R-06-83

The biosphere at Laxemar

Data, assumptions and models used in the SR-Can assessment

Svensk Kärnbränslehantering AB

October 2006

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Contents

1 Introduction

This is essentially a compilation of a variety of reports concerning the site investigations, the research activities and information derived from other sources important for the safety assessment. The main objective is to present prerequisites, methods and data used, in the biosphere modelling for the safety assessment SR-Can /SKB 2006a/ at the Laxemar site. A major part of the report focuses on how site-specific data are used, recalculated or modified in order to be applicable in the safety assessment context; and the methods and sub-models that are the basis for the biosphere modelling. Furthermore, the assumptions made as to the future states of surface ecosystems are mainly presented in this report. A similar report is provided for the Forsmark area /SKB 2006b/.

Many authors have provided the original texts for, commented upon, or edited this report:

- Rodolfo Avila, Facilia AB, section on landscape dose factors and doses to biota.
- Sten Berglund, SKB, hydrology modelling.
- Emma Bosson, SKB, hydrology modelling.
- Lars Brydsten, Umeå University, modelling of shoreline displacements, distribution of quarternary deposits and the future development of the site.
- Anna Hedenström, SGU, development of projections describing the site in the future.
- Sara Karlsson, SKB, site investigation Forsmark, site data compilation and editing, development of projections describing the site in the future.
- Ulrik Kautsky, SKB coordinator of the research program, the safety analysis of the biosphere, landscape development and dose modelling.
- Linda Kumblad, Department of Systems Ecology, marine ecosystems.
- Tobias Lindborg, SKB coordinator of analysis of site biosphere, landscape modelling, site data.
- Anders Löfgren, EcoAnalytica, terrestrial ecosystems, coordinator of compilation of site-generic parameter data, editing.
- Helena Nyman, Sweco, GIS and figures.
- Jens-Ove Näslund, SKB, climate development.
- Björn Söderbäck, SKB, limnic ecosystems, future development of the site, surface water chemistry, editing.
- Erik Wijnbladh, SKB, marine ecosystems.

Sara Karlsson, Ulrik Kautsky, Anders Löfgren and Björn Söderbäck edited the text, and Mike Thorne (SIERG) and Regina Lindborg (Department of Botany, Stockholm University) suggested many improvements on earlier versions of this report.

2 Summary and guidance to the reader

This section serves both as a summary and guidance for the reader. The section put this report into a wider context and presents its aims, but perhaps more importantly, it describes how the sections in this report are related, and how they are used in the different steps of the biosphere safety assessment.

2.1 Overview

Radioactive waste from nuclear power plants in Sweden is managed by the Swedish Nuclear Fuel and Waste Management Co, SKB. Within SKB's programme for the management of spent nuclear fuel, an interim storage facility and a transportation system are today (October 2006) in operation. An application to build a final repository will be made at the end of 2009 according to current plans. In the proposed approach to spent fuel disposal, copper canisters with a cast iron insert containing spent nuclear fuel are surrounded by bentonite clay and deposited at approximately 500 m depth in saturated, granitic rock. Around 9,000 tonnes of spent nuclear fuel is forecasted to arise from the Swedish nuclear power programme, corresponding to roughly 4,500 canisters in the repository. SKB is currently pursuing site investigations for a final repository in the municipalities of Östhammar (Forsmark area) and Oskarshamn (Laxemar area). One critical issue is to be able to characterise the long-term safety for a deep repository and a safety report will be produced in order to support the application in 2009. A preliminary version for such a safety report is the SR-Can report /SKB 2006a/. The SR-Can report is based on a number of reports, of which the current report is one, describing the methodology and input data for those aspects of the safety assessment relating to the biosphere in the Laxemar area (Figure 2-1). A similar report is found for the Forsmark area /SKB 2006b/.

2.2 Aims

The overall objective of this report is to describe the methodology and input data used in the biosphere modelling of radiation dose to biota and humans, and to present the results of this modelling. The report presents descriptions and estimates not presented elsewhere, as well as summaries of important steps in the biosphere modelling that are presented in more detail in separate reports. The intention is firstly, to give the reader a coherent description of the steps taken to calculate doses to biota and humans, including a description of the data used, the rationale for a number of assumptions made during parameterisation, and of how the landscape context is applied in the modelling, and finally also to present the models used and the results obtained. The major outputs can be summarised as:

- Current biosphere state: A description of the different ecosystem types found local to the Laxemar site, along with descriptions of their successional development.
- Historical and future development: A description of the landscape succession at the site over the period between 8,000 BC and 10,000 AD.
- Climatic change: A description of potential permafrost, glacial ice-margin and greenhouse conditions at the site.
- Spatial model development: A landscape model consisting of a number of hydrologically connected Biosphere Objects that are identified as recipients of potential discharge of radionuclides.
- Temporal model development: A description of the successional development of the Biosphere Objects within the landscape model during the specified time period.

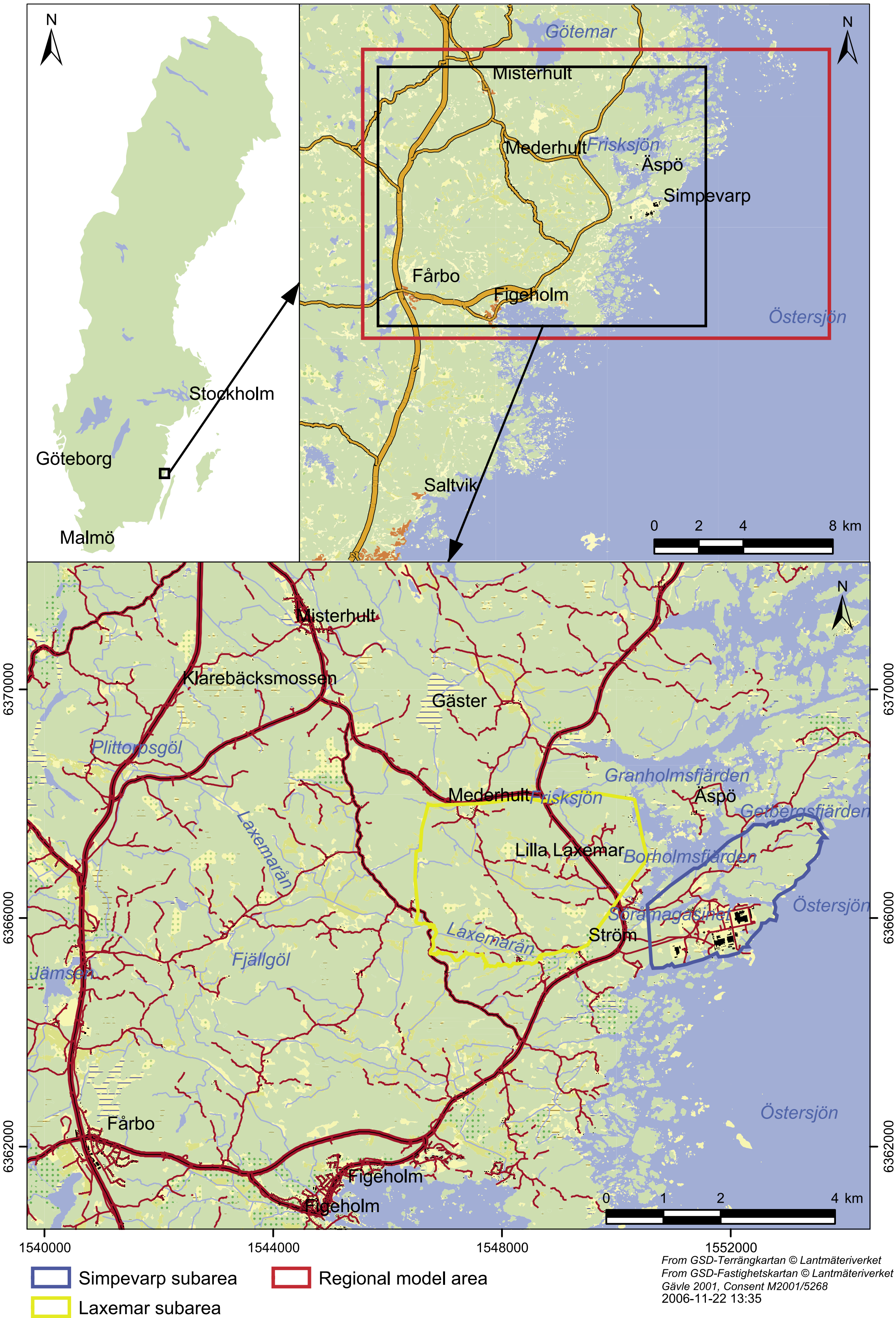


Figure 2-1. *The location of the Laxemar site, where the detailed map includes the geographical names used throughout this report. The red rectangle shows the regional model area.*

- The dose model input parameters: A presentation of the methodology, assumptions and calculations of the input data used in the description of the Biosphere Objects in the biosphere dose modelling.
- The dose model: A presentation of the methodology, assumptions and calculations underpinning estimates of doses to biota and humans.
- Conclusions: Presenting the overall conclusions from the dose-modelling.

2.3 Report content and the biosphere safety assessment approach

The report comprises a description of a number of distinct but related aspects of the integrated biosphere modelling approach. The relationships between the various components of the approach, and where they are discussed in the report, are illustrated in Figure 2-2. The assessment approach starts with the potential discharge points in the biosphere and ends with the calculation of landscape dose factors that is used to evaluate the potential doses to humans and biota. In the subsections below a general description of the content in the different chapters is given along with the major references used.

2.3.1 The site

As an introduction to the site a short description of the abiotic and biotic conditions, from quaternary deposits to human activities, is presented (see Chapter 3). Generally, the overall site description puts the biosphere modelling into a site-specific context. More detailed information about the site conditions can be found in /Lindborg 2006/.

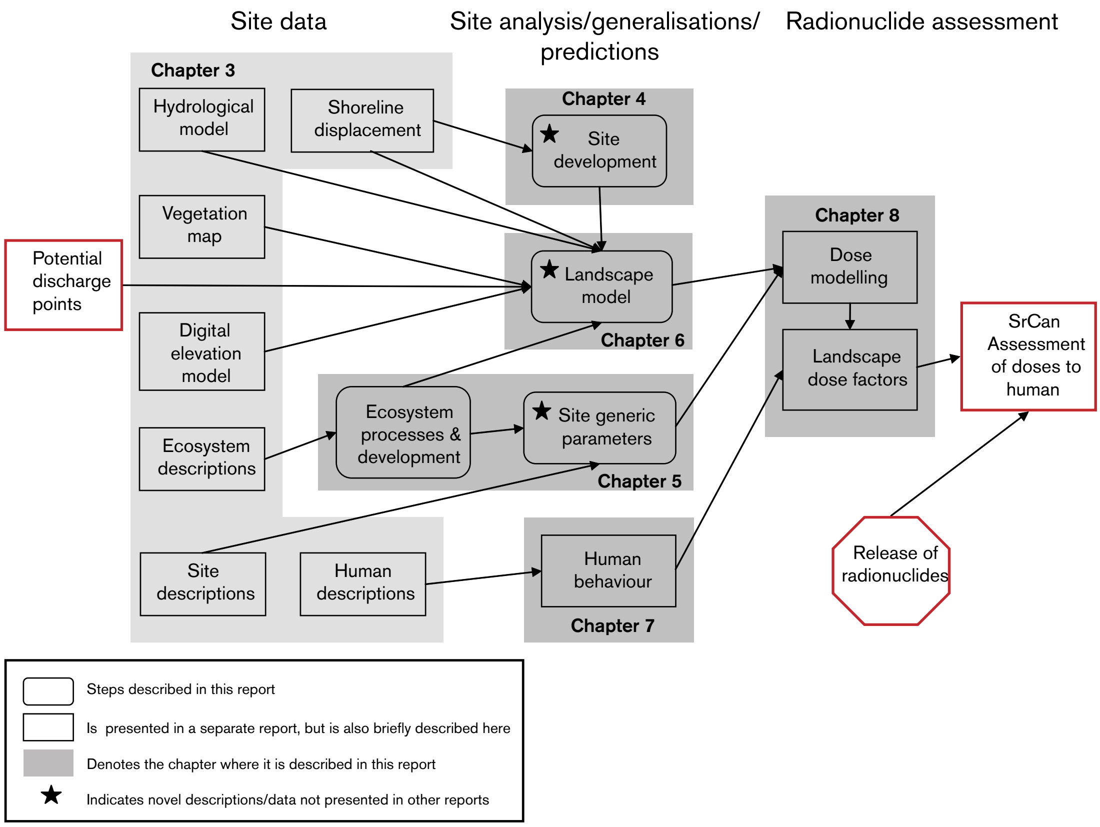


Figure 2-2. A schematic picture of how the different chapters in this report are related and where major input data feeds into the biosphere dose modelling. The grey shaded boxes are treated within this report.

2.3.2 Historical and future site development

An understanding of the historical and future development of the site is required as a basis for impact modelling in a long-term safety assessment. Consequently, Chapter 4 is devoted to a historical and projected future description of the site, starting at the time of the latest deglaciation in 8,000 BC and ending at approximately 20,000 AD. The description is based on a shoreline displacement model /Brydsten 2006a/ that is built upon a mathematical evaluation of shore displacement /Påsse 1997/. This section also includes a description of conditions during periods of permafrost and altered climatic conditions due to the influence of greenhouse gases released by human activities /SKB 2006c/. This section is based on studies from the site /Lindborg 2006/ but also projections of the future, which are described in the present report.

2.3.3 Ecosystems, biosphere objects and site-generic parameters

The landscape at the site constitutes of a number of different terrestrial and aquatic environments that can be defined from their functional properties with regard to the biogeochemical cycling of elements, so called ecosystems. An ecosystem exposed to radionuclides is hereafter called a Biosphere Object, and is the smallest unit within the biosphere dose modelling. The different types of major ecosystems found at the site are described in Chapter 5 together with their successional development through time. Moreover, a radionuclide transfer model is presented for each ecosystem /Avila 2006/, along with the different parameters that are used in the modelling of radionuclide transport and accumulation within the Biosphere Objects. Each ecosystem description is followed by a presentation of the data used in, and assumptions underlying, the site-generic parameterisation of the radionuclide model. All the site-generic parameter values characterising the different ecosystems are presented in Appendix I.

2.3.4 The landscape model

In the biosphere dose modelling, the landscape model (represented by a box in Figure 2-2 and discussed in Chapter 6), describes the spatial distribution, connectivity and succession of biosphere objects in the landscape (Figure 2-3). The spatial extent of the landscape model is delimited by a number of potential discharge points, originating from a deep repository, at the regolith surface /Hartley et al. 2006a/. These potential discharge points are used to identify the specific Biosphere Object associated with radionuclide release in the landscape. Assuming a hydrologically driven transfer process between objects, the biosphere objects are interconnected using a hydrological model. As the landscape changes over time, due to shore level displacement, the description of the landscape model is updated for each 1,000 y step within the interglacial period using the shoreline displacement model /Brydsten 2006a/, together with a number of criteria describing ecosystem succession. During this process, a Biosphere Object may change from one ecosystem type to another, e.g. a marine basin turns into a lake, and must accordingly be assigned new object-specific parameters, such as area, water depth and water volume. Thus, this model provides the dose model with radionuclide recipients (Biosphere Objects), their spatial connectivity, successional development and Biosphere Object specific descriptions.

2.3.5 Human exposure

When modelling doses to humans from exposures to radionuclides, site-specific data on environmental conditions are of importance, but so also is information concerning human behaviour. Chapter 7 describes the methodology and the assumptions behind the calculations of doses to humans from exposures to radionuclides in environmental media, such as air, water, food and soil /Avila and Bergström 2006/. Dose to humans includes effective dose, in the ICRP publication 60 sense /ICRP 1991/, from external exposure and committed effective dose from ingestion and inhalation. To make certain that the annual average lifetime dose to humans is not underestimated, the maximum dose conversion factor for any of the age classes considered

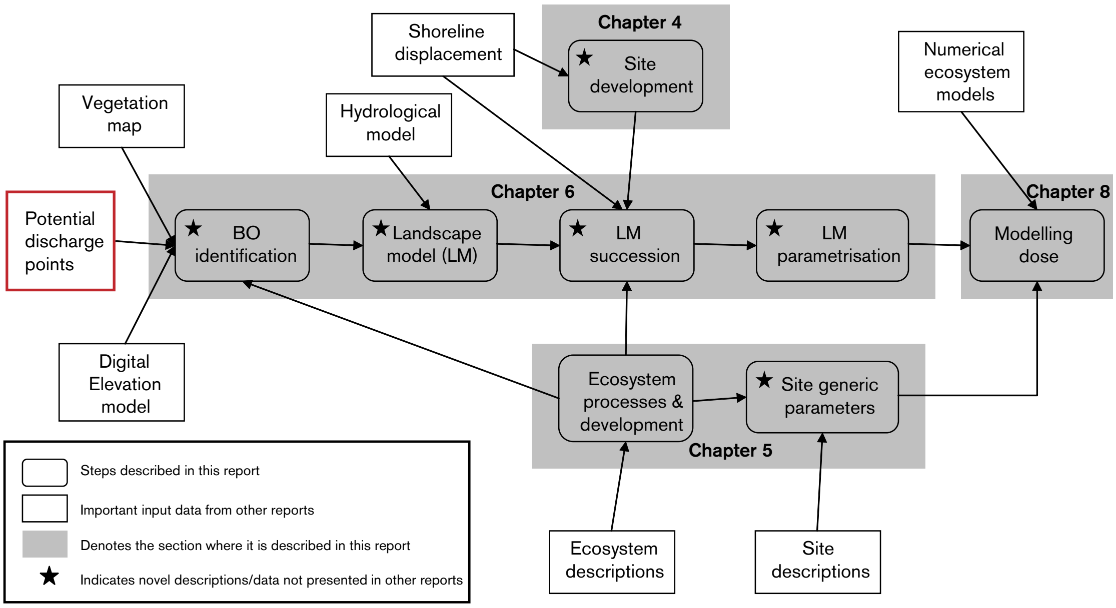


Figure 2-3. *A schematic picture of the major steps during the construction of the landscape model (LM) presented in Chapter 6, and the major sources of input. This model provides the dose modelling with radionuclide recipients (Biosphere Objects), their spatial connectivity and successional development, and Biosphere Object specific descriptions, such as area and depth.*

is used. No assumptions have been made regarding human food preferences (see Chapter 7); instead the calculations are based on values of food energy intake. However, it is assumed that humans will exploit the contaminated landscape to a maximum, thus eating all potential edible food produced within the Biosphere Object. Thus, the number of persons that can be sustained by a Biosphere Object is constrained by the annual productivity of edible products and the size of the Biosphere Object. The production of natural food items is constrained by the primary production of the site and can be assessed separately. The adopted approach makes it possible to estimate not only the effective dose rate to individuals utilising a particular Biosphere Object, but also the number of individuals that the Biosphere Object can fully support. For the Biosphere Object giving the highest effective dose rate, this is the maximum number of people that may be associated with that effective dose rate. In practice, individuals would utilise resources from more than one ecosystem, so the effective dose rate that they receive would be lower.

2.3.6 Biosphere modelling of doses to humans and biota

The radiological impacts are calculated for constant unit release rates of radionuclides to the surface environment. By using this approach, Landscape Dose Factors (LDFs), i.e. effective dose rates for unit flux of each radionuclide, are derived /Avila et al. 2006/. These LDF values can then be multiplied by radionuclide fluxes emerging from the geosphere for radiological impact estimation. The LDF values are calculated over the entire time period with a minimum time step of 1,000 years. A cautious approach is applied in which the maximum of the effective dose rate to the representative individual from the most exposed group over the reference times considered for each radionuclide is defined as the LDF for that radionuclide. As an example, in a developing landscape, as is represented in the landscape model, radionuclides can accumulate in marine or lacustrine sediments, but give rise to an increased radiological impact when, as a consequence of shore-level displacement, those sediments are converted to agricultural land /Avila 2006/. To allow for this, the LDF values used are the maximum values of effective dose rate that apply over the period of release.

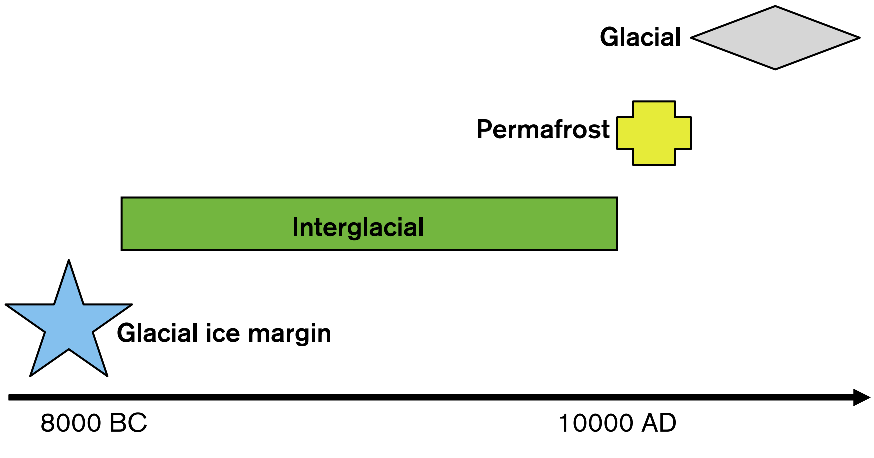
The modelling time-frame adopted for the base case covers a glacial cycle of 120,000 years and includes periods of glacial ice margin, interglacial, permafrost and glacial conditions (Figure 2-4). The interglacials are represented by the current interglacial as 8,000 BC to 10,000 AD. The different periods are integrated over the glacial cycle according to present knowledge of the Weichselian cycle (see Chapter 4). In addition, a greenhouse variant affecting future climate was modelled by prolonging interglacial conditions until 50,000 AD followed by the same conditions as in the base case after 50,000 AD.

The radiological impact on biota other than humans was not calculated for Laxemar. However, it was calculated for Forsmark by estimating the concentration of radionuclides in water and regolith for the different ecosystems using the landscape model and the specified release of radionuclides /SKB 2006b/. The concentrations were compared with the suggested screening limits from ERICA /ERICA 2006/. No further evaluation was performed for Forsmark as concentrations were below these screening limits /SKB 2006b/.

2.4 Concluding remarks

This report summarises the method adopted for safety assessment following a radionuclide release into the biosphere. The approach utilises the information about the site as far as possible and presents a way of calculating risk to humans. A central tool in the work is the description of the topography, where there is good understanding of the present conditions and the development over time is fairly predictable. The topography affects surface hydrology, sedimentation, size of drainage areas and the characteristics of ecosystems. Other parameters are human nutritional intake, which is assumed to be constant over time, and primary production (photosynthesis), which also is a fairly constant parameter over time. The Landscape Dose Factor approach (LDF) gives an integrated measure for the site and also resolves the issues relating to the size of the group with highest exposure.

If this approach is widely accepted as method, still some improvements and refinement are necessary in collecting missing site data, reanalysing site data, reviewing radionuclide specific data, reformulating ecosystem models and evaluating the results with further sensitivity analysis.



Figur 2-4. *The climate conditions that are modelled for the assessment of the biosphere during a glacial cycle. Glacial ice margin, interglacial, permafrost and glacial (as defined in /SKB 2006c/), are integrated over the glacial cycle according to present knowledge of the Weichselian cycle.*

3 Site description

This chapter provides a brief description of the biosphere in the Laxemar area. A more detailed description of the site can be found in the site description report /SKB 2006d/ or in the surface description report /Lindborg 2006/.

3.1 Abiotic characteristics

Abiotic characteristics set the physical limits for the distribution of ecosystems and biota within these, and, accordingly, these characteristics are an important part of the site descriptive models. Moreover, the abiotic characteristics are important input parameters in the radionuclide transport modelling.

3.1.1 Geometry

SKB has developed a Digital Elevation Model (DEM) to describe the terrain relief. The model shows the current site conditions (see Figure 3-1), and it can, together with other models, be used to describe both past and projected future conditions. The DEM is a central tool for the site characterisation, and it has been used as input to most of the descriptions and models produced for the surface system. A comprehensive description of it is provided in /Brydsten and Strömgren 2005/.

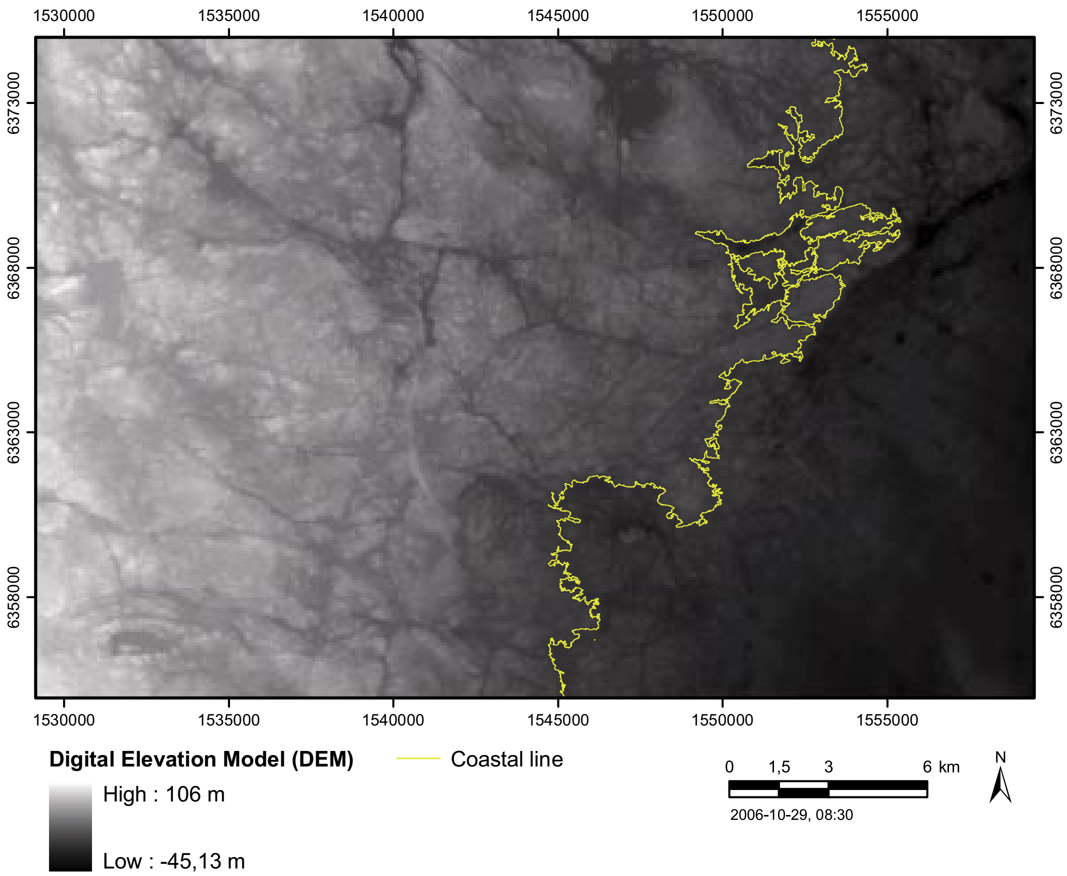


Figure 3-1. The Digital Elevation Model for the Simpevarp area /Brydsten and Strömgren 2005/, with the coastal line indicated in yellow.

3.1.2 Regolith

Data describing the overburden of the Laxemar area is an important input when modelling the transport of water and contaminants between the geosphere and the biosphere, through the soil and sediments. Data describing accumulation of matter in sediments have been used in the aquatic ecosystem models, and soil data have a strong influence on vegetation types in the terrestrial ecosystems of the site.

Both marine and terrestrial parts of the investigated area are characterised by a relatively flat bedrock surface with numerous fissure valleys. The distribution of the fine-grained, water laid overburden is mainly related to the local bedrock morphology. The higher topographical areas are dominated by bedrock and till exposures due to erosion from waves and streams during the land upheaval, and the sediments are mostly restricted to the valleys /Lindborg 2006/. 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 latest deglaciation took place during the Quaternary period and the overburden is therefore at some places in the forthcoming text referred to as Quaternary deposits (QD).

Till is, together with exposed bedrock, strongly dominating the areal coverage of different QD classes in the terrestrial parts of the Laxemar area (Table 3-1). The distribution of QD on the sea floor is similar to that in the terrestrial parts of the regional model area. Fine-grained, water laid sediments (sand and clay) are present in narrow valleys, surrounded by shallower areas dominated by exposed bedrock and till /Lindborg 2006/. When data on the chemical composition of till from the Simpevarp regional model area are compared with regional and national data, only minor differences are found, indicating that the till in the area is relatively representative in a Swedish context.

Most of the till in the Laxemar area is sandy, but as a consequence of wave washing, the uppermost till often has a relatively high frequency of coarse material compared to the underlying till, and the till surface is often rich in stones and boulders. There are two types of peatlands in the area; bogs and fens. Small bogs are common in the bedrock-dominated areas and many of the fens are small and situated in bedrock depressions. The fens are characterised by different species of sedges. Most of the larger fens have been drained 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 generalised stratigraphical distribution of QD in the Simpevarp regional model area is presented in Table 3-2. The thickness of the QD in the Laxemar area, as recorded by drillings, varies between 1.3 and 12.6 m /Lindborg 2006/. There are, however, no drillings down to the bedrock surface in the valleys where a thicker overburden can be expected. A soil depth model has been created using data from several different investigations (Figure 3-2). The model is described in detail in /Nyman 2005/.

Table 3-1. The proportional distribution of QD in the Simpevarp area (modified from /Lindborg 2006/).

QD	Coverage (%) Regional model area	Coverage (%) Laxemar subarea	Coverage (%), Simpevarp subarea
Peat	7.6	5.3	1.9
Gyttja clay	3.3 (all clay and silt)	5.8	0.05
Glacial clay and silt		0.7	1.1
Glaciofluvial deposits	1.4	0.1	0
Post-glacial sand and gravel	1.3	4.8	5.8
Till	51.7	45.2	35.0
Precambrian bedrock	34.6	38.2	38.2
Artificial fill	0.13		17.9

Table 3-2. Generalised stratigraphical distribution of QD in the Simpevarp regional model area /Lindborg 2006/.

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

The upper part of the overburden is referred to as the soil. Soils are formed during interactions among 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.

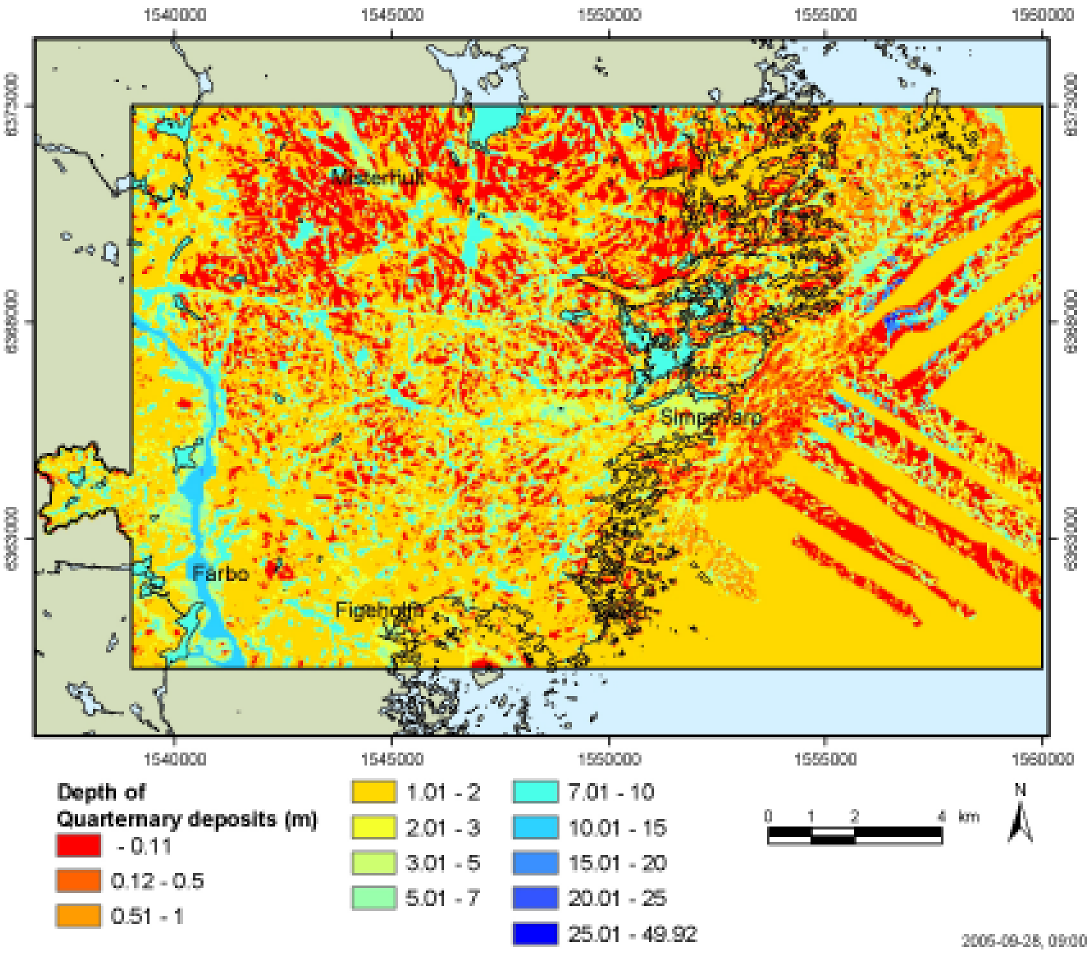


__Figure 3-2.__ The distribution of total overburden depths in the Simpevarp regional model area. The map was constructed after calculations with Geo Editor /Nyman 2005/. The marine part of the regional model area partly lacks field information. In these areas the average depth of QD in the mapped marine areas was used.

Accordingly, the soils in Sweden are relatively young compared to many other parts of the world. Moreover, as the entire Simpevarp regional model area is situated below the highest coastline, the time available for soil forming processes has been short, especially at the lowest altitudes.

The soil classes podzol and regosol dominate areas of glacial till, whereas areas with bedrock exposure (where the bedrock is partly covered by up to a few decimetres of soil) is dominated by leptosol. 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. A more thorough description of soil properties in the Laxemar area is given in /Lundin et al. 2005/.

3.1.3 Climate and surface hydrology

Climate data sets the framework for many processes and is an important input for the surface hydrological modelling. As water is the main transport medium in the ecosystem models, the magnitude of different flows in the hydrological constitute critical input to these models.

The conceptual and descriptive modelling of the meteorological, surface hydrological and near-surface hydrogeological conditions in the Laxemar area is presented in /Werner et al. 2005/. The conceptual-descriptive model is based on three types of "elements": type areas, flow domains, and interfaces between flow domains. The identified type areas are (1) *high altitude areas* (dominated by exposed or very shallow bedrock), (2) *valleys* (with thicker QD, and postglacial sediments at the surface), (3) *glaciofluvial deposits* (of which the Tuna esker in the western part of the regional model area is the largest), and (4) *hummocky moraine areas* (primarily existing in the south-western part of the regional model area and in the central part of the Laxemar subarea).

The Simpevarp area has a relatively small-scale topographical undulation and shallow QD. This implies that there are a large number of relatively small catchments with mostly small watercourses. Surface runoff is to a large degree taking place in the exposed/shallow bedrock areas, from which water is diverted into the valleys, and further into watercourses, lakes and wetlands. The average (corrected) precipitation in the Simpevarp area is c. 600–700 $mm \cdot y^{-1}$, and the average specific discharge is estimated to 150–180 $mm \cdot y^{-1}$ /Larsson-McCann et al. 2002/. Hence, the evapotranspiration is estimated to be in the interval 420 to 550 $mm \cdot y^{-1}$.

Shallow groundwater

The groundwater table in the Laxemar area is generally shallow and located within a few metres below the ground surface in most parts of the area /Werner et al. 2005/. Precipitation and snowmelt are the dominant sources of groundwater recharge. The whole near-surface groundwater flow system is transient, due to temporally variable meteorological conditions (primarily precipitation and temperature), and the near-surface groundwater level is generally lowest in 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 in spring.

Each catchment can be divided into recharge and discharge areas. In general, recharge takes place in areas of relatively high altitudes and discharge in lower-lying areas. However, the transient nature of the system implies that the extents of the recharge and discharge areas vary during the year. The modelling performed by /Werner et al. 2005/ indicates that permanent discharge areas can be found in the vicinity of the main watercourses and Lake Frisksjön, and also along the coastline towards the innermost bays of the Baltic Sea (see Figure 3-3).

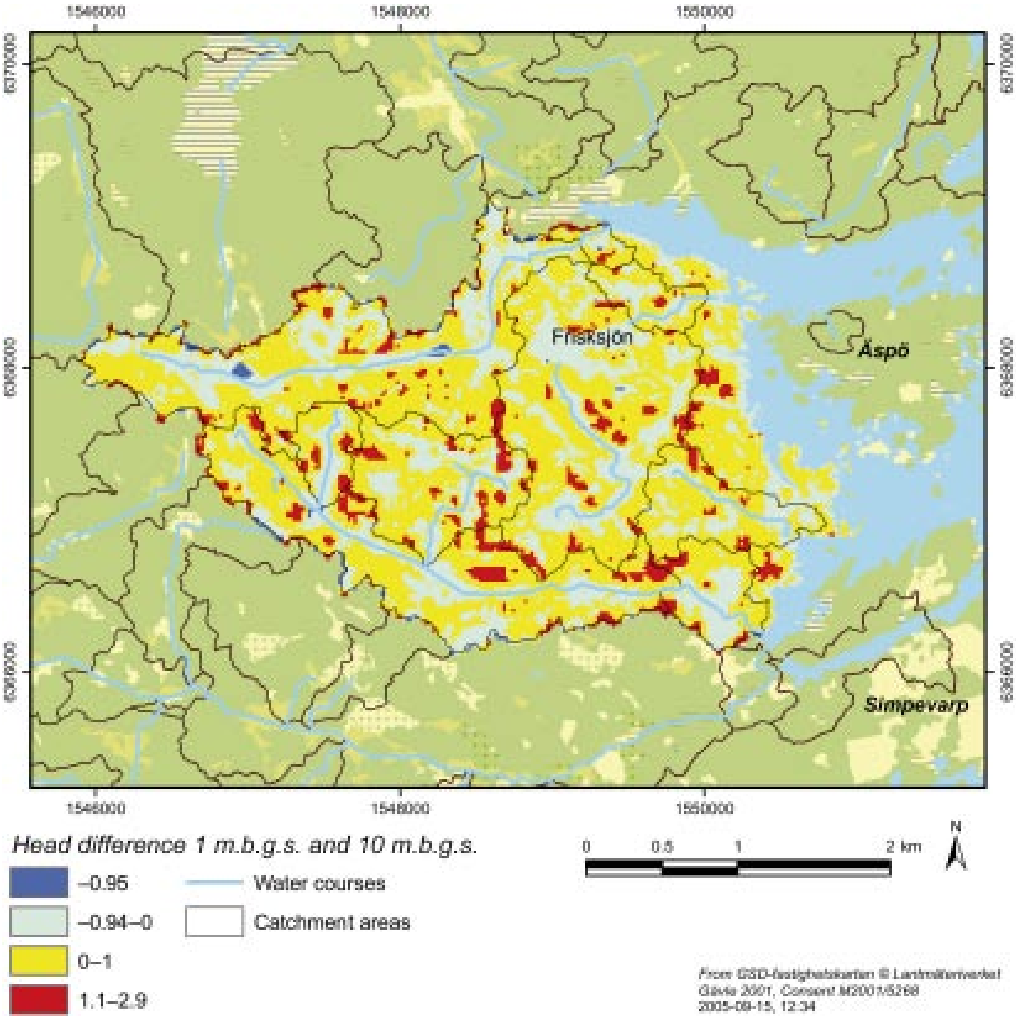


Figure 3-3. *Annual average head difference between the ground surface and calculation layer 5, located c. 8–10 m below the ground surface (m.b.g.s.). The red and yellow areas in the figure are (average) recharge areas, whereas the blue areas are discharge areas. The light blue lines are the main watercourses in the area covered by the figure /from Lindborg 2006/.*

The shallow groundwater in the Laxemar area is characterised by neutral or slightly acid pH-values, normal content of major constituents, and alkalinity ranging from high to very low /Tröjbom and Söderbäck 2006/. Groundwater in the area is influenced by marine relics, resulting in elevated content of e.g. chloride and sulphate in both groundwater and fresh surface water. Several parameters show large deviations when the Laxemar area is compared to typical Swedish conditions. 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 /Tröjbom and Söderbäck 2006/.

Surface water

The Simpevarp regional model area has been divided into 26 catchment areas (Figure 3-4), which are further divided into 96 small catchments and sub-catchments /Brunberg et al. 2004/. The 26 catchment areas range in size from 0.07 km^2 to 27.1 km^2. The regional model area contains 5 small lakes, ranging in size from 0.03 km^2 to 0.24 km^2. Besides the small and often ephemeral watercourses, there is one major watercourse, River Laxemarån, which flow through the model area and enters the shallow bay Borholmsfjärden.

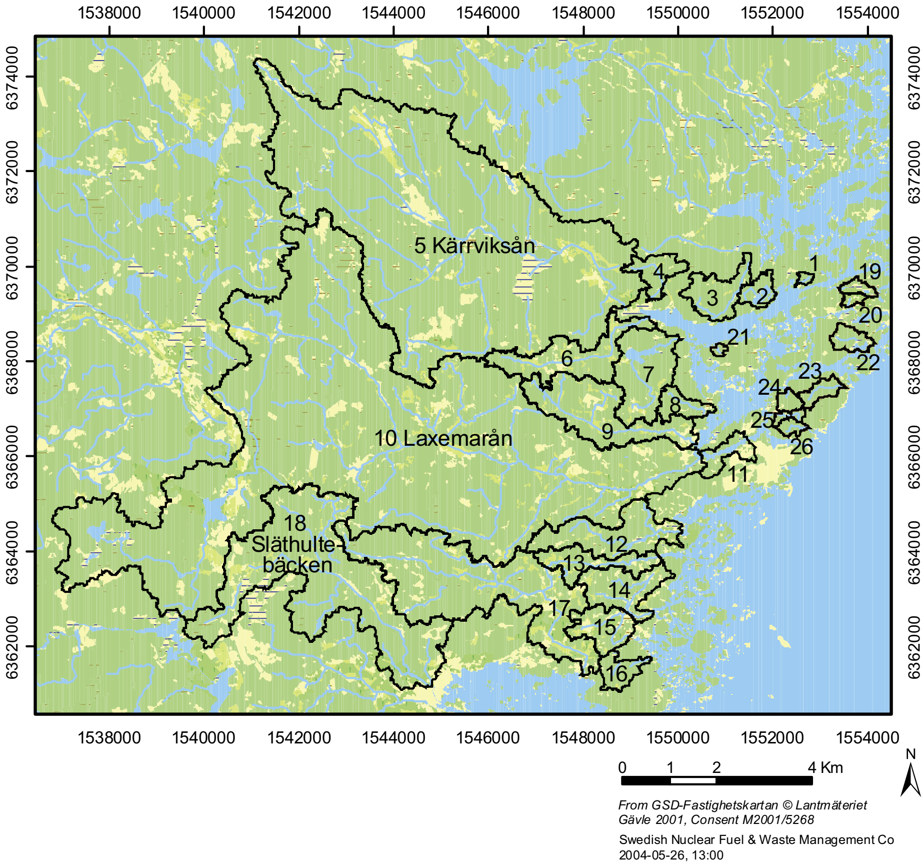


Figure 3-4. *Delineated catchment areas in the Simpevarp regional model area /Brunberg et al. 2004/.*

The freshwater systems in the Simpevarp area can generally be classified as mesotrophic, brown-water types /Tröjbom and Söderbäck 2006/. Most fresh surface waters are markedly coloured due to a high content of humic substances, indicating very high levels of dissolved organic carbon. Streams and lakes are also relatively rich in nitrogen and phosphorus. These high levels of dissolved organic carbon and nutrients imply poor light penetration conditions in the lakes, and periodically also high levels of chlorophyll in the surface water and low oxygen concentrations in the bottom water of the lakes.

3.1.4 Coastal oceanography

Oceanographic data is used to quantify water exchange of the coastal area, which, in turn, is used as input data to the marine ecosystem model.

In the open waters outside the Laxemar area, the hydrographical conditions are strongly affected by coastal processes with large variability in the surface temperature. This is due to the local wind conditions resulting in near-shore upwelling. The salinity stratification is weak and the water exchange is good, as observed in measurements of high values of oxygen saturation in the water column. The currents in the near-shore area are weak and dominated by long-shore directions /Larsson-McCann et al. 2002/.

In order to estimate water exchange of the Laxemar coastal area, two types of numerical models were deployed: one 3Dmodel of the near-shore oceanographic region and one model of the interior coastal basins around the Äspö island formulated as hydraulically coupled entities /Lindborg 2006/. The coastal area was partitioned into a number of non-overlapping sub-basins, based on the consideration of present underwater bathymetrical structures that in the future will become catchment areas when terrestrial conditions prevail. The locations of the sub-basins are shown in Figure 3-5. The calculated average age (AvA) residence time for each of theses basin is presented in Table 3-3, together with appreciations of their variance.

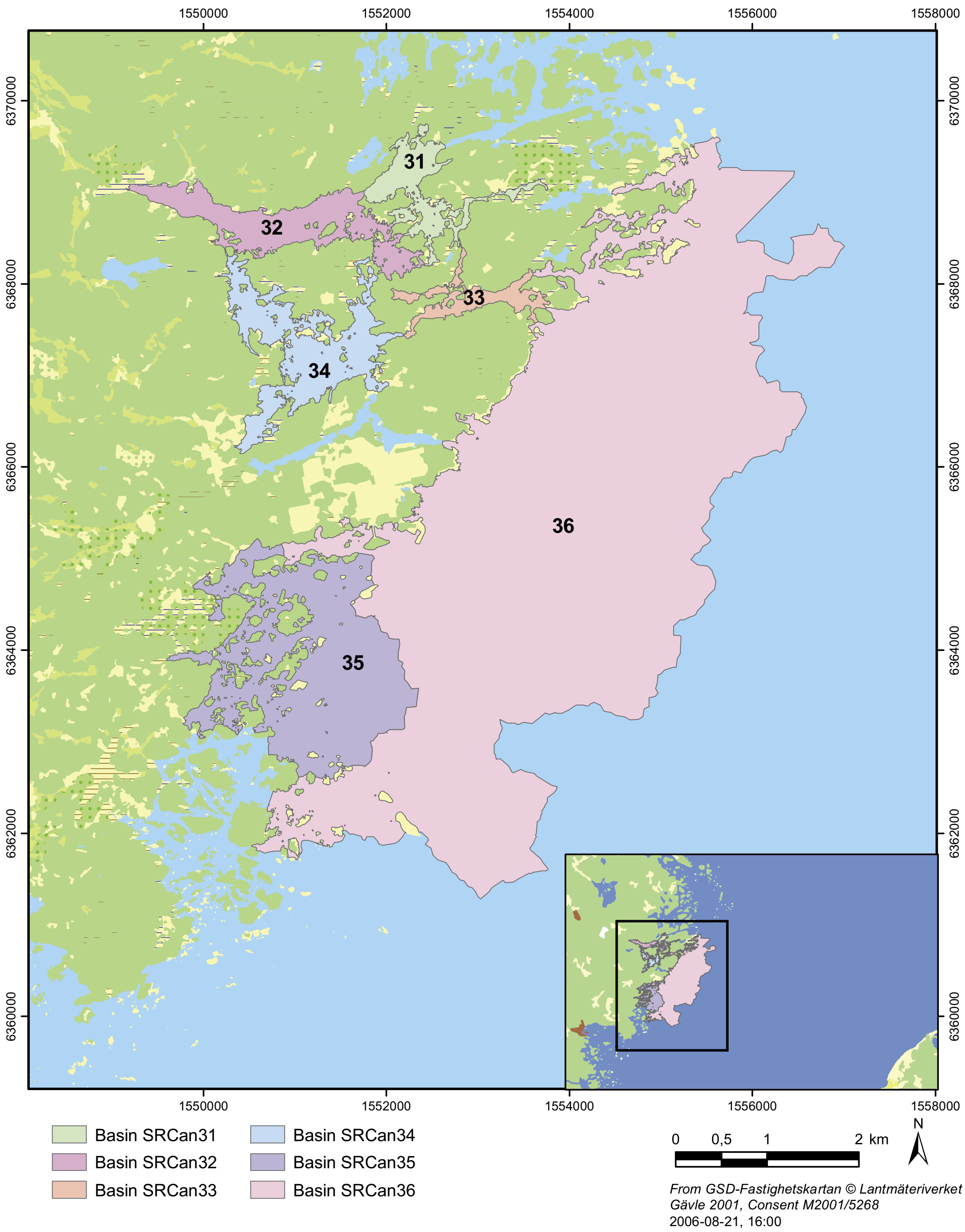


***Figure 3-5.** The location of sub-basins in the Laxemar coastal area with subdivision according to the SR-Can-context.*

Table 3-3. Estimated Average Age (AvA) residence time (days) and some morphometric characteristics for the six coastal sub-basins in the Laxemar area.

IDnr	Area [10^6 m^2]	Mean depth [m]	Volume [10^6 m^3]	Average Age (AvA) [days] min	mean–S.D.	mean	mean+S.D.	max
SRCan31	0.49	3.9	1.92	4.21	8.28	11.27	14.25	20.16
SRCan32	0.97	5.3	5.15	16.90	23.95	29.52	35.10	43.23
SRCan33	0.29	3.8	1.09	1.05	1.62	2.70	3.79	7.03
SRCan34	1.2	1.9	2.18	0.39	3.21	8.88	14.55	22.69
SRCan35	3.4	4.2	14.5	0.07	0.13	0.42	0.71	1.27
SRCan36	21	11	219	0.09	0.38	0.58	0.79	1.00

3.2 Biotic characteristics

This section provides a general description of the biota of the Laxemar area. Detailed information on the parameters used in the ecosystem models, e.g. biomass, production, and turnover of organic matter, can be found in /Lindborg 2006/.

3.2.1 Terrestrial biota

Vegetation

The vegetation in the Laxemar area is highly influenced by the bedrock composition, QD and human land management. As described above, QD in the area consist mainly of wave-washed till, whereas deposition of silt and clay has been restricted to the narrow valleys. This is manifested in the vegetation where pine forests dominate on the till, and all the arable land and pastures are found in the valleys. Human land-use has been restricted to agriculture activities in the valleys, and forestry has been the dominating activity elsewhere.

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*) are abundant where a deeper soil cover is found, whereas deciduous tree species, mainly *Quercus robur* but also *Corylus avelana*, *Sorbus aucuparia*, *S. intermedia* and *Acer platanoides*, are an important constituent near the coast, 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 determined by boulder frequency, nutrient availability and earlier history of management.

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. *Betula pendula* is the dominating species in many of the earlier successional stages, until it is replaced by young Norway spruce or Scots pine, depending on soil type and/or management.

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 *Sphagnum*-dominated community, much bog-like, with *Rhododendron tomentosum* and *P. sylvestris*, and a peat layer accumulating on the bedrock. These rock pools vary a lot in size and may in some cases be relatively large.

Mammals and birds

The most common larger mammal species in the Simpevarp regional model area is roe deer (*Capreolus capreolus*) with 4.9 deer·km^{-2} /Cederlund et al. 2004/. Moose (*Alces alces*, 0.8 moose km^{-2}), and also European hare (*Lepus europaeus*) and Mountain hare (*L. timidus*) are fairly common (3.5 hares km^{-2}), compared to other regions. A comprehensive description of the mammals is found in /Lindborg 2006/. In total, about 126 breeding bird species were found in the area /Green 2005/. The most common species on land are Chaffinch (*Fringilla coelebs*) and Willow warbler (*Phylloscopus trochilius*).

3.2.2 Limnic biota

The lakes in the area are generally small and the water is markedly coloured due to high contents of humic substances. This implies poor light conditions even at relatively shallow water depth. Accordingly, there are large areas of non-vegetated bottoms in the lakes, despite the generally shallow mean depths, and the profundal is the dominating habitat in most lakes /Brunberg et al. 2004/. Emergent and floating-leaved vegetation is restricted to the near-shore areas and is generally dominated by Common reed (*Phragmites australis*) and Bulrush (*Typha latifolia*) /Lindborg 2006/. Phytoplankton is dominated by dinophytes in summer and by diatoms in winter and spring /Sundberg et al. 2004/. The benthic fauna is generally dominated by detrivores in the littoral and sublittoral zones, and by predators in the profundal zone /Ericsson and Engdahl 2004/. The fish fauna, dominated by roach and perch, and with pike as the main top predator /Engdahl and Ericsson 2004/, is typical for mesotrophic brown-water lakes in the region.

3.2.3 Marine biota

The marine system in Simpevarp 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 have a variable geometry, large shallow areas (less than 1 m) are found as well as depth down to 18 m. The bay areas have an average surface salinity of 3.5–4.5‰ whereas the bottom water (16 m) has a salinity close to the surrounding coastal area of 6‰. The bay areas are characterized of humic, low transparency conditions, averaging a light penetration of 2–3 m in enclosed bays, 4–7 m in the archipelago and 12 m in the open sea.

The vegetation in the inner, soft-bottom parts of the archipelago north of Simpevarp (around Äspö) is dominated by *Chara sp*., whereas corresponding bottoms in the southern parts of the regional model area are dominated by vascular plant communities, mainly *Potamogeton pectinatus* and *Zostera marina*. 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*. is recorded down to approximately 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. In the coastal hard bottom areas, filter feeders may comprise up to 95% of the total biomass, whereas in the inner areas, e.g. Basin Borholmsfjärden, detritivores constitutes 50–80% of the biomass /Fredriksson 2005/.

3.3 Humans in the Laxemar area

The description of humans in the Laxemar area /Miliander et al. 2004/ is mainly based on the situation in the Misterhult parish, since much of the statistics is available only at the parish level. In total, 2,709 people lived in Misterhult parish in 2002. The population was slowly decreasing over the studied 10-years period, with a maximum of 2,987 inhabitants in 1993. The density is on average 7.1 inhabitants per square kilometre, which is approximately one third of the population density in Kalmar County. 55.5% of the inhabitants were over 45 years, compared to 47.2% in Kalmar County. The number of inhabitants in the Laxemar model area in 2002 was estimated to 69 persons /Miliander et al. 2004/.

The dominant employment sector within the 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.

The forests in the area are strongly influenced by forestry; approximately one third of the forest within the regional model area is younger than 30 years. The average age of the productive forest is approximately 53 years. About 1/4 of the logging products are used for pulp production, and the rest are used as timber.

The agricultural activities in Misterhult parish are limited. The farm density in Misterhult parish is on average 0.2 farms·km^{-2}, which is half of the density in Kalmar County as a whole. There were in average 70 farms larger than 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 in the parish is almost five times larger than the amount of grassland. The main part of the arable land (64%) is used for fodder production. Barley is the major crop in the area. The number of cattle, sheep and fowls in the parish decreased between 1990 and 1999, whereas the number of pigs increased.

Kalmar County is the fifth largest fishing county in Sweden, and it answers for more of the commercial catch than the rest of the east coast altogether /Miliander et al. 2004/. The major catch is from off-shore areas outside the coast of the Kalmar County, but also the coastal fishing in the Simpevarp area is important. Also recreational fishing is important, both in lakes and in coastal areas, and the fishing tourism is well expanded and still growing. Another common leisure activity in the area is wildlife hunting. The most important games are moose and roe deer, for which the harvest in the Misterhult parish is 0.35 and 2.15 individuals per km^2, respectively.

4 Site development

In this chapter, the long-term development of the Laxemar landscape is described. The description is based on the elevation model, the shoreline displacement equation /cf. Påsse 2001/, old cadastral maps and site-specific information on QD. Prediction of the future development is associated with more uncertainties than the historical description. The future development of the area may be different than expected due to e.g. greenhouse gas-induced warming inducing a climate change which cannot be predicted today. Such changes are expected to influence important characteristics of the biosphere, such as the hydrological cycle, sea level, and salinity of the Baltic Sea. In SR-Can this uncertainty has been handled through the definition of a number of scenarios /SKB 2006a/.

It should be noted that the descriptions of the future development in the following text are based on existing knowledge of the past, known processes (e.g. shoreline displacement) and knowledge about the current situation e.g. existing ecosystems, climate, geometry and geology of the seafloor etc. All these descriptions have their uncertainties. Thus, the descriptions presented here are a sketch of the future, which is logical coherent, but the exact dates and spatial extent of the various domains are uncertain because of limitations in the underlying data and conceptual models.

The text in the sections describing periods with permafrost and glaciation are not site-specific, and describes only in broad outline how the biosphere appears during such conditions. These descriptions are the base for how those time periods have been treated in the model calculations in SR-Can /SKB 2006a/. Thus, the descriptions relate only to processes that may be important for the distribution of radionuclides.

Land uplift and the resulting shore-line displacement have strongly influenced the biosphere conditions in the past and will do so also in the future, e.g. succession on newly exposed land and sediment redistribution (sedimentation and resuspension/erosion). The estimated rate of shore-line displacement is shown in Figure 4-1. In the future ecosystems, today's early successional stages of vegetation and associated fauna are assumed to gradually move in the landscape, following the shore-line displacement.

4.1 Interglacial period

The latest deglaciation in the Laxemar area took place before or during the relatively cold Older Dryas chronozone, c. 14,000 years ago /Lundqvist and Wohlfarth 2001/. 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 $m \cdot y^{-1}$ /Kristiansson 1986/. There are, however, indications of an ice marginal oscillation in the Vimmerby area, 40 km north-west of the regional model area /Agrell 1976/. This presumed oscillation may have taken place during or after the Older Dryas chronozone (c. 14,000 years ago).

4.1.1 Vegetation

The relatively cold Older Dryas chronozone was characterised by tundra vegetation dominated by herbs and bushes and a low coverage of trees. During the following Alleröd chronozone (Figure 4-2) a sparse *Pinus* and *Betula* forest dominated the vegetation.

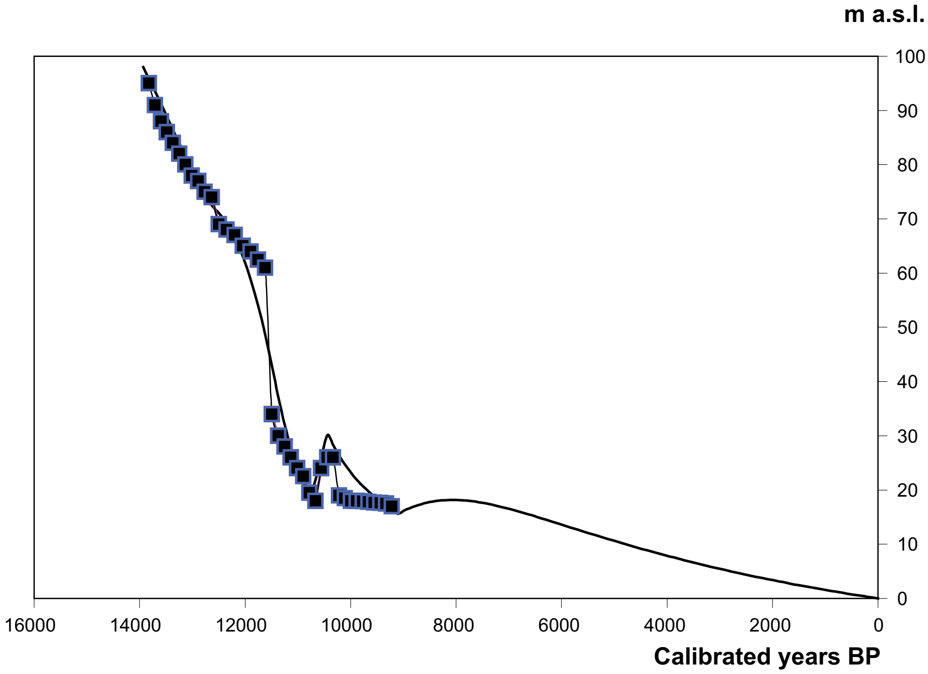


Figure 4-1. *Shoreline displacement curve for the Oskarshamn area after the latest glaciation. The blue symbols show a curve established by /Svensson 1989/ after a study of lake sediments in the region. The curve without symbols has been calculated by the use of a mathematical model /Påsse 2001/.*

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* (birch) 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 south-eastern Sweden. *Picea* (spruce) reached the Simpevarp area c. 2,000 years ago.

A pollen investigation, covering the last c. 1,500 years, have been carried out on sediments from two lakes situated 20 and 25 km west of Fårbo (M. Aronsson and T. Persson, Dept. of Quaternary Geology, Lund University, unpublished data). The results show an increase of *Juniperus* (juniper) and *Cerealea* (corn) c. 1,200 years ago, indicating that areas used as arable land and pasture increased during that time.

4.1.2 Shoreline displacement

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. The isostatic recovery is an ongoing process, which is an effect of the disappeared load of the Weichselian ice. The rate of recovery has decreased significantly since the deglaciation, and has during the last 100 years has been c. 1 mm per year /Ekman 1996/.

The highest shoreline in the Oskarshamn region is located c. 100 m above the present sea level /Agrell 1976/. Thus, the whole Simpevarp regional model area is situated below the highest shoreline. According to e.g. /Svensson 1989, Björck 1995/, the shoreline dropped instantaneously c. 25 m due to drainage of the Baltic Ice Lake 11,500 years ago. The Yoldia Sea stage was characterised by a regressive shoreline displacement. The onset of the following Ancylus Lake stage was characterised by a transgression with an amplitude of c. 11 m. There are no studies from the Oskarshamn area dealing with the shoreline displacement during the Littorina Sea stage. Results from a study c. 100 km north of Simpevarp /Robertsson 1997/ suggest a regressive shore displacement during Littorina time. However, more detailed stratigraphical

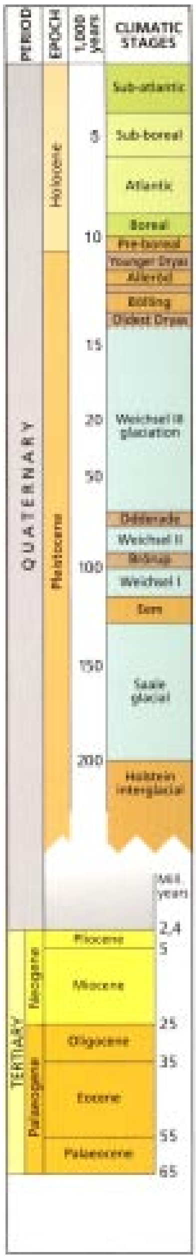


Figure 4-2. *The geological timescale showing the subdivision of the late Quaternary period with climatic stages from /Fredén 2002/. The ages are approximate and given in calendar years before present. From: Swedish National Atlas, www.sna.se.*

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. Figure 4-3 shows the former shoreline in the Simpevarp regional model area at three different occasions during Holocene. A large part of the Simpevarp regional model area was free of water already during the end of the Baltic Ice Lake 9,700 years ago (cf. Figure 4-3A).

4.1.3 Salinity changes in the Baltic Sea

The development of the Baltic Sea since the last deglaciation is characterised by changes in salinity, caused by variations in the relative sea level. This history has therefore been divided in four main stages /Björck 1995, Fredén 2002/, summarised in Table 4-1. The Baltic Ice Lake stage was characterised by freshwater conditions. Weak brackish conditions prevailed 11,300–11,100 years ago during the Yoldia Sea stage /e.g. Andrén et al. 2000/. The salinity was between 10‰ and 15‰ in the central 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/. The past salinity in the Baltic Proper since the onset of the Littorina period has been reviewed by /Westman et al. 1999, Gustafsson 2004a/ with updated chronology from /Fredén 2002/. Freshwater conditions prevailed during most of the deglaciation of Sweden. Salinity was probably low during the first c. 1,000 years of the Littorina Sea stage but started to increase 8,500 years ago. Salinity variations since the onset of the Littorina Sea are shown in Figure 4-4. The most saline period occurred 6,000–5,000 years ago when the surface water salinity in the Baltic proper (south of Åland) was 10–15‰ compared with approximately 7‰ today /Westman et al. 1999/. Variations in salinity during the Littorina Sea stage have mainly been caused by variations of freshwater input and changes of the cross-sectional areas in the Danish Straits /cf. Westman et al. 1999/. 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 4-4.

4.1.4 Quaternary deposits

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, was 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. The maps in Figure 4-3 clearly show that the present areas covered with gyttja clay coincide with areas which were once sheltered bays. The areas that today are

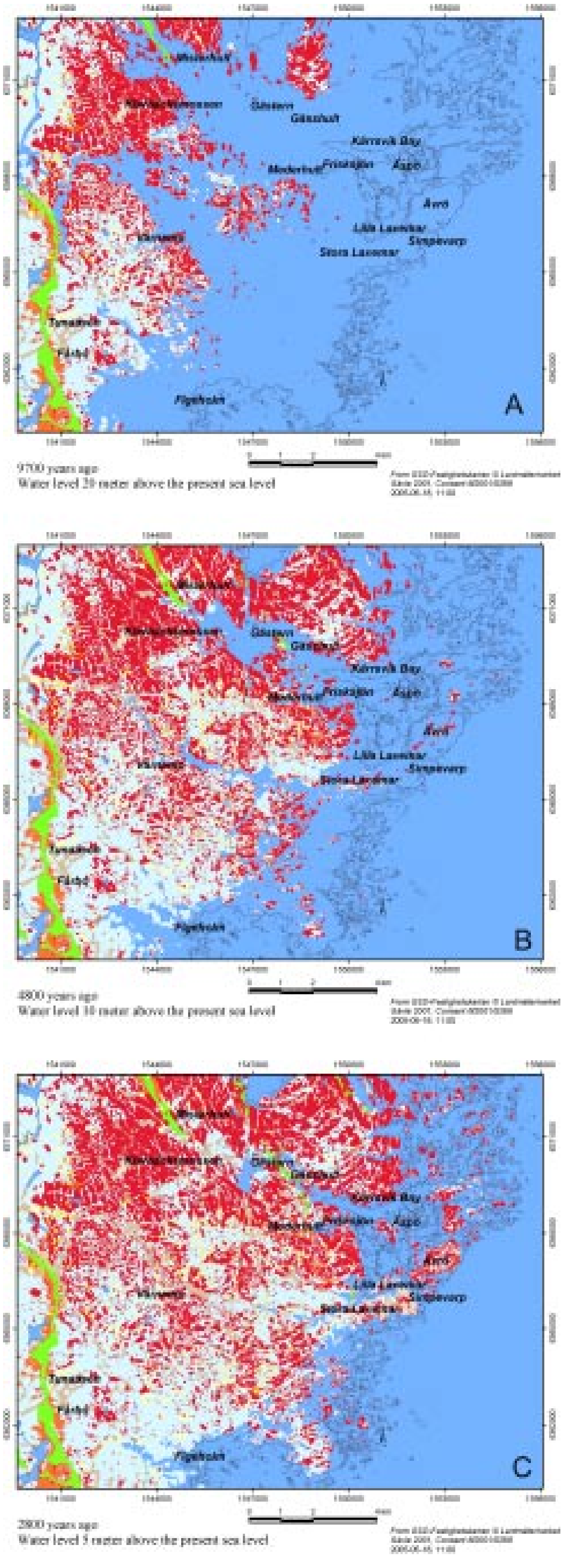


Figure 4-3. *The distribution of land and sea at three different occasions during Holocene, A) 9,700 years ago, B) 4,800 years ago, C) 2,800 years ago.*

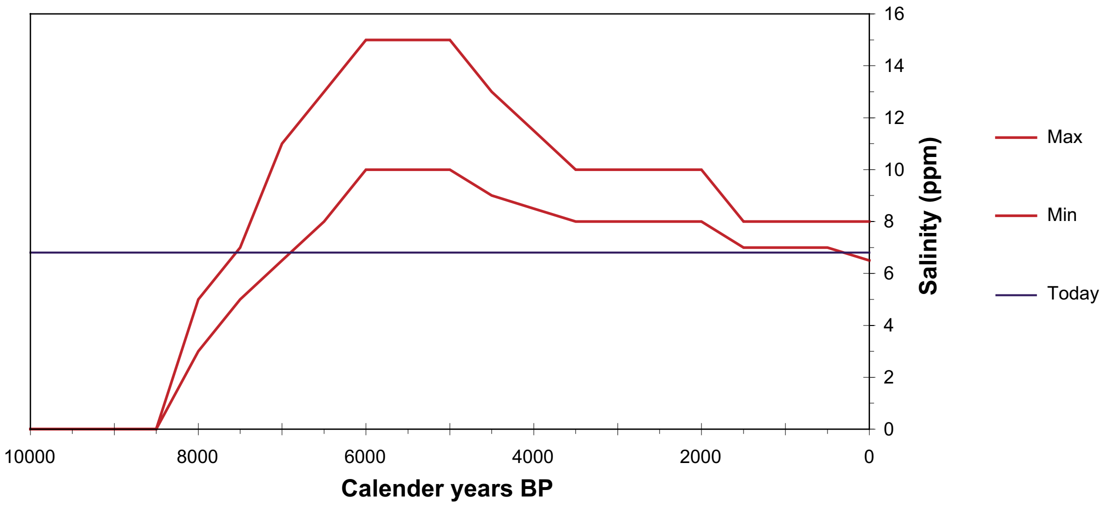


Figure 4-4. *Range for estimated salinity in the open Baltic proper outside Oskarshamn from the onset of the Littorina period until today. Maximum and minimum estimates are derived from /Westman et al. 1999/ and /Gustafsson 2004ab/. The present salinity in the area is shown as a horizontal reference line.*

Table 4-1. Summary of the stages of the Baltic Sea, years before present /Fredén 2002, Westman et al. 1999/. Note that the Littorina Sea stage is based on the palaeogeography in the threshold areas and includes e g the Mastogloia Sea stage and the present Baltic conditions. Note also that the altitudes and ages are approximate values, based on regional extra- and interpolations.

Baltic stage	Calender year	Salinity	Environment in Simpevarp
Baltic Ice Lake	15,000–11,500 BP (13,050–9,600 BC)	Glacio-lacustrine	Regressive shoreline from 40 m.a.s.l. to 20 m.a.s.l.
Yoldia Sea	11,500–10,800 BP (9,550–8,850 BC)	Lacustrine/Brackish /Lacustrine	Deglaciation. Regressive shoreline from c. 100 m.a.s.l. to c. 40 m.a.s.l.
Ancylus Lake	10,800–9,500 BP (8,850–7,550 BC)	Lacustrine	This period started with a transgressive shoreline reaching 30 m.a.s.l. and was followed by a regression to 20 m.a.s.l.
Littorina Sea sensu lato	9,500 BP-present (7,550 BC-present)	Brackish	Regressive shoreline interrupted by transgressions.

used as arable land were during the Littorina Sea long and narrow bays (cf. Figure 4-3B and C). 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.

Results from three radiocarbon dates of sediments from Borholmsfjärden show that the clay gyttja at that site started to accumulate in the Littorina Sea c. 3,000 years ago. The accumulation rate calculated from the ^{14}C analyses is c. 1.2 mm·y^{-1}. /Lidman 2005/ has used ^{210}Pb dates to calculate the peat growth rate in wetlands. The accumulation rate in the peat bog Klarebäcksmossen is 1.45 ± 0.06 mm·y^{-1} according to these dates. That corresponds to an annual accumulation of material of 51.0 ± 0.8 g·m^{-2}·y^{-1} (see also Table 5-5).

4.1.5 Development from the present situation and 500 years ahead

The relatively low rate of land uplift in the Laxemar area today in combination with the generally relatively deep areas near today's coastline means that no major changes in the landscape due to the shoreline displacement is to be expected during the next 500 years.

4.1.6 Development from 2,500 AD until next period with permafrost

The Laxemar area will even continuously be situated at, or at least near, the coast, most likely for the whole period until the next period with permafrost. The most important change in the future landscape will be the isolation of the inner coastal basins from the Baltic Sea, which means that a number of new lakes will be formed. Lake Frisksjön will be filled up with sediments and in-growing vegetation and is projected to become a mire at 3,000 AD.

At 4,000 AD, the bays north and south of Äspö are expected to become isolated from the sea and form large lakes. Thereafter, a terrestrial landscape dominates the surroundings of the repository, and most of the area close to the repository is assumed to be agricultural land. The remaining lakes will be gradually infilled, a process which will take c. 2,000 years for the shallow Borholmsfjärden. However, the deeper Granholmsfjärden with its relatively steep shores will remain a lake even after 10,000 AD. Also, the coastline on the seaward side of the Simpevarp peninsula will change only slightly.

The surface ecosystems around the proposed repository location stabilise quite early in the period as potential agricultural land, which is maintained through the rest of the interglacial period. The terrestrial period of the Laxemar area is assumed to end at 10,000 AD, when a permafrost period starts (see below).

4.2 Periglacial period (permafrost)

In the SR-Can main scenario /SKB 2006a/, covering a time span of 121,000 years after repository closure, permafrost conditions prevail at Laxemar for a total duration of 46,000 years (38% of the time). Temperate- and glacial conditions prevail for 41,000 years (35%) and 19,000 years (16%) respectively, whereas the site is submerged for 13,000 years (11% of the time) (Figure 4-5).

The first periglacial period, with shallow permafrost, occurs after approximately 8,000 years (10,000 AD) (Figure 4-5). After that, temperate conditions and permafrost conditions will alternate until the first glacial period occurs at around 50,000 AD. During this interval, the periglacial periods get longer and the permafrost grows progressively deeper.

In the SR-Can greenhouse scenario, the present warm interglacial climate will prevail for about 60,000 years after repository closure before the first period of permafrost conditions occurs

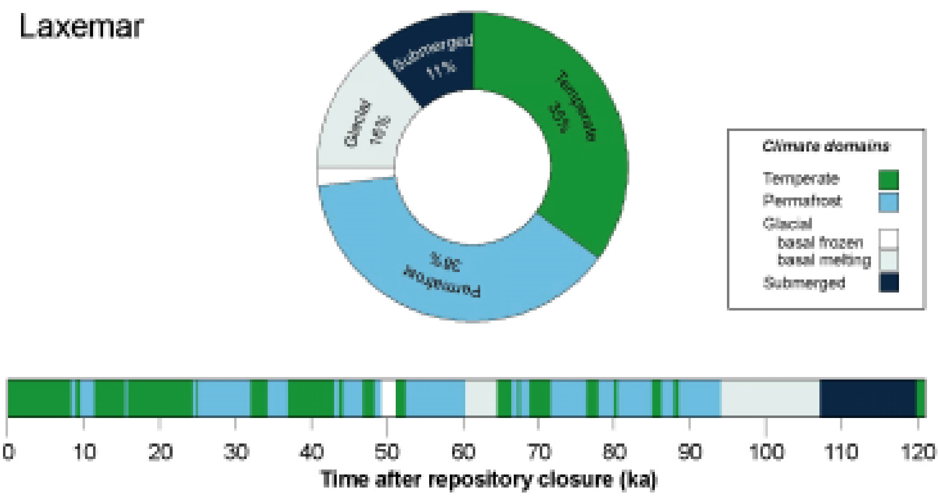


Figure 4-5. *Duration of climate domains at Laxemar, expressed as percentage of the total time for the base variant of the SR-Can main scenario. The bars below the pie charts show the development of climate-related conditions for the base variant as a time series of climate domains and submerged periods. From /SKB 2006c/.*

/SKB 2006c/. After that, the same alterations between temperate and permafrost conditions follow as after the first permafrost period in the base case (Figure 4-5). Another possibility with a generally warming climate, due to an increased greenhouse effect, is that the thermohaline circulation in the North Atlantic is affected, so that less heat is transported towards Fennoscandia by the North Atlantic Drift. This would lead to a regional cooling over Fennoscandia, a cooling that would occur earlier than the cooling described in the base variant of the main scenario /SKB 2006c/. In such a case, permafrost conditions at Laxemar would occur earlier than at 10,000 AD.

The permafrost periods are characterized by a tundra ecosystem. The tundra is devoid of forests. The precipitation is often less than 200 mm/year due to low evaporation transporting water through the atmosphere. The low evaporation makes the climate humid and surplus water is unable to seep into the ground because of the permafrost. This would lead to extensive swamps, but the amount of peat formed would be negligible because plant productivity is low. Even if there is a snow cover of 50 cm during winter, raised parts are blown free of snow where intensive erosion occurs by the blowing ice crystals. The vegetation consists of herbs and shrubs, at raised dryer places lichens, whereas on wet ground mosses dominate. The vegetation period is short and the species present are those adapted to this climate, i.e. they flower and set buds in different years. Most of the plants develop thick roots, which serve as storage and the plants can live up to 200 years. No plants produce berries for their dispersal of seeds /French 1996/.

The major part of the vertebrate fauna of the tundra migrates south during winter. The birds, which are abundant during summer, migrate long distance to subtropical areas. During the summer they thrive on the enormous amount of mosquitos. Rodents, e.g. lemmings, do not migrate and spend most of their life under the isolating snow-cover. Specialised mammals like reindeer can utilize lichens in snow-free areas in winter or they migrate into forested land.

Even on gentle slopes, the soil moves downhill with the peat cover on top, i.e. solifluction. Other processes are upfreezing of stones causing patterned ground, such as tundra-polygons. Thus, there are several processes disturbing the soil and also exposing it to erosion. When the upper soil thaws during summer, large quantities of water are available.

Taliks, i.e. unfrozen windows in the permafrost region beneath lakes and rivers, are potentially places that animals and humans can settle nearby. The taliks can be a result of discharge of warmer groundwater that could include some water coming from a repository. However, even if taliks can be a potential waterhole, the low productivity in the permafrost region requires a large foraging area. During summer, surface water will be abundant in the landscape, which means that taliks will not be the only waterholes.

4.3 Glacial period

In the SR-Can main scenario, the first ice advance that covers Laxemar occurs after 48,000 years (Figure 4-5). It is later followed by two ice advances over the site. During these glacial periods, the site will be covered by an ice sheet. The longest period of ice coverage occur about 90,000 years into the scenario. Periods when the site is submerged under the sea follows only after the longest period of ice coverage (Figure 4-5). In contrast to the Forsmark site, Laxemar is not submerged after the ice advance occurring around 60,000 years into the scenario. During the glacial periods, contact between biosphere and geosphere will occur only during the very short periods when the ice sheet is thin over the site. At these times, elevated parts can protrude above the ice surface where lichens or occasional herbs can occur. The productivity will, however, be low and due to their elevated positions, there will be no contact with groundwater in the protruding areas.

On the ice surfaces, microbes, algae and some insects can exist. At the ice margin, a productive aquatic community can occur. This can sustain a rich fish population, which can be exploited by the animals living on the ice (e.g. polar bears, birds) and by humans. The populations of vertebrates migrate over a large area to avoid winter climate or to exploit the resources to a maximum extent. In most cases, the human population would probably be occasional, due to the hostile environment and the variable ice configuration. It is possible that a population can exist for longer periods at ice-free spots along the coast and live on fish. However, at such coastal locations the water-turnover is most likely to be rapid (otherwise the water would be frozen) which would give a larger dilution-rate. During periods of glacial domain, no long-term accumulation of contaminants can occur in sediments or soils, due to rapid turnover of these potential reservoirs.

Between the two major glacial phases, during a period around 65,000–94,000 years from present, Laxemar is in the SR-Can main scenario subjected to interstadial ice-free conditions. This period is dominated by periglacial conditions with permafrost (Figure 4-5).

4.4 Greenhouse variant

A greenhouse variant is included in the description of the future climate. There are two main reasons for doing this; 1) modelling studies of the climate response to increased greenhouse gas emissions, mainly CO_2, indicate that global temperatures will increase in the future under such scenarios /e.g. IPCC 2001/, and 2) climate cycles are believed be driven by changes in insolation. The coming 100,000 year period is initially characterised by exceptionally small amplitudes of insolation variations /Berger 1978/, possibly making the present interglacial exceptionally long. /Berger and Loutre 2002/ and others suggest it may not end until ~ 50,000 years from now, even in the absence of significant human-induced greenhouse-gas, warming.

In the greenhouse variant, it is assumed that the temperate domain will prevail for another 50,000 years before the relatively mild onset of the next glacial cycle takes place. After the initial 50,000 years the first 70,000 years of the reference evolution is assumed to follow. The first major ice advance in Laxemar will, therefore, occur about 100,000 years in the scenario. This is in broad agreement with results simulated for two greenhouse-warming cases within the BIOCLIM project /BIOCLIM 2003/.

Noting the uncertainties and assumptions used in the climate modelling undertaken in the BIOCLIM and SWECLIM projects /BIOCLIM 2003, Rummukainen 2003/, and the limited range of greenhouse-gas emission scenarios used, the results of these climate modelling studies suggest that the climate in the Laxemar region will experience increased summer temperatures of 2–3°C within the initial long period of temperate conditions. The climate model results also suggest increased winter temperatures in these regions. Precipitation is also predicted to increase, especially in summer /SKB 2006c/.

Climate change or variability due to greenhouse gas-induced warming over the coming 1,000 years is also expected to influence important parameters in the biosphere such as the hydrological cycle, sea level, and salinity of the Baltic Sea. In respect of the hydrological cycle, increased precipitation could lead to higher runoff, if it was not balanced by increased evapotranspiration due to higher temperatures. The projected changes of sea level would reduce, negate or reverse the shore-level displacement and thus maintain the sites and surface ecosystems close to the sea. Thus, the water turnover rates would be dominated by the sea for the ecosystems closest to the repository. The salinity of the sea is dependent on the runoff to the Baltic Sea /Gustafsson 2004ab/, and might decrease if the runoff increases.

Due to higher winter temperatures in a greenhouse-warming scenario, the vegetation period would increase and thus give higher productivity and a shift in species composition. However, this would have a minor impact on the safety assessment, as is shown by considering the impact the north-south gradient of climate in Sweden has on vegetation today.

5 Ecosystems, biosphere objects and site-generic parameters

The biosphere in Laxemar is described using an ecosystem approach, where differences in important ecosystem functions, such as accumulation of organic matter or presence or absence of functional groups, define the ecosystem type and its spatial extent. Six ecosystem types, commonly found in the Laxemar area, are described in the following sections; sea, lake, running water, mire, agriculture land and forest. In addition, one section describes a well, which is a potential transport route for radionuclides to humans. The following descriptions of the six ecosystems and the well are the basis for delimiting and for the parameterisation of Biosphere Objects (further described in Chapter 6). Biosphere Objects are specific areas in the landscape potentially exposed to radionuclide releases and are the smallest unit in the modelling of radionuclide transport and accumulation in the landscape (radionuclide transport modelling is described in Chapter 8 and in /Avila 2006/).

The description of each ecosystem type comprises the most important fluxes of matter and water, extracted from the descriptive ecosystem models in /Lindborg 2006/. The descriptive ecosystem models relate to the pools and fluxes of carbon, but carbon can also be used as a proxy for organic matter and energy /Chapin et al. 2002/. This approach may be useful to describe the behaviour of a wide range of bioavailable radionuclides assimilating into living tissue. The development or succession of the different ecosystems is also described in terms of transitions to other ecosystems over longer temporal scales. This description is followed by a presentation of the conceptual models used to represent the transfer and accumulation of radionuclides (further described in /Avila 2006/). These conceptual models show how the different parameters characterising the systems are related and used to describe transfer and accumulation. There are two types of parameters presented in this report; the parameters characterising a specific type of ecosystem within the site, termed site-generic parameters (described in this chapter), and parameters that are regarded as unique for the identified biosphere object, termed object-specific parameters, such as area and water volume (described in Chapter 6). The site-generic parameters in the models have been estimated using site-specific data or models in most cases, but when such were lacking, data were taken from other sources from as similar areas as possible. Site-generic parameters describing biota, which is presented in this chapter, is not found in the conceptual models presented below, but are used in estimating potential effects on non-human biota from exposure to radionuclides (described in Section 8.2.3). The premises for estimation of each parameter are described in this chapter, and the parameter values are presented in Appendix 1, along with statistical descriptions, such as means, medians, maximum and minimum values, and standard deviation of the value. For some data, e.g. modelled or literature data, no statistical descriptions are available. In the section with the parameter descriptions, all reports initiated by SKB have been denoted with an asterisk (*).

5.1 Sea

Most of the surface water from the terrestrial parts of the regional model area drains into a few, relatively confined, coastal basins. The water chemistry of these inner basins differs considerably from the water chemistry of the outer parts of the archipelago. The marine system in the area is therefore divided into two different types, the first type representing the open sea and outer archipelago (two sub types), and the second type the relatively confined bays close to the mainland. The bays show lower concentrations of ions than the open sea, whereas the concentrations of organic compounds and nutrients, especially the nitrogen fractions, are considerably higher. As a consequence of the relatively high concentration of organic compounds (humus) in the bays, water transparency is rather low throughout the year. The oxygen concentration in the bottom water of the open sea is high throughout the year, whereas almost anoxic conditions seem to be common in the bottom water of bays in late summer.

From a general survey, different vegetation communities were defined on the basis of dominating species or higher taxa. For the area around Simpevarp, nine vegetation communities were defined. The red algae community covered the largest area with almost 6 million square metres. Second highest coverage was associated with the *Potamogeton pectinatus*-community with an area of almost 2 million square metres. Regarding coverage, the *P. pectinatus* community was followed by the *Chara sp*. and *Fucus vesiculosus*-communities with coverage of about 1.3 and 1 million square metres, respectively.

The benthic fauna in all basins is dominated by detritivores. Detritivores, often *Macoma baltica* or *Hydrobia sp*., often constitutes 50–80% in the three selected basins. In total, 45 species associated with the vegetation occurred in the area around Simpevarp and 41 in the sediments. The *Fucus sp*. communities are the most diverse concerning associated fauna and harbour 31 species or higher taxa, whereas the soft bottoms without vegetation have 14 species /Lindborg 2006/.

5.1.1 Major flows of matter

The largest carbon pool in the marine system is found in the sediments /Lindborg 2006/. Primary production, which brings in carbon to the system through the utilisation of DIC from the air, is dominated by macroalgae, phytoplankton and reed. Lake respiration is dominated by filter feeders and bacteria, both benthic and pelagic. A schematic view of the coastal ecosystem in the Laxemar area /Lindborg 2006/ is presented in Figure 5-1.

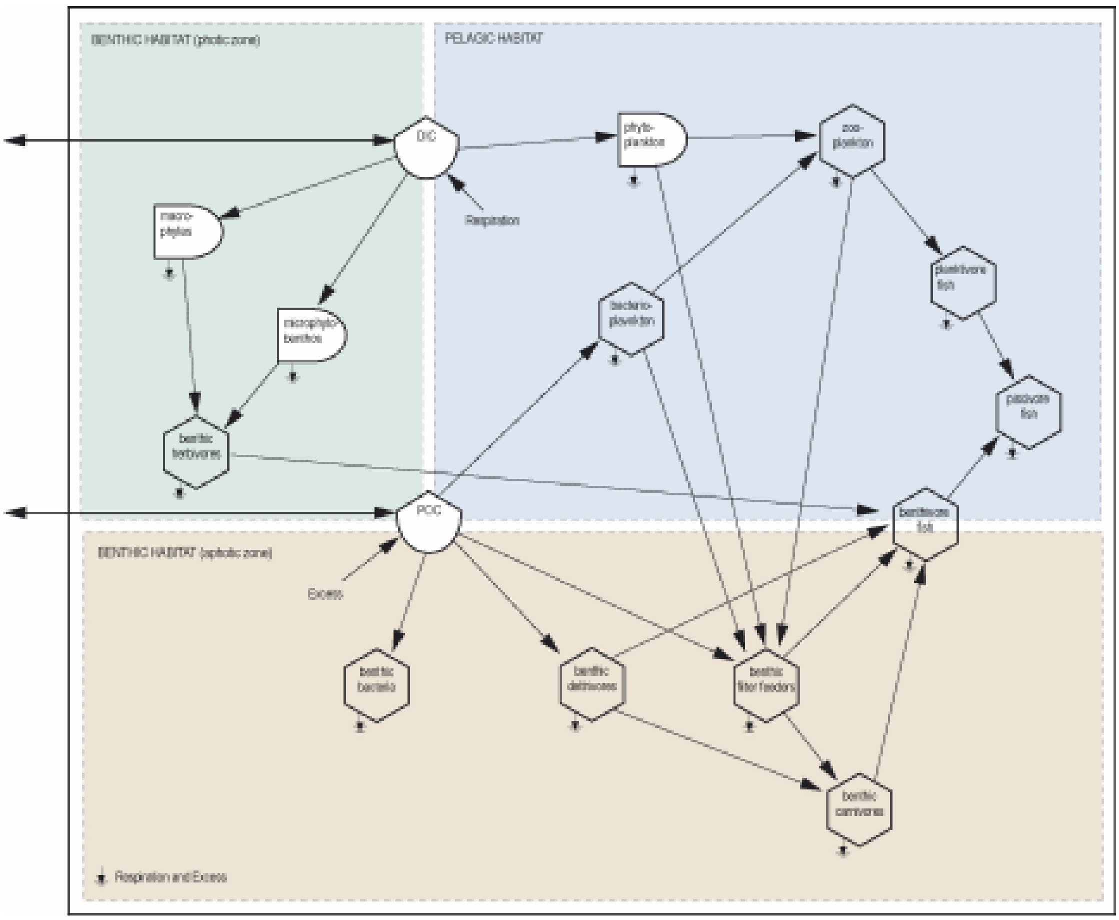


Figure 5-1. Conceptual illustration of the marine coastal ecosystem in the Laxemar area, including the three different habitats (phytobenthic, soft benthic and pelagic) /Lindborg 2006/.

In most of the marine basins in the Simpevarp regional model area (see map in Figure 3-5), the flow of matter is dominated by the transport generated by water exchange between the basins and the Baltic Sea. The water exchange is generally large, and the calculated overall carbon residence time range between less than one day in the outer, exposed basins, to one month in the innermost basins /Lindborg 2006/. Other processes, e.g. primary production, heterotrophic respiration, discharge of organic matter from terrestrial areas and detrital accumulation, contribute substantially to the carbon budgets in the innermost, sheltered basins.

5.1.2 Development over time

Shoreline displacement

The vertical shoreline displacement is projected to be 1 m for the next 1,000 years, based on c. 1 mm per year /Ekman 1996/. This means that the coastline will move only marginally during the next 1,000 years, but some of the shallow, near-shore bays will be affected by the shoreline displacement. For example, the bay Borholmsfjärden south Äspö is estimated to have 40% of its former area and 30% of its volume at 3,000 AD, but is expected to remain a bay of the Baltic Sea.

At 4,000 AD, the coastal period ends and a terrestrial landscape dominate the surroundings of the Laxemar area. The bays north and south of Äspö are expected to become isolated from the sea and form large lakes, whereas the coastline on the seaward side of the Simpevarp peninsula will change only slightly.

Salinity

The vertical structure of the salinity in the future Baltic Sea is strongly dependent on saline-water inflow, freshwater inflow and turbulent mixing. A change in any of these factors can have a large impact on the vertical stratification. For example, with an increased inflow of ocean water, the halocline depth could decrease, forcing the Baltic Sea towards conditions similar to the Skagerrak or the Hudson Bay, with a thin brackish layer over a deeper saline layer. At the other extreme, with much reduced inflows, the Baltic Sea could become a lake with negligible salinity. The sensitivity of the Baltic Sea surface salinity to changes in freshwater inflow, wind and sea level fluctuations in the Kattegatt are shown in Figure 5-2. A 20% change in freshwater inflow has a strong impact on the surface salinity.

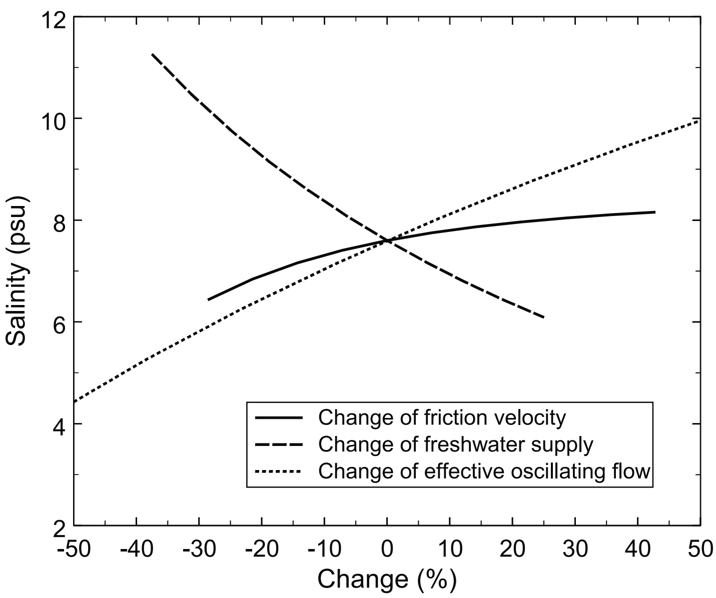


Figure 5-2. *Model results for the response of Baltic Sea salinity to changes in wind stress (solid line), freshwater input (dashed line) and effective flow oscillations (dotted line) /Westman et al. 1999/.*

/Westman et al. 1999/ have developed a model to describe the importance of changes in the cross-section areas of the Öresund strait and the Darss sill compared with direct climatic influences (temperature and net freshwater input). A steady-state model for the salt exchange between the Baltic Sea and Kattegat /Gustafsson 1997/ has been used to study past changes of salinity during the Holocene. The model will be used to study future development of the salinity of Baltic Sea.

Coastal ecosystem

The shoreline displacement will gradually shrink the area of the inner coastal basins, until the last inner bay north of the Simpevarp peninsula is isolated from the sea at around 7,000 AD (cf. Table 6-2 (matrisen med BO-objektens utveckling)). There is no reason to expect any dramatic changes in ecosystem function or in species composition during this gradual turning of the coastal ecosystem into a lake ecosystem. However, the sedimentation rate will increase due to reduced exchange of water with the open sea. This means an increasing retention of organic matter in the coastal area during the process of isolation, which in turn means that any radionuclides associated with organic matter will be buried in the sediment at an increasing extent.

5.1.3 Simplified radionuclide model

A schematic view of the numerical model that describes the transport and accumulation of radionuclides in marine basins is presented in Figure 5-3. The figure shows the different parameters and how these are related in order to describe fluxes of radionuclides. The site-generic parameters are presented in further detail below, whereas object-specific parameters are treated in Chapter 6.

5.1.4 Radionuclide model parameterisation

This section describes assumptions and data behind the parameterisation of the site-generic parameters in the conceptual radionuclide model (described above). The parameter name within brackets is the name in the radionuclide model. The parameter values are presented in Appendix I.

Regolith

Depth of top regolith (z_uppers)

The value represents an estimation of the zone where bioturbation occur. The range 0.5–5.5 cm is given as the total variation in /Eckhéll et al. 2000/.

Porosity of top regolith (porosity_upper)

The value is an average of the porosity of sediments situated in the lowest areas of the sea floor (the valleys). The most common deposits in these areas are post-glacial clay and sand /Elhammer and Sandkvist 2005*, Ingvarson et al. 2004*/. It is assumed that 50% of the lowest areas of the sea floor are covered by sand and 50% by post-glacial clay. The porosity for sand is taken from /Almén and Talme 1978/. The porosity for gyttja clay was calculated from the water and organic contents presented by /Nilsson 2004*/.

Density of top regolith (density_upper)

The value is an average of the bulk density of sediments situated in the lowest areas of the sea floor (the valleys), i.e. post-glacial clay and sand /Elhammer and Sandkvist 2005*, Ingvarson et al. 2004*/. The bulk density for sand is taken from /Almén and Talme 1978/. It is assumed

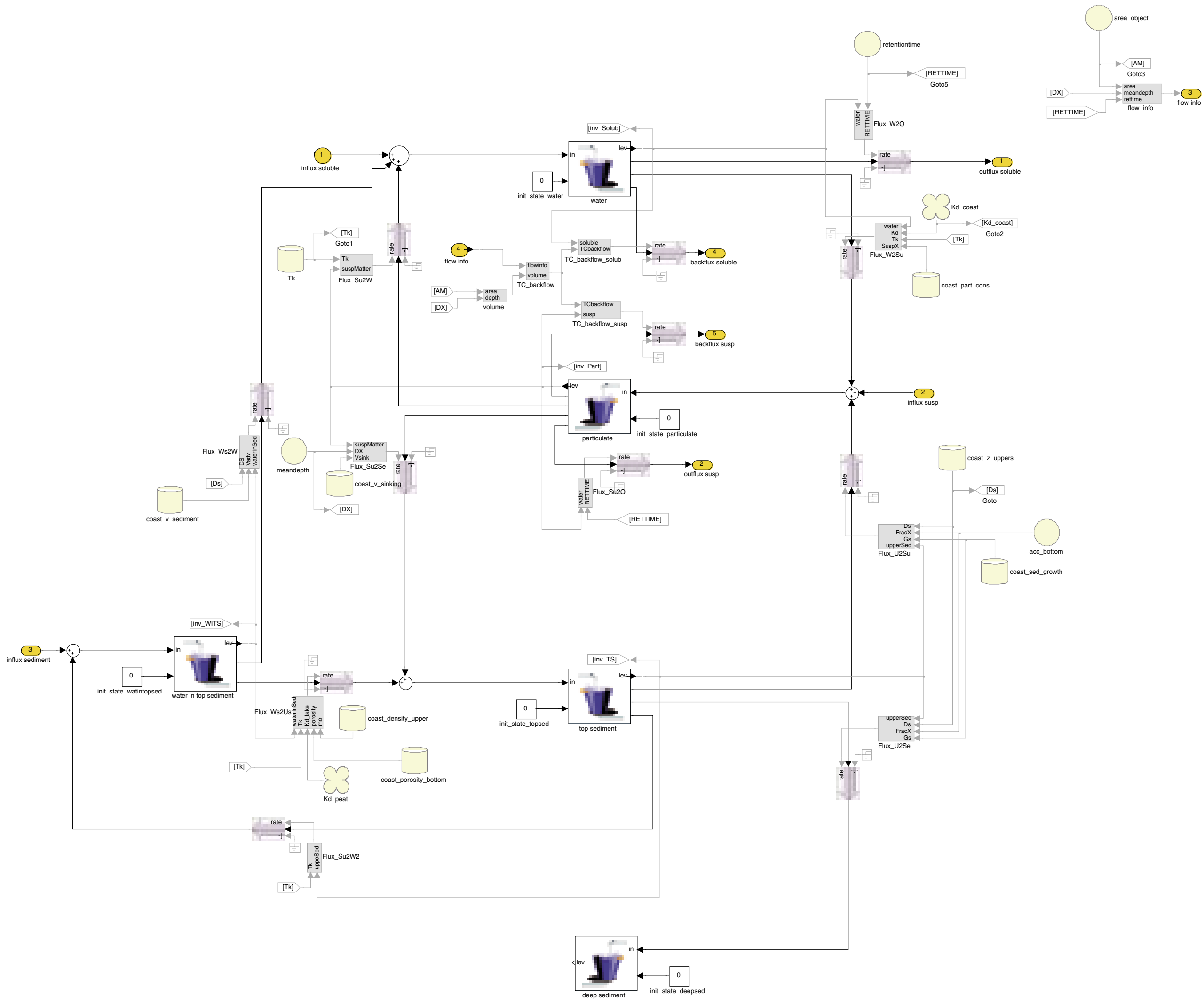


Figure 5-3. *The model that describes the transport and accumulation of radionuclides for a marine basin. Orange symbols are radionuclide fluxes into and out of the system. Large boxes denote the amount of radionuclides within the system, distinguished into soluble and particulate phases, whereas the smaller grey boxes are transfer coefficients used to calculate fluxes. Yellow circles show object-specific parameters, whereas yellow cylinders are site-generic parameters (but the Tk-cylinder is half-time to sorption equilibrium and is further treated in /Avila 2006/). Yellow propellers show radionuclide-specific parameters. Large arrows show fluxes of radionuclides between compartments, whereas small arrows show how functions and parameters are connected within the model. From /Avila 2006/.*

that 50% of the lowest areas of the sea floor are covered by sand and 50% by post-glacial clay. The density for gyttja clay was calculated from the water and organic contents presented by /Nilsson 2004*/.

Depth of deeper regoltih (z_deeps)

The value represents the sum of the mean depths of Quaternary sediments in areas covered by post-glacial clay (Table 5-1). The general stratigraphy presented in /Lindborg 2006*/ shows that the post-glacial clay is underlain by sand, glacial clay and till. The results in Table 5-1 are based on data from the marine geological investigations outside Laxemar /Elhammer and Sandkvist 2005*/.

Table 5-1. The depth (m) of QD in the Simpevarp regional model area /from Nyman 2005*/.

	Mean	Median	Min	Max	Std	N
Till in areas covered by clay	3.6	2.9	0.5	48.5	2.6	4,575
Glacial clay	2.6	1.9	0.5	28.0	2.3	14,886
Post-glacial sand	0.8	0.73	0.5	2.9	0.3	2,405
Post-glacial clay	1.7	1.5	0.5	4.7	0.8	2,539

Porosity of deeper regolith (porosity_bottom)

The value is based on a weighted average of the QD at the deepest bottoms, which are covered by post-glacial clay. The general stratigraphy presented in /Lindborg 2006*/ shows that the post-glacial clay is underlain by sand, glacial clay and till. The porosity values for till and post-glacial sand (Table 5-2) were take from /Almén and Talme 1978/. These values represent typical values for these deposits. However, the porosity of till can probably show large local variations. The porosity for glacial and post-glacial clay (Table 5-2) were calculated using water and organic contents presented by /Nilsson 2004*/.

Density of deeper regolith (density_bottom)

The value is based on a weighted average of the QD at the deepest bottoms, which are covered by post-glacial clay. The general stratigraphy presented in /Lindborg 2006*/ shows that the post-glacial clay is underlain by sand, glacial clay and till. The bulk density values for till and post-glacial sand (Table 5-3) were take from /Almén and Talme 1978/. These values represent typical values for these deposits. However, the density of till can probably show large local variations. The bulk density for glacial and post-glacial clay (Table 5-3) were calculated by the use of the water and organic contents presented by /Nilsson 2004*/.

Sediment growth rate (sed_growth)

This value is based on interpolations between three ^{14}C dates of post-glacial clay from a sediment core sampled in Borholmsfjärden /Risberg 2002/.

Table 5-2. The porosity of QD in the Simpevarp regional model area. The data was collected from /Nilsson 2004*/ (clay) and from /Almén and Talme 1978/ (till and sand).

	Mean	Median	Min	Max	Std	N
Till	0.1–0.25	–	–	–	–	–
Glacial clay	0.71	–	–	–	–	2
Post-glacial sand	0.3	–	–	–	–	–
Post-glacial clay	0.9	0.90	0.82	0.93	0.03	22

Table 5-3. The wet density (kg/m^3) of QD in the Simpevarp regional model area. The data was collected from /Nilsson 2004*/ (clay) and from /Almén and Talme 1978/ (till and sand).

	Mean	Median	Min	Max	Std	N
Till	2,250	–	2,100	2,400		–
Glacial clay	1,460	–	–	–	–	2
Post-glacial sand	2,000	–	–	–	–	–
Post-glacial clay	1,100	1,090	1,060	1,160	30	22

Hydrology

The water balance data presented in this report are based on calculated values from the near-surface hydrological model for Laxemar, L1.2 /Werner et al. 2005*/. The physically based and spatially distributed modelling tool MIKE SHE was used for the near-surface hydrological modelling. The model is driven by local meteorological data from the Laxemar area from 2004. Meteorological input data to the model are temperature, potential evapotranspiration and precipitation. The actual evapotranspiration and its different components (transpiration, evaporation from soil, interception) is calculated in timesteps less than periods of twenty-four hours during the simulation.

Particle concentration in water (part_conc)

The estimate is based on the concentration of Particulate Organic Carbon (POC), sampled biweekly to monthly at five different coastal sampling sites (PSM000060–PSM000064) in the Simpevarp area /Tröjbom and Söderbäck 2006*/. Note that there are large differences in POC concentration between sampling sites situated in confined basins, and those situated in the open sea, and that the statistics presented here are based on all sampling sites in the area, regardless of position in relation to the coastline.

Velocity of sinking fine particles (v_sinking)

/Estrum-Yuosef et al. 2000/ estimated the sinking velocity of particulate organic carbon to range between 0.01–0.32 $m \cdot day^{-1}$ in inner coastal southern Baltic. The arithmetic mean of this range was used.

Advective transport in sediment (v_sediment)

Calculated values of water flows from the MIKE SHE model /Werner et al. 2005*/ were used to describe the advective transport in sediments (both in lake sediments and the sediments in water courses). Modelling results represented the vertical water flow between the bedrock, the till and the sediments under the lakes. The value presented in Appendix 1 is a mean value based on modelling results from Lake Frisksjön in the Laxemar area. In abscence of other data it has been considered appropriate to use the same value also in the marine environment.

Biota

Productivity of food normally consumed (productivity_food)

The productivity of food is based on estimations of the productivity of fish in 16 marine basins in Laxemar /Lindborg 2006*/.

5.2 Lake

The northern part of the Kalmar County, where the Laxemar area is situated, is rich in lakes and running waters. The Simpevarp regional model area contains, however, only five small lakes. In general, freshwater systems in the area are classified as mesotrophic brown-water types. Most freshwaters are markedly coloured due to high contents of humic substances, leading to very high levels of dissolved organic carbon. The lakes are also relatively rich in nitrogen and phosphorus, leading to high levels of chlorophyll, low visual depths and strained oxygen conditions in the bottom water during periods of stratification /Tröjbom and Söderbäck 2006/. The lake areas in the Simpevarp regional model area range between 0.03 and 0.24 km^2 and the mean depth range between 1.1 and 3.7 m /Brunberg et al. 2004/.

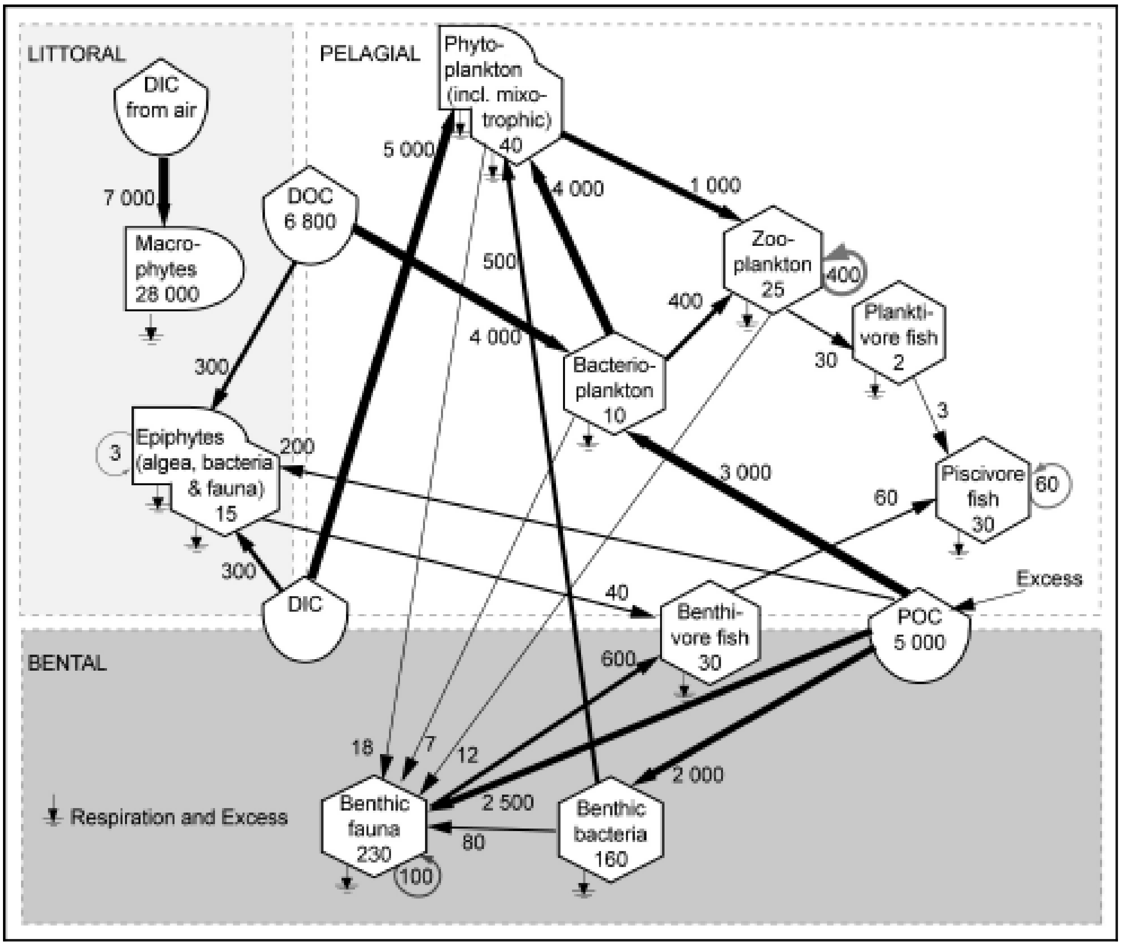


Figure 5-4. Carbon budget for Lake Frisksjön. Values within symbols denote the carbon pool (kgC) and values beside arrows denote annual carbon flow (kgC·y⁻¹). Arrow sizes indicate the magnitude of carbon flow between different functional groups. Since the biomasses of all epiphytic groups (algae, bacteria, and fauna) are so small, they have been treated as a single epiphyte group in the figure.

5.2.1 Major flows of matter

The largest carbon pool in the limnic system is found in the sediments /Lindborg 2006/. Primary production, which bring in carbon to the lake ecosystem through the utilisation of DIC from the air, is dominated by macrophytes (mainly reed) and phytoplankton, whereas mean annual biomass of primary producers is totally dominated by macrophytes. Lake respiration is dominated by mixotrophic phytoplankton and bacteria, both benthic and pelagic. The within-system transport of carbon (and other elements) to the top predator (piscivorous fish) may occur through two different pathways. The first and probably most important pathway is through benthic bacteria to benthic fauna, to benthic feeding fish and further to piscivorous fish. The other pathway is through bacterioplankton to zooplankton, to zooplankton feeding fish and further to piscivorous fish. A schematic view of the carbon budget set up for Lake Frisksjön /Lindborg 2006/ is presented in Figure 5-4.

5.2.2 Development over time

The mesotrophic brownwater lakes of today will develop into a new successional stage when *Sphagnum* mosses start to colonise the littoral and a mire is formed around the lake /Brunberg and Blomqvist 1999/. The *Sphagnum* becomes more and more dominant and turns the system increasingly acidic. The final stage is likely to be a raised bog ecosystem with an autonomous hydrological system /Brunberg and Blomqvist 1999/. For Lake Frisksjön, this process is projected to end at around 3,000 AD, when the lake is transformed into mire.

At 4,000 AD, the bays north and south of Äspö are expected to become isolated from the sea. Borholmsfjärden will form a large, shallow lake which will be gradually infilled over the next 2,000 years, whereas the deeper Granholmsfjärden will remain a lake even after 10,000 AD.

5.2.3 Simplified radionuclide model

A schematic view of the numerical model that describes the transport and accumulation of radionuclides in lakes is presented in Figure 5-5. The figure shows the different parameters and how these are related in order to describe fluxes of radionuclides. The site-generic parameters are presented in further detail below, whereas object-specific parameters are treated in Chapter 6.

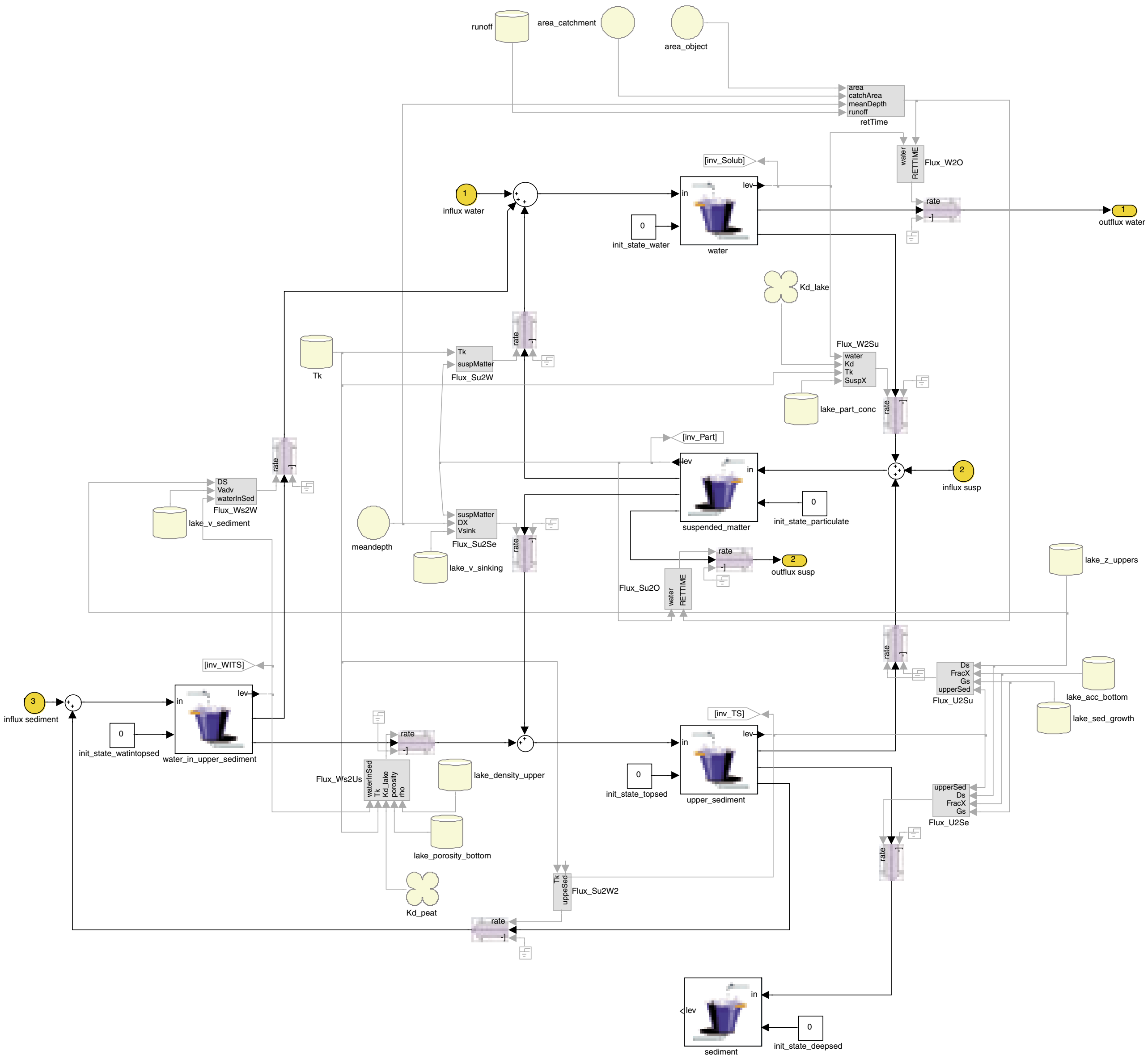


Figure 5-5. *The model that describes the transport and accumulation of radionuclides for a lake. Orange symbols are radionuclide fluxes into and out of the system. Large boxes denote the amount of radionuclides within the system, distinguished into soluble and particulate phases, whereas the smaller grey boxes are transfer coefficients used to calculate fluxes. Yellow circles show object-specific parameters, whereas yellow cylinders are site-generic parameters (but the Tk-cylinder is half-time to sorption equilibrium and is further treated in /Avila 2006/). Yellow propellers show radionuclide-specific parameters. Large arrows show fluxes of radionuclides between compartments, whereas small arrows show how functions and parameters are connected within the model. From /Avila 2006/.*

5.2.4 Radionuclide model parameterisation

This section describes assumptions and data relavant to the site-generic parameters in the conceptual radionuclide model (described above). The parameter name within brackets is the name in the radionuclide model. The parameter values are presented in Appendix I.

Regolith

Depth of top regolith (z_uppers)

The value represents an estimation of the zone where bioturbation occur. The range 0.5–5.5 cm is given as the total variation in /Eckhéll et al. 2000/.

Porosity of top regolith (porosity_upper)

The porosity of gyttja was used as it is the most common QD at the floor of the lakes /Nilsson 2004*/. The value has been calculated by using the water and organic contents presented by /Nilsson 2004*/. The data presented by /Nilsson 2004*/ are, however, not obtained from samples taken from the uppermost gyttja. The data from /Nilsson 2004*/ was used due to the lack of data form the top sediments.

Density of top regolith (density_upper)

The bulk density of gyttja was used as it is the most common QD at the floor of the lakes /Nilsson 2004*/. The value has been calculated by using the water and organic contents presented by /Nilsson 2004*/. The data presented by /Nilsson 2004*/ are, however, not obtained from samples taken from the uppermost gyttja. The data from /Nilsson 2004*/ was used due to the lack of data form the top sediments.

Depth of deeper regolith (z_deeps)

The value represents the average depth of post-glacial clay in the marine areas (Table 5-1). The post-glacial clay in the marine areas has a high organic content and occurs at the floor of the narrow bays characterising the coast. Since the post-glacial clay at the sea floor has similar properties as the gyttja from the lakes the average value for post-glacial clay was used also for the lakes. It is, however possible that the average depth of gyttja is higher than the value used here.

Porosity of deeper regoltih (porosity_bottom)

The porosity of gyttja was used as it is the most common QD at the floor of the lakes. The value has been calculated by using the water and organic contents presented by /Nilsson 2004*/.

Density of deeper regolith (density_bottom)

The bulk density of gyttja was used as it is the most common QD at the floor of the lakes. The value has been calculated by using the water and organic contents presented by /Nilsson 2004*/.

Fraction of accumulation bottom (acc_bottom)

The investigated lakes in the Simpevarp area differ considerably in their bathymetry /Brunberg et al. 2004*/. Lake Frisksjön and Lake Söråmagasinet show small depth variations and an almost complete lack of erosion bottoms. For these lakes it was assumed that the fraction of erosion bottom corresponds to 90% of total lake area (Table 5-4). For the other lakes it was assumed that the accumulation bottom corresponds to the area below the deepest depth contour shown in /Brunberg et al. 2004*/. For Lake Jämsen, also the shallow and relatively isolated bay in the NE part of the lake was assumed to comprise accumulation bottom.

Table 5-4. The estimated fraction of accumulation bottoms in a number of lakes in the Simpevarp area /Brunberg et al. 2004*/.

Lake	Estimated fraction of acc. bottom	Comment
Frisksjön	0.90	Acc. bottom assumed to correspond to 90% of lake area.
Fjällgöl	0.38	Acc. bottom assumed to correspond to the area deeper than 1.5 m.
Plittorpsgöl	0.26	Acc. bottom assumed to correspond to the area deeper than 6 m.
Jämsen	0.05	Acc. bottom assumed to correspond to the area deeper than 10 m + an equally large area of the shallow bay in the NE part of the lake.
Söråmagasinet	0.90	Acc. bottom assumed to correspond to 90% of lake area.

Sediment growth rate (sed_growth)

The carbon pool in profundal sediments (which almost exclusively consists of organic carbon, cf. was calculated as follows: Two sediment cores from profundal accumulation bottoms in Lake Frisksjön show a transition from marine-like sediments to lacustrine sediments at 3.2 and 1.15 m sediment depth, respectively /Nilsson 2004*/. Hence, a mean thickness of lacustrine sediments in Frisksjön of 2.2 m was estimated. As Lake Frisksjön separated from the Baltic Sea about 1,100 years BP (L. Brydsten, Dept. of Ecology and Environmental Science, Umeå University, personal communication), this results in a sedimentation rate of 2 $mm \cdot y^{-1}$.

Hydrology

The water balance data presented in this report are based on calculated values from the near-surface hydrological model for Laxemar, L1.2 /Werner et al. 2005*/. The physically based and spatially distributed modelling tool MIKE SHE was used for the near-surface hydrological modelling. The model is driven by local meteorological data from the Laxemar area from 2004. Meteorological input data to the model are temperature, potential evapotranspiration and precipitation. The actual evapotranspiration and its different components (transpiration, evaporation from soil, interception) is calculated in timesteps less than periods of twenty-four hours during the simulation.

Particle concentration in water (part_conc)

The estimate is based on average concentrations of Particulate Organic Carbon (POC) in four lakes in the Simpevarp area, sampled biweekly to monthly during 2002–2004 /Tröjbom and Söderbäck 2006*/.

Velocity of sinking fine particles (v_sinking)

There are no site data available for the velocity of sinking fine particles. The approximation given here is based on the estimated velocity given in Table 4-1 in /Karlsson et al. 2001*/.

Advective transport in sediment (v_sediment)

Calculated values of water flows from the MIKE SHE model /Werner et al. 2005*/ were used to describe the advective transport in sediments (both in lake sediments and the sediments in water courses). Modelling results represented the vertical water flow between the bedrock, the till and the sediments under the lakes. The value presented in this report is a mean value based on modelling results from Lake Frisksjön in the Laxemar area.

Biota

Total productivity of primary producers weighted over the area of the object (productivity_plants)

Productivity of all primary producers, i.e. macrophytes, phytoplankton and benthic algae, is calculated for one lake in the Laxemar area, Lake Frisksjön, in /Lindborg 2006*/. The calculations are based on site data from Lake Frisksjön (phytoplankton, macrophytes and microphytobenthos) and the nearby coastal area (additional macrophyte data) and on generic data on epiphytic algae.

Total productivity of secondary producers (productivity_animal)

Productivity of secondary producers, i.e. all heterotrophic production, is calculated for one lake in the Laxemar area, Lake Frisksjön, in /Lindborg 2006*/.

Total productivity of food normally consumed (productivity_food)

Productivity of food normally consumed by humans, i.e. all fish production, is calculated for one lake in the Laxemar area, Lake Frisksjön, in /Lindborg 2006*/. Range and standard deviation of the mean for the estimate was assessed by assuming that the estimate for Frisksjön is a mean with the same coefficient of variation as the investigated lakes in the Forsmark area /cf. Borgiel 2004*/.

Total productivity of edible products (productivity_edible)

Productivity of edible products, i.e. fish and macroinvertebrate production, is calculated for one lake in the Laxemar area, Lake Frisksjön, in /Lindborg 2006*/.

5.3 Running water

In the Laxemar area, the running waters are excavated streams and dug ditches /Carlsson et al. 2005*/. The water flow varies very much over the year and during dry years many streams may cease to flow for long periods.

5.3.1 Major flows of matter

The flow of matter in running waters has not been studied explicitly at Laxemar. There are, however, certainly processes that will affect turnover of elements and accumulation of matter. For example, wetland areas adjacent to streams will regularly be flooded during periods of high discharge. There may potentially be a significant accumulation of matter in such areas.

5.3.2 Development over time

Running waters are located in lows of the environment. An important factor for the existence and size of watercourses is the runoff in the area upstream. Assuming no changes in climate, the amount of water in watercourses in the Laxemar area will decrease over time due to the process of lakes turning into wetlands. This leads to increased evapotranspiration and slower water turnover resulting in lower water flows. The running waters in the Laxemar area today will continue in their present courses in the area unless ditching by humans occurs. New watercourses will develop in the areas uplifted above sea level by the ongoing land elevation.

5.3.3 Simplified radionuclide model

For rivers a compartment model was not used. Instead, instantaneous and complete missing of the released radionuclides with the river water was assumed. The flow of water was calculated using the depth and width, and the run-off from the catchment area above a specific point (further described in /Avila 2006*/).

5.3.4 Radionuclide model parameterisation

This section describes assumptions used in the specification of the site-generic parameters in the conceptual radionuclide model (described above). The parameter name within brackets is the name in the radionuclide model. The parameter values are presented in Appendix I.

Hydrology

The water balance data presented in this report are based on calculated values from the near-surface hydrological model for Laxemar /Werner et al. 2005*/ The physically based and spatially distributed modelling tool MIKE SHE was used for the near-surface hydrological modelling. The model is driven by local meteorological data from the Laxemar area for the period September 2003–June 2005. Meteorological input data to the model are temperature, potential evapotranspiration and precipitation. The actual evapotranspiration and its different components (transpiration, evaporation from soil, interception etc) is calculated in timesteps less than periods of twenty-four hours during the simulation.

Runoff (runoff)

The parameter "runoff" represents the annual amount of water leaving the model domain (see above) in the watercourses and as direct runoff to the sea.

5.4 Mire

Wetlands are scarse in the Laxemar area and cover about 1% of the area in the 14 catchments. The wetlands 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. Roughly, there are two types of wetlands identified; those that accumulate peat and those where decomposition is fairly high thereby minimising peat formation. The latter has a more or less thick humus layer on mineral soil, hence having less organic matter in the soil organic matter pool.

The stratigraphy of the wetlands has been investigated by /Nilsson 2004/. Peat has developed in the more elevated areas with a thickness less than one metre. In more low-lying areas the peat layer is very thin or missing. The peat (when present) is underlain by clay gyttja and gyttja, silt-sand-gravel, postglacial clay, and glacial clay. From existing borings /Nilsson 2004/ it is known that peat in wetlands can rest directly on till or be underlain by gyttja and/or clay above the till. 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.

The map of quaternary deposits 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 /Lindborg 2006/.

5.4.1 Major flows and processes

An investigation by /Nilsson 2004*/ shows that a typical top-down stratigraphy in wetlands and peat areas are peat (when present), clay gyttja and gyttja, silt-sand-gravel, postglacial clay, and glacial clay. The individual layers are on the order of 0.5–2 m, except from the silt-sand-gravel layer, which generally is very thin. Hence, the investigation results indicate that the bottom layers of the wetlands and peat areas consist of low-permeable materials, which would correspond to limited interactions between groundwater and surface water in these areas.

The largest flux of carbon is the gross primary production in the field and bottom layer, where approximately 50% is the net primary production (NPP). A large part of the NPP is turned into litter from both above-ground and below-ground plant functional parts, whereas the rest is stored in perennial plant tissue. C-mineralisation is the largest flux of carbon leaving the mire and the difference between litter input and C-mineralisation is the accumulation of organic matter. The position of the water table is the principal factor affecting CO_2 fluxes from boreal wetlands /Silvola et al. 1996/, which have consistently shown a strong positive relationship between CO_2 fluxes and water-table depth. For wetlands, there are data describing the accumulation of carbon based on the age of the site and the thickness of the peat layer (Table 5-5), suggesting that wetlands on peat soils accumulate on average 60 $gC \cdot m^{-2} y^{-1}$. Unfortunately, there are few references describing carbon cycling from forested wetlands, especially fen-like wetlands.

The anaerobic conditions created in the inundated soil lead to emission of methane gas during decomposition. This emission rate is low compared with the carbon dioxide emitted during heterotrophic respiration (e.g. a boreal bog, 1–2 $gC \cdot m^{-2} \cdot y^{-1}$ /Alm et al. 1999/ and 4 $gC \cdot m^{-2} \cdot y^{-1}$ /Waddington and Roulet 2000/).

/Brydsten 2004*/ found that data from six investigated lakes in the Forsmark area suggested that sediments had a high degree of material of autochtonous origin. Several other factors supported this conclusion, such as small topographic variation (small watersheds), low current velocities and low abundance of fine-grained sediments. This pattern suggests that a similar pattern would be likely for wetlands in the Laxemar area. Studies of DOC exports to lakes, as a function of vegetation types, in a drainage area have shown that wetlands export more DOC than other vegetation types /e.g. Canhem et al. 2004, Humborg et al. 2004/. By using a predictive model based on 2,750 lakes and their drainage areas in Canada, /Canhem et al. 2004/ estimated the export from temperate conifer wetlands, "emergent marches" and forests, to 17.5 $gC \cdot m^{-2} \cdot y^{-1}$, 12.5 $gC \cdot m^{-2} \cdot y^{-1}$ and 3.5 $gC \cdot m^{-2} \cdot y^{-1}$ respectively. /Waddington and Roulet 2000/ estimated the lateral transport from a boreal bog in Sweden to be 4.2 $gC \cdot m^{-2}$ and 6.7 $gC \cdot m^{-2}$ in two consecutive years. Consequently, import and export of carbon are small in comparison with the local wetland carbon budgets /see Lindborg 2006/, but their impact on the recipient ecosystem may be large depending on the size of the drainage area and the number of wetlands.

Table 5-5. 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 time since the wetland emerged from the sea. From /Lindborg 2005*/.

Locality in Forsmark	$gC \cdot m^{-2} \cdot y^{-1}$	Reference
Stenrösmossen	43.2	/Fredriksson, 2004*/
Lersättermyran	66.3	/Fredriksson, 2004*/
T1	58.3	/Lundin et al. 2004*/
T2	73.8	/Lundin et al. 2004*/
Mean	60.4	

5.4.2 Development over time

Mires are formed basically through three different processes; terrestrialisation, paludification and primary mire formation /Rydin et al. 1999, Kellner 2003/. Terrestrialisation is the filling-in of shallow lakes. Paludification, which is the predominant way of mire formation in Sweden, is an ongoing water logging of more or less water-permeable soils, by expanding mires or beaver activities. Primary mire formation is when peat is developed directly on soils exposed after post glacial land uplift. All three types of processes are likely to occur in the Laxemar area. The richer types of mires will undergo a natural long-term acidification, when turning into a more bog-like mire. It seems that the final result of mire development, in the boreonemoral and southern boreal areas of Sweden, is the bog /Rydin et al. 1999/. The bog can, however, have Scots pines if the peat can support their weight and some studies (e.g. /Gunnarsson et al. 2002/ and references therein) indicate that Scots pine have established and become more common in recent years on bogs. The mires can be drained for forestry and such activities peaked in the 1930's in Sweden. Mires have also been used for haymaking and, in this context the rich fens were more important than the poor fens. Haymaking slows down or stops the succession of the rich fen resulting in poorer fen-like stages due to the inhibition of peat formation /Elveland 1978/. Mires have also been used for agriculture purposes and such use was during the 1850's and subsequently, often preceded by ditching activities to ensure the best possible conditions for the crops cultivated. This resulted in lowering of the water table inducing a switch from anaerobic conditions to aerobic conditions, initiating decomposition and erosion of peat-dominated soil.

5.4.3 Simplified radionuclide model

A schematic view of the numerical model that describes the transport and accumulation of radionuclides in mires is presented in Figure 5-6. The figure shows the different parameters and how these are related in order to describe fluxes of radionuclides. The site-generic parameters are presented in further detail below whereas object-specific parameters are treated in Chapter 6.

5.4.4 Radionuclide model parameterisation

This section describes assumptions used in specification of the site-generic parameters in the conceptual radionuclide model (described in the section above). The parameter name within brackets is the name in the radionuclide model. The parameter values are presented in Appendix I.

Regolith

Depth of top regolith (z_uppers)

The average depth of peat was used. Depth data from altogether 41 sites was collected during the mapping of QD /Rudmark et al. 2005*/.

Porosity of top regolith (porosity_upper)

The average water content of 10 peat sample investigated during the soil survey was used /Lundin at al. 2005*/.

Density of top regolith (density_upper)

The average dry bulk density of 18 peat sample investigated during the soil survey was used /Lundin at al. 2005*/.

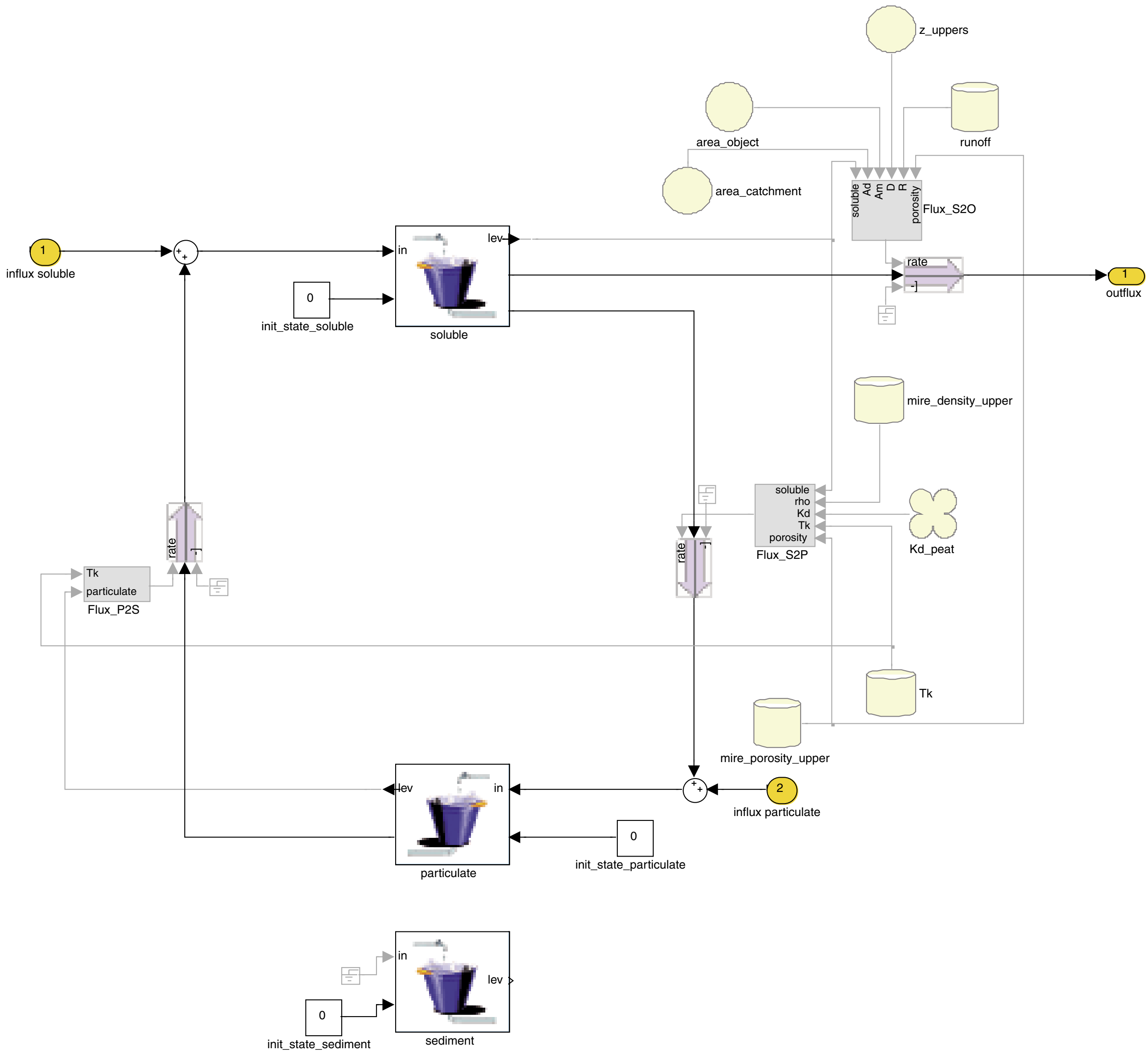


__Figure 5-6.__ The model that describes the transport and accumulation of radionuclides for a mire. Orange symbols are radionuclide fluxes into and out of the system. Large boxes denote the amount of radionuclides within the system, distinguished into soluble and particulate phases, whereas the smaller grey boxes are transfer coefficients used to calculate fluxes. Yellow circles show object-specific parameters, whereas yellow cylinders are site-generic parameters (but the Tk-cylinder is half-time to sorption equilibrium and is further treated in /Avila 2006/). Yellow propellers show radionuclide-specific parameters. Large arrows show fluxes of radionuclides between compartments, whereas small arrows show how functions and parameters are connected within the model. From /Avila 2006/. The parameter z_uppers is objects-specific in the figure for future conditions (see Chapter 6), but is treated as site-generic in the text below for present conditions.

Hydrology

The water balance data presented in this report are calculated values from the near-surface hydrological model for Laxemar, L1.2 /Werner et al. 2005*/. The physically based and spatially distributed modelling tool MIKE SHE was used for the near-surface hydrological modelling. The model is driven by local meteorological data from the Laxemar area for 2004. Meteorological input data to the model are temperature, potential evapotranspiration and precipitation. The actual evapotranspiration and its different components (transpiration, evaporation from soil, interception) was calculated in timesteps less than periods of twenty-four hours during the simulation.

Runoff (runoff)

The parameter "runoff" represents the annual amount per unit of area of water leaving by the network of watercourses and as direct runoff to the sea.

Biota

Productivity of food normally consumed (productivity_food)

The mire produces berries, mainly cloudberry and cranberry that may be consumed. The estimation is from three years and comprises collected cloudberries from Sweden /Berggren and Kyläkorpi 2002*/. The collected amount is estimated to be 5% of the production. The abundance of cloudberries is, however, low in the Laxemar area in comparison with the northern part of Sweden. This estimate, therefore is adopted for cloudberry and cranberry, but is probably an overestimate of the actual production. Due to lack of better data, the carbon content in bilberries (7.0% of the fresh weight in Section 3.10 in /Lindborg 2006*/) was used as an estimate of the carbon content in cloudberries. Berry production was divided by the total mire area in Sweden /Statistics Sweden 1998/. Estimates of wild game production (moose and roe deer) is from /Lindborg 2006*/ and these figures were adjusted, as the densities were estimated after the hunting season, by increasing the density figures by a value corresponding to the loss from hunting in the area using local hunting statistics /Lindborg 2006*/.

5.5 Agricultural land

The agriculture land is the arable land and the seminatural grassland. Arable land and seminatural grassland are found close to settlements. The agricultural land is situated along the valleys and constitutes 3.6% of the total land area within the regional model area /Lindborg 2006/. The valleys have been sheltered from wave exposure and sedimentation of clay and gyttja clay has been considerable. The groundwater level is high in the valleys (median –0.6 m below surface /Lindborg 2006/) explaining why there often was a peat layer covering the clay /Lindborg 2006/. Most of the larger fens have been drained by various types of ditches and are presently used as arable land or for forestry. 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. Most of the agriculture areas have therefore ditches surrounding or crossing the areas. Due to the spatial location the agriculture areas are often stretched out along the valleys. A number of different crops are cultivated in the Simpevarp area, but the overall agricultural production is dominated by green fodder, such as grass for hay and silage. Approximately 18% of the agriculture land is used for cereals, where barley dominates (71%) followed by oats (17%) /Miliander et al. 2004/.

In Sweden, the cultivated area which is irrigated, is very small, 3–4% /Bergström and Barkefors 2004/. Potatoes and vegetables are the crops that are most often irrigated. According to /Bergström and Barkefors 2004/ approximately 80% of the irrigation water is drawn from lakes and rivers and 15% is groundwater (mostly in Skåne and Halland).

A smaller version of arable land is a garden plot, where vegetables and root crops can be grown for personal use. There are permanent residents in the Laxemar area. It has not been investigated if the residents have garden plots and the degree of self-sustainability concerning different kind of crops is unknown. Although the extent of irrigation of garden plots is not known, the figures in /Bergström and Barkefors 2004/ indicate a general need in drier summers.

5.5.1 Major flows and processes

The arable land is subjected to regular harvest that either provides humans with crops or cattle with fodder. In both cases, the final products are destined for human consumption. The cattle produce manure that may be used as fertiliser on arable land. The soil of the arable land is constantly being disturbed by ploughing, which makes well mixed and aerated down to ploughing depth. Depending on fertilisation, litter quality, and initial nutrient and carbon status, the decomposition and accumulation of carbon and nitrogen may vary /e.g. Hyvonen et al. 1996/.

Irrigation water supplies the arable land not only with water, but also with its contents of soluble and particulate matter. The water may be retained on the crop (interception) or land on the soil surface and infiltrate. The water in the soil may be taken up by the crop or leave the upper soil horizon by downward percolation. Some elements may accumulate in the soil, whereas others follow the water into the crop or down to the groundwater.

5.5.2 Development over time

The arable land in Sweden had its maximal extent in the 1920's and over-production in the 1940's led to a decrease in arable land and the number of cattle. In 1989 had 25% been taken out of production /Bernes and Grundsten 1992/. This pattern is even more pronounced in Oskarshamn, where 64% of the agricultural land was taken out of production between 1940 and 1980 /Berg et al. 2006/.

Before agricultural modernisation, only fairly dry soils could be cultivated, heavy clays and wetlands were used for mowing and stone ridden tills and bedrock were grazed. In Nynäs in Södermanland, it was found that thin soils on bedrock were used for cultivation close to the villages in the 17^{th} and 18^{th} centuries /Cousins 2001/. As management intensity and population increased, more of the medium fertile soils were used for agriculture while the poorest soils were assigned to the livestock /Rosén and Borgegård 1999/. However, this trend came to an end as management was rationalised by using fertilisers and better equipment in the early 20^{th} century. This development of farming and the development of forest tools and machinery altered the utilization of land-covers and thus their association with different soils. The distribution of agricultural land in Sweden is today largely associated with postglacial deposits /Angelstam 1992, Sporrong et al. 1995/. The agricultural land in Laxemar today is characterised by having clay-silt as the dominating QD in the surface layer (Figure 5-7), closely followed by clayey gyttja (and gyttja clay). However, the clay-silt category includes both clay gyttja and gyttja clay, and clay because of differences in the classification for parts of the area. A closer look at Figure 5-7 reveals that when clay was separated, it constitutes a small fraction of the clay-silt category, suggesting that clay gyttja and gyttja clay dominates. The clay originates from the earlier stages of the Baltic Sea and has low organic content, while clay gyttja originates from an earlier phase as sea bay, where organic matter has been deposited as sediment. Sohlenius /in Lindborg 2006/ showed that present areas covered with gyttja clay coincide with areas once being sheltered bays. Gyttja as a dominating soil in agriculture land is scarce in this area, which suggests that present agriculture areas seldom is preceded by a longer lake phase with organic sediment deposition. A large part of the agriculture land has a dominating peat layer, which is built up during the phase as a wetland. Due to different mapping techniques, the peat classification into different types has not been uniform at all the objects (Figure 5-7). In areas where detailed mapping has been performed, the more nutrient rich fen and nutrient poor bog peat were separated /Rudmark et al. 2005/. In these areas, all agricultural areas were located on fen peat. In the western area, peat was mapped as unclassified peat. However, fen peat is probably dominating also in this area. One category having clay gyttja (and gyttja clay) with a thin layer of peat suggests a somewhat faster succession where the wetland stage was rather short or that the peat has oxidized during a long period of cultivation. Another category of agriculture land with regard to QD is characterised by more coarse grained non-organic materials that was deposited during the sea phase, such as wave-washed sand, gravel and till.

The seminatural grassland was earlier intensively used, but is today mainly a part of the abandoned farmland following the nationwide general regression of agricultural activities. If these areas are left unattended, they will eventually develop into forests that in most cases will be dominated by Norway spruce. During the latter parts of the 1900's, farmers have been encouraged to plant coniferous trees on arable land, thereby accelerating the succession into forest.

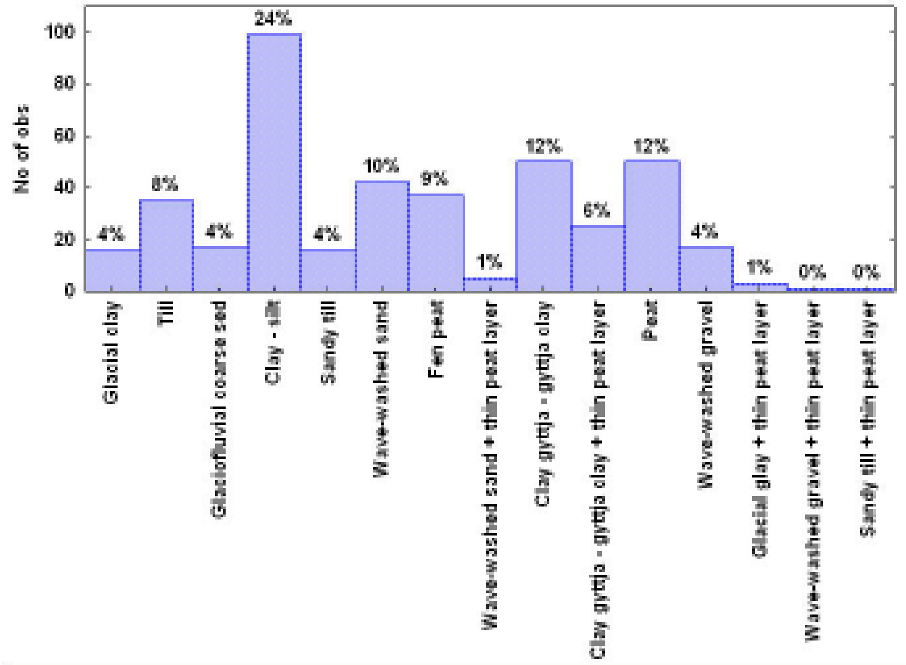


Figure 5-7. *The dominating quaternary deposit in the surface layer of the agriculture objects identified within the regional model area. Peat has not been separated into fen peat and bog peat in the whole investigation area, but where this has been done only fen peat was found. Similarly, clay-silt was not separated into different clay types in the whole investigation area.*

5.5.3 Simplified radionuclide model

A schematic view of the numerical model that describes the transport and accumulation of radionuclides in agricultural land is presented in Figure 5-8. The figure shows the different parameters and how these are related in order to describe fluxes of radionuclides. The site-generic parameters are presented in further detail below, whereas object specific parameters are treated in Chapter 6.

5.5.4 Radionuclide model parameterisation

This section describes assumptions relating to parameterisation of the site-generic parameters in the conceptual radionuclide model (described above). The parameter name within brackets is the name in the radionuclide model. The parameter values are presented in Appendix I.

Regolith

Depth of top regolith (z_uppers)

Defined as the depth of the plough layer in agricultural soils. The value is from /Karlsson et al. 2001*/.

Porosity of top regolith (porosity_upper)

This value is based on the results from two samples investigated during a soil survey /Lundin et al. 2005*/. The samples were taken from the uppermost part of the soil.

Density of top regolith (density_upper)

This value is based on the results from two samples investigated during a soil survey /Lundin et al. 2005*/. The samples were taken from the uppermost part of the soil. The data presented here represent the dry density.

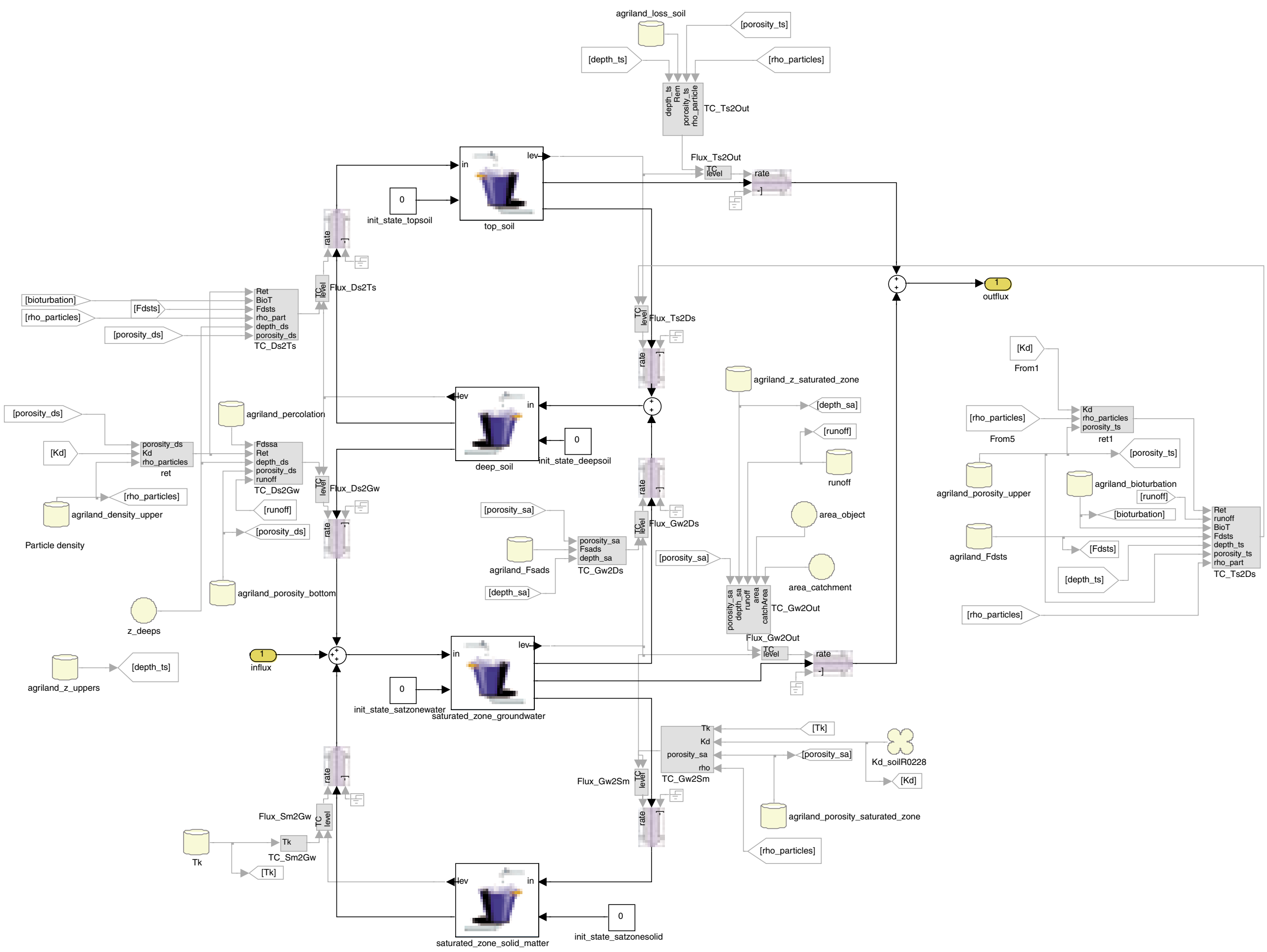


Figure 5-8. *The model that describes the transport and accumulation of radionuclides for an agricultural land. Orange symbols are radionuclide fluxes into and out of the system. Large boxes denote the amount of radionuclides within the system, distinguished into soluble and particulate phases, whereas the smaller grey boxes are transfer coefficients used to calculate fluxes. Yellow circles show object-specific parameters, whereas yellow cylinders are site-generic parameters (but the Tk-cylinder is half-time to sorption equilibrium and is further treated in /Avila 2006/). Yellow propellers show radionuclide-specific parameters. Large arrows show fluxes of radionuclides between compartments, whereas small arrows show how functions and parameters are connected within the model. From /Avila 2006/. The parameter z_deeps is objects-specific in the figure for future conditions (see Chapter 6), but is treated as site-generic in the text below for present conditions.*

Depth of deeper regolith (z_deeps)

This value was used in the soil depth model presented by /Nyman 2005*/. The value is assumed to represent the uppermost part of the QD, which are affected by soil forming processes.

Porosity of deeper regolith (porosity_bottom)

Three values from one of the sites situated on agricultural land investigated during a soil survey /Lundin et al. 2005*/. The investigated site is situated at post-glacial clay.

Density of deeper regolith (density_bottom)

One value from one of the sites on agricultural land investigated during the soil survey /Lundin et al. 2005*/. The data presented here represent the dry density of post-glacial clay.

Depth of saturated zone (z_saturated_zone)

A large proportion of the agricultural land is situated on post-glacial clay. The value used here represents the sum of the mean depths of Quaternary sediments in areas covered by post-glacial clay (Table 5-1). The general stratigraphy presented in /Lindborg 2006*/ shows that the post-glacial clay is underlain by sand, glacial clay and till. The results in Table 5-1 are based on data from the marine geological investigations outside Simpevarp /Elhammer and Sandkvist 2005*/. It is, however, possible that the average thickness of QD is different in terrestrial areas compared to the marine areas.

Porosity of saturated zone (porosity_saturated_zone)

A large proportion of the agricultural land is situated on post-glacial clay. The value used here is based on a weighted average of the QD in areas covered by post-glacial clay. The general stratigraphy presented in /Lindborg 2005*/ shows that the post-glacial clay is underlain by sand, glacial clay and till. The porosity values for till and post-glacial sand (Table 5-2) were taken from /Almén and Talme 1978/. These values represent typical values for these deposits. However, the porosity of till can probably show large local variations. The porosity for glacial and post-glacial clay (Table 5-2) were calculated by the use of the water and organic contents presented by /Nilsson 2004*/.

Soil removal (loss_soil)

The soil erosion value is based on studies presented in /Karlsson et al. 2001*/.

Hydrology

The water balance data presented in this report are calculated values from the near-surface hydrological model for Laxemar, L1.2 /Werner et al. 2005*/. The physically based and spatially distributed modelling tool MIKE SHE was used for the near-surface hydrological modelling. The model is driven by local meteorological data from the Laxemar area for 2004. Meteorological input data to the model are temperature, potential evapotranspiration and precipitation. The actual evapotranspiration and its different components (transpiration, evaporation from soil, interception) was calculated in timesteps less than periods of twenty-four hours during the simulation.

Precipitation (precipitation)

The precipitation is based on local meteorological data from the Laxemar area for 2004 /Werner et al. 2005*/.

Runoff (runoff)

The parameter "runoff" represents the annual amount of water leaving the model domain (see above) in the river network and as direct runoff to the sea.

Downward flow (percolation)

The MIKE SHE model consists of a number of compartments; overland, unsaturated zone and saturated zone. The parameter "Downward flow (percolation)" represents the annual water flow from the unsaturated zone to the saturated zone.

Upward flow deep soil to top soil (Fdsts)

The MIKE SHE model consists of a number of compartments; overland, unsaturated zone and saturated zone. The parameter “Upward flow deepsoil to topsoil (Fdsts)” represents the annual water flow from the saturated zone to the overland compartment, i.e. the water flow from the groundwater to wetter areas on the ground.

Upward flow (Fsads)

The value for the transpiration given in this report is the annual mean transpiration from the model area, i.e. a mean value both in time and space. The area is dominated by coniferous trees, but the value of the transpiration represents a mean for all the different types of vegetation within the model area.

Biota

Productivity of primary producers weighted over the area of the object (productivity_plants)

Productivity of crops was estimated using production statistics from Kalmar County between 1965 and 1996 /SCB website/ of the four most commonly grown crops (barley, rye, oates and hay) and taking the area weighted average yield for these crops during this period using data from Misterhults parish /Miliander et al. 2004*/. Production estimates for hay was only representing the year of 1999. Carbon content was assumed to be 46.1% of the dry weight /Fridriksson and Öhr 2003*/, which was 0.85% of the fresh weight.

Productivity of secondary producers (productivity_animal)

Secondary producers comprise cattle, hare, voles, mice and roe deer. Productivity of cattle (including both meat and milk production) is from /Lindborg 2006*/ and is averaged over the arable land and seminatural grasslands. The number of cattle is calculated based on a number of assumptions presented in /Miliander et al. 2004*/. Productivity for the other animals were taken from /Lindborg 2006*/.

Productivity of food normally consumed (productivity_food)

This parameter includes productivity of crops (above) and cattle and wild game. These figures are extracted from the two parameters above. Cattle and wild game contribute with less than 5% of the total productivity and statistics, describing minimum, maximum and standard deviation, are therefore based on the statistics describing crop production.

Productivity of edible products (productivity_edible)

This parameter comprises the parameter above and potential food not consumed today, e g worms in contrast to tree trunks. Earthworms are therefore included and production is estimated assuming a yearly biomass turnover. Biomass estimates are from a grassland in Uppland /Lindborg 2005*/. Cattle, wild game and earthworms contribute less than 9% of the total productivity, and statistics, describing minimum, maximum and standard deviation, are therefore based upon the statistics describing crop production.

Transport of soil by earthworms (bioturbation)

This is an estimate of how much soil that is transported by soil organisms in the soil /Karlsson et al. 2001*/.

5.6 Forest

The forests are dominated by dry Scots pine (*Pinus sylvestris*) situated on bedrock or nutrient poor thin soils with shrubs, mostly *Calluna vulgaris*, 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 most common 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. The predominant humus form is Moder in Scots pine and Norway spruce forests, where Regosols dominates but Podzol becomes more common where there is a deeper soil cover. The mull like humus form becomes more dominant as deciduous trees becomes more prevalent /Lundin et al. 2005*/ and here is the soil types Regosols and Umbrisols.

The Laxemar area has a long history of forestry, which is seen today as a fairly high percentage of younger and older clear-cuts in different successional stages in the landscape. *Betula pendula* is the dominate species in many of the earlier successional stages until it is replaced by young Norway spruce or Scots pine depending on soil type and/or management.

5.6.1 Major flows and processes

The soil carbon pool is the largest carbon pool in the terrestrial environments of Laxemar /Lindborg 2006*/. The primary producers are also a large carbon pool, whereas the total biomass of herbivores and carnivores is small. The latter may, however, be important due to the relative high carbon flow (in relation to weight) through herbivores. This pool also includes several species, which are regularly hunted by humans. The largest flux of carbon leaving forests (except for autotrophic respiration) is the heterotrophic soil respiration /Lindborg 2006*/.

Boreal forests are generally assumed to be a sink for carbon /Schlesinger 1997/. This sink can be attributed to the building up of biomass in the vegetation and carbon accumulation in the soil. A downward flow of carbon from the leaching of DOC from the litter layer, 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/. This fraction is probably a substantial part of the carbon that is retained over time in woodland soils.

The main transport from the terrestrial ecosystem is that of dissolved organic carbon (DOC) via more or less diffusive discharge, which is related to the precipitation. This carbon flux is, however, comparably low in comparison to other carbon fluxes within the ecosystem /Algesten et al. 2004, Humborg et al. 2004, Canhem et al. 2004/.

5.6.2 Development over time

The uplift of land continuously creates new terrestrial areas. The most important abiotic conditions, affecting the vegetation community on the sea shore, are the soil type, the degree of exposure and the salinity /Jerling 1999/. The soil type is strongly connected to the degree of exposure, where more wave exposed areas contain larger stone fractions than areas with low exposure. Studies of the vegetation on the Baltic Sea shores show that emerging areas are rapidly colonised by vegetation /Ericson and Wallentinus 1979/. Because of the flooding frequency and salt spray intensity, the vegetation composition does not change independently from the land uplift rate until many years after emergence of sites from the sea /Cramer 1986/. The Baltic Sea shore can be divided into four different types: rocky shores, shores with wave-washed till, sandy shores and shores with fine sediments. In the Laxemar area, rocky shores followed by shores with wave-washed till are the most common; shores with fine sediments do occur. The emerging rocky and till shores outside Laxemar have a sea shore vegetation zonation that is defined from their tolerance to water inundation and salt sprays /Jerling 1999, Jerling et al. 2001/. The first pioneer woody species are (*Prunus spinosa*) and the tree Alder (*Alnus glutinosa*). Both these species have a litter that is rich in nitrogen and this facilitates the establishment of many species. From bushes and trees a varied light environment and new habitats are created. In this way, the flora and vegetation is steadily changing but with a relatively high degree of determinism /e.g. Svensson and Jeglum 2000/. In most areas with a thicker soil layer, the Norway spruce forest has to be regarded as the climax vegetation type in this area. The Scots pine would probably be more restricted to areas with a shallower, more nutrient poor soil layer, if forestry management were to decrease and fire, again, was to become a natural disturbance in the landscape /Sjörs 1967, Engelmark and Hytteborn 1999/.

5.6.3 Simplified radionuclide model

A schematic view of the numerical model that describes the transport and accumulation of radionuclides in forests is presented in Figure 5-9. The figure shows the different parameters and how these are related in order to describe fluxes of radionuclides. The site-generic parameters are presented in further detail below whereas object-specific parameters are treated in Chapter 6.

5.6.4 Radionuclide model parameterisation

This section describes assumptions and data behind the parameterisation of the site-generic parameters in the conceptual radionuclide model (described above). The parameter name within brackets is the name in the radionuclide model. The parameter values are presented in Appendix I.

Regolith

Depth of top regolith (z_uppers)

This depth is defined as the fine root zone depth. /Lundin et al. 2005/ investigated the fine root depth at a number of sites in Laxemar. Data is used from two plots representing deciduous forest and two plots from Norway spruce forest (on a shallow soil layer). These estimates were weighted to a value representing the Laxemar area, where the coniferous forest represents 78% and the deciduous forest 22% of the total wood land area (including clear-cuts, but excluding pine forest on acid rock), respectively /Boresjö Bronge and Wester 2003*/. Total standard deviation was calculated according to the formula:

$sd_{tot} = sqrt(sd_1^2+sd_2^2)$.

Density of top regolith (density_upper)

Data from the soil survey performed by /Lundin et al. 2005*/ was used. The density was estimated in 10 till samples from the uppermost 60 cm of the soil.

Volumetric water content in soil (waterContent)

This data was taken from studies of till from two trenches studied within the Forsmark site investigation /Lundin et al. 2005*/. The value used here is the mean of measurements on 16 samples from the upper metre. The till in Forsmark is generally more fine-grained than the till in the Laxemar area. It is therefore possible that the value is too high.

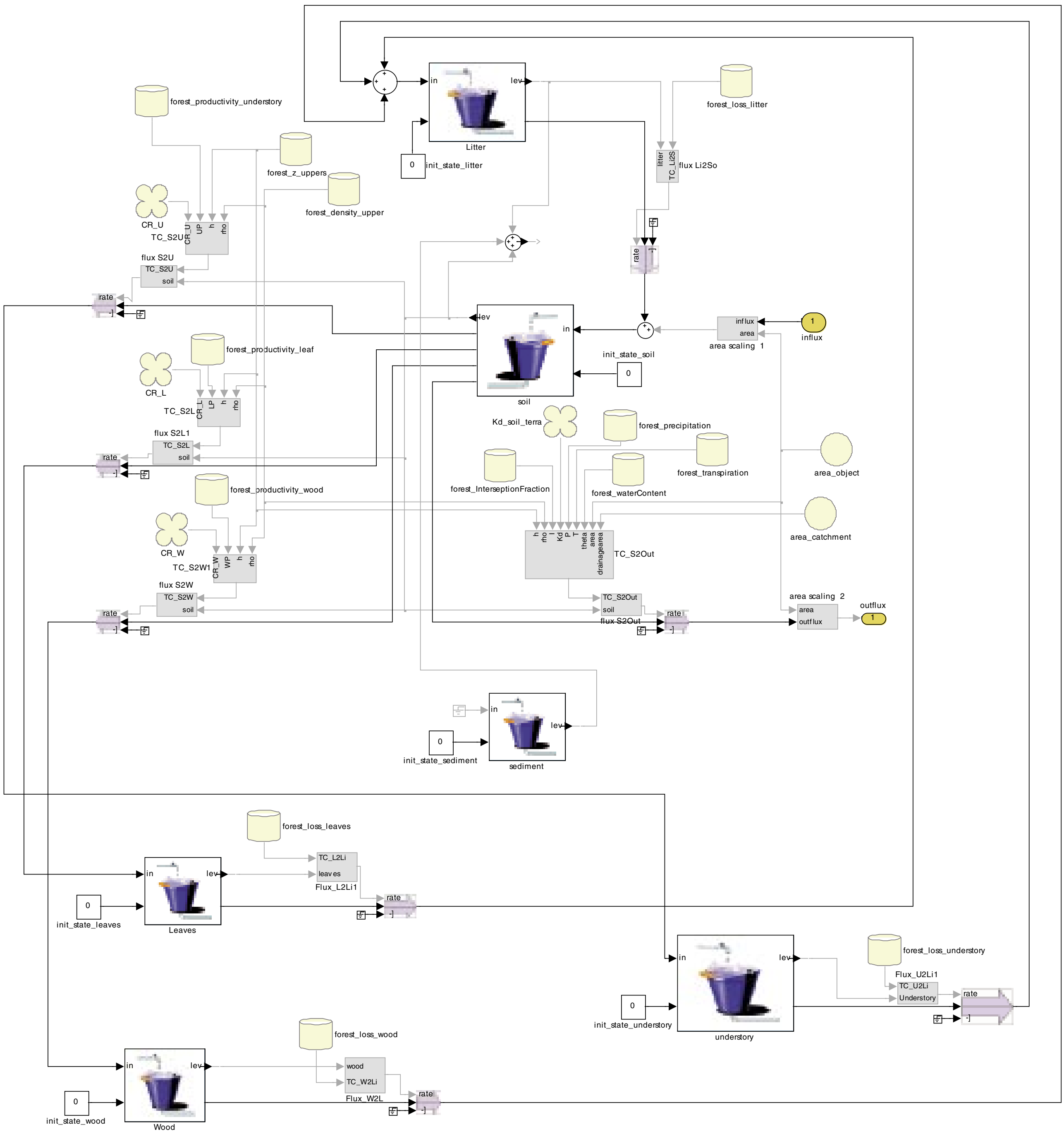


Figure 5-9. *The model that describes the transport and accumulation of radionuclides for a forest. Orange symbols are radionuclide fluxes into and out of the system. Large boxes denote the amount of radionuclides within the system, distinguished into soluble and particulate phases, whereas the smaller grey boxes are transfer coefficients used to calculate fluxes. Yellow circles show object-specific parameters, whereas yellow cylinders are site-generic parameters (but the Tk-cylinder is half-time to sorption equilibrium and is further treated in /Avila 2006/). Yellow propellers show radionuclide-specific parameters. Large arrows show fluxes of radionuclides between compartments, whereas small arrows show how functions and parameters are connected within the model. From /Avila 2006/.*

Hydrology

The water balance data presented in this report are calculated values from the near-surface hydrological model for Laxemar, L1.2 /Werner et al. 2005*/. The physically based and spatially distributed modelling tool MIKE SHE was used for the near-surface hydrological modelling. The model is driven by local meteorological data from the Laxemar area for 2004. Meteorological input data to the model are temperature, potential evapotranspiration and precipitation. The actual evapotranspiration and its different components (transpiration, evaporation from soil, interception) was calculated in timesteps less than periods of twenty-four hours during the simulation.

Precipitation (precipitation)

The precipitation is based on local meteorological data from Äspö from 2004.

Evaporation (evaporation)

The value for the evaporation given in this report is the annual mean evaporation from the model area, i.e. a mean value both in time and space.

Transpiration (transpiration)

The value for the transpiration given in this report is the annual mean transpiration from the model area, i.e. a mean value both in time and space. The area is dominated by coniferous trees, but the value of the transpiration represents a mean for all the different types of vegetation within the model area.

Interception fraction (InterceptionFraction)

The value for the interception fraction given in this report is the annual mean interception fraction for the model area, i.e. a mean value both in time and space. The area is dominated by coniferous trees, but the value of the interception fraction represents a mean for all the different types of vegetation within the model area.

Biota

Norway spruce and Scots pine of mesic types are the most commonly found forest type in the Laxemar area followed by mixed (conifers/deciduous) and deciduous forests. Most estimates concerning the vegetation are therefore representing a weighted value between these vegetation types, if not stated otherwise.

Understorey biomass (biomass_understorey)

/Löfgren 2005*/ investigated biomass of the field and bottom layer on six site types with different soils. A weighted estimate is used from a Norway spruce forest and a deciduous forest on herb dominated moist soil, which represents 78% and 22% of the total wood land area (including clear-cuts, but excluding pine forest on acid rock), respectively /Boresjö Bronge and Wester 2003*/. A mean of 0.45 from /Fridriksson and Öhr 2003*/ was used to convert dry weight to the carbon content.

Tree leaves biomass (biomass_leaves)

Data from 148 plots within the Swedish National Forest Inventory /Anonymous 2002/ classified as coniferous forest (Norway spruce dominates) older than 30 years was used to estimate the biomass of needles and 34 plots was used to extract data describing leaf biomass for deciduous forests. This fraction also includes the smallest fractions of branches. These estimates were weighted to value representing the Laxemar area, where the coniferous forest represents 78% and the decidouos forest 22% of the total wood land area (including clear-cuts, but excluding pine forest on acid rock), respectively /Boresjö Bronge and Wester 2003*/. The plots were located within and in the immediate neighbourhood of the regional model area. Carbon content was assumed to be 0.49 of the dry weight /Alriksson and Eriksson 1998/.

Tree wood biomass (biomass_tree)

Data from 148 plots within the Swedish National Forest Inventory /Anonymous 2002/ classified as coniferous forest (Norway spruce dominates) older than 30 years were used to estimate the biomass of wood and 34 plots were used to extract data describing wood biomass for deciduous forests. These estimates were weighted to value representing the Laxemar area, where the coniferous forest represents 78% and the decidouos forest 22% of the total wood land area (including clear-cuts, but excluding pine forest on acid rock), respectively /Boresjö Bronge and Wester 2003*/.The plots are located within and in the immediate neighbourhood of the regional model area. Wood from the stem (without bark) and the branches are included. Carbon content is assumed to be 0.48 of the dry weight /Alriksson and Eriksson 1998/.

Productivity of food normally consumed (productivity_food)

Products normally consumed from the forest comprise fungi, berries, roe deer, moose and mountain hare. The estimate of edible fungi production (40 $kg \cdot ha^{-1}$) is based on a three year field study between 1974 and 1977 /Eriksson and Kardell 1987/, and berry production is based on production estimates from forests of lingonberry, bilberry and raspberry between 1975 and 1977 ($429 \cdot 10^6$ $kg \cdot y^{-1}$) /SCB 1999/. Berry production was divided by the total forest area in Sweden /Statistics Sweden 1998/. The carbon content is assumed to be 1.2% in fresh fungi and 10% in fresh berries /Lindborg and Kautsky 2004*/. Production estimates of the most hunted mammals are based on densities in the area /Truvé and Cederlund 2005*/.

Yearly production of understorey plants (productivity_understorey)

/Löfgren 2005*/ investigated the production of field and bottom layer on six site types with different soils. The field layer was harvested at the time of peak biomass and all biomass produced during the year was taken as an estimate of the production. Bryophyte production was estimated from shoot elongation. Here, the estimate is based on a area-weighted values from a coniferous forest and a deciduous forest (see above). A mean of 0.45 from /Fridriksson and Öhr 2003*/ was used to convert dry weight production to the carbon content.

Yearly production of tree leaves (productivity_leaf)

Data from 148 plots within the Swedish National Forest Inventory /Anonymous 2002/, were classified as coniferous forest (Norway spruce dominates) older than 30 years was used to estimate the net primary production of needles and 34 plots were used to extract data describing net primary production of leaves for deciduous forests. These estimates were weighted to value representing the Laxemar area, where the coniferous forest represents 78% and the decidouos forest 22% of the total wood land area (including clear-cuts, but excluding pine forest on acid rock), respectively /Boresjö Bronge and Wester 2003*/. The plots are located within and in the immediate neighbourhood of the regional model area. The net annual increase of needles was calculated as a function of the stem biomass increase using values from a nearby study area (0.09 of the annual stem biomass increase is the annual needle biomass increase; Asa, /Berggren et al. 2004/). To that figure the litter fall was added, using the assumption of a steady state between litter fall and production. The litter fall was estimated using a figure from a moist Norway spruce forest in same study area (0.22 of the needle biomass was shed each year /Berggren et al. 2004/. Net primary production was assumed to equal the litter fall from deciduous trees that was equal the leaf biomass. Carbon content is assumed to be 0.49 of the dry weight /Alriksson and Eriksson 1998/.

Yearly production of tree wood (productivity_wood)

Data from 148 plots within the Swedish National Forest Inventory /Anonymous 2002/ classified as coniferous forest (Norway spruce dominates) older than 30 years and 34 plots for deciduous forests were used to extract data describing the net primary production of wood. These estimates were weighted to a value representing the Laxemar area, where the coniferous forest represents 78% and the decidouos forest 22% of the total wood land area (including clear-cuts, but excluding pine forest on acid rock), respectively /Boresjö Bronge and Wester 2003*/. The plots are located within and in the immediate neighbourhood of the regional model area. The variable "AVSTILLV" in the Swedish National Forest Inventory was converted from volume to dry weight using a conversion factor (0.404) from /Fink et al. 2003/. Carbon content is assumed to be 0.48 of the dry weight /Alriksson and Eriksson 1998/.

Yearly fractional loss of understorey plants biomass (loss_understorey)

Figures from /Löfgren 2005*/ was used to describe the fraction that was lost from the above-ground fraction of grasses, herbs and dwarf shrubs from a coniferous forest and a descidouos forest. These estimates were weighted to value representing the Laxemar area, where the coniferous forest represents 78% and the decidouos forest 22% of the total wood land area (including clear-cuts, but excluding pine forest on acid rock), respectively /Boresjö Bronge and Wester 2003*/. All non-woody tissue (except for *Vaccinium vitis-idaea* that is evergreen) was assumed to be lost, while woody tissue was retained. No bryophyte loss is included in this estimate.

Yearly fractional loss of litter biomass (loss_litter)

An estimate from a mixed forest was taken from /Chapin et al. 2002/.

Yearly fractional loss of tree leaf biomass (loss_leaves)

The mean fraction lost by litter fall was estimated using a figure from a moist Norway spruce forest in a nearby study area (0.22, Asa /Berggren et al. 2003/). Minimum and maximum values were taken from the dry and moist plots, respectively.

Yearly fractional loss of tree wood biomass (loss_wood)

The figure was taken from /Garten 1999/.

Tree life time (lifelenght_tree)

A mean tree life length of 300 years was assumed for Norway spruce (not taking consequences of forestry into account), whereas the minimum was defined by when a tree becomes a tree, passing a height of 1.3 m.

Fraction of tree leaves in the diet of moose (food_leaves_moose)

Based on a literature survey presented in /Truvé and Cederlund 2005*/.

Fraction of mushrooms in the diet of moose (food_mush_moose)

Based on a literature survey presented in /Truvé and Cederlund 2005*/.

Fraction of understorey plants in the diet of moose (food_plants_moose)

Based on a literature survey presented in /Truvé and Cederlund 2005*/.

Fraction of tree wood in the diet of moose (food_wood_moose)

Figures from /Cederlund et al. 1980/.

Fraction of tree leaves in the diet of roe deer (food_leaves_deer)

Based on a literature survey presented in /Truvé and Cederlund 2005*/.

Fraction of mushrooms in the diet of roe deer (food_mush_deer)

Based on a literature survey presented in /Truvé and Cederlund 2005*/.

Fraction of understorey plants in the diet of roe deer (food_plants_deer)

Based on a literature survey presented in /Truvé and Cederlund 2005*/.

Fraction of tree wood in the diet of roe deer (food_wood_deer)

Figures from /Cederlund et al. 1980/.

Body weight of a roe deer (weight_deer)

The body weight of carbon is 22.9% of the fresh weight. Body weight is presented in /Truvé and Cederlund 2005, Appendix 1*/.

Body weight of a moose (weight_moose)

The body weight of carbon is 22.9% of the fresh weight. Body weight is presented in /Truvé and Cederlund 2005, Appendix 1*/.

5.7 Well

The depth to the groundwater table in the Laxemar area is generally low; typically the groundwater table is located 0.5–1.5 m below ground surface. Both manual and automatic groundwater level measurements indicate that the temporal variations are relatively small; the amplitude of the groundwater levels are usually in the range between 0.5–1 m /Werner et al. 2005/. However, it is not only the groundwater level that is important for the location of a well. The geology has large influence on the capacity of the well. The transmissivity of the bedrock or the QD has to be high enough for the water to flow to the well /Grip and Rodhe 1985/. The well capacity can be good both in discharge and recharge areas.

The capacity of the well is more depending on the geology than of the topography. Often, the geology and the topographic conditions coincide, valleys between high altitude areas are often filled with thick layers of Quaternary deposits.

The overburden in Laxemar is dominated by sandy till. The transmissivity of this fine grain till can be limiting for the water flow to the well and it is necessary to find high conductive layers of sand or gravel of sufficient extension to ensure the water supply in the well /Grip and Rodhe 1985/. For drilled wells in the bedrock it is the fracture zones that play an important role for the water supply. The well capacity is limited by the hydraulic conductivity of the fractures close to the well.

5.7.1 Major flows and processes

The well creates a local discharge area for the water if it is in use /Grip and Rodhe 1985/ and the transport of organic material is generally low, due to percolation through Quaternary deposits.

5.7.2 Development over time

The well capacity and the quality of the water in the well can deteriorate. Meteorological conditions can affect the water supply of the well (a drier climate will cause a lowering of the water levels in the area) but also human activities can cause a decreased water supply in a well. Excavations, ditching or large water outtake in the surroundings can cause a lowering of the water table and the capacity of the well will decrease /Grip and Rodhe 1985/. The impact on a well from excavations or water outtake is largest in coarse soils.

The quality of the water can be affected by different kind of pollution in the area. Dry or wet deposits of chemicals in the drainage area of the well will be dissolved by the water and transported to the well.

5.7.3 Simplified radionuclide model

The concentration of the radionuclide in the well water was calculated by dividing the release rate by the well capacity /Avila 2006/.

5.7.4 Radionuclide model parameterisation

This section describes assumptions and data behind the parameterisation of the site-generic parameters in the conceptual radionuclide model (described above). The parameter name within brackets is the name in the radionuclide model. The parameter values are presented in Appendix I.

Hydrology

Capacity of the well to deliver water (wellcapacity)

The well capacity for the wells in Laxemar is taken from /Morosini and Hultgren 2003*/. A list of the wells in the Simpevarp/Laxemar area is presented in the report, the value used is the mean well capacity of six wells in the area.

5.8 Uncertainties in the site-generic parameterisation

The site-generic parameterisation is in most cases derived from investigations made at the site. This ensures that local conditions are used to constrain the possible output from the biosphere radionuclide modelling. However, some aspects of uncertainty associated to spatial and temporal variation, and to the extrapolation of today's site properties to the future, are discussed below.

5.8.1 Spatial and temporal variation

In the present work we have, for most of the parameters, beside an estimate of the central value, also estimates of standard deviation and min and max values, in order to describe the potential variation under present conditions. These estimates are a basis for sensitivity analysis that pin-point the relative importance of different parameters under present conditions (see Section 8.1.5 and /Avila et al. 2006/. However, some of the field estimates do not have neither the spatial, nor, and perhaps more important, the temporal extension that would be desirable in a short-term perspective (e.g. 100 years). For example, the modelling of climate parameters, such as precipitation and run-off lacks a variation range in this version (see Appendix 1). This implies that the described variation for some parameters at the site does not comprise the potential variation range, even though the estimated mean may be close to the true mean even for a longer time period. Most of the parameters describing the regolith have a rather low range, which further emphasize the use of, so called, site-generic parameters in comparison to parameters describing a specific Biosphere Object, e.g. areas or volumes (described in Chapter 6). However, in future versions some of the site-generic descriptions with a large variation range will be replaced by a Biosphere Object specific description. Generally, the variation range or range of the site-generic parameter statistics have to be regarded as low in comparison to the uncertainties associated with the radionuclide specific parameterisation that is presented in /Avila 2006/.

5.8.2 Future conditions

The parameterisation of the situation today is used for the modelling of future conditions as far as to 50,000 AD. This modelling includes both permafrost conditions and a greenhouse variant, both of which will have profound effects on e.g. production and the hydrological cycle. In some cases, the estimated parameters together with their measures of variation will, most certainly, be valid even under permafrost conditions, e.g. the porosity of peat in a mire or the density of soil used for agriculture purposes. In other cases the estimates will be overestimates for permafrost conditions, such as tree net primary production or bioturbation. Still, as pointed out above, the variation generated by a changing climate, will probably be subordinate to the large range found in radionuclide specific parameterisation. However, these issues will be further penetrated in later versions as a result of the feedback from the sensitivity analyses, described in Section 8.1.5 and /Avila et al. 2006/.

6 Landscape model

The landscape, into which radionuclides may be released, is comprised of a number of different terrestrial and aquatic ecosystems (see Chapter 5). In order to model the fate of a potential radionuclide release into the biosphere, the specific ecosystems subjected to such an release, here called Biosphere Objects, are interconnected by the major water flows. The potential discharge points i.e. the exit points from the deep ground water modelling /Hartley et al. 2006a/, are in this chapter used as input to define the spatial configuration of the landscape model. The main objective in this chapter is to describe the methods and input data used to define the spatial and temporal extent of the Biosphere Objects and their interconnections in the landscape model. In Chapter 5, the different ecosystems and their corresponding dose models are presented along with their site-generic parameterisation, and in Chapter 8 a dose model, based on the landscape model, is presented.

The time span for the landscape development concerns the period 8,000 BC to 9,000 AD, evaluated in time steps of 1,000 years. The duration is considered to be typical of a temperate interglacial during which it is anticipated that substantial changes in the landscape will occur (cf. Chapter 4). It should be noted that the modelling was based on the assumption that the current climate condition is valid for the whole period modelled. In contrast, the time span for the radionuclide modelling stretches over a temperate period (an interglacial period) and a permafrost period (a glacial period) beyond 10,000 AD until 50,000 AD, see Figure 2-4 and Chapter 8. In addition, a greenhouse variant, in which temperate conditions prevailed was modelled.

In this section, we describe the different steps involved in building the landscape model from site data, presenting the methodology, the delimitation of Biosphere Objects, and how to link them into a landscape model. Finally, we describe the methodology for landscape development over time. The different steps in the development and parameterization of a landscape model can be described as:

1. Visualisation of the potential Discharge Points (DP) on a land use map.
2. Identification of Biosphere Objects by identifying clusters of DP's on the map, assigning each cluster to a specific ecosystem and delimiting the Biosphere Object. Areas situated downstream identified objects, and identified by the future lake model as future lakes, were also identified as Objects.
3. Construction of the landscape model by linking the Biosphere Objects based on current and future drainage patterns.
4. Description of the development over time for each Biosphere Object.
5. Compiling a database describing each Biosphere Object, through object-specific parameters, at each time step.

The database with the object-specific parameters may be retrieved, upon request, from SKB.

6.1 Input data

A large part of the information in the analysed Geographical Information System (GIS) layers was based on other models, see for example /Brydsten 2006b/ (elevation); /Werner et al. 2006/ (hydrology) and /Lindborg 2006/ (terrestrial) for site-specific data. In Table 6-1, various input datasets and models are identified. The interrelationship between the input models and the landscape model is shown in Figure 6-1.

Table 6-1. The descriptive data that was used during the GIS modelling along with the data location, the dates and the references where data is presented.

GIS data	Name in SKB's GIS database	Date	Report reference
DEM	SDEADM.UMEU_SM_HOJ_3086	2005-09-23	
Shoreline displacement	Equation from /Påsse 1997/ applied in the DEM.		/Påsse 1997/
Regolith (land)	SDEADM.POS_SM_GEO_2653	2005-06-29	/Bergman et al. 2005, Sohlenius et al. 2004, Rudmark et al. 2005/
Boulderness (land)	SDEADM.SGU_SM_GEO_2501	2004-10-27	/Sohlenius et al. 2004/
Regolith (sea)	SDEADM.SGU_SM_GEO_2623, SDEADM.SGU_SM_GEO_2624, SDEADM.MMT_SM_GEO_2612	2005-06-29, 2004-10-27, 2004-10-11	/Elhammer and Sandkvist 2005, Ingvarson et al. 2004/
Depth of regolith	SDEADM.POS_SM_GEO_2655	2005-07-07	/Nyman 2005/
Soil	SDEADM.SLU_LX_GEO_2497	2005-01-20	/Lundin et al. 2005/
Hydrological model	Not stored in the database. Created from the DEM, with the Hydrology Modelling Tool in ArcGIS 9.1.		/Löfgren and Lindborg 2003/
Vegetation map (land)	SDEADM.SWP_OSK_BIO_1251	2002-08-29	/Boresjö Bronge and Wester 2003/
Vegetation map (sea)	SDEADM.HSK_SM_BIO_1618	2003-06-23	
Lake characterization	SDEADM.UMEU_OH_VTN_2268	2004-09-28	/Brunberg et al. 2004/
Catchment	SDEADM.POS_SM_VTN_3286	2005-09-13	/Brunberg et al. 2004/
Future lakes and water courses			/Brydsten 2006b/
Future catchment			/Brydsten 2006b/
Lake sedimentation			/Brydsten 2006b/
Basin table			/Brydsten 2006b/
Accumulation bottom			/Brydsten 2006b/
Land use	SDEADM.LMV_SM_FK_MY_358	2003-09-25	–

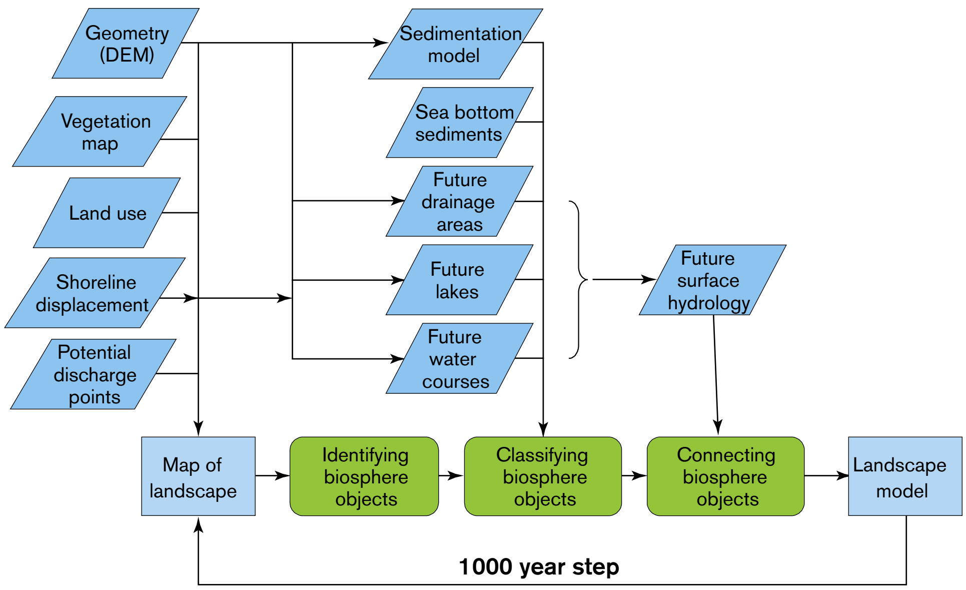


Figure 6-1. Flow chart describing the iterative process of constructing a landscape model. The blue boxes show different input models, green boxes represents actions described in this chapter. This process generates a landscape model for time steps of 1,000 years, describing the configuration and succession of Biosphere Objects in the landscape.

6.2 Visualisation of Discharge Points and identification of Biosphere Objects

Based on the radionuclide transport modelling of the rock /Hartley et al. 2006a/, potential Discharge Points (DP) from a hypothetical repository were presented in a GIS. The delivered exit locations were calculated using the Reference Case model (see Table 7-1 in /Hartley et al. 2006a/). The Reference Case model used in SR-Can /Hartley et al. 2006b/ is identical to that model, except that the western boundary is slightly trimmed to avoid numerical problems that occurred in the predictive modelling. In comparison, except for a handful of particles in a few time steps, the differences in exit locations are small. The transport modelling of the rock uses both continuum and discrete fracture network models on many scales, to investigate the radionuclide transport from each canister position in the potential disposal facility, up to the biosphere, and a discussion on the uncertainties associated with the different models is provided in Section 6.8. In Figure 6-2, the DP's are plotted in the landscape according to the time of particle release from the repository, which started 2,020 AD and continued in steps of 1,000 years until 9,000 AD. The results from this exercise show that discharge points are attracted to nearby low elevation points in the landscape, e.g. shorelines, lakes and mires. This was further confirmed by a study of surface and near surface hydrology with the MIKE-SHE model, that has a higher resolution of the surface and near surface regime /Werner et al. 2005/. Moreover, the future DP's are for the most part located in areas which are covered by the sea today. The potential DP's, with the time for advective transport added to the release time, were also plotted over time, but this did not differ much from the pattern in Figure 6-2. The location of the DP's may be affected by future hydraulic changes, however, such hydraulic changes were not included in the transport model /Hartley et al. 2006a/.

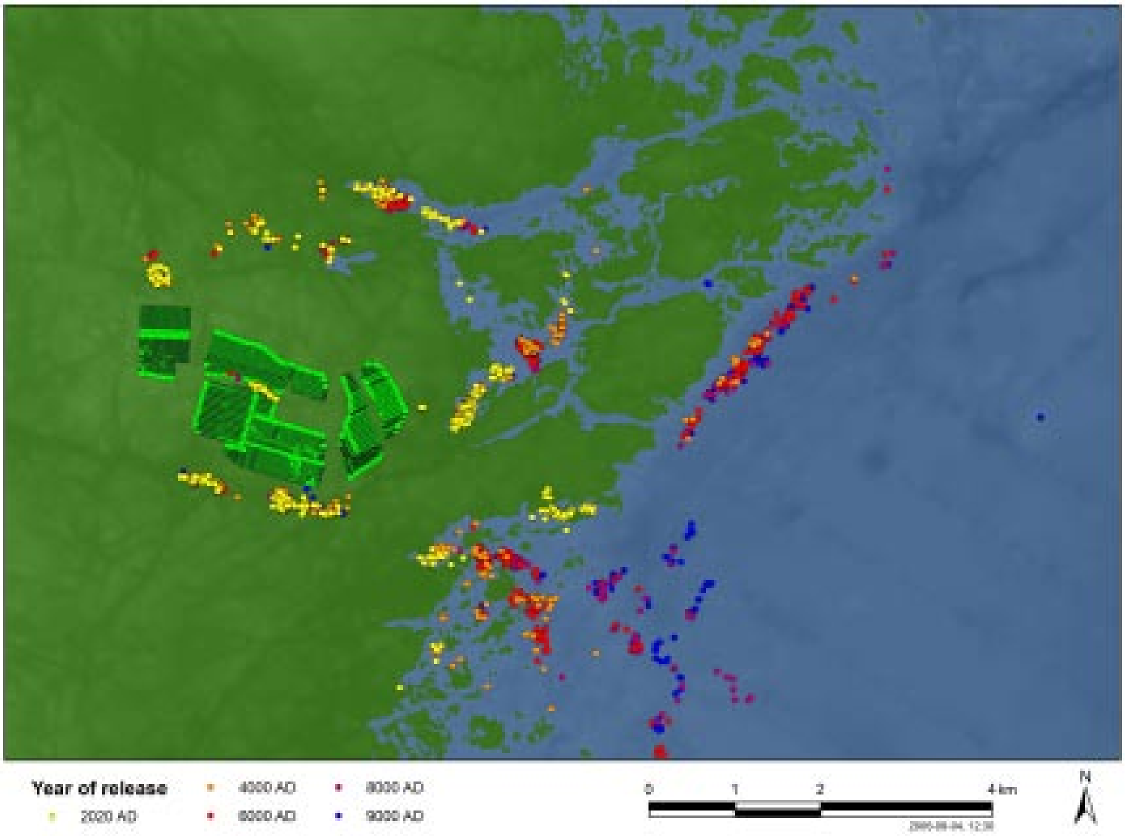


__Figure 6-2.__ Laxemar site with the location of the repository (green) and the calculated exit points over time (yellow), based on the reference case in /Hartley et al. 2006a/.

Together with maps of land use and vegetation, the DP's were visualised and clusters of DP's were identified. Generally, each identified cluster fell within a specific ecosystem (see Chapter 5 for a description of ecosystems). Accordingly, each cluster was assigned to the specific ecosystem and a Biosphere Object was delimited based on the spatial extent of the ecosystem, as described below. Very few DP's were isolated from the identified clusters, and the isolated points found were transferred to the closest object downstream. This procedure was repeated until all of the DP's had been included in a Biosphere Object. To identify all possible Biosphere Objects (historical, current and future), the DP's were plotted on the map of historical and future identified sub-catchment areas, lakes and running waters. Thus, clusters of DP's were used to identify Biosphere Objects relevant both at the present day and in the future.

6.2.1 Delimitation of Biosphere Objects

For lakes as well as for terrestrial ecosystems, the borders of the Biosphere Objects were defined from the existing or projected geometry of the ecosystem, e.g. a defined shoreline of a lake /Brunberg et al. 2004/, or firm ground for wetlands and borders of agriculture land, taken from the land use map (see Table 6-1). For marine Biosphere Objects, the shoreline and the future sub-catchments (called basins) of the area were used as limits for the objects. Thus, some Biosphere Objects were aggregated when they were in their sea period and shared the same drainage area.

In the Laxemar area, 26 objects were identified (21 + 5 running waters, see Figure 6-3). Object 1 is the Baltic Sea and is assumed to be outside the boundary of the model area, whereas Object 2 is a marine basin. These two objects remain as Sea Objects over the whole modeled time period. Sea objects were created for every step of 1,000 years (8,000 BC to 9,000 AD) from existing or future catchments. If some parts of the catchment were situated on land, the land areas were excluded. The running water objects were delimited based on the layer with future water courses, and their lengths were defined by the shoreline at the time. Accordingly, the geometry for these objects changes over time, due to shoreline displacement. No forest objects were identified during the defined time period.

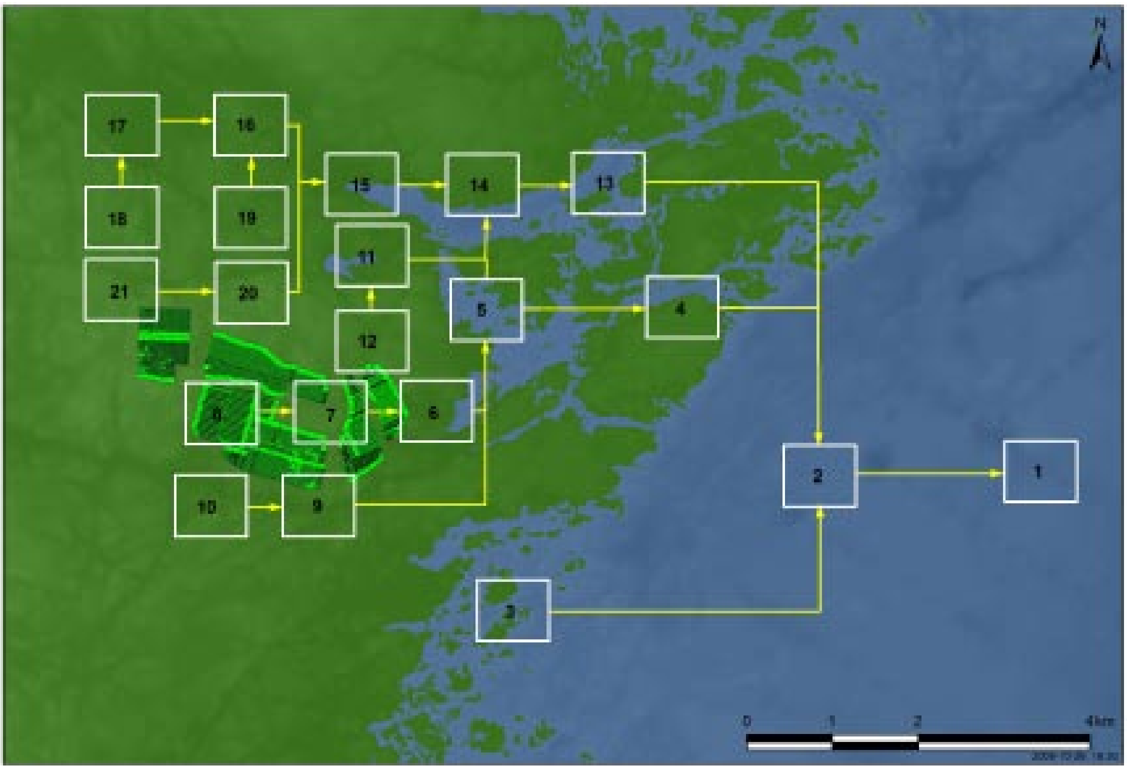


Figure 6-3. The identified objects in Laxemar. All biosphere objects marked with idcodes. Running water objects are not shown.

6.3 Linking Biosphere Objects and their successional development

6.3.1 Linking Biosphere Objects

The defined and delimited Biosphere Objects were linked together in chains based on current and future drainage patterns, determined from the Digital Elevation Model (DEM). This procedure was reiterated for all time periods during the construction of the landscape model. The classification of the present-day Biosphere Objects into different ecosystems was done from site investigation data /Lindborg 2006/. For future and past Biosphere Objects, the classification of ecosystem type was done by a procedure described in the following section.

6.3.2 Successional development of Biosphere Objects

After construction of the current landscape model, including all the potential Discharge Points and Biosphere Objects, the landscape development over time was described. The work was performed by describing each Biosphere Object in the landscape model over time, in time steps of 1,000 years, from 8,000 BC to 9,000 AD. To create the past and future landscape, a land/sea grid for every thousand year step, from 2,000 BC when the whole area was covered by sea, to 9,000 AD, was constructed by using the DEM /Lindborg 2006/ and the shoreline displacement equation /Påsse 1997/. A generic flow chart of the work process is illustrated in Figure 6-4, and the work is further described below.

Successional development of aquatic Biosphere Objects

For each object, the location in relation to the sea level was examined by using the land/sea-grid. If the Biosphere Object was below sea level, it was classified as a sea object during the time period. The sedimentation model /Brydsten 2006b/ was run for defined time steps of 1,000 years, and thereafter the same procedure was repeated until the Biosphere Object was above sea level. The Biosphere Object was then compared with the “future lake map”, created by the Future lake model /Brydsten 2006b, Påsse 1997/ (see Figure 6-5). The sedimentation model uses the DEM /Lindborg 2006/, the future lake model and the marine geology map /Elhammer and Sandkvist 2005/ as input when calculating sediment growth and lake infilling.

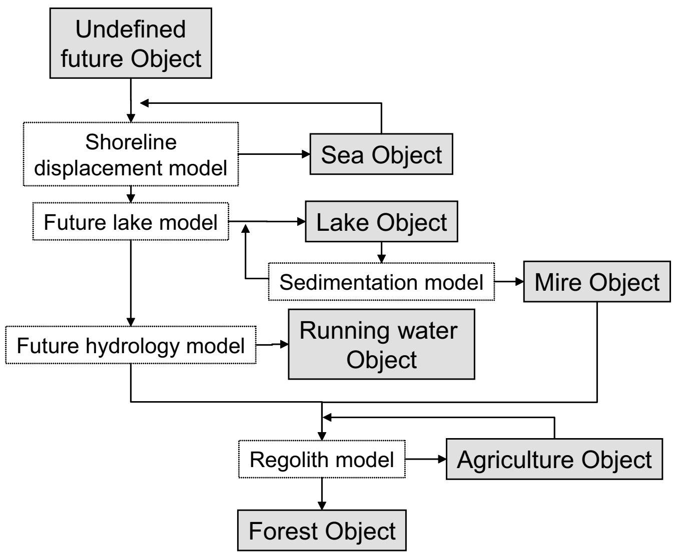


Figure 6-4. *Flow chart describing the process of assigning the successional stages of future Biosphere Objects. Each model will answer the question if an Object will be transformed to a new type of object in the next successional stage by Yes/No. If Yes, the next model in the chain is applied.*

***Figure 6-5.** Existing and future lakes and running waters in the Laxemar area, based on the future lake model /Brydsten 2006b/.*

One output from the sedimentation model is the proportion of lake and mire for an object at the specific time (depending on e.g. water depth). The sedimentation accumulation model was run until the whole lake basin was defined as mire. However, if less than 50% of the surface area was open water and the bathymetry of the lake basin was flat the lake was defined as a mire.

Successional development of terrestrial Biosphere Objects

An important factor for the fate of a mire object is the hydrology. Mire objects were assumed to be drained and used for agriculture after the first time step if five criteria were met.

- The boulder frequency of the underlying regolith should be low (< 1 boulder/100 m^2 /Sohlenius et al. 2004/). Unfortunately, the current marine geology map does not include this kind of detailed information. If boulders were present they were represented as till on the map. When information from this map was used, it was assumed that areas defined as clay may be used for agricultural purposes in the future.

- A suitable soil type with appropriate clay content.
- The object should be larger than a minimum size. The smallest area used for cultivation at either of the two site investigation areas (Forsmark and Simpevarp/Laxemar) is about 750 m^2 /SKB GIS database/. If the area of an object was smaller, it was assumed to be too small to be worth cultivating. If a mire object did not meet these three criteria, it continued the mire stage or was assumed to slowly transform into a forest object.
- If an object had a topographical wetness index (TWI) higher than 9.8 (which is the lowest mean TWI value found for a wetland in the Laxemar area today) it was classified as a mire object, otherwise it was classified as a forest object.
- The object had to be at least one metre above sea level. No present agricultural area in Forsmark or Simpevarp/Laxemar site investigation areas is situated below this height.

It was assumed that future agricultural activities in Forsmark will be performed on previous mires. Whether cultivation is possible depends on the thickness of the organic layer, accumulated during earlier stages, and the deposits underlying the peat. When cultivating peat areas, oxidation processes will increase the weathering of the organic layer. It could be assumed that the thickness of the organic soil layer would decrease by 1 cm per year during the cultivation period /Osvald 1937, Kasimir-Klemedtsson et al. 1997/. In the approach used here, after a certain period, the agricultural object would turn into a forest object due to this oxidation process. The time-scale for that transition would be governed by the thickness of the regolith, assuming that the cultivation of an area would end when the thickness is below 1 m. However, this assumption can be disputed, as the cultivated areas in Sweden have the potential, if fertilised, to stay arable for long time periods. Therefore, the transition from agriculture to forest was not necessarily determined by this criterion in the landscape model. In the final landscape model only one object, Object 21, was set to forest after a period of agriculture, and this, due to the shallow soil depth and unfavourable underlying mother material.

If a future object, situated above sea level, was not classified as a future lake according to the Future lake model, four different object classifications were available depending mainly on hydrological criteria;

1. it was classified as a mire object if the Geomorphic model indicated likelihood for water discharge /Brydsten 2006a/ and TWI > 9.8, and if the Hydrology model /Werner et al. 2005/ showed that the characteristics for running water were not fulfilled, else,
2. if the characteristics for running water according to the Hydrology model were fulfilled, it was classified as a running water object, else
3. it was classified as one of the other terrestrial objects, forest or agriculture.

6.4 The resulting landscape development

Creating the landscape model was an iterative procedure. After a Biosphere Object had been identified and delimited, the procedure was rerun to identify neighbouring objects in the same sub-catchments. Sub-catchment objects were displayed on maps in 1,000 year steps and combined to one object if they were in the same stage of development. Some sub-catchments, with Biosphere Objects not synchronised in time, were instead distinguished into several Biosphere Objects. During this process, the difference in height above sea level for the objects was also compared to evaluate if a further subdivision was relevant.

The modelled development of the landscape over time was plotted in a series of maps at 1,000 years interval. Examples of different time periods are shown in Figure 6-6. In Table 6-2 the Biosphere Objects are listed for all time periods.

Three main periods with different conditions were identified; the sea period from 8,000 BC to about 3,000 BC, a coastal period from 3,000 BC to about 7,000 AD and a terrestrial period thereafter. From the deglaciation (see Chapter 4) and until 3,000 BC, the site is submerged under the sea. During this period, the water volume of the marine Biosphere Objects decreases and only three objects are modelled; the basin above the repository, the basin outside the Simpevarp peninsula (Object 2) and the rest of the Baltic Sea (Object 1). The shoreline displacement gradually reveals more objects and a continued succession of existing Biosphere Objects make the landscape heterogeneous. During the coastal period, the largest representation of different Biosphere Object types occurred. From 7,000 AD and onwards there were only few sea objects (1, 2 and 3) and three lakes (4, 13 and 14), the other Biosphere Objects having turned into forests and mires, and some transformed to agricultural land.

In order to investigate the landscape development after 10,000 AD, the landscape succession was also investigated for 12,000 AD and 20,000 AD (Table 6-2). However, this information was not used in the modelling of landscape doses described in Chapter 8.

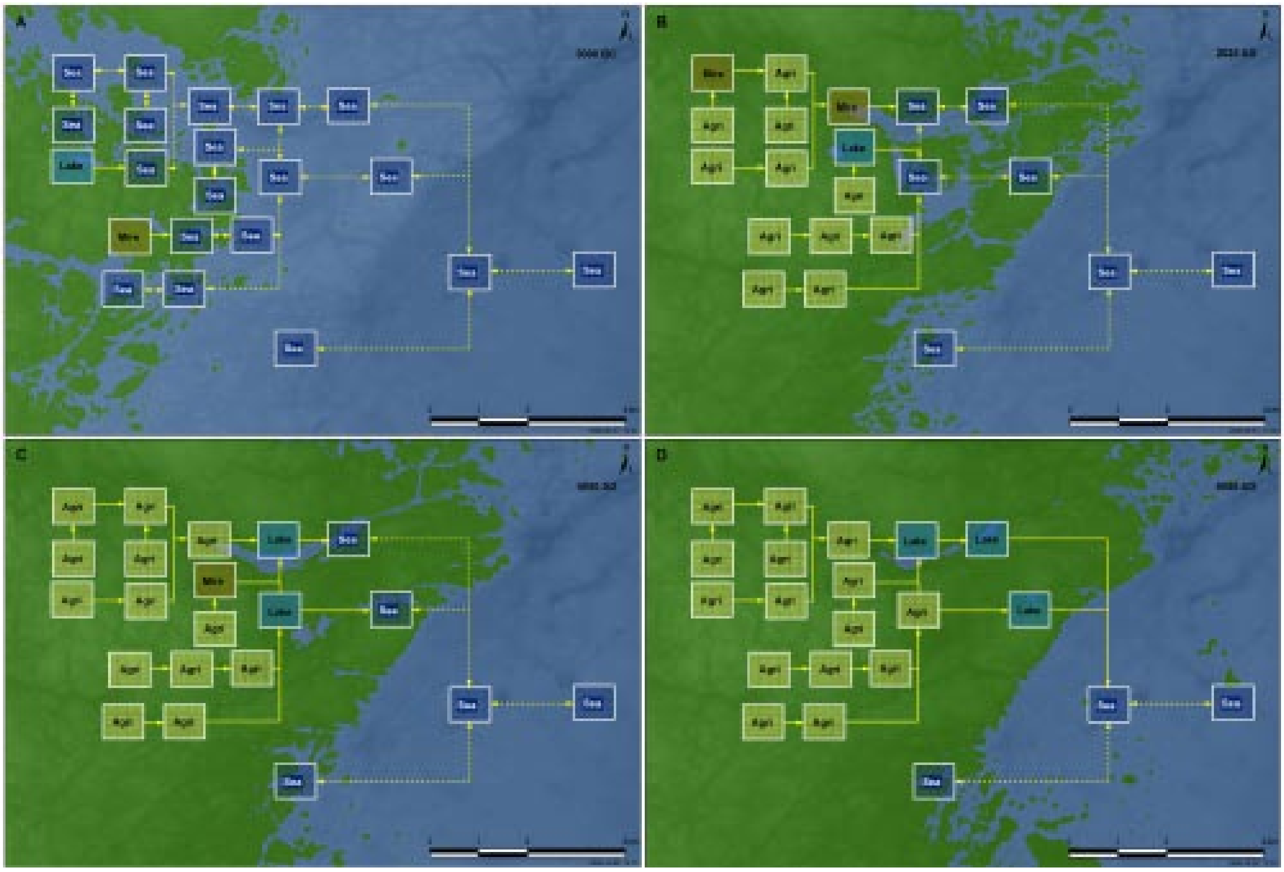


Figure 6-6. *The landscape at four different time periods in Laxemar. Marine stage from 8,000 BC to 3,000 BC (A), coastal stages at 2,020 AD (B), and at 4,000 AD (C), and a terrestrial stage at 9,000 AD (D). The ecosystems of the objects change gradually according to Table 6-2.*

Table 6-2. The table describes the succession of the different identified biosphere objects. The object number corresponds to those in Figure 6-3. The colors denotes the different biosphere object types, dark blue-sea, blue-lake, green-running water, orange-mire, yellow-agriculture land.

Object number	7980BC	6000BC	5000BC	4000BC	3000BC	2000BC	1000BC	0AD	1000AD	2020AD	3000AD	4000AD	5000AD	6000AD	7000AD	8000AD	9000AD	12 000AD	20 000AD
1	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea
2	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea
3	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Lake	Mire
4	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Lake	Lake	Lake	Mire	Agriculture land
5	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Lake	Lake	Mire	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land
6	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
7	Sea	Sea	Sea	Sea	Sea	Mire	Mire	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
8	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
9	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
10	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
11	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Lake	Lake	Mire	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
12	Sea	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
13	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Lake	Lake	Lake	Lake	Lake	Mire
14	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Mire
15	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Mire	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
16	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
17	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Lake	Lake	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
18	Sea	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
19	Sea	Sea	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
20	Sea	Sea	Sea	Sea	Sea	Sea	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land
21	Sea	Sea	Sea	Sea	Lake	Mire	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land	Agriculture land

6.5 Object-specific parameterisation

The Biosphere Objects are characterised both with regard to ecosystem properties, so called site generic-parameters, that are described in Chapter 5, and in regard to parameters that are taken as unique for each identified Biosphere Object, so called object-specific parameters, such as area and water volume. Below follows a description of how these object-specific parameters were estimated. The estimated values are available upon request from SKB.

6.5.1 Sea, lake, mire and forest objects (polygon objects)

Objects that were created out of existing or future lakes already had their area, volume, surface elevation, mean depth and maximum depth assigned /Brunberg et al. 2004, Brydsten 2006b/. The lake objects also have information about when they are cut off from the sea (time of initiation) and time when they are overgrown (time of extinction).

Areas of the other object types (sea, mire and forest) were calculated by using the tool XTools in ArcGIS 9. The surface elevation for every time-step was calculated with the shoreline displacement equation /Påsse 1997/. With the tool Zonal Statistics, minimum, maximum and mean elevation today was computed from the DEM. The mean depth (sea objects) for each time step was calculated as the difference between the surface elevation of the time step and the mean elevation of today. The volumes for sea-, mire- and forest objects were calculated as mean depth multiplied by area. Catchment, slope and basin areas were assigned to the objects using the DEM model. The mean slope was assigned to the objects by using the ArcGIS tool Zonal Statistics.

The properties of the dominant regolith type for each object were obtained by a union of the regolith map and the object polygon. Regolith data were not available for some objects outside the regional site investigation area. For those objects, generic regolith data were applied and this is noted in the attribute list.

The proportion of accumulation bottom within each sea object was calculated from the accumulation bottom map /Brydsten 2006b/. The proportion of accumulation bottom was calculated as the area of accumulation bottoms divided by total object area.

6.5.2 Running water objects (line objects)

For the running water objects, the length was calculated and assigned to the objects. The modelling resulted in a GIS project file (an mxd file created in ArcGIS 9.1), that comprises two shape files relating to the Biosphere Objects (a polygon and a line file).

6.6 Permafrost conditions and the landscape model

Permafrost conditions occur in several episodes during the Weichselian glacial cycle that is used as a model for future glacial cycles. At the Laxemar site, the next permafrost episode is assumed to start about 10,000 AD, following the present interglacial (see Chapter 4). At that time, the coastline is located at some distance from the repository and major discharge areas are not located offshore. The situation is similar at the end of any future interglacial when global sea levels are falling. To simulate the permafrost conditions, it was assumed that the spatial distribution of landscape objects is similar to that at the end of the temperate interglacial period (Figure 2-4), except that agricultural land is replaced by forests or mires, reflecting the consideration that a significant degree of agriculture would not be tenable in such a context.

6.7 Greenhouse variant and the landscape model

In the dose modelling of the greenhouse variant, in which the temperate conditions are prolonged until 50,000 AD, the landscape model at 9,000 AD was used throughout the period until 50,000 AD (see also Figure 2-4).

6.8 Uncertainities of the landscape model

In the development of a landscape model, a number of assumptions and simplifications have had to be made. From one step to another, uncertainties associated with these assumptions are accumulated. For this reason, the major underlying models that affect the properties of the overall model (e.g. classification of ecosystems, ecosystem changes over time (both natural succession and changes caused by humans) and location of Biosphere Objects have to be simple and robust. The strategy to use the sites as they appear today as basic input, and to use simple geometrical models to further describe the history and the future, is a way to decrease uncertainties. This argument, of course, depend on the reliability of the underlying models used, e.g. geometry, shoreline displacement, hydrogeological transport models and surface hydrology.

Our approach to evaluate the uncertainties in the landscape model is firstly to assess the uncertainties in the underlying models upon which the landscape model is built, and secondly to evaluate the assumptions made within the landscape model. Below are the main models described in terms of uncertainty, followed by an evaluation of the uncertainties of the overall landscape model.

Digital elevation model (DEM)

The DEM is constructed by interpolation from irregularly spaced elevation data using a Kriging interpolation method. Kriging weights the surrounding measured values to derive a prediction for unmeasured locations. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial distribution of the measured points. A validation procedure is then used in order to change the Kriging parameters to minimise the prediction errors. An indisputable best combination of Kriging parameters is impossible to find, but in the development of the DEM the validation procedure was performed until only minor changes was noted in the prediction errors. The final choice of parameters is presented in /Brydsten and Strömgren 2005/.

The DEM has a high resolution and the uncertainties in the model must be considered as generally small. However, due to the relatively flat terrain in the Laxemar area and to human encroachment in the area (mainly ditching), the DEM has some small errors. These errors, which may affect the modelled flow paths in the GIS model, are possible to evaluate by estimating the deviation between the modelled flow paths and the actual water courses that exist today. This type of evaluation has been done /Brydsten 2006a/, and the results show that the major part of the GIS model deviates only marginally from the actual water courses, and that the Biosphere Objects on present land are connected in the same way when using the GIS model. It is, however, difficult to evaluate errors in the DEM model for areas that are submerged today.

Surface hydrology

The evaluation of time series of local meteorological data and surface water and groundwater levels, enabling comparisons between different processes and hydrological sub-systems, has lead to an improved understanding of the site that supports some of the fundamental aspects of the descriptive model. The locations of recharge and discharge areas at different scales are crucial for the understanding of the groundwater system. Ongoing work is evaluating the modelled recharge and discharge areas using independent data, such as hydrological measurements, Quaternary deposits and vegetation /Werme et al. in prep./. The present overall descriptive model of the surface-hydrological and near-surface hydrogeological system is considered to be acceptable in a qualitative sense, which means that the general description of the hydrological and hydrogeological driving forces and the overall flow pattern is not thought likely to change substantially in future models.

Potential discharge points

Different conceptual models of the bedrock provide different discharge points. Specifically, in a continuum representation discharge points tend to follow the displacing shoreline, whereas in a Discrete Fracture Network (DFN) representation the discharge points are primarily governed by vertical deformation zones and larger vertical fractures. Thus, discharge points do not move in time to the same extent as in a continuum models. However, in both model types discharge takes place in low altitude areas such as lakes, sea, wetlands and agricultural areas. Furthermore, a correlation exists between these low points in the landscape and the occurrence of major vertical deformation zones. Discharge thus predominantly takes place at these low points irrespective of whether an DFN or continuum representation is used.

In the models, particle tracking identifying the discharge points has been performed in steady-state velocity fields. In reality, migrating solutes are subject to changes in the velocity field implied by e.g. the receding shore line. In a numerical study relevant for deep repository conditions, /Moreno et al. 2006/ investigated the effect of transient flow fields on solute transport subject to both matrix diffusion and sorption. It was shown that non-interacting solutes pre-dominantly are governed by the flow field at the release time, whereas strongly sorbing solutes are governed by the late time flow field. Intermediately sorbing solutes, however, experience the evolving flow field to a greater extent. The discharge locations calculated with the models in SR-Can for different times may consequently be seen to represent the span of possible discharge locations for a solute release consisting of nuclides with different sorption properties. It should be kept in mind, however, that some nuclides will have travel times of hundreds of thousands of years. Over such time periods, permafrost and glacial conditions will occur for extended intervals. The effect of such climatic conditions on the final discharge points of a solute affected by retention processes in the geosphere has not been evaluated.

The landscape model

In the first two steps of the construction of the landscape model, potential discharge points are displayed and the Biosphere Objects are delimited. The main uncertainty related to these tasks is the combination of many and sometimes scattered, discharge points to define a single Biosphere Object. As mentioned above, the potential discharge points are most often found in low altitude areas, which also was confirmed by /Werner et al. 2006/. These low altitude areas most often coincide with a specific ecosystem, which also by it's low altitude will constitute the recipient for discharge points within the catchment of that ecosystem.

In the next step, the identified Biosphere Objects are connected to each other. The technique uses the hydrological GIS models of the surface flow paths and is fairly straightforward and simple. The main uncertainty related to this step is the accuracy in the terrain model (DEM), which is treated above.

Finally, the development of the landscape model over time, including successional development of the different Biosphere Objects, has to be described during the whole time period between 8,000 BC and 9,000 AD. This task is dependent on a number of assumptions and sub-models (see Section 6.1). The major uncertainties recognised are:

- The successional development of Biosphere Objects, and the timing of these changes.
- In the climate conditions adopted.

Due to the complexity of processes involved in the natural development of the landscape and the ecosystems there within, coupled with anthropogenic influences on the landscape, the description of the succession is built on just a few "master-parameters". For example, from parameters describing the geometry and the shoreline displacement model, we can predict when a sea object turns into a lake object, and by modelling the sedimentation rate we can tell when the lake turns into mire. We will not know the biotic properties of these future objects, but from the present situation we can predict the upper limits of their production capabilities.

All this is, of course, dependent on how the climate develops. In this work with the landscape model we used the present climate conditions for the whole time period. For example, no greenhouse effects were taken into account in the shoreline displacement model. The effect of this assumption of no change in climate in terms of uncertainties has not been evaluated. However, we are modelling the Laxemar site for the whole temperate interglacial, so we can, for example, use the time periods with a higher sea level to simulate site conditions for a rising sea level or vice versa.

In conclusion, we believe that this methodology that uses few and physically driven parameters to build the landscape model, not only minimises the uncertainties and limits the potential for error, but shows a clear and precise methodology that limits the speculations of possible future landscape changes.

7 Humans

When modelling doses to humans from exposures to radionuclides, site-specific data have an important influence on the result obtained, but, in addition, a number of assumptions concerning human behaviour have to be made. This section describes the methodology and the assumptions behind the calculations of doses to humans from exposures to radionuclides.

7.1 Food intake, production and population size

In previous assessments of doses to humans, a standardised diet was used /e.g. Bergström et al. 1999, Karlsson et al. 2001/. An important task in order to improve the assessment is to populate the models with food data from the site. Previously, the food production has been generalised from national food statistics, without any reference to the productivity of that particular food item at the site. The problem is that in a specific ecosystem, only a subset of all food items is available or possible to produce. For some food items this is obvious, e.g. it is impossible to get fish from agricultural land. However, for other food items, for which production may occur, but may not be sufficient to feed one person, the question is more difficult to address. The other problem is to weight the importance of different food items, according to their varying nutritional value and to human preferences. For long-term assessments, it is difficult to postulate a particular dietary composition, as human habits and choices may change over time.

To avoid speculations in SR-Can about future food habits and exploitation of the landscape, the nutritional demand corresponding to 110 $kgC \cdot y^{-1}$ was used as the intake of food by an adult /Avila and Bergström 2006/. Organic carbon was used as a unit of caloric intake to weight different food items proportionally to their nutritional value, as is commonly done in ecosystem studies /Odum 1983/. It was assumed that nutritional demand will be fairly constant even for future humans. The intake of water, food and air adopted is tabulated in Table 7-1, which is taken from /Avila and Bergström 2006/.

Table 7-1. Values for human intake of food, water and air used in calculation of doses to humans via water ingestion, food ingestion, inhalation and external exposure. All values are chosen at the high end of the range of values in, or estimated from, ICRP recommendations (see further /Avila and Bergström 2006/).

Parameter	Units	Value	Comments
Intake rate of water by an individual	$m^3\ y^{-1}$	0.6	Intake rate of water by adults, excluding water consumed as a component of food. /ICRP 1975, 2004/.
Intake rate of carbon by an individual	$kg\ C\ y^{-1}$	110	Estimated from the intake of protein, carbohydrates and fats by adult males given in /ICRP 1975/.
Inhalation rate	$m^3\ h^{-1}$	1	Based on values of total ventilation during a day for adult males given in /ICRP 1975, 2004/.

Another important assumption is that humans will exploit the contaminated landscape maximally, thus eating all potentially edible food produced within the Biosphere Objects. Thus the number of persons that can live of the production from a specific Biosphere Object is constrained by the annual area-specific productivity of edible products and the size of the object. The production of naturally occurring food items is constrained by the primary production of the object and can be assessed separately (cf. Chapter 4).

In principle, individuals can consume, occupy or otherwise utilise environmental media (e.g. food, water for consumption or irrigation, construction materials) from several different Biosphere Objects, and it is this overall pattern of utilisation that determines the time-averaged effective dose rate that they receive. However, the regulatory requirements place emphasis on the most highly exposed subgroup of individuals in the population. Consequences should be calculated for a representative individual in the group exposed to the greatest risk (the most exposed group). SSI's general guidance indicates that the group should be defined to include "the individuals that receive a risk in the interval from the highest risk down to a tenth of this risk" /SSI 2005/.

In order to ensure that the effective dose rate to the most exposed subgroup is identified, calculations of effective dose rate are made for population groups that are taken to occupy a single Biosphere Object and obtain all their resources from that object. This ensures that individuals make maximum reasonable use of local resources and that the effective dose rate arising from utilising the most contaminated part of the landscape is not diluted by utilisation of less contaminated parts of the landscape.

Having adopted this approach, it is possible to estimate not only the effective dose rate to individuals utilising a particular Biosphere Object, but also the number of individuals that object can fully support. For the Biosphere Object giving the highest effective dose rate, this is the maximum number of people that could be associated with that effective dose rate. In practice, most individuals would utilise resources also from other parts of the landscape, so the effective dose rate that they receive will be lower.

The number of individuals that the identified Biosphere Objects in the Laxemar area can support varies from less than one (0.003) for some terrestrial objects, to slightly above one thousand in the case of some marine objects /cf. Avila et al. 2006/. Clearly, where the Biosphere Object that gives the highest effective dose rate based on sole utilisation can support less than one person, that effective dose rate is too high to be applicable to the most exposed individual, since an individual utilising that Object would also have to utilise resources from other Objects. Conversely, where the Biosphere Object that gives the highest effective dose rate based on sole utilisation can support a large number of people, heterogeneities in environmental concentrations would mean that, in practice, some individuals would receive higher effective dose rates than that calculated, whereas others would receive lower effective dose rates.

In reality, the utilisation of natural food production is overestimated for some of the ecosystems (e.g. mire and forest) since only minor fractions of the produced berries or mushrooms are utilised.

7.2 Dose conversion factors

A revised methodology for the calculation of doses from exposures to radionuclides in the environment, starting from radionuclide concentrations in environmental media (i.e. air, water, food and soil) is presented in /Avila and Bergström 2006/. The methodology considers the main exposure pathways that may arise from a continuous input of radionuclides into the biosphere with contaminated groundwater, which is the release scenario of most relevance for the safety assessment of geologic repositories. The report also describes the methodology implementation in Pandora /Åstrand et al. 2005/, which is the tool currently used by SKB and POSIVA (The Finnish equivalent to SKB) for biosphere dose modelling. The dose estimations obtained from this modelling can be considered pessimistic, but still realistic, life-time dose estimates in most relevant exposure situations /Avila and Bergström 2006/.

Humans can be exposed both externally and internally to radionuclides occurring in the environment. The external exposure comes from radiation emitted by the radionuclides in surrounding environmental media; air, water and soils. Previous safety assessments of planned geologic repositories in Sweden and Finland /Bergström et al. 1999, Karlsson and Bergström 2000/ have shown that for most radionuclides of concern, external exposure gives a minor contribution to the total dose. External exposure from air and water is negligible for all radionuclides of interest, but for radionuclides with high gamma-energy and low bioavailability, such as Nb-94, external exposure to radionuclides accumulated in the ground (soil) may give an important contribution to total dose. Hence, exposure from radionuclides accumulated in the ground is the only external exposure pathway included in this methodology /Avila and Bergström 2006/.

Internal exposure is always preceded by incorporation of radionuclides into the human body. This can occur mainly by inhalation of contaminated air, or by ingestion of contaminated water, soil and food. For inhalation (and external exposure), the applied methodology considers outdoor exposure for hundred percent of time, which in most cases gives a cautious estimate for inhalation, as the radionuclide contamination of the air comes from resuspension of soil particles.

The methodology also considers the internal exposure due to oral intake of radionuclides. This exposure will, among other things, depend on the fraction of contaminated food, soil and water consumed, and on the level of activity in the foodstuffs, soil and water. In this methodology it is assumed that the annual demand of water and food is contaminated. Hence, no assumptions have been made regarding food preferences (see Section 7.1) and instead the calculations are based on values of food energy intake given by the ICRP for the reference human /ICRP 1975, 2004/.

The dose coefficients used in SR-Can are tabulated in Table 7-2 and described further in /Avila and Bergström 2006/. All recommended values, with the exception of the values for Rn-222, are taken from the European Union recommendations /EUR 1996/. Values for radon, Rn-222, are missing in the European Union recommendations and were taken from /NRC 1999/.

Table 7-2. Dose coefficients used in SR-Can modelling for ingestion and inhalation (Sv/Bq), and for external exposure (DCC, Sv/h per Bq/m³), for human adults. The values are based on /EUR 1996/ and, for ingestion of Rn-222, on /NRC 1999/. The dose coefficients for external exposure are taken from /Eckerman and Leggett 1996/. See further /Avila and Bergström 2006/.

Nuclide	Ingestion (Sv/Bq)	Inhalation (Sv/Bq)	DCC (Sv/h per Bq/m³)
H-3	1.8E–11	2.6E–10	–0.0E+00
Be-10	1.1E–09	3.5E–08	1.9E–17
C-14	5.8E–10	5.8E–09	2.1E–19
Cl-36	9.3E–10	7.3E–09	4.8E–17
Ca-41	1.9E–10	1.8E–10	0.0E+00
Co-60	3.4E–09	3.1E–08	3.0E–13
Ni-59	6.3E–11	4.4E–10	0.0E+00
Ni-63	1.5E–10	1.3E–09	0.0E+00
Se-79	2.9E–09	6.8E–09	3.0E–19
Sr-90	2.8E–08	1.6E–07	1.2E–17
Zr-93	1.1E–09	2.5E–08	0.0E+00
Nb-94	1.7E–09	4.9E–08	1.8E–13
Mo-93	3.1E–09	2.3E–09	8.0E–18
Tc-99	6.4E–10	1.3E–08	2.1E–18
Pd-107	3.7E–11	5.9E–10	0.0E+00
Ag-108m	2.3E–09	3.7E–08	1.7E–13
I-129	1.1E–07	9.8E–09	1.8E–16
Cs-134	1.9E–08	2.0E–08	1.7E–13
Cs-135	2.0E–09	8.6E–09	6.2E–19
Cs-137	1.3E–08	3.9E–08	6.5E–14
Sm-151	9.8E–11	4.0E–09	1.3E–20
Eu-152	1.4E–09	4.2E–08	1.3E–13
Eu-154	2.0E–09	5.3E–08	1.4E–13
Eu-155	3.2E–10	6.9E–09	3.1E–15
Ho-166m	2.0E–09	1.2E–07	1.9E–13
Pb-210	6.9E–07	5.6E–06	3.8E–17
Po-210	1.2E–06	4.3E–06	9.5E–19
Rn-222	0.0E+00	3.5E–09	4.2E–17
Ra-226	2.8E–07	9.5E–06	5.6E–16
Ac-227	1.1E–06	5.5E–04	8.6E–18
Th-229	4.9E–07	2.4E–04	5.6E–15
Th-230	2.1E–07	1.0E–04	2.1E–17
Th-232	2.3E–07	1.1E–04	8.8E–18
Pa-231	7.1E–07	1.4E–04	3.4E–15
U-233	5.1E–08	9.6E–06	2.4E–17
U-234	4.9E–08	9.4E–06	6.6E–18
U-235	4.7E–08	8.5E–06	1.3E–14
U-236	4.7E–08	8.7E–06	3.4E–18
U-238	4.5E–08	8.0E–06	1.5E–18
Np-237	1.1E–07	5.0E–05	1.3E–15
Pu-238	2.3E–07	1.1E–04	2.2E–18
Pu-239	2.5E–07	1.2E–04	5.1E–18
Pu-240	2.5E–07	1.2E–04	2.2E–18
Pu-241	4.8E–09	2.3E–06	1.0E–19
Pu-242	2.4E–07	1.1E–04	1.9E–18
Am-241	2.0E–07	9.6E–05	7.2E–16
Am-242m	1.9E–07	9.2E–05	2.8E–17
Am-243	2.0E–07	9.6E–05	2.4E–15
Cm-244	1.2E–07	5.7E–05	1.7E–18
Cm-245	2.1E–07	9.9E–05	5.9E–15
Cm-246	2.1E–07	9.8E–05	1.6E–18

8 Landscape dose factors and, doses to humans and biota

The Landscape Model with the interconnected Biosphere Objects, described in Chapter 6, was, together with the ecosystem-specific radionuclide models (Chapter 5), used to construct a radionuclide exposure model. This model was populated with site-generic parameter values (Chapter 5) and object specific parameters values (Chapter 6) for the different time periods listed in Table 6-2. The number of potential discharge points in each Biosphere Object and time period was used to weight the importance of the different objects. This chapter describes how the exposure model was run in the Pandora tool, to obtain the Landscape Dose Factor (LDF) values used in SR-Can.

8.1 Modelling of long-term distribution of radionuclides in the landscape during an interglacial

All ecosystem models applied are briefly outlined in Chapter 5. A more detailed description can be found in /Avila 2006/. The models are in principle the same that were used in the assessments performed for SR-Can Interim /SKB 2004/, with the exception of the forest model, which was not available at that moment. The radionuclides included in the simulations are presented in Table 7-2. For radionuclides with decay chains, the distribution of the daughter radionuclides in the landscape, resulting from unit releases of the parent, were also considered.

8.1.1 Data

The numerical modelling with the Landscape Model use three different types of model parameters 1) site generic parameters describing properties of the different ecosystems (Chapter 5), 2) radionuclide specific parameters describing the behaviour of specific radionuclides, such as distribution coefficients (K_d) and the transfer factors from soils and waters to biota /Avila 2006/, 3) object specific parameters describing properties of specific objects (Chapter 6).

The parameter databases were version controlled using Subversion (http://tortoisesvn.tigris.org/). The versions, used in the Pandora modelling, of the site-generic parameter database and the object-specific parameter database were number 469 and 563, respectively /SKB database, 2006/.

8.1.2 Model implementation

The landscape models were implemented in the software package Pandora /Åstrand et al. 2005/. Pandora is a development of Tensit /Jones et al. 2004/ and an extension of the well-known software Matlab© and Simulink© from Mathworks (www.mathworks.com). Pandora simplifies the development of models resulting in large systems of differential equations and the handling of radionuclide decay chains. The Pandora tool comprises a library of Simulink© blocks that facilitates the creation of compartment models and a standalone Toolbox for management of parameter values and probabilistic simulations.

A library of ecosystem models was created in Pandora, which facilitates handling several instances of the ecosystem models in the landscape model. For each landscape object a Simulink© subsystem was created, which includes models of all ecosystem types that may exist in this object during the whole simulation period. The discrete transition between ecosystem models was implemented using switches available in Simulink©. The decay and in growth of radionuclides in a chain was handled with the help of the Pandora Radionuclide block. For integrating the model, the solver ode15s was used, which is an appropriate solver for stiff systems of equations with discrete events. The activity concentrations and doses were calculated from the amount of activity in different compartments predicted with the Pandora model by using a post-processing routine created in Matlab©.

8.1.3 Landscape change

The transformation between ecosystems (every thousand years) was modelled as discrete events, by substituting one model by another. The activity in different compartments of the "mother" ecosystem was transferred instantaneously to the appropriate compartments of the "daughter" ecosystem following specified rules that were set so as not to underestimate the potential doses (see Table 2-3 in /Avila et al. 2006/ for the rules). For example, if an ecosystem was transformed into a forest from e.g. a seabed or mire, then the total activity in the ecosystem, including the fraction in the deep sediment, was transferred to root zone of the forest soil. As the inventory is transferred, this is equivalent to setting the initial conditions of the compartments in the daughter ecosystem to a value equal to the transferred inventory. In the Laxemar landscape model, three main periods of landscape development were identified in the interglacial period (Figure 6-6). Quite soon after the de-glaciation, at about 8,000 BC, parts of the hills closest to the repository are small islands. These are then re-submerged during a regression of the shoreline which occurs between 7,000 BC and 5,000 BC. All release points are located in the sea until 3,000 BC (Sea Period). Thereafter, a Coastal Period starts, during which mires and lakes are formed in narrow valleys around the repository footprint, and already around 3,000 BC the first potential agricultural areas are formed. From 3,000 BC, release points occur also in terrestrial ecosystems. At around 0 AD, the landscape resembles the present conditions at Laxemar, with several small agricultural areas situated in long and deep valleys. Only a few of the lakes and mires that are formed from the sea objects have properties that preclude them from being transformed into agricultural lands. Mires are assumed to be transformed to agricultural lands unless factors such as size and boulder content make this unlikely (see Chapter 6). This overestimates the area of agricultural land, which in most cases is cautious for estimating radiological impact on humans. At 4,000 AD the Coastal Period ends and terrestrial objects, mainly agricultural lands, dominate the surroundings of the repository (Terrestrial Period). Thereafter, the remaining bays and lakes are gradually filled, but Granholmsfjärden (Object 14) remains as a lake in 10,000 AD.

8.1.4 Results

This section presents briefly some results describing the radionuclide inventories and concentrations obtained for Laxemar for the interglacial period that is presented in more detail in /Avila et al. 2006/.

The landscape

For all radionuclides the total inventory increases monotonically during the Sea Period (8,000 BC to 3,000 BC). This behaviour is consistent with the persistence of accumulation conditions in the sediments during the whole period, as determined by the presence of accumulation bottoms. The most mobile radionuclides, Cl-36 and Tc-99, decreases during the Coastal Period (3,000 BC to 4,000 AD) and stabilises during the Terrestrial Period, whereas some radionuclide inventories increase further but shows a tendency for stabilisation in the end of the terrestrial period. The observed between-radionuclide differences in the time dynamics are consistent with the assumed between-radionuclide differences in K_d values

Retention in the landscape varies strongly between radionuclides, ranging at the end of the simulation period from less than 1% for the most mobile radionuclides (Tc-99 and Cl-36) to around 30% for the radionuclides with the highest K_d values (Pu-239 and Am-241). The remaining fraction of the releases ends up in the Baltic Sea. As for Forsmark, the between-radionuclide variation in the retained inventories is lower than the assumed variability of K_d values.

All Biosphere Objects have some radionuclide inventory at the end of the simulation period, independently of whether or not they receive a release fraction (Figure 8-1).

Terrestrial Biosphere Objects

The soil activity concentrations at the end of the simulation period are nearly the same or in some cases lower than at the beginning of the Coastal Period (3,000 BC). For Pu-239 there is a slight increase. Hence, there is no substantial accumulation of radionuclides in topsoils during the Terrestrial Period. Pronounced differences in the activity concentrations in soil are observed between the different objects (Figure 8-1), with a few objects having concentrations more than 10 times higher than the rest of the objects. A pronounced variation of the dose rates for these objects can therefore be expected. Biosphere Objects with the highest release fractions often show higher concentrations.

Lake and running water Biosphere Objects

The maximum radionuclide concentrations in waters of lakes and rivers for all radionuclides, except for Am-241 because of its shorter half-life, stabilise at the same value starting from around 2,000 AD. After 2,000 AD the highest concentrations in fresh water are observed in the running water flowing through the mire objects and receiving inputs also from agricultural lands. This is due to stabilisation of the activity concentrations in pore waters, which is characteristic for situations with continuous uniform input rates. A high between-objects difference in freshwater activity concentrations is observed at the end of the simulation period and Object 25, which is a running water, shows much higher concentrations than all other freshwater objects. This running water is the largest represented in the simulation and receives inputs from several terrestrial Biosphere Objects, which in combination with the assumption of complete instantaneous mixing of the releases in the running water, leads to high activity concentrations.

Marine Biosphere Objects

The predicted time dynamics of the maximum activity concentrations in sea water objects for the case of a constant unit release rates distributed in the landscape shows an increasing non-monotonic trend observed for all radionuclides with some periods of decrease due to transformations of sea Biosphere Objects to terrestrial Biosphere Objects, leading to "losses"

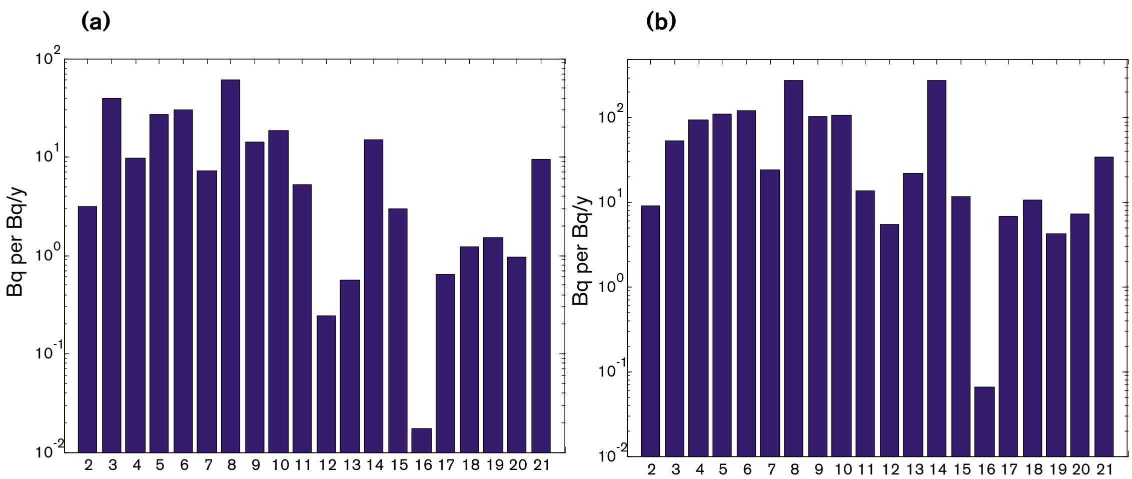


***Figure 8-1.** Inventory of I-129 (a) and Ra-226 (b) in different Biosphere Objects in Laxemar, excluding the Baltic Sea (Object 1) and running waters (Objects 22, 23, 24 and 25) at the end of the simulation period (10,000 AD). Biosphere Object number corresponds to the number in Table 6-2.*

of inventory from the sea. The form of the time dynamics resembles the time variation of the fraction of accumulation bottoms and the area of the sea objects that receive the largest fraction of the direct releases.

During most of the simulation period, the between-object differences in sea water concentrations were small and they approached nearly the same value for the various radionuclides at the end of the period.

8.1.5 Sensitivity and uncertainty analysis

A sensitivity analysis of the ecosystem models was carried out to identify which parameters had the largest effect on the simulation endpoints of interest. The endpoints considered were the fraction of the release that is retained in the ecosystem, the activity concentrations in soil, water and sediments, and the dose rates from external exposure, inhalation, and ingestion of water and food; evaluated at different times after the start of the simulations. A detailed description of the sensitivity study is given in /Avila 2006/. The sensitivity analysis was carried out using the Morris method /Morris 1991/ implemented in the software package Eikos /Ekström and Broed 2006/. With this method, it is possible to screen out parameters that have negligible effects and to rank the parameters by their effect on the endpoints of interest. It is also possible to identify which parameters have non-linear effects or are involved in interactions with other parameters.

From the sensitivity analysis of the ecosystem models, the parameters with the highest impact on the fraction of the releases retained in the objects and the doses were identified. It is reasonable to expect that uncertainties in the LDF values will be determined by the uncertainty in these parameters. However, the influence of the parameters is not linear and depends on multiple parameter interactions. For the landscape model, interactions between objects have also to be taken into account. Hence, for elucidating the effects of the parameter uncertainties on the uncertainties in the predictions for the landscape, it is necessary to make sensitivity studies for the landscape models as a whole. Such studies have not been yet carried out to the needed extend. Preliminary analyses were carried out for the LDF values and these are presently briefly in Section 8.2.5 and in more detail in /Avila et al. 2006/.

8.2 Modelling of landscape doses to humans and biota

8.2.1 Method for calculation of landscape doses

In principle, it is possible to drive the Landscape Model with time-dependent fluxes of radionuclides derived from a model of the repository, and of flow and transport through the geosphere. Such an approach would give time-dependent radionuclide concentrations in the environmental media of which the various Biosphere Objects are composed, and hence time-dependent effective dose rates to individuals utilising those Biosphere Objects. However, radionuclide fluxes from the deep repository would vary slowly with time. It is convenient to decouple the calculation of those fluxes from calculations of their radiological impact, both from a practical point of view and for purposes of transparently demonstrating the nature of all steps of the calculations leading from a canister failure to annual effective dose. Therefore, in conformance with previous SKB practice /SKB 1999/, and using an approach that is widely adopted internationally, radiological impacts are calculated for constant unit release rates of radionuclides to the surface environment. By this approach, single values of LDF, i.e. effective dose rates for unit flux of each radionuclide, are derived. These LDF values can then be multiplied by radionuclide fluxes from the geosphere for radiological impact estimations.

In applying this approach, various cautious assumptions are made concerning the duration of the period of chronic release and the additivity of contributions from different radionuclides. These cautious assumptions are described in more detail below.

The periods of temperate climate of relevance (i.e. a complete interglacial cycle) includes both the period from the present day until the next major episode of climatic cooling, but also part of the subsequent temperate period after that episode of cooling. In order to give the potential for application of LDF values for a complete interglacial cycle, an extended period of release is assumed, beginning after the glacial ice has retreated from the area (approx. 8,000 BC in the Holocene period of temperate climate) and finishing when the first effects of permafrost are starting (taken as 10,000 AD in the current temperate period). This allows the maximum reasonable time span for radionuclides to accumulate in the surface environment. It also ensures that a comprehensive range of temperate environments is studied, and that the post-glacial isostatic and eustatic changes are fully expressed, with the associated changes to the location of the coastline and the characteristics of local marine and terrestrial ecosystems.

In a non-evolving landscape with a constant rate of input of a radionuclide, concentrations of that radionuclide in the various environmental media would be expected to increase monotonically and, if the period of discharge was sufficiently long, would eventually be expected to stabilise at constant values /Bergström et al. 1999/. However, with an evolving landscape, as is represented in the landscape model, such a concept of equilibrium is not applicable. For example, radionuclides can accumulate in marine or lacustrine sediments, but give rise to an increased radiological impact when, as a consequence of shore level displacement, those sediments are converted to agricultural land. To allow for this, the LDF values used are the maximum values of effective dose rate that apply over the period of release. This is a cautious assumption, as it implies that the geosphere release is sufficiently protracted for the maximum value to be realised. Furthermore, the maxima for different radionuclides occur at different times, so multiplying geosphere fluxes by these maximum values and summing the results, as is done, will over-estimate the overall effective dose rate, as when one radionuclide is exhibiting its maximum effective dose rate others will be exhibiting less than their maximum effective dose rates /Avila et al. 2006/.

Because the individual Biosphere Objects are interconnected and radionuclide discharges can occur to several of them, radionuclide concentrations in environmental media not only vary with time but also differ in the various Biosphere Objects (cf. Figure 8-1).

An illustration of the obtained dose vs. the population is plotted in Figure 8-2. Because these plots are based on calculations for finite-sized Biosphere Objects that will fully support specific numbers of people, they exhibit stepwise characteristics. To eliminate these discontinuities, which essentially arise from the representation of the landscape as a finite number of Biosphere Objects, results from the effective dose rate calculation at each time of evaluation are plotted as a complementary cumulative distribution function (CCDF) in which the number of people exceeding a particular effective dose rate is plotted against the effective dose rate /Avila et al. 2006/. Examination of these CCDFs shows that they typically are well fitted by log-normal distribution functions (see Figure 8-2). In considering whether it is justified to use the smoothed version of the curve for assessment purposes, two different issues arise. We can envisage that if individuals utilises resources from more than one Biosphere Object, the curve would be smoother, as the stepwise distinction of numbers of people associated with particular effective dose rates would disappear. However, the curve would also tend to narrow, as individuals would move away from full utilisation of Biosphere Objects associated with the highest and lowest effective dose rates. Alternatively, if the landscape was decomposed into a greater number of Biosphere Objects, the curve would also become smoother, but it would not narrow. In justifying use of a smoothed curve, we take account of the latter consideration and view smoothing the curve as being an approach that moves from a discrete to a continuous representation of the landscape. However, no narrowing of the curve is permitted, as the emphasis still needs to be placed on the individual making maximum reasonable use of local resources /cf. Avila et al. 2006/.

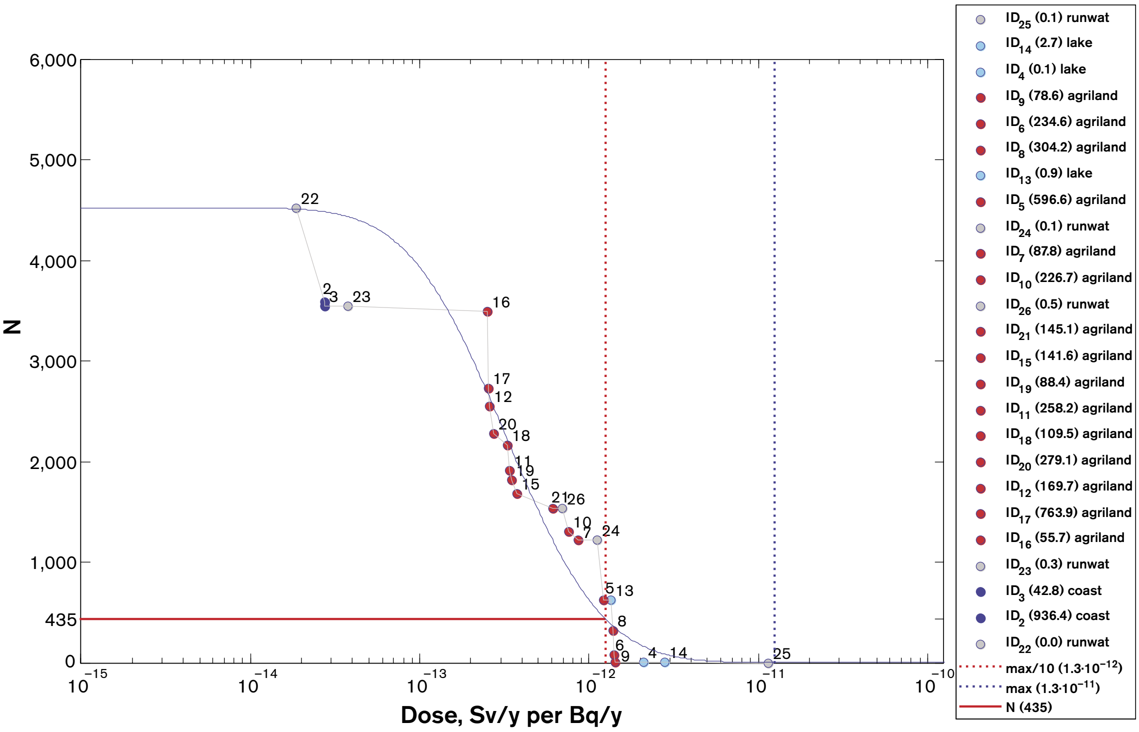


Figure 8-2. *Total effective dose rate from I-129 associated with different Biosphere Objects at 10,000 AD at Laxemar. The blue curve is the fitted log-normal distribution. The legend gives object id-number, ecosystem type and number of people (in brackets) that can be sustained for each Biosphere Object. The Landscape Dose Factor (LDF) is the average for a population receiving an annual effective dose in the range from the maximum dose to 1/10 of the maximum, i.e.* $1.3 \cdot 10^{-12}$ *Sv·Bq*$^{-1}$ *in this case (red vertical line). The vertical blue line indicates the maximum value of the effective dose rate. The number of people in the most exposed group is 435 (red horizontal line) /from Avila et al. 2006/.*

Once a smooth curve has been generated, it can be used to make an estimate of the effective dose rate to the most exposed individual. This is the effective dose rate at which the CCDF has a total number of individuals exceeding that effective dose rate of 1.0. This is a real upper bound on individual effective dose rate within the context of the modelling assumptions. To choose an effective dose rate higher than this would be to adopt a contaminated area that would support less than one individual. Thus, any individual utilising that area would also have to utilise other areas, so reducing the effective dose rate received.

However, having determined the effective dose rate to the most exposed individual, consideration has to be given to identifying a representative individual from the most exposed group and determining the effective dose rate to that individual. Regulatory guidance indicates that the degree of variation in individual doses within that group should not be greater than a factor of ten, see /SSI 1998, 2005/. For this reason, the effective dose rate to the representative individual from the most exposed group is obtained by finding the arithmetic mean of the fitted log-normal distribution in the interval between the effective dose rate to the most exposed individual and one tenth of that value.

In summary, the method adopted for calculating effective dose rates and hence individual risks in SR-Can is to:

- Use the landscape model to calculate effective dose rates as a function of time for unit flux of each radionuclide of interest partitioned over the various Biosphere Objects in accordance with results obtained from geosphere flow and transport calculations.

- At each of a set of reference times (for practical convenience taken as every 1,000 years) and for each radionuclide to calculate the CCDF of number of individuals against effective dose rate for all the Biosphere Objects considered in the model.
- Fit a log-normal distribution to each CCDF and use that to calculate the effective dose rate at each reference time and for each radionuclide to the most exposed individual, i.e. the effective dose rate at which the fitted CCDF gives one person exceeding that effective dose rate.
- Find the effective dose rate to a representative individual from the most exposed group at each reference time and for each radionuclide by finding the arithmetic mean of the fitted log-normal distribution in the interval between the effective dose rate to the most exposed individual and one tenth of that value.
- Find the maximum of the effective dose rate to the representative individual over the reference times considered for each radionuclide and define this as the LDF for that radionuclide.
- Compare the LDF with the Well dose concentration factor, which reflects the estimated well capacity measured at the site (Section 5.7) and use the maximum value for each radionuclide.

8.2.2 Handling of the climatic development during a glacial cycle

In order to describe the climatic development above the repository at the Laxemar site over the entire one million year assessment period, two variants were analysed:

- A base variant where the external conditions during the first 120,000 year glacial cycle are assumed to be similar to those experienced during the latest cycle, the Weichselian (see Section 4.2 and Figure 4-9). The latest glacial cycle contains a number of temperate, permafrost, glacial and submerged phases. The glacial cycle is then repeated eight times to cover the entire 1,000,000 year assessment period.
- A greenhouse variant in which the future climate and hence external conditions are assumed to be substantially influenced by human-induced greenhouse gas emissions.

Below is the modelling of climatic conditions further described.

An interglacial or temperate period

The interglacial is represented by the current temperate period as 8,000 BC to 10,000 AD, for which the development is described in Chapter 4. The conditions during the current temperate period represent the conditions during all the temperate periods found within the latest glacial cycle.

Permafrost

Permafrost conditions occur in several episodes in the reference evolution covering the Weichselian glacial cycle /SKB 2006c/. The first permafrost episode starts about 10,000 AD following the present interglacial (see Chapter 4). The coastline is some distance from the repository at this time and major discharge areas are not located offshore. The situation is similar at the end of an interglacial when global sea levels are falling. To simulate the permafrost conditions, it is assumed that the spatial distribution of Biosphere Objects is similar to that at the end of the temperate interglacial period, except that agricultural land is replaced by forest or mires, reflecting the consideration that significant degree of agriculture would not be tenable in such a context. For calculating the LDF, a release of 1 Bq y^{-1} is assumed until 50,000 AD.

A glacial period

During the glacial period there can be periods when the repository is at the ice margin and submerged under the sea (see Chapter 4). For this period, the LDF for the landscape conditions directly after the ice has melted away is used, i.e. the conditions applicable to conditions at the beginning of an interglacial (see Figure 6-6A), but in the calculation of the LDF the release of 1 Bq y^{-1} is continued for 50,000 years into these landscape conditions.

The greenhouse variant

For the greenhouse variant of the reference evolution, the landscape and ecosystems at the end of the interglacial are used and the LDF is calculated for a continuing release of 1 Bq y^{-1} until 50,000 AD. After that, the same alterations between temperate and permafrost conditions follow as after the first permafrost period in the base variant.

8.2.3 Results of the biosphere modelling of doses to humans and biota

Landscape Dose Factors

The LDF values obtained for Laxemar are presented in Table 8-1. The values range from around 10^{-16} to around 10^{-10} $SvBq^{-1}$. The maximum values occur at different times for the different radionuclides, either during the coastal or the terrestrial periods. The number of individuals in the most exposed group also differs between radionuclides.

The maximum values of the effective dose rate per unit release rate increase towards the end of the period for all radionuclides (Figure 8-3). Over the interglacial period, the dose conversion factors increase 3-4 orders of magnitude at around 3,000 BC when the discharge starts occurring to terrestrial objects (Figure 8-3). During the remaining terrestrial period, the dose conversion factors are fairly constant /Avila et al. 2006/.

For the entire Weichselian cycle, the LDF values are highest during the interglacial period and lowest during the glacial period, see tables in /SKB 2006a, Avila et al. 2006/. For the greenhouse variant, the LDF values are similar to the values of the interglacial LDFs. Of the two calculated LDF for permafrost conditions, the one with forest ecosystems showed about ten times higher values than the variant with mires.

Doses to biota

The potential effects on non-human biota from exposure to released radionuclides were only assessed using the Forsmark landscape model, where the simulations were carried out for a whole interglacial period /see SKB 2006b/.

8.2.4 Results of the biosphere modelling of doses to humans using specific scenarios

A key feature in managing uncertainties in the future development of the repository system is the reduction of the number of potential situations of exposure to analyse by selecting a set of representative scenarios. Below three different exposure scenarios are presented.

The drilling case

The potential exposure to large quantities of the radiotoxic material is an inescapable consequence of the deposition of spent nuclear fuel in a final repository, and consequently intrusion into the repository needs to be considered in repository design and safety assessment. In this case the radiological consequences of a drilling that affects a canister in the repository were studied. The drilling angle is assumed to be 85° as this will make the longest hole through

Table 8-1. Landcape Dose Factors (LDF) for an interglacial period at Laxemar expressed in units of Sv y^{-1} per Bq y^{-1}. N is the number of persons in the most exposed group, Year indicates the time period when the maxim LDF is observed with positive values for the period AD and negative values for the period BC, DCF Well is the Dose Conversion Factor for the well (in Sv Bq^{-1}, which is equivalent to Sv y^{-1} per Bq y^{-1}, so a direct comparison can be made with the LDF value) and Maximum indicates which conversion has the highest value.

Radionuclide	LDF	N	Year	DCF Well	Maximum
Cl-36	8,1E–15	905	7,250	3.7E–14	Well
Ca-41	5,6E–14	106	1,250	5.5E–15	LDF
Ni-59	4,4E–15	147	750	2.5E–15	LDF
Ni-63	3,8E–15	41	750	5.9E–15	Well
Se-79	1,1E–12	28	750	1.2E–13	LDF
Sr-90	8,0E–13	46	1,750	1.1E–12	Well
Zr-93	2,9E–14	68	7,250	4.3E–14	Well
Nb-94	2,1E–11	207	1,500	4.7E–13	LDF
Tc-99	3,1E–15	520	750	2.6E–14	Well
Pd-107	2,2E–15	133	1,250	1.4E–15	LDF
Ag-108m	1,0E–10	82	1,750	4.5E–12	LDF
Sn-126	2,0E–12	35	2,250	3.2E–13	LDF
I-129	1,6E–11	141	1,250	4.4E–12	LDF
Cs-135	2,3E–12	18	–1,750	7.9E–14	LDF
Cs-137	4,1E–12	18	7,250	1.9E–12	LDF
Sm-151	2,0E–16	221	750	4.0E–15	Well
Ho-166m	2,9E–11	100	1,500	1.4E–12	LDF
Pb-210	5,3E–12	27	–2,250	2.7E–11	Well
Ra-226	4,7E–11	45	6,250	1.1E–11	LDF
Th-229	3,2E–12	2,513	–2,250	2.0E–11	Well
Th-230	1,0E–10	60	6,250	8.3E–12	LDF
Th-232	1,2E–12	2,513	–2,250	9.1E–12	Well
Pa-231	7,6E–12	556	8,250	2.8E–11	Well
U-233	3,7E–13	140	750	2.0E–12	Well
U-234	2,4E–12	78	6,250	1.9E–12	LDF
U-235	3,2E–13	175	750	2.1E–12	Well
U-236	3,4E–13	139	750	1.8E–12	Well
U-238	3,2E–13	140	750	1.8E–12	Well
Np-237	8,7E–13	135	750	4.5E–12	Well
Pu-239	9,5E–13	241	750	9.9E–12	Well
Pu-240	9,1E–13	234	750	9.9E–12	Well
Pu-242	8,9E–13	258	750	9.4E–12	Well
Am-241	6,3E–13	144	750	8.0E–12	Well
Am-243	5,6E–12	198	1,750	5.9E–12	Well
Cm-244	6,6E–14	1,116	–2,250	4.7E–12	Well
Cm-245	7,0E–13	337	750	8.5E–12	Well
Cm-246	7,5E–13	215	750	8.1E–12	Well

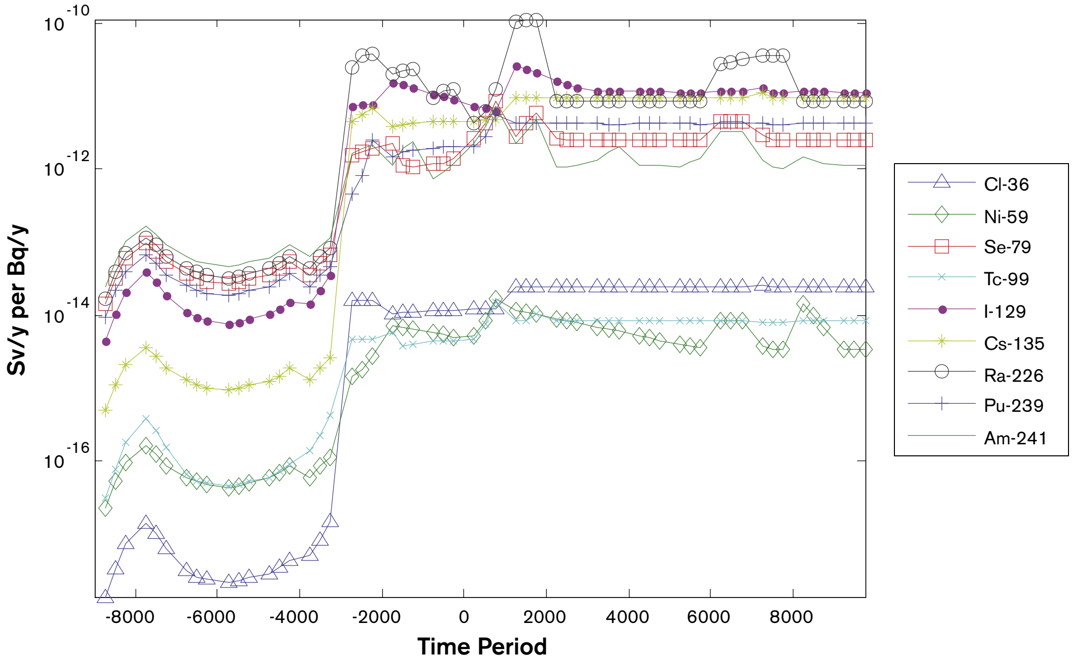


Figure 8-3. *The maximum effective dose rate for some radionuclides at different times when 1 Bq y^{-1} has been released starting from 8,000 BC. The results are plotted for each period of 250 years. The stepwise character of the curves is due to the fact that most parameters and classifications are altered on time steps of 1,000 y /Avila et al. 2006/*

the canister and bring most fuel to the surface. The cuttings are assumed to be spread on the ground, but the cores containing spent nuclear fuel are removed. It is assumed that the purpose of the drilling is to reach great depth and that the drill rig therefore is placed at a low point in the terrain. When the backfilled tunnel is reached the borehole is assumed to be grouted and the drilling continued. The buffer is assumed to be grouted as well, the drilling continued and the canister penetrated. When the drill core containing the canister and fuel is brought to the surface the anomalous situation is taken to be recognised and the drilling is stopped. The site and the borehole are abandoned without further measures. About a month later, a family moves to the site and operates a domestic production farm there. The abandoned borehole is used as a well by the family. The consequences for the repository and the annual effective doses to the family are assessed /SKB 2006a/.

If a canister is penetrated and the safety functions of the buffer and backfill are lost and the borehole is used as a well for drinking and irrigation, the annual effective doses to representative members of critical groups will exceed the individual limit on annual effective dose for members of the public but not the annual effective dose due to background radiation. Assuming the site-specific mean capacities of wells, at Laxemar the dose limit is only exceeded if the intrusion occurs during the first 500 years after closure. If it is assumed that the instant release fraction and crushed material from the fuel elements is brought to the surface, that the land is used for cultivation the same year as the intrusion occurs and that a person spends time in the contaminated area, then the annual absorbed and effective doses may reach very high levels. The exposed person in the example given would be severely injured. One could expect that if the borehole is used as a well, the contaminated area immediately adjacent to the hole will be used for the pump and not for cultivation.

The pulse case

The LDF values are calculated for constant releases over long time periods. These long time periods imply that near steady state situations develop and that the effect of downstream accumulation should be considered in the doses calculations. For a pulse release, steady state does not develop for many radionuclides and downstream accumulation is very low compared to the levels in the object that receives the release. Moreover, the annual average lifetime risk will be lower for pulse releases with a duration that is less than a lifetime (< 50 years). Preliminary analyses show that, for pulse releases with a duration of 1 year, using the LDF values in the dose calculations would overestimate the doses by about one order of magnitude /Avila 2006/.

In these preliminary analyses annual doses resulting from unit releases of the dominant radionuclides to representative landscape objects (forests, lakes, mires, seas and agricultural lands) were calculated. The doses were integrated over 50 years to obtain estimated of annual average lifetime doses. For all radionuclides and ecosystems, except for agricultural lands, the maximum doses occurred the first year and declined rapidly over time. For agricultural lands, however, the peak dose rate may occur after more than 1,000 years for some radionuclides /Avila 2006/.

In the Sr-Can assessment /SKB 2006a/ the LDF values divided by 50, the assumed lifetime, were used as a cautious factor for estimating the risk of pulse releases.

The gas release case

Model calculations have shown that C-14 and Rn-222 may be released from nuclear waste disposals in gaseous form and may enter the biosphere via soil as a diffuse source /SKB 2006a/. C-14 may be released as methane (CH_4) or carbon dioxide (CO_2). It is assumed that if C-14 is released as methane from the repository, it will be oxidised to carbon dioxide by soil organisms. Radon is a noble gas and will not undergo chemical transformations. For C-14, exposure may occur via inhalation or ingestion, for Rn-222 only inhalation of Rn-222 and its radioactive daughter products needs to be taken into account.

Ingestion dose from C-14

The ingestion dose is estimated by means of a modified specific activity model. The key assumption is that C-14 is released during a relative short time, which may be in the range of a few to tens of days. If the release occurs during the vegetation period, C-14 is metabolised by the photosynthesis and enters via this pathway the human food chain. A release during the vegetation period is more likely, since then the soil is not frozen, which facilitates the exchange of gases from deep soil to the lower atmosphere. For a specification of the boundary assumptions, see /Avila 2006/. The release would cause an additional exposure of 1.8 µSv (Table 8-2). However, wind speed and mixing height vary with the weather conditions. Varying wind speed and mixing height in the ranges of 1–10 m s^{-1} and 10–50 m respectively, the resulting effective dose varies in the range of 0.15–7.3 µSv. The release in winter would not cause an ingestion dose due to the missing photosynthesis.

Inhalation of C-14 and Rn-222 outdoors

The same boundary conditions as above are assumed and the calculations are presented in /Avila 2006/. For C-14, an inhalation rate of 8,100 m^3 a^{-1} is assumed /ICRP 1995/and an inhalation dose factor of 6.2E–12 Sv Bq^{-1} /ICRP 1996/ is taken. For a wind speed in the range of 1–10 m s^{-1} and a mixing height of 10–50 m, this causes an inhalation dose of about 0.00018–0.009 µSv (Table 8-3).

Table 8-2. Ingestion dose due to a pulse release of C-14, from /Avila 2006/.

Quantity	Value
Assumptions	
Total release (Bq)	1.00E+10
Area (m^2)	1.00E+04
Radius of the area (m)	56,4
Release (Bq m^{-2})	1.0E+06
Carbon content of air (g m^{-3})	0.13
Seconds per year (s a^{-1})	31,536,000
Conversion factor: µSv per Bq C-14 per g C-12	52.9
Factor for local production	0.1
Exposure (effective dose, µSv)	
Wind speed = 2 m/s, Mixing height = 20 m	1.8 µSv
Range:	
Wind speed: 1–10 m/s	
Mixing height 10–50 m	0.15–7.3 µSv

Table 8-3. Outdoor inhalation dose due to a pulse release of C-14 and Rn-222, from /Avila 2006/.

Quantity	Value C-14	Rn-222
Assumptions		
Total release (Bq)	1.0E+10	2.5E+10
Area (m^2)	1.0E+04	1.0E+04
Radius of the area (m)	56.4	56.4
Release (Bq m^{-2})	1.0E+06	2.5E+06
DoseFactor	6.2E–12 Sv Bq^{-1}	47 µSv a^{-1} per Bq m^{-3}
Underlying equilibrium factor	not applicable	0.6
Exposure (effective dose, µSv)		
Wind speed = 2 m s^{-1}, Mixing height = 20m	0.0022 µSv	11 µSv
Range:		
Wind speed: 1–10 m s^{-1}		
Mixing height 10–50 m	0.00018–0.009 µSv	0.4–20 µSv

For Rn-222, a release rate of 25 GBq is assumed. The dose is calculated using a dose conversion factor of 47 µSv a^{-1} per Bq m^{-3}. This dose factor assumes an equilibrium factor of 0.6 /UNSCEAR 2000/, which is typical for outdoor conditions where the unattached fraction of the Rn-222 daughters is high. For a wind speed in the range of 1–10 m s^{-1} and a mixing height of 10–50 m, this causes an inhalation dose varying in the range of 0.4–20 µSv.

Inhalation of C-14 and Rn-222 indoors

The activity concentration of C14 and Rn-222 indoors is calculated from the release (Bq m^{-2}), the ground area of the house A (m^2), the volume of the house V (m^3) and the ventilation rate, see /Avila 2006/.

The same release inside and outside the house is assumed, which is very cautious since walls and floors inhibit the diffusion of C-14 and Rn-222 from soil to indoor air. For the ventilation rate a value of 2 h^{-1} is assumed, which should typical for an average over winter and summer.

In winter, it is less due to the lower temperatures, whereas it is higher in summer. However, also in winter a minimum value for the ventilation is not much less than 1 h^{-1} to maintain a reasonable air quality indoors. An occupancy factor of 0.5 is assumed, this means that people stay 50% of their time in their house. The same dosimetric parameters are assumed as above, however, for the dose conversion factor of Rn-222, a value of 32 µSv a^{-1} per Bq m^{-3} is assumed due to the lower equilibrium factor of 0.4, which is a typical indoor value /UNSCEAR 2000/.

The resulting indoor exposures for a house of with a volume of 1,000 m^3 and a ventilation rate of 2 h^{-1} are 0.14 µSv and 230 µSv for C-14 and Rn-222 respectively (Table 8-4). For house volumes of 500–1,500 m^3 and ventilation rates of 1–5 h^{-1} the inhalation dose varies for C-14 from 0.038 to 0.57 µSv and for Rn-222 from 60 to 900 µSv.

The highest dose from a gas pulse occurs in buildings for Rn-222, with 7.2 µSv/year. It is below the regulatory limits for an annual average life time risk for a repository, and it is considerably lower than the consequences of today limits of 200 Bq/m^3 for radon in buildings in Sweden, which gives about 2 mSv.

8.2.5 Uncertainties in the LDF values

For elucidating the effects of the parameter uncertainties on the uncertainties in the LDF values, it is necessary to make sensitivity analyses for the whole landscape model, similar to the studies that were done for the ecosystem models /Avila 2006/. Such studies have not yet been carried out to the needed extent. Preliminary analyses have been done by varying important parameters one-at-a-time within their range of variation, while keeping other parameters at their best estimate values. These analyses show, for example, that the effect of the K_d on the maximum total dose rate was different in different periods with practically no effect in some periods (for example the Sea Period) and pronounced effects in other periods, particularly in periods when ecosystem shifts occur. The effect of the K_d was also different for different radionuclides. The maximum LDF values are obtained at different time periods for the different cases and the values differ by a factor of 10 or more. Similar responses of the LDF values were observed when making one-at-a-time variations of other important parameters.

Table 8-4. Indoor inhalation dose due to a pulse release of C-14 and Rn-222, from /Avila 2006/. Annual life time risk is estimated by dividing the dose with 50 years.

Quantity	Value C-14	 Rn-222
Assumptions		
Total release (Bq)	1.0E+10	2.5E+10
Area (m^2)	1.0E+04	1.0E+04
Ground area of the house (m^2)	100	100
Release (Bq m^{-2})	1.0E+06	2.5E+06
DoseFactor	6.2E–12 Sv Bq^{-1}	32 µSv a^{-1} per Bq m^{-3}
Underlying equilibrium factor	not applicable	0.4
Occupancy factor	0.5	0.5
Exposure (effective dose, µSv)		
House volume = 1,000 m^3,		
Ventilation rate = 2 h^{-1}	0.14 µSv	230 µSv
Range:		
House volume = 500–1,500 m^3,		
Ventilation rate = 1–5 h^{-1}	0.038–0.57 µSv	60–900 µSv

The analysis of the results /Avila et al. 2006/ indicates that the topography, which affects the drainage area, the hydrology, the sedimentation environment and the size of the biosphere objects are also important factors. The topography is a robust property that is rather well understood at the sites and is predictable in time, especially where the regolith is thin and the topography is mainly determined by the solid rock. Several of the radionuclide-independent parameters that have the highest effect on the retained fractions, such as the area of the objects, the catchment areas, the run-off, depend on the topography of the sites. During the sea period, the fraction of accumulation bottoms and the water velocity in the bottom sediments has the largest effect on the retained fraction of the releases. These parameters are more difficult to estimate. However, the accumulation during the Sea Period does not seem to have a significant impact on the maximum dose rates and the LDF values.

The permafrost case, where two alternative cases were considered, one with mires and other with forests prevailing in the landscape, was only studied in Laxemar /Avila et al. 2006/. The differences between these cases were within a factor of ten. The assumptions and parameter values for the other climatic stages have higher uncertainties and thus it is expected that differences of one order of magnitude will be within the uncertainty ranges of the interglacial stage.

9 References

Agrell H, 1976. The highest coastline in south-eastern Sweden. Boreas 5, 143–154.

Algesten G, Sobek S, Bergström A-K, Ågren A, Tranvik L J, Jansson M, 2004. Role of lakes for organic carbon cycling in the boreal zone. Global Change Biol. 10:141–147.

Alm J, Schulman L, Walden J, Nykanen H, Martikainen P J, Silvola J, 1999. Carbon balance of a boreal bog during a year within an exceptional dry summer. Ecology, 80:161–174.

Almén K-E, Talme O, 1978. Jordartsanalys. Laboratorieanvisningar, del 2. Department of Quaternary Research, Stockholm University, 133 pp.

Alriksson A, Eriksson H M, 1998. Variations in mineral nutrient and C distribution in the soil and vegetation compartments of five temperate tree species in NE Sweden. Forest Ecology and Management 108:261–273.

Andrén E, Andrén Th, Sohlenius G, 2000. The Holocene history of the southwestern Baltic Sea as reflected in a sediment core from the Bornholm Basin. Boreas 29, 233–250.

Angelstam P, 1992. Conservation of communities. The importance of edges, surroundings and landscape mosaic structure. In: Hansson L (ed.), Ecological principles of nature conservation. Elsevier Science Publishers LTD, Essex, England. pp. 436.

Anonymous, 2002. Forestry statistics 2002. Official statistics of Sweden. Swedish University of Agricultural Sciences, Umeå. 107 pp.

Avila R, 2006. The ecosystem models used for dose-assessments in SR-Can. SKB R-06-81, Svensk Kärnbränslehantering AB.

Avila R, Bergström U, 2006. Methodology for calculation of doses to man and implementation in Pandora. SKB R-06-68, Svensk Kärnbränslehantering AB.

Avila R, Ekström P A, Kautsky U, 2006. Development of Landscape dose factors for dose-assessments in SR-Can. SKB TR-06-15, Svensk Kärnbränslehantering AB.

Berg J, Jansson U, Wästfelt A, 2006. Landscape, history and people in a geographical perspective. Studies of land-use, settlement and livelihood in Oskarshamn and Forsmark. SKB R-06-37, Svensk Kärnbränslehantering AB.

Berger A, 1978. Long-term variations of daily insolation and Quaternary climatic changes, Journal of the Atmospheric Sciences 35: 2362–2367.

Berger A, Loutre M F, 2002. An exceptionally long interglacial ahead? Science 297: 1287–1288.

Berggren J, Kyläkorpi L, 2002. Ekosystemen i Simpevarpsområdet Sammanställning av befintlig information. SKB R-02-10, Svensk Kärnbränslehantering AB.

Berggren D, Fröberg M, Bergkvist B, 2003. Transport and leaching of DOC as affected by site properties and climate – a synthesis based on LUSTRA data. A report from LUSTRA, Uppsala.

Berggren D, Bergkvist B, Johansson M-B, 2004. A description of LUSTRA's common field sites. Department of Forest Soils, Swedish University of Agriculture Sciences, Uppsala, Report 87.

Berglund B, 1971. Littorina transgressions in Blekinge, South Sweden. A preliminary survey. Geologiska Föreningens i Stockholm Förhandlingar 93, 625–652.

Berglund B, Sandgren P, Barnekow L, Hannon G, Jiang H, Skog G, Yu S-Y, 2005. Early Holocene history of the Baltic Sea, as reflected in coastal sediments in Bekinge, southeastern Sweden. Quaternary International 130, 111–139.

Bergman T, Malmberg Persson K, Persson M, Albrecht J, 2005. Characterisation of bedrock and quaternary deposits from excavations in the southern part of laxemar subarea. Oskarshamn site investigation. SKB P-05-47, Svensk Kärnbränslehantering AB.

Bergström U, Nordlinder S, Aggeryd I, 1999. Models for dose assessments – Modules for various biosphere types. SKB TR-99-14, Svensk Kärnbränslehantering AB.

Bergström U, Barkefors C, 2004. Irrigation in dose assessments models. SKB R-04-26, Svensk Kärnbränslehantering AB.

Bernes C, Grundsten C, 1992. National Atlas of Sweden. The Environment. Almqvist & Wiksell international.

BIOCLIM, 2003. Continuous climate evolution scenarios over Western Europe (1000 km scale), Deliverable D7. Work package 2: Simulation of the future evolution of the biosphere system using the hierarchical strategy. 88 p.

Björck S, 1995. A review of the history of the Baltic Sea, 13.0–8.0 ka BP. Quaternary International 27, 19–40.

Boresjö Bronge L, Wester K, 2003. Vegetation mapping with satellite data of the Forsmark, Tierp and Oskarshamn regions. SKB P-03-83, Svensk Kärnbränslehantering AB.

Borgiel M, 2004. Forsmark site investigation. Sampling of freshwater fish. SKB P-04-06, Svensk Kärnbränslehantering AB.

Brunberg A-K, Blomqvist P, 1999. Characteristics and ontogeny of oligotrophic hardwater lakes in the Forsmark area, central Sweden. SKB R-99-68, Svensk Kärnbränslehantering AB.

Brunberg A-K, Carlsson T, Brydsten L, Strömgren M, 2004. Oskarshamn site investigation – Identification of catchments, lake-related drainage parameters and lake habitats. SKB P-04-242, Svensk Kärnbränslehantering AB.

Brydsten L, 2004. A mathematical model for lake ontogeny in terms of filling with sediments and macrophyte vegetation. SKB TR-04-09, Svensk Kärnbränslehantering AB.

Brydsten L, Strömgren M, 2005. Digital elevation models for site investigation programme in Oskarshamn. Site description version 1.2. SKB R-05-38, Svensk Kärnbränslehantering AB.

Brydsten L, 2006a. Modelling groundwater discharge areas using only digital elevation models as input data. SKB TR-06-39, Svensk Kärnbränslehantering AB.

Brydsten L, 2006b. A model for landscape evolution in terms of shoreline displacement, sediment dynamics, lake formation, and lake choke-up processes. SKB TR-06-40, Svensk Kärnbränslehantering AB.

Canhem C D, Pace M L, Papaik M J, Primack A G B, 2004. A spatially explicit watershed-scale analysis of dissolved organic carbon in Adirondack lakes. Ecological Application 14(3):839–854.

Carlsson T, Brunberg AK, Brydsten L, Strömgren M, 2005. Characterisation of running waters, including vegetation, substrate and technical encroachments. Oskarshamn site investigation. SKB P-05-40, Svensk Kärnbränslehantering AB.

Cederlund G, Ljunqqvist H, Markgren G, Stålfelt F, 1980. Foods of moose and roe deer at Grimsö in central Sweden. Results of rumen content analyses. Swedish Wildlife Res. 11: 171–247.

Cederlund G, Hammarström A, Wallin K, 2004. Surveys of mammal populations in the areas adjacent to Forsmark and Oskarshamn. Results from 2003. SKB P-04-04, Svensk Kärnbränslehantering AB.

Chapin F S, Matson P, Mooney H A, 2002. Principles of Terrestrial Ecosystem Ecology. Springer-Verlag New York, Inc. pp 436.

Cousins S A O, 2001. Analysis of land cover transitions based on 17th and 18th century cadastral maps and aerial photographs. Landscape Ecology 16. 41–54.

Cramer W, 1986. Vegetation dynamics on rising sea shore in eastern central Sweden. Doctoral Thesis at Uppsala University, Acta Universitatis Upsaliensis 25, ISBN 91-554-1825-2.

Eckerman K F, Leggett R W, 1996. DCFPAK: Dose coefficient data file package for Sandia National Laboratory. Oak Ridge National Laboratory Report ORNL/TM-13347. Oak Ridge National Laboratory, Oak Ridge, TN.

Eckhéll J, Jonsson P, Meili M, Carman R, 2000. Storm influence on the accumulation and lamination of sediments in deep areas of the north-western Baltic proper. Ambio 29: 238–245.

Ekman M, 1996. A consistent map of the postglacial uplift of Fennoscandia. Terra-Nova 8/2, 158–165.

Ekström P-A, Broed R, 2006. Sensitivity Analysis Methods and a Biosphere Test Case Implemented in Eikos. Posiva Working Report 2006-31.

Elhammer A, Sandkvist Å, 2005. Oskarshamn site investigation: Detailed marine geological survey of the sea bottom outside Simpevarp. SKB P-05-35, Svensk Kärnbränslehantering AB.

Elveland J, 1978. Skötsel av Norrländska rikkärr. Studier av vegetationsförändringar vid olika skötselåtgärder och annan påverkan. SNV PM 1007.

Engdahl A, Ericsson U, 2004. Sampling of freshwater fish. Description of the fish fauna in four lakes. SKB P-04-251, Svensk Kärnbränslehantering AB.

Engelmark O, Hytteborn H, 1999. Coniferous forests. In Rydin H, (ed.). Swedish plant geography. Acta Phytogeographica Suecica 84, Opulus Press AB, Uppsala, pp 238.

ERICA, 2006. Environmental Risk from Ionising Contaminants: Assessment and Management. EC-EURATOM 6 Framework Programme (2002–2006). Project Contract FI6R-CT-2004-508847.

Ericsson U, Engdahl A, 2004. Benthic macro invertebrates. Results from sampling in the Simpevarp area 2004. SKB P-04-75, Svensk Kärnbränslehantering AB.

Ericson L, Wallentinus H-G, 1979. Sea-shore vegetation around the Gulf of Bothnia. Wahlenbergia 5.1–142.

Eriksson L, Kardell L, 1987. Kremlor, riskor, soppar. Skogsbruksmetodernas inverkan på produktionen av matsvampar. SST 2/1987, Sveriges Skogsvårdsförbund.

Estrum-Yousef S R, Feuerpfeil P, Schubert H, Schumann R, 2000. Quality of particulate matter and its potential sinking rates in pelagic samples of inshore and Bodden waters of the southern Baltic Sea. Internat. Rev. Hydrobiol. 85, 341–357.

EUR, 1996. Directive from the council 96/29/Euratom of the 13th of May 1996. In Swedish: Rådets direktiv 96/29/Euratom av den 13 maj 1996. EU Official Journal L 159, 29 June 1996.

Fink S, Hammarskjöld G, Petterson S, Staaf H, 2003. Sweden's National Inventory Report 2003 – submitted under the United Nations Convention on Climatic Change. Swedish Environmental Protection Agency. Available on www.naturvardsverket.se.

Fredén C (red), 2002. Berg och jord. Sveriges nationalatlas. Tredje upplagan. 208 pp. (In Swedish).

Fredriksson R, Tobiasson S, 2003. Inventory of macrophyte communities at Simpevarp nuclear power plant. Area of distribution and biomass determination. Simpevarp site investigation, SKB P-03-69, Svensk Kärnbränslehantering AB.

Fredriksson D, 2004. Peatland investigation Forsmark. Forsmark site investigation. SKB P-04-127, Svensk Kärnbränslehantering AB.

Fredriksson R, 2005. Inventory of the marine fauna attached to hard substrates in the Simpevarp area. Oskarshamn site investigation, SKB P-05-45, Svensk Kärnbränslehantering AB.

French H M, 1996. The periglacial environment, Addison Wesley Longman. Essex, England.

Fridriksson G, Öhr J, 2003. Assessment of plant biomass of the ground, field and shrub layers of the Forsmark area. SKB P-03-90, Svensk Kärnbränslehantering AB.

Garten C T, 1999. Modeling the potential role of a forest ecosystem in phytostabilisation and phytoextraction of ^{90}Sr at a contaminated watershed. J. Environ. Radioactivity 43: 305–323.

Green M, 2005. Oskarshamn site investigations. Bird monitoring in Simpevarp, 2002–2005. SKB P-05-42, Svensk Kärnbränslehartering AB.

Grip H, Rodhe A, 1985. Vattnets väg från regn till bäck. Forskningsrådens Förlagstjänst, Karlshamn, Sweden. ISBN 91-86344-17-X. (In Swedish).

Gunnarsson U, Malmer N, Rydin H, 2002. Dynamics or constancy in Sphagnum dominated mire ecosystems? A 40-year study. Ecography 25: 685–704.

Gustafsson B, 1997. Interaction between Baltic Sea and North Sea. Deutsche Hydrographische Zeitschrift 49, 2/3: 165–183.

Gustafsson B, 2004a. Millennial changes of the Baltic Sea salinity – studies of the salinity to climate change. SKB TR-04-12, Svensk Kärnbränslehantering AB.

Gustafsson B, 2004b. Sensitivity of the Baltic Sea salinity to large perturbations in climate. Climate research, 27: 237–251.

Hartley L, Hunter F, Jackson P, McCarthy R, Gylling B, Marsic N, 2006a. Regional hydrogeological simulations using CONNECTFLOW. Preliminary site description Laxemar subarea – version 1.2. SKB R-06-23, Svensk Kärnbränslehantering AB.

Hartley L, Hoch A, Jackson P, Joyce S, McCarthy R, Swift B, Gylling B, Marsic N, 2006b. Groundwater flow and transport modelling during the temperate period for the SR-Can assessment: Laxemar sub-area – version 1.2. SKB R-06-99, Svensk Kärnbränslehantering AB.

Humborg C, Smedberg E, Blomqvist S, 2004. Nutrient variations in boreal and subarctic Swedish rivers: Landscape control of land-sea fluxes. Limnology and Oceanography 49(5): 1871–1883.

Hyvonen R, Agren G I, Andren O, 1996. Modelling Long-Term Carbon and Nitrogen Dynamics in an Arable Soil Receiving Organic Matter. Ecological Applications, 6:1345–1354.

ICRP, 1975. Reference man: anatomical, physiological, and metabolic characteristics. Publication 23, Pergamon Press, Oxford.

ICRP, 1991. ICRP Publication 60: 1990 Recommendations of the International Comission on Radiological Protection. Elsevier, 1991.

ICRP, 1995. Human respiratory tract model for radiological protection, ICRP Publication 66.

ICRP, 1996. Age-dependent doses to members of the public from intake of radionuclides: ICRP Publication 71 and 72.

ICRP, 2004. Basic anatomical and physiological data for use in radiological protection: Reference Values. Publication 89, Pergamon Press, Oxford.

Ingvarson N H, Palmeby A S L F, Svensson L O, Nilsson K O, Ekfeldt T C I, 2004. Oskarshamn site investigation – Marine survey in shallow coastal waters, Bathymetric and geophysical investigation 2004. SKB P-04-254, Svensk Kärnbränslehantering AB.

IPCC, 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Eds: J T Houghton, Y Ding, D J Griggs, M Noguer, P J van der Linden, X Dai, K Maskell, and C A Johnson. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

Jerling L, 1999. Sea shores. In: Rydin H, Snoeijs P and Diekmann M (eds). Swedish plant geography, Acta Phytogeographica Suecica 84, Uppsala.

Jerling L, Isaeus M, Lanneck J, Lindborg T, Schüldt R, 2001. The terrestrial biosphere in the SFR region. SKB R-01-09, Svensk Kärnbränslehantering AB.

Jones J, Vahlund F, Kautsky U, 2004. Tensit – a novel probabilistic simulation tool for safety assessments Tests and verifications using biosphere models TR-04-07, Svensk Kärnbränslehantering AB

Karlsson S, Bergström U, 2000. Dose rate estimates for the Olkiluoto site using the biospheric models of SR97. POSIVA Working Report 2000-20. POSIVA Oy, Finland.

Karlsson S, Bergström U, Meili M, 2001. Models for dose assessments – Models adapted to the SFR-area, Sweden. SKB TR-01-04, Svensk Kärnbränslehantering AB.

Kasimir-Klemedtsson Å, Klemedtsson L, Berglund K, Martikainen P, Silvola J, Oenema O, 1997. Greenhouse gas emission from farmed organic soils: a review. Soil Use and Management 13, 245–250.

Kellner E, 2003. Wetlands – different types, their properties and function. SKB TR-04-08, Svensk Kärnbränslehantering AB.

Kristiansson J, 1986. The ice recession in the south-eastern part of Sweden. University of Stockholm. Department of Quaternary Research 7, 132 pp.

Larsson-McCann S, Karlsson A, Nord M, Sjögren J, Johansson L, Ivarsson M, Kindell S, 2002. Meteorological, hydrological and oceanographical information and data for the site investigation program in the community of Oskarshamn. SKB TR-02-03, Svensk Kärnbränslehantering AB.

Lidman F, 2005. Isotopic disequilibria for assessment of radionuclide transport in peat lands – Uranium-Thorium series nuclides in a core from Klarebäcksmossen, Oskarshamn, Sweden. W05-019 M. Sc. Thesis Work, Department of Physics, Uppsala University.

Lindborg T, Kautsky U (eds), 2004. Ecosystem modelling in the Forsmark area – proceedings from two workshops modelling Eckarfjärden and Bolundsfjärden catchment areas. SKB R-04-71, Svensk Kärnbränslehantering AB.

Lindborg T (ed), 2005. Description of surface systems. Preliminary site description Forsmark area – version 1.2. SKB R-05-03, Svensk Kärnbränslehantering AB.

Lindborg T (ed), 2006. Description of surface systems. Preliminary site description Laxemar subarea – version 1.2. SKB R-06-11, Svensk Kärnbränslehantering AB.

Lundin L, Lode E, Stendahl J, Melkerud P-A, Björkvald L, Thorstensson A, 2004. Soils and site types in the Forsmark area. SKB R-04-08, Svensk Kärnbränslehantering AB.

Lundin L, Lode E, Stendahl J, Björkvald L, Hansson J, 2005. Soils and site types in the Oskarshamn area. SKB R-05-15, Svensk Kärnbränslehantering AB.

Lundqvist J, Wohlfarth B, 2001. Timing and east-west correlation of south Swedish ice marginal lines during the Late Weichselian. Quaternary Science Reviews 20, 1127–1148.

Löfgren A, Lindborg T, 2003. A descriptive ecosystem model – a strategy for model development during site investigations. SKB R-03-06, Svensk Kärnbränslehantering AB.

Löfgren A, 2005. 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. SKB P-05-80, Svensk Kärnbränslehantering AB.

Miliander S, Punakivi M, Kyläkorpi L, Rydgren B, 2004. Human population and activities at Simpevarp. SKB R-04-11, Svensk Kärnbränslehantering AB.

Moreno L, Crawford J, Neretnieks I, 2006. Modelling radionuclide transport for time varying flow in a channel network, J Contaminant Hydr, 86, 215–238.

Morosini M, Hultgren H, 2003. Inventering av privata brunnar i Simpevarpsområdet, 2001–2002. SKB P-03-05, Svensk kärnbränslehantering AB.

Morris M D, 1991. Factorial sampling plans for preliminary computational experiments. Technometrics (2): 239–245.

Neff J C, Ashner G P, 2001. Dissolved organic carbon in terrestrial ecosystems. Ecosystems 4:29–48.

Nilsson G, 2004. Oskarshamn site investigation – Investigation of sediments, peat lands and wetlands Stratigraphical and analytical data. SKB P-04-273, Svensk kärnbränslehantering AB.

NRC, 1999. Risk Assessment of Radon in Drinking Water. NRC (National Research Council): Committee on Risk Assessment of Exposure to Radon in Drinking Water, Washington, DC, National Academy Press, 1999.

Nyman H, 2005. Depth and stratigraphy of QD. Preliminary site description Laxemar subarea – version 1.2. SKB R-05-54, Svensk Kärnbränslehantering AB.

Odum E P, 1983. Basic Ecology, Holt-Saunders International Editions. New York.

Osvald H, 1937. Myrar och myrodling. Kooperativa förbundets bokförlag. 407 pp. (In Swedish)

Persson T, Nilsson L-O (ed), 2001. Skogabyförsöket – Effekter av långvarig kväve- och svavel tillförsel till ett skogsekosystem. Naturvårdsverket rapport 5173. (In Swedish).

Påsse T, 1997. A mathematical model of past, present and future shore level displacement in Fennoscandia. SKB TR 97-28, Svensk Kärnbränslehantering AB.

Påsse T, 2001. An empirical model of glacio-isostatic movments and shore-level displacement in Fennoscandia. SKB R-01-41, Svensk Kärnbränslehantering AB.

Risberg J, Miller U, Brunnberg L, 1991. Deglaciation, Holocene shore displacement and coastal settlements in eastern Svealand, Sweden. Quaternary International 9, 33–39.

Risberg J, 2002. Holocene sediment accumulation in the Äspö area. SKB R-02-47, Svensk Kärnbränslehantering AB.

Robertsson A-M, 1997. Shore displacement in north-eastern Småland c. 9000–2500 BP. Sveriges Geologiska Undersökning Ca 86, 145–152.

Rosén E, Borgegård S-O, 1999. The open cultural landscape. In: Rydin H, Snoeijs P and Diekmann M (ed.), Swedish plant geography. Acta Phytogeographica.

Rudmark L, Malmberg-Persson K, Mikko H, 2005. Oskarshamn site investigation – Investigation of QD 2003–2004. SKB P-05-49, Svensk Kärnbränslehantering AB.

Rummukainen M, 2003. The Swedish regional climate modeling program, SWECLIM, 1996–2003. Final report. Reports Meteorology and Climatology 104, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, 47 pp.

Rydin H, Sjörs H, Löfroth M, 1999. Mires. In Rydin H, Snoeijs P, Diekmann M, (ed.). Swedish plant geography, Acta Phytogeographica Suecica 84, Uppsala.

Rühling Å, 1997. Floran i Oskarshamns kommun. Svensk Botanisk Förening, Lund.

SCB, 1999. Skogsräkenskaper – en delstudie avseende fysiska räkenskaper, rapport 1999:3.

SCB website (http://www.ssd.scb.se/databaser, accessed 2005-10-17).

Schlesinger W H, 1997. Biogeochemistry – an analysis of global change. 2nd edition, Academic press, Harcourt Brace & Co, London, UK.

Schoning K, Klingberg F, Wastegård S, 2001. Marine conditions in central Sweden during the early Preboreal as inferred from a stable oxygen gradient. Journal of Quaternary Science 16, 785–784.

Silvola J, Alm J, Ahlholm U, Nykanen H, Martikainen P J, 1996. CO_2 fluxes from peat in boreal mires under varying temperature and moisture conditions. Journal of Ecology 84, 219–228.

Sjörs H, 1967. Nordisk växtgeografi. 2nd edition, Bonniers Stockholm. (In Swedish).

SKB, 1999. Deep repository for spent fuel SR 97 – Post closure safety. SKB TR-99-06 Main Report volume I and II, Svensk Kärnbränslehantering AB.

SKB, 2004. Interim main report of the safety assessment SR-Can. SKB TR-04-11, Svensk Kärnbränslehantering AB.

SKB, 2006a. Long-term safety for KBS-3 repositories at Forsmark and Laxemar – a first evaluation. SKB TR-06-09, Svensk Kärnbränslehantering AB.

SKB 2006b. The Biosphere at Forsmark. Data, assumptions and models used in the SR-Can assessment. SKB R-06-82, Svensk Kärnbränslehantering AB.

SKB, 2006c. Climate and climate related conditions – report for the safety assessment SR-Can. SKB TR-06-23, Svensk Kärnbränslehantering AB.

SKB, 2006d. Preliminary site description. Laxemar subarea – version 1.2. SKB R-06-10, Svensk Kärnbränslehantering AB.

SKB database, 2006. svn://s-sth-proper.skb.se/projekt/SR-Can Bio/Laxemar/Syntes/Objekt_parameterlista_Lm.xls

SKB GIS database, 2006. N-STH-SDEAPP. ArcSDE ver. 9.1, ESRI. Oracle9i Release 9.2.

SNV, 1984. Våtmarksinventering inom fastlandsdelen av Kalmar län: Del 1 Allmän beskrivning och katalog över särskilt värdefulla objekt. Statens Naturvårdsverk, Solna, Rapport PM 1787.

Sohlenius G, Hedenström A, Rudmark, L, 2004. Mapping of unconsolidated Quaternary deposits 2002–2003. Map description. Forsmark site investigation. SKB R-04-39, Svensk Kärnbränslehantering AB.

Sporrong U, Ekstam U, Samuelsson K, 1995. Swedish landscapes. Swedish Environmental Protection Agency. 184 p.

SSI, 1998. Statens strålskyddsinstituts föreskrifter om skydd av människors hälsa och miljön vid slutligt omhändertagande av använt kärnbränsle och kärnavfall (Swedish Radiation Protection Institute's Code of Statutes). SSI FS 1998:1, Statens strålkyddsinstitut. (In Swedish).

SSI, 2005. Statens strålskyddsinstituts allmänna råd om tillämpning av föreskrifterna (SSI FS 1998:1) om skydd av människors hälsa och miljön vid slutligt omhändertagande av använt kärnbränsle och kärnavfall. SSI FS 2005:5, Statens strålkyddsinstitut. (In Swedish).

Statistics Sweden, 1998. Markanvändningen i Sverige, tredje utgåvan, table B24. ISBN 91-618-0888-1. (In Swedish).

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

Svensson N-O, 1989. Late Weichselian and early Holocene shore displacement in the central Baltic, based on stratigraphical and morphological records from eastern Småland and Gotland, Sweden. LUNDQUA 25,181 pp.

Svensson J, Jeglum J K, 2000. Primary succession and dynamics of Norway spruce coastal forests on land-uplift ground moraine. Studia Forestalia Suecica 209. 32pp

Tobiasson, 2003. Tolkning av undervattensfilm från Forsmark och Simpevarp 2003, SKB P-03-68, Svensk Kärnbränslehantering AB.

Truvé J, Cederlund G, 2005. Mammals in the areas adjacent to Forsmark and Oskarshamn. Population density, ecological data and carbon budget. SKB R-05-36, Svensk Kärnbränslehantering AB.

Tröjbom M, Söderbäck B, 2006. Chemical characteristics of surface systems in the Simpevarp area. SKB R-06-18, Svensk Kärnbränslehantering AB.

UNSCEAR, 2000. UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Sources and effects of ionizing radiation. Report to the general assembly, with scientific annexes Volume I: Sources; New York, 2000.

Waddington J M, Roulet N T, 2000. Carbon balance of a boreal patterned peatland. Global Change Biology 6:87–97.

Werner K, Bosson E, Berglund S, 2005. Description of meteorology, surface hydrology, and near-surface hydrogeology. Preliminary site description Laxemar subarea – version 1.2. SKB R-05-61, Svensk Kärnbränslehantering AB.

Werner K, Bosson E, Berglund S, 2006. Analysis of water flow paths – methodology and example calculations for a potential geological repository in Laxemar, Sweden. Ambio, vol. 5, No. 8.

Werme K, Berglund S, Johansson P-O, Bosson E, Brydsten L, Tröjbom M, in manus. Recharge and discharge of near-surface groundwater in Forsmark – comparison of classification methods SKB R-report, Svensk Kärnbränslehantering AB.

Westman P, Wastegård S, Schoning K, Gustafsson B, 1999. Salinity change in the Baltic Sea during the last 8,500 years: evidence causes and models. SKB TR 99-38, Svensk Kärnbränslehantering AB.

Åstrand P-G, Jones J, Broed R, Avila R, 2005. Pandora technical description and user guide. Posiva Working Report 2005-64, Posiva Oy.

Appendix I

Parameters describing the Biosphere Objects that was identified and delimited as targets for a modelled radionuclide release at the Laxemar site. The definition of the parameter and the method behind the calculation of the parameter value is described in Chapter 5 under the specific ecosystem. The column “Object” denotes which ecosystem the parameter describes, while the column “SiteSpecificData” shows whether site specific data has been used to calculate the value. N shows the number of observations that the statistics in the table are built upon.

Object	Parameter	SiteSpecificData	Units	Mean	Median	Min	Max	Std	N
sea	z_uppers	No	m	0.02					–
sea	porosity_upper	No	–	0.6					
sea	density_upper	No	kg·m^{-3}	1,550					
sea	z_deeps	Yes	m	8.7					
sea	porosity_bottom	Yes	–	0.49					
sea	density_bottom	Yes	kg·m^{-3}	1,800					
sea	sed_growth	Yes	m·y^{-1}	0.00121	0.00125	0.00158	0.00133		3
sea	part_conc	Yes	kg·m^{-3}	3.0E–04	1.8E–04	1.1E–04	6.0E–04	2.2E–04	5
sea	v_sinking	No	m·y^{-1}	60.225		3.65	116.8		–
sea	v_sediment	Yes/Modeled	m·y^{-1}	0.058		0.0003	0.369	0.063	1.000
sea	productivity_food	Yes	kgC·m^{-2}·y	0.0066	0.0068	0.0000	0.0091	0.001	16.000
lake	z_uppers	Yes	m	0.02					–
lake	porosity_upper	Yes	–	0.91	0.91	0.75	0.94	0.04	19
lake	density_upper	No	kg·m^{-3}	1,060	1,050	1,020	1,150		19
lake	z_deeps	Yes	m	1.7	1.5	0.5	4.7	0.8	2,539
lake	porosity_bottom	Yes	–	0.91	0.91	0.75	0.94	0.04	19
lake	density_bottom	Yes	kg·m^{-3}	1,060	1,050	1,020	1,150	30	19
lake	acc_bottom	Yes	–	0.50	0.38	0.05	0.90	0.39	5
lake	sed_growth	Yes	m·y^{-1}	0.00200					1
lake	part_conc	Yes	kg·m^{-3}	6.3E–04	7.1E–04	2.2E–04	8.6E–04	2.8E–04	4
lake	v_sinking	No	m·y^{-1}	183		37	3,600		
lake	v_sediment	Yes/Modeled	m·y^{-1}	0.058		0.0003	0.369	0.063	1
lake	productivity_plants	Yes	kgC·m^{-2}·y^{-1}	0.3509					1
lake	productivity_animal	Yes	kgC·m^{-2}·y^{-1}	0.0546					1
lake	productivity_food	Yes	kgC·m^{-2}·y^{-1}	0.0024		0.0019	0.0028	0.0007	1
lake	productivity_edible	Yes	kgC·m^{-2}·y^{-1}	0.0147					1
mire	z_uppers	Yes	m	0.9	0.9	0.5	3.7	0.53	41
mire	porosity_upper	Yes	–	0.926	0.92	0.87	0.98	0.03	10
mire	density_upper	Yes	kg·m^{-3}	100	70	30	190	57	18
mire	runoff	Yes/Modeled	m^{3}·m^{-2}·y^{-1}	0.154	0.166	0.095	0.188	0.044	4
mire	productivity_food	No	kgC·m^{-2}·y^{-1}	5.5E–05					–
agricultural land	z_uppers	No	m	0.25		0.2	0.3		–
agricultural land	porosity_upper	Yes	–	0.6		0.52	0.65		2
agricultural land	density	Yes	kg·m^{-3}	700		690	700		2
agricultural land	z_deeps	Yes	m	0.75					–
agricultural land	porosity_bottom	Yes	–	0.6		0.54	0.68		3
agricultural land	density_bottom	Yes	kg·m^{-3}	680					1
agricultural land	z_saturated_zone	Yes	–	0.6	0.5	0	3	0.6	60
agricultural land	porosity_saturated_zone	Yes	–	0.43					
agricultural land	Loss_soil	No	kg m^{-2} y^{-1}	0.005		0.002	0.020		
agricultural land	precipitation	Yes/Modeled	m^{3}·m^{-2}·y^{-1}	0.655					1
agricultural land	runoff	Yes/Modeled	m^{3}·m^{-2}·y^{-1}	0.154	0.166	0.095	0.188	0.044	4
agricultural land	percolation	Yes/Modeled	m^{3}·m^{-2}·y^{-1}	0.143					1
agricultural land	Fdsts	Yes/Modeled	m^{3}·m^{-2}·y^{-1}	0.137					1

Object	Parameter	SiteSpecificData	Units	Mean	Median	Min	Max	Std	N
agricultural land	Fsads	Yes/Modeled	$m^3 \cdot m^{-2} \cdot y^{-1}$	0.2					1
agricultural land	productivity_plants	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.20	0.21	0.05	0.26	0.06	30
agricultural land	productivity_animal	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.0117					–
agricultural land	productivity_food	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.22	0.21	0.05	0.26	0.06	30
agricultural land	productivity_edible	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.22	0.21	0.05	0.26	0.06	30
agricultural land	bioturbation	No	$kg \cdot m^{-2} \cdot y^{-1}$	2		1	3		–
forest	z_uppers	Yes	m	0.29	0.29	0.25	0.89	0.15	16
forest	density_upper	Yes	$kg \cdot m^{-3}$	1,250	1,210	1,040	1,380	120	10
forest	precipitation	Yes/Modeled	$m^3 \cdot m^{-2} \cdot y^{-1}$	0.655					1
forest	evaporation	Yes/Modeled	$m^3 \cdot m^{-2} \cdot y^{-1}$	0.266					1
forest	transpiration	Yes/Modeled	$m^3 \cdot m^{-2} \cdot y^{-1}$	0.2					1
forest	InterceptionFraction	Yes/Modeled	–	0.28					1
forest	waterContent	No	m^3/m^3	0.19	0.17	0.07	0.43	0.08	–
forest	biomass_understorey	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.060	0.054	0.033	0.282	0.051	5
forest	biomass_leaves	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.611	0.505	0.001	2.207	0.470	33–148
forest	biomass_tree	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	5.05	4.55	0.05	18.99	4.98	33–148
forest	productivity_food	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.0038		0.00336	0.0040237		1 and 3
forest	productivity_understorey	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.040	0.040	0.020	0.069	0.022	5
forest	productivity_leaf	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.095	0.080	0.001	0.438	0.114	33–148
forest	productivity_wood	Yes	$kgC \cdot m^{-2} \cdot y^{-1}$	0.119	0.105	0.000	0.522	0.127	33–148
forest	loss_understorey	Yes	y^{-1}	0.774	0.774	0.380	1.000	0.337	5
forest	loss_litter	No	y^{-1}	0.4		0.1	0.7		–
forest	loss_leaves	No	y^{-1}	0.22		0.1	0.43		–
forest	loss_wood	No	y^{-1}	0.004					–
forest	lifelenght_tree	No	y	300		20	400		–
forest	food_leaves_moose	No	–	0.47		0.43	0.5		–
forest	food_mush_moose	No	–	0.07		0.59	0.08		–
forest	food_plants_moose	No	–	0.26		0.07	0.45		–
forest	food_wood_moose	No	–	0.016					–
forest	food_leaves_deer	No	–	0.3		0.12	0.48		–
forest	food_mush_deer	No	–	0.07		0.06	0.07		–
forest	food_plants_deer	No	–	0.57		0.34	0.81		–
forest	food_wood_deer	No	–	0.009					–
forest	weight_deer	No	kg dwC	5.6		4.6	6.4		–
forest	weight_moose	No	kg dwC	81.3		6.3	103.1		–
running water	runoff	Yes/Modeled	$m^3 \cdot m^{-2} \cdot y^{-1}$	0.154	0.166	0.095	0.188	0.044	4
well	wellcapacity	Yes	$m^{-3} \cdot y^{-1}$	15,680	7,884	2,102	43,800	16,135	6