphar lutea	Yellow Pond-lily	Gul näckros
Nymphea alba	White Water lily	Vit näckros
Phragmites australis	Common Reed	Vass
Typha sp	Cattail	Kaveldun
Vaucheria sp	–	–
Chara sp	–	Kransalger
Potamogeton pectinatus	–	Ålnate
Zostera marina	–	Ålgräs
Fucus vesiculosus	Bladderwrack	Blåstång
Potamogeton perfoliatus	–	Gäddnate
Polysiphonia sp	–	–

Benthic fauna

Anodonta anatina	Duck mussel	Allmän dammussla
Mytilus edulis	Blue mussel	Blåmussla
Macoma baltica	–	Östersjömussla
Hydrobia sp		
Cerastoderma hauniense		Hjärtmussla
Theodoxus fluviatilis		
Gammarus sp		
Nereis diversicolor		Rovborstmask

Phytoplankton

Cladocerae
Rotatifera
Dinophyta
Perdinium willei
Merismopedia warmingiana
Cryptomonas spp
Monoraphidium dybowskii
Trachelemonas sp
Aulacoseira spp
Cryptomonas spp
Cyanophyceae

Zooplankton

Daphnia cucullata
Leptodora kindti
Thermocyclops sp
Eudiaptomus sp

Plants

Pinus sylvestris	Scots Pine	Tall
Calluna vulgaris	Heather	Ljung
Deschampsia flexuosa	Wavy Hair-grass	Kruståtel
Agrostis vinealis	Brown Bent	Bergven
Festuca ovina	Sheep’s-Fescue	Fårsvingel
Vaccinium vitis-idaea	Cowberry	Lingon

Vacinium myrtillus	Bilberry	Blåbär
Picea abies	Norway Spruce	Gran
Quercus robur	Pedunculate Oak	Ek
Corylus avelana	Hazel	Hassel
Sorbus aucuparia	Rowan	Rönn
Sorbus intermedia	Swedish Whitebeam	Oxel
Acer platanoides	Norway Maple	Lönn
Betula pendula	Silver Birch	Vårtbjörk
Rhododendron tomentosum	Labrador-tea	Skvattram
Salix sp	Willow species	Videarter
Fagus sylvatica	Beech	Bok
Juniperus communis	Common Juniper	En
Rubus idaeus	Raspberry	Hallon
Abies amabilis	Pacific Silver Fir	Purpurgran

Fungi

Cenococcum graniforme	–	Jordgryn

Bryophyte

Sphagnum	Vitmossor	Peat moss

Mammals

Alces alces	Moose	Älg
Capreolus capreolus	Roe deer	Rådjur
Cervus elaphus	Red deer	Kronhjort
Dama dama	Fallow deer	Dovhjort
Lepus europaeus	European (common) hare	Fälthare
Lepus timidus	Mountain hare	Skogshare
Martes martes	Marten	Mård
Vulpes vulpes	Red fox	Rödräv
Lynx lynx	Lynx	Lo
Sus scrofa	Wild boar	Vildsvin
Cletrionomus glareolus	Bank vole	Skogssork/Ängssork
Microtus agrestis	Field vole	Åkersork
Arvicola terrestris	Water vole	Vattensork
Apodemus flavicollis	Yellow necked mouse	Större skogsmus

Apodemus sylvaticus	Wood mouse	Mindre skogsmus
Sorex araneus	Common shrew	Vanlig näbbmus
Chiroptera	Bats	Fladdermus
Erinaceus europaeus	Hedgehog	Igelkotte

Birds

Fringilla coelebs	Chaffinch	Bofink
Phylloscopus trochilus	Willow Warbler	Lövsångare
Erithacus rubecula	Robin	Rödhake
Turdus philomelos	Song Thrush	Taltrast
Turdus merula	Blackbird	Koltrast
Parus major	Great Tit	Talgoxe
Carduelis spinus	Siskin	Grönsiska
Sturnus vulgaris	Starling	Stare
Columba palumbus	Wood Pigeon	Ringduva
Regulus regulus	Goldcrest	Kungsfågel
Emberiza citrinella	Yellow hammer	Gulsparv
Carduelis chloris	Green finch	Grönfink
Parus caeruleus	Blue tit	Bålmes
Anthus trivialis	Tree pipit	Trädpiplärka
Troglodytes troglodytes	Wren	Gärdsmyg

Reptiles and Amphibians

Vipera berus	Adder	Huggorm
Natrix natrix	Grass snake	Vanlig snok
Coronella austriaca	Smooth snake	Hasselsnok
Anguis fragilis	Slow-worm	Kopparödla
Lacerta vivipara	Common lizard	Skogsödla
Lacerta agilis	Sand lizard	Sandödla
Rana arvalis	Moor frog	Åkergroda
Bufo bufo	Common toad	Vanlig padda
Triturus vulgaris	Smooth newt	Mindre vattensalamander
Triturus cristatus	Great creasted newt	Stor vattensalamander’

Appendix 3
Catchment
Subcatchment
Contour, 1m
Contour, 5m
Contour, -3m
Contour, -6m
Contour, -10m
Contour, -15m
Contour, -20m
N
0 0.5 1 2 km
From GSD-Fastighetskartan © Lantmäteriverket Gävle 2001, Consent M2001/5268
2006-04-12, 15:30
Berga
Gersebo
Götehult
Mörkviken
Göten
Götemar
Stubbhult
Misterhult
Gimmerfjärden
Sanghusfjärden
Lillefjärd
Ärnhult
Kråkemåla
Marsö
Bussvik
Grundfjärden
Fjällgöl
Dunsjön
Gästersnäs
Gässhult
Bjurhide
Plattorpesjön
Nöjgöl
Plittorpsgöl
Plittorp
Kärrsvik
Granholmsfjärden
Åsperum
Ekenäs
Frisksjön
Äspö
Mederhult
Getbergsfjärden
Stora Basthult
Lilla Laxemar
Kristineberg
Borholmsfjärden
Ävrö
Halö
Lilla Basthult
Granggöl
Sörå
Lilla Laxemar
Värnamo
Lidhem
Simpevarp
Nuclear Power plant
Ström
Fjällgöl
Stora Laxemar
Jämsen
Äsen
Östersjön
Stora Grytsjön
Köksmåla
Bastebola
Kalmarsund
Fårbo
Långgölen
Egelgöl
Gubbesjön
Hägnad
Djupesund
Fårbosjön
Virvhult
Figgeholm
Sandvik