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Ecosystem modelling in the Forsmark area

– proceedings from two workshops modelling Eckarfjärden and Bolundsfjärden catchment areas

Lindborg Tobias, Kautsky Ulrik (ed)
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November 2004

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1 Introduction

The siting program for a repository of spent fuel currently collects large set of data from the surface ecosystem, as well as from the geosphere. The program for the surface ecosystem is described in /Lindborg and Kautsky, 2000/ and /Löfgren and Lindborg, 2003/, and the general siting program in /SKB R-01-10/. The data collected at the sites will be used for various purposes, mainly for the safety assessment for the repository and for environmental impact assessment (MKB). The safety assessment of the encapsulation plant also includes an assessment of the postclosure of the repository (SRCAN) at the two sites of current interest for a repository. To show important methods on how data from the sites should be used in a safety assessment, a report for methods concerning SRCAN will be produced.

This report is a first step in showing how the site data will be used to understand the function and dynamics of the ecosystems and how it may be translated in various dose models. A more extensive report will be presented early 2005 from The SurfaceNet taskforce /Lindborg, 2005/. This report is based on two workshops held in Grisslehamn, Uppland October 20–23, 2003 and in Marholmen, Uppland April 16–19, 2004. Participants from the site investigation program, the analysis group, safety assessment and research (cf Table 1-1) attended the workshops. The groups worked intensively for 3 full days respectively, and achieved the major findings in this report. The two workshops had approximately the same approach, although Marholmen was more focused on the terrestrial ecosystems and Grisslehamn on aquatic systems. Besides the major aim of the workshops, to examine function and dynamics of ecosystems translated into dose modelling, another purpose was to communicate the reasons for the sampling programmes, to train new resources and to get plenty of undisturbed time to generate a large amount of creative work. It also got the important role of increased understanding between different scientific disciplines. High quality data is important for validating the dose- and ecosystem models. In this report all the site specific data, collected at the Forsmark site, are marked in grey to clarify potential shortage in data quality.

Table 1-1. The persons who attended and contributed with data and knowledge at one or both workshops in Grisslehamn (G) and Marholmen (M).

Participants	Subject	G	M	Participants	Subject	G	M
Amelie Darracq	Chemical balance GIShhdyrp	x		Lasse Kyläkorpi	GIS terrrest	x	x
Anders Löfgren	GIS terrest ecosystem		x	Linda Kumblad	Aquatic ecosystem	x	
Anna Hedenström	Soil properties		x	Per-Erik Jansson	CoupModel		x
Antonia Sandman	GIS aquatic system	x		P-O Johansson	Limnic system		x
Björn Söderbäck	Chemical balance	x	x	Regina Lindborg	Terrest ecosystem		x
Emma Bosson	Limnic system		x	Rodolfo Avila	Dose model		x
Erik Wijnbladh	Aquatic ecosystem	x		Sara Karlsson	Terrest ecosystem	x	x
Eva Andersson Nilsson	Aquatic ecosystem	x		Sofia Miliander	GIS terrest		x
Fredrik Vahlund	Simulink modell	x		Tobias Lindborg	GIS terrest ecosystem	x	x
Jacob Jones	Simulink modell		x	Ulla Bergström	Dose model	x	x
Johan Stendahl	Soil properties		x	Ulrik Kautsky	Aquatic ecosystem/ dose model	x	x
Lars Brydsten	GIS hydrologi	x	x				

1.1 The study area

The Forsmark area is situated between two large river catchments entering the Baltic Sea; River Tämnarån in north (SMHI catchment no 54) and River Forsmarksån in south (SMHI catchment no 55). The area between these two catchments, including the Forsmark area, is called no 54/55 according to the SMHI system. However, the siting programme needs a more detailed resolution, where sub-catchments are identified, e.g. for lakes situated within the site investigation area /Brunberg et al. 2004/.

Bolundsfjärden catchment area, named catchment Forsmark 2 in the /SKB P-03-27/, is divided into eleven different sub-areas (Figure 1-1): Lake Norra Bassängen (sub-area no 2:1), Lake 2:2 (no 2:2), Lake Bolundsfjärden (sub-area no 2:3), Lake Graven (sub-area no 2:4), Lake Fräkengropen (no 2:5), Lake Vambörsfjärden (no 2:6), Lake Kungsträsket (no 2:7), Lake Gällsboträsket (no 2:8), Lake Stocksjön (sub-area no 2:9), Lake Eckarfjärden (no 2:10) and Lake Puttan (no 2:11).

The upstream sub-areas are all draining to the most downstream sub-area no 2:1, which enters the Baltic Sea in Asphällsfjärden east of the Forsmark nuclear power plant. The central lake in this water system is Lake Bolundsfjärden, which receives water from three branches of the water system: from Lake Graven – Lake Fräkensjön to the east, from Lake Vambörsfjärden to the south, and finally, from Lake Kungsträsket, Lake Gällsboträsket and Lake Stocksjön – Lake Eckarfjärden in south/west. The water draining downstream from Lake Bolundsfjärden enters Lake Norra Bassängen. Lake Puttan is situated East of Lake Norra Bassängen and North of Lake Bolundsfjärden.The direction of drainage between Lake Puttan and Lake Norra Bassängen is unclear and probably varies during the year. The connection (or lack of connection) between Lake Puttan and Lake Bolundsfjärden also remains to elucidate. Here we have chosen to place Lake Puttan as the last sub-catchment of the area (Forsmark 2:11), draining to Lake Norra Bassängen and then further to the Baltic Sea.

***Figure 1-1.** The Forsmark area with the eleven sub-areas in the Bolundsfjärden catchment area (catchment Forsmark 2) marked with yellow boundaries.*

2 General physical properties of the landscape

2.1 Regolith

The landscape in Forsmark is a relatively flat peneplain, which dips gently towards the east. The whole area is situated below the highest coastline. Most of the area has been raised above the sea during the last 1,000 years, which means that processes such as chemical weathering and peat formation has affected the area during a relatively short period of time. The till and glacial clay are rich in $CaCO_3$ emanating from Palaeozoic limestone, which occurs at sea bottom north of the area.

A detailed mapping of the distribution of the Quaternary deposits in the Forsmark area has been performed within the site investigations /Sohlenius et al. 2004/. There are numerous bedrock exposures in the area and altogether 5% of the area constitutes bedrock. The frequency of exposed bedrock varies throughout the investigated area and some areas are poor in bedrock exposures, e.g. a zone in NW-SE direction including Lake Fiskarfjärden. An ice moving from the north (350°–360°) has formed most glacial striae but striae formed by older ice movements from north-west and almost west (300°) are also observed.

Glacial till is the most common Quaternary deposit, covering c 75% of the Forsmark region (Figure 2-1, Table 2-1). Based on the surface layer, the till was subdivided into three main domains: I) sandy till with a normal frequency of superficial boulder, II) clayey till with a low to normal frequency of superficial boulder, III) sandy till with a high superficial frequency of often large boulders (Figure 2-1). Most of the sandy till is covered by forest, whereas the clayey till is used as arable land and for pasture. Bolundsfjärden is completely situated within till area I with sandy till dominating in the surface.

A glaciofluvial esker with a north-south direction, the Börstilsåsen esker, follows the coast in the eastern part of the mapped area. In the most exposed positions, till and glaciofluvial deposits have been affected by erosion from waves and streams. The areas constituting of fine-grained water laid sediments are restricted (Table 2-1). The major parts of the wetlands constitute of glacial clay, sand or gyttja clay. The south-western part of the mapped area is situated at altitudes > 5 m above the present sea level. The wetlands in that area have been above the sea for a period long enough for a peat layer to form.

Table 2-1. The proportional surface distribution of Quaternary deposits in the mapped area, extracted from the geological map, (Figure 2-1) /Sohlenius et al. 2004/. All data in the table are site specific.

Quaternary deposit	Coverage %
Peat	2.81
Gyttja sediments	3.75
Clay	4.03
Postglacial sand and gravel	3.95
Glaciofluvial sediment	1.72
Till, clayey	11.30
Till, sandy with a medium boulder frequency	52.30
Till, sandy with a high boulder frequency	8.40
Till, sandy with a high frequency of large boulder	2.86
Total area covered by till	*74.86*
Artificial fill	4.05
Precambrian bedrock	4.84

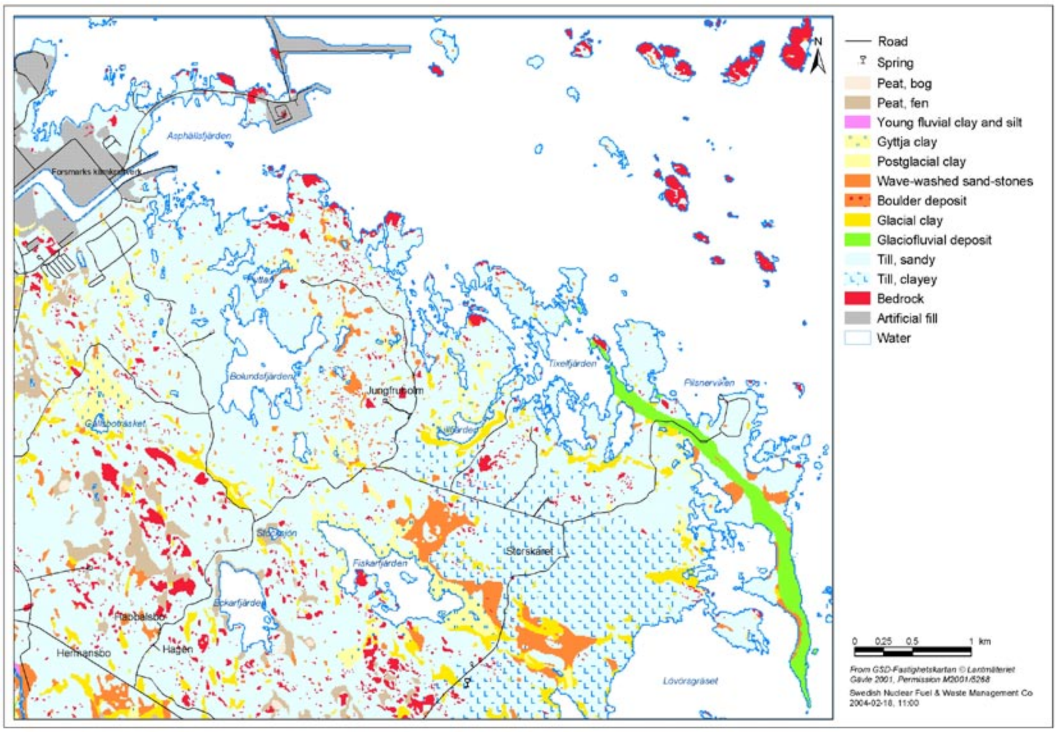

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Figure 2-1. *Map showing the distribution of the Quaternary deposits in the central part of the Forsmark regional model area /Sohlenius et al. 2004/.*

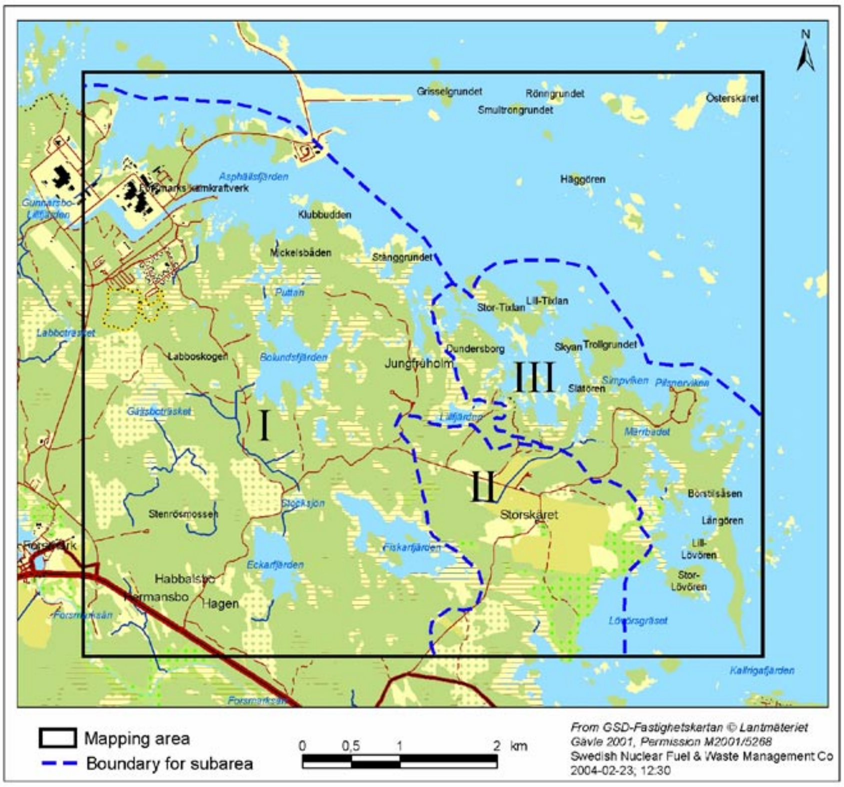

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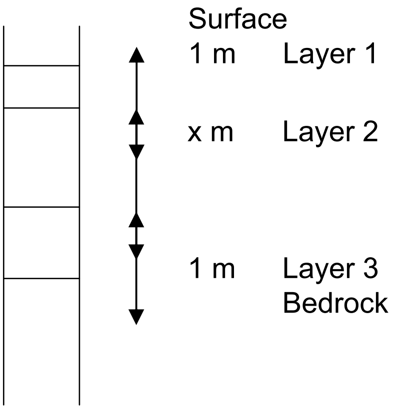
***Figure 2-2.** The surface distribution of glacial till has been subdivided into three main domains: I) sandy till with a normal frequency of superficial boulder, II) clayey till with a low to normal frequency of superficial boulder, III) sandy till with a high superficial frequency of often large boulders. The model area, Bolundsfjärden, is completely situated within the first domain /from Sohlenius et al. 2004/.*

2.1.1 Simplified stratigraphical model of the glacial till in Forsmark

Within the site investigations, stratigraphical corings has been performed at c 40 sites distributed within the till domains I and II /Johansson 2003; Hedenström et al. 2004/. Available data consist of field classification of the till stratigraphy together with analyses of grain size distribution from 54 samples, collected from representative till units. The information gained from these point observations was used to construct a first and very simple model of 1) total thickness and 2) stratigraphical distribution of the glacial till (Table 2-2, Figure 2-3). Each layer was assigned the grain size distribution from the dominating Quaternary deposit of the layer. After assigning a grain size curve to each layer, they were compared to grain size curves from generic data, stored in a database connected to the CoupModel (see CoupModel 6-2).

In this first model, the stratigraphical sequences were divided into three layers:



Layer 1 represents the upper 1 metre, which has been effected by wave washing and soil-forming processes, with a positive effect on the porosity of the till. If the depth to bedrock was less than 2 m, Layer 1 was still set to 1 m and layer 2 was given the same grain size composition as layer 1. The residual depth to bedrock was assigned to Layer 3. If the depth of the till exceeded 2 m, Layer 3 was set to 1 m. All samples from Layer 1 were compared with top soil samples from the data base, while Layers 2 and 3 were compared with deeper profiles. Samples representing top soils were sufficient for matching the different till types classified in Layer 1. For the samples representing Layers 2 and 3, the database only contained data from two sites (Emmaboda 3 pits and Stäket 6 pits), hence exact match of till type was not possible. It was however estimated that the comparison with a deep soil sample was more crucial than finding a perfectly matching grain size distribution curve for the samples from layers 2 and 3.

Table 2-2. The generalised 2D model of glacial till within Bolundsfjärden. The thickness of Layers 1 and 3 were set to 1 m while Layer 2 was the residual. Z3 is the depth to bedrock from the upper soil surface. Z4 are from corings in lakes and does not continue to bedrock why Z4 is a minimum value of depth to bedrock. Data from /Johansson, 2003; Hedenström et al. 2004; Hedenström, 2004/. All data in the table are site specific.

Borehole	QD (till) type Layer 1	QD (till) type Layer 2	QD (till) type Layer 3	Z 3 total depth to bedrock (m)	Z 4 bedrock min
SFM0004	sandy silty till	Clayey sandy till	sandy silty till	5.00	
SFM0005	sandy till	Sandy till	sandy till	2.00	
SFM0010	clayey sandy silty till	Clayey sandy silty till	clayey sandy silty till	1.4	
SFM0011	sandy till	Sandy till	sandy till	3.9	
SFM0012	Gyttja	Sandy till	sandy till		5.35
SFM0013	grus	Sandy till	sandy till	4.6	
SFM0014	sandy silty till	Sandy silty till	sandy silty till	1.95	
SFM0015	Gyttja	Clay	sandy till		6.75
SFM0016	sandy till	Sandy till	clayey sandy till	7.2	
SFM0017	Peat	Gravelly till	clayey sandy silty till	4	
SFM0018	Peat	Clayey sandy till	Clayey gravelly till	4.6	
SFM0019	sandy till	Sandy till	sandy till	4.8	
SFM0023					4.30
SFM0030	sand	Clayey sandy silty till	clayey sandy silty till	3.6	
SFM0031	sand	Clayey sandy silty till	clayey sandy silty till	3.6	
SFM0032	sand	lerig sandy till	clayey sandy till	2.9	
SFM0034	clayey sandy till	Clayey sandy till	sandy till	1.8	
SFM0036	sandy till	Sandy till	clayey sandy till	1.90	
SFM0039	gyttja	Gyttja	Gyttja		3.40
SFM0040	gyttja	Sandy till	sandy till		4.20

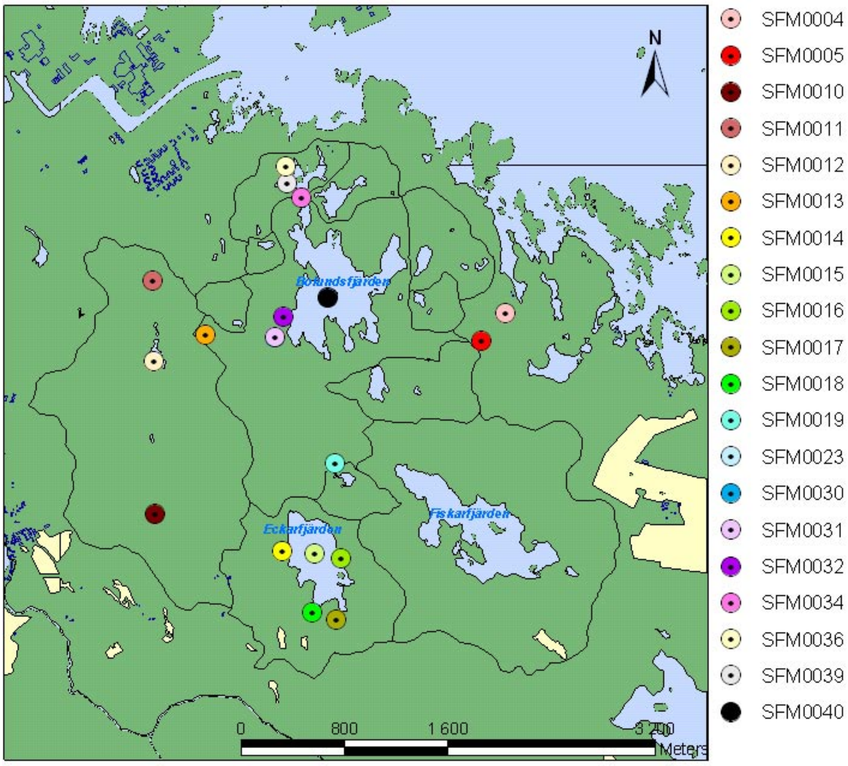


Figure 2-3. *Locations of bore holes cf Table 2-2.*

2.2 Soil properties

The soils in the Forsmark area are typically poorly developed soil types on till or sedimentary parent material, which is influenced by calcareous material. The poor soil development is a result of young age; most of the area emerged from the sea approximately 1,500 years ago. As the sea withdrew it influenced the soil by wave action, which washed out the tills and redistributed the soil material into sedimentary deposits. In exposed position all soil was washed away and in many places across the area there is bare rock or very thin soil cover. Further, former sea bays that were cut off now form inland lakes or are being developed into swamps and peatland. This has produced a heterogeneous area with a large variety of soil parent material, from bare rock to washed out tills, and sorted sediments. The calcareous soil material has yielded nutrient-rich conditions, which can be observed in the rich and diverse flora of the area. This can also be seen in the predominant humus forms of mull type and of the intermediate moder type, which indicate a rich soil fauna. Because of the young age of the soils, the Forsmark area exhibit less soil of Podsol type than most similar areas in Sweden, and instead the typical soil types are the less developed Regosols soils, together with Gleysols and Histosols, which are formed under moist conditions.

The predominant soil classes of the Forsmark area (names according to the soil classification, /WRB, 1998/) are shortly summarized below /see Lundin et al. 2004 for details/:

Histosol (HI) – peatland and open mires as well as forested peatland with at least 40 cm depth.

Leptosol (LP) – shallow soils with less than 25 cm depth overlaying the bedrock.

Gleysol (GL) – moist soils (not peatlands), which are periodically saturated with water

Gleysol/Cambisol (GL/CM) – forest soils on fine texture parent material with deciduous trees.

Arenosol/Gleysol (AR/GL) – soils along the sea shoreline on sandy material of sediment origin.

Regosol/Gleysol (RG/GL) – less developed soils on course till with mixed coniferous forests.

Regosol/Gleysol on arable land (RG/GL-a) – less developed sediment soils and clayey till soils of Cambisol type

Regosol (RG) – less developed soil on course glacifluvial material (esker in the eastern part of the area).

The soils in Bolundsfjärden are essentially of the same type as in the rest of the Forsmark area. However, the distribution between the classes deviates to some extent (Table 2-3).

The Bolundsfjärden soils consist of more Histosols, which are often more developed than the common young organic soils found along the border of lakes in other parts of the Forsmark area. Also the coniferous forest soils of Regosol/Gleysol type are more common. Further, Bolundsfjärden has much less Regosol/Gleysol on arable land than Forsmark in general since no areas with clayey till parent material occur within this catchment. The catchment also has less Gleysol soils. Two soil classes do not occur in Bolundsfjärden at all, i.e. Arenosol/Gleysol, which is associated with the Baltic shoreline area, and Regosol, which is found by the esker southeast of the catchment.

The soils in the Bolundsfjärden catchment are more nutrient poor than the Forsmark area in general, especially due to the small amount of fertile arable land. The high proportion of Histosols might also indicate large discharge areas in low positions in the landscape that might be associated with the outflow of water-soluble substances. The drainage water from the area should also be of a more humic character than the whole Forsmark area.

Table 2-3. Distribution of soil classes for Bolundsfjärden and the whole Forsmark area.

Code	Soil class	Bolundsfjärden (%)	Forsmark area (%)
	Unclassified	0.03	3.15
HI	Histosol	17.00	12.90
GL	Gleysol	0.83	2.70
GL/CM	Gleysol/Cambisol	22.20	20.90
RG/GL	Regosol/Gleysol	46.90	36.40
RG/GL-a	Regosol/Gleysol on arable land	1.30	8.85
AR/GL	Arenosol/Gleysol	0.00	1.40
RG	Regosol	0.00	1.42
LP	Leptosol	11.80	12.30

2.2.1 The use of the soil map in analysis

The soil is formed by many different soil-forming factors that have been active over time, such as climate, parent material, topography and vegetation. Since the soil is the integration of many fundamental factors it reflects the behaviour of the soil in the ecosystem. This makes it useful for extrapolating information from e.g. soil investigations over large areas.

This can be information on soil chemical (pH, carbon content) or physical properties (soil moisture), which may be useful for modelling soil processes over a large area. The soil map was also used for prediction of groundwater level, which improved the results compared to the use of information on parent material, topography or vegetation alone.

The soil map of the Forsmark area (Figure 2-4) was derived from secondary spatial data on vegetation types, distribution of quaternary deposits and a topography-based hydrological index. Soil moisture is to a large extent dependent on topography, or rather, the hydrological conditions given by the topography. The wetness in a certain location relates to its specific catchment area, i.e. the upslope area draining through that location, and the slope. The topographical wetness index (TWI) attempts to describe the spatial distribution of the depth to the groundwater table, which reflects the soil moisture in the upper part of the soil. The index (TWI) in a point is a non-linear function of the upslope area (α) and slope (β), which can be derived from the digital elevation model:

$$\mathrm{TWI} = \ln(\alpha/\tan\beta)$$

The index is valid as long as the groundwater surface varies according to the topography and the soil transmissivity is constant. The limit chosen to differentiate between fresh and moist soils was a TWI value of 8 (Figure 2-5).

Based on analysis of the soil samples collected in the field several properties for each soil class have been estimated. These soil properties include soil texture, pH, carbon, nitrogen etc.

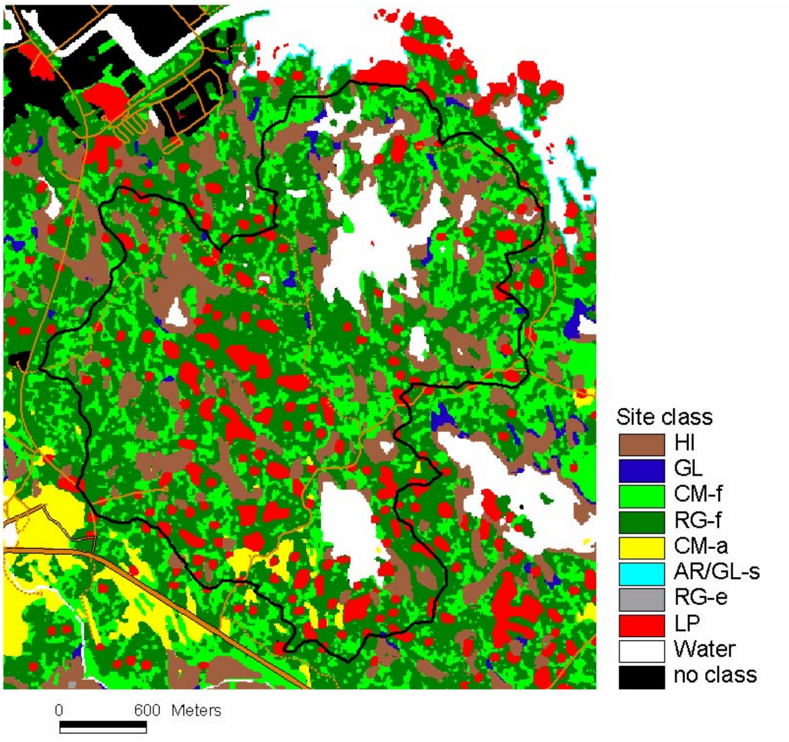


Figure 2-4. *The soil map of Bolundsfjärden. A description of the soil codes and the area distribution of the soil classes can be found in Table 2-3.*

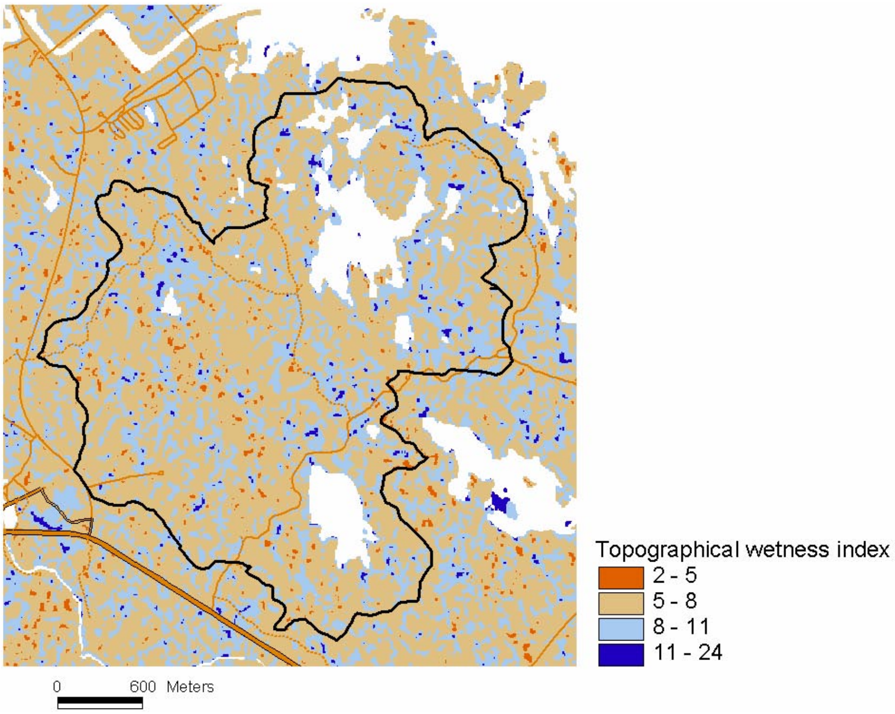


Figure 2-5. *Map of the topographical wetness index (TWI) for Bolundsfjärden. The TWI was derived from the digital elevation model.*

2.2.2 Calculations of soil carbon stock

An important parameter for modelling the carbon dynamics in the soil, e.g. with the CoupModel /Jansson and Karlberg, 2001/, is the total carbon stock and the distribution of carbon in the soil profile. In the work to characterize the soils in the Forsmark area, the necessary data was collected to calculate the carbon stocks for each dominant soil class /Lundin et al. 2002/. The soil carbon pools for each soil layer can be calculated and added together using the following formula:

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

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

The bulk density was determined by weighting a specified volume of soil for each horizon. The stone content can be estimated from the result of the so-called Viro's rod penetration method. It is based on the mean penetration depth (PD), which is estimated in the field using a Viro rod. The stone content (C_{stone}, %) can be calculated from PD based on linear relationships, which have been calibrated in the field. In the original work by /Viro, 1952/, two function were presented, of which the most commonly used is the one below:

$$C_{stone} = 100.3 - 3.27 \times PD_{30cm} \qquad (1)$$

Later work combined the two functions into one /Tamminen and Starr, 1994/, which produced the following function:

$$C_{stone} = 83 - 2.75 \times PD_{30cm} \quad (2)$$

, where PD_{30cm} is the mean penetration depth down to a maximum of 30 cm. Which function that is preferable depends on the type of soil parent material, but since the original function (1) was calibrated on sedimentary soil material function (2) should be preferable in most of the Forsmark area.

2.3 Climate

The climate is described for the whole Forsmark region, including Bolundsfjärdens catchment area. For more detailed information see /Larsson-McCann et al. 2002/.

2.3.1 Precipitation

The total gauged precipitation amount holds for about 600 mm annually at the coastline. A maximum can be identified 5–15 km inland, after which the precipitation amount decreases further south-west in Uppland and a minimum is reached over Lake Mälaren with about 500 mm per year. In relative terms this geographical distribution is valid all year. The estimated true annual precipitation (adjusted for measuring losses) exceeds the gauged amounts with about 100 mm or more.

Disregarded the mountainous region in Northern Sweden with as high as about 2,000 mm (gauged value) per year, the Swedish region with the highest precipitation is the western slopes of the South Swedish highlands with up to about 1,100 mm. On the other hand, appreciably less than 500 mm of yearly mean precipitation can be found only in the northernmost part of Sweden with locally about 400 mm, though associated with considerably weaker evaporation rates than in southern Sweden.

2.3.2 Temperature

The temperature climate is typical Central Swedish with a yearly mean of 5 to 6°C. This could be compared to Stockholm (6.6°C), Malmö (8.2°C) and Östersund (2.5°C). The average monthly mean temperature is in January about –4°C, in July 15 to 16°C. The vegetative period (daily mean temperature exceeding 5°C) has a duration of about 180 days, i.e. approximately half the year.

The temperature variation over Northern Uppland largely depends on the sea-land dualism, implying smaller annual variations over sea, i.e. higher winter and lower summer temperatures than over land. This is combined with a similar day-night pattern, connected to the small diurnal variations over sea. The monthly mean temperature has its greatest coast-inland difference in November–December, with 1°C lower mean temperature 10–15 km inland from the coast than at the coastline itself. In May–June an almost as great opposite difference is at hand. May has a difference in average daily maximum temperature amounting to 2°C between locations 10 km inland relative to sites at the coastline.

2.3.3 Wind

The most frequent wind directions in southern Sweden are west and south-west, with some local and regional deviations. This makes the East Coast climate somewhat less maritime than that on the West Coast, which also means that the differences are less pronounced between the actual coastal sites and their inland neighbourhood than is the case on the West Coast.

2.3.4 Sunshine

The yearly sunshine time is about 1,700 hours in Northeast Uppland, somewhat more (up to 1,800 hours) at the coast, somewhat less (1,600–1,700 hours) in the interior parts. Few places in Sweden have much higher values than the studied near-coast sites. This fits in a general pattern of comparatively abundant sunshine along the coast, while in the interior of Götaland the values go down to 1,300 hours. The cloudiness percentage is 65% or slightly more, as yearly mean, and does not vary much over Uppland. In early summer the cloudiness tends to decrease near the coast compared to inland conditions.

2.3.5 Snow cover

The ground is covered by snow in average 120–130 days a year, with an average yearly maximum depth of snow of about 50 cm. The coast does not differ much from the conditions 10–20 km inland, but further to south-east, at Lake Mälaren, the number of snow-cover days decreases to below 100 and the mean maximum snow-depth diminishes to about 30 cm.

2.4 Hydrology

All data concerning hydrology are collected and calculated only for Eckarfjärden catchment area.

2.4.1 Calculation of specific runoff and discharge

The monthly specific runoff for Eckarfjärden was calculated using data from Vattholma /Larsson-McCann et al. 2002/. Vattholma Q-station is situated in the upper part of River Fyrisån and runoff has been measured sins 1917. Characteristic discharge values for Vattholma are quite similar to the values for Forsmarksån situated close to the Eckarfjärden catchments (Table 2-4).

Table 2-4. Characteristic discharge for Vattholma and Forsmarksån (dm^3 s^{-1} km^{-2}).

Station	Area (km^2)	LLQ50	MLQ	MQ	MHQ	HHQ50
Vattholma	294	0.18	1.10	7.5	30	69
Forsmarksån	376	0.19	1.15	8.0	37	91

Data for 1988, with an accuracy of 6 hours, was used for the calculation. The average monthly values for specific runoff (dm^3 s^{-1} km^{-2}) were calculated using the Pivot table function in Excel (Table 2-5).

Table 2-5. Calculated specific runoff (SR, dm^3 s^{-1} km^{-2}) for Vattholma Q-station for the year 1988 and 1917–2000, respectively.

Month	SR (1988)	SR (1917–2000)
1	5.4	7.6
2	4.4	6.8
3	4.4	8.1
4	8.3	16.8
5	8.9	14.2
6	9.9	4.3
7	15.1	2.1
8	13.1	2.4
9	5.4	3.7
10	11.6	5.4
11	6.2	7.9
12	8.4	9.0
Year	7.6	7.5

The average monthly discharge (m^3 s^{-1}) for Eckarfjärden was calculated using values for specific runoff for Vattholma 1917–2000 (Table 2-6).

Table 2-6. Calculated monthly variation in discharge (m^3 s^{-1}) in the Eckarfjärden outflow.

Month	Discharge
1	0.0099
2	0.0088
3	0.0105
4	0.0218
5	0.0184
6	0.0056
7	0.0027
8	0.0031
9	0.0048
10	0.0070
11	0.0102
12	0.0117
Year	0.0097

2.4.2 Calculation of precipitation

The precipitation in Forsmark area has a strong east – west gradient with higher precipitation in westerly parts, i.e. 720 mm in Lövsta approximately 10 km W from the coastline and 588 mm at Örskär situated in the archipelago. The monthly average precipitation at Eckarfjärden catchments was therefore calculated as the average of these two stations (Table 2-7).

Table 2-7. Measured precipitation (mm) at Örskär and Lövsta and calculated precipitation at Eckarfjärden.

Month	Örskär	Lövsta	Eckarfjärden
1	46	65	56
2	35	44	40
3	31	39	35
4	34	44	39
5	34	41	38
6	39	46	43
7	58	87	73
8	79	95	87
9	64	78	71
10	51	66	59
11	65	80	73
12	52	71	62
Year	588	760	674

2.4.3 Calculation of potential evapotranspiration

The average monthly sum of potential evapotranspiration (mm) is calculated for Films Kyrkby in /Larsson-McCann et al. 2002/. Films Kyrkby is situated approximately 15 km SW of Eckarfjärden. The share of evapotranspiration of precipitation was calculated for Films Kyrkby for each month. This share was then applied to Eckarfjärden with the assumption that the share is equal in Films Kyrkby and Eckarfjärden (Table 2-8).

Table 2-8. Calculated monthly variation in specific potential evapotranspiration ($dm^3\ s^{-1}\ km^{-2}$) for the catchments of Eckarfjärden.

Month	Evapotranspiration
1	0.0000
2	0.0007
3	0.0059
4	0.0139
5	0.0199
6	0.0283
7	0.0285
8	0.0269
9	0.0039
10	0.0017
11	–0.0003
12	–0.0006
Year	0.0133

The runoff was then calculated as precipitation minus potential evapotranspiration (Table 2-9).

Table 2-9. Calculated monthly variation in precipitation, potential evapotranspiration and runoff ($dm^3\ s^{-1}\ km^{-2}$) for the catchments of Eckarfjärden.

Month	Precipitation	Evapotranspiration	Runoff
1	0.0230	0.0000	0.0111
2	0.0144	0.0007	0.0145
3	0.0193	0.0059	0.0104
4	0.0164	0.0139	0.0215
5	0.0093	0.0199	0.0100
6	0.0137	0.0283	0.0020
7	0.0263	0.0285	0.0006
8	0.0348	0.0269	0.0012
9	0.0100	0.0039	0.0027
10	0.0175	0.0017	0.0041
11	0.0121	–0.0003	0.0066
12	0.0204	–0.0006	0.0044
Year	0.0227	0.0133	0.0094

The specific runoff for the whole year is calculated to 9.4 $dm^3\ s^{-1}\ km^{-2}$ compared to 7.5 $dm^3\ s^{-1}\ km^{-2}$.

2.4.4 Calculation of discharge in each cell in a rasterized Eckarfjärden catchments

The share of the precipitation that infiltrates into the soil and builds up the groundwater assumes to be constant for all cells in catchments. Then it is possible to calculate yearly averages (or monthly) of discharges in each cell using the calculated specific runoff (Table 2-5). If a sub-catchments (for instance the catchments of a cell with contaminated groundwater outflow) has approximately the same share of land use types as the catchments used for calculation of specific runoff, should the calculations of discharge be accurately enough to be used for radionuclide dynamics. On the other hand, if the distribution of land use types in the sub-catchments differs remarkable from the total catchments, the calculated discharge will be under- or overestimated due to the dominating land use type (for instance an extremely high lake percent will give an overestimation since the transpiration is higher from a lake surface compared to vegetated land surface).

An example of calculation of discharge in each cell in rasterized catchments will be presented here using ArcGis 8 GIS-programme. Initially, the ArcObjects Developer Kit must be installed. The programme is found on the installation CD in the ArcObjects Developer Kit catalog.

> Start the ArcMap programme and open the digital elevation model (DEM). If the DEM contains negative values it is necessary to add a constant positive value to each cell with the Raster Calculator function. Activate the extension Spatial Analyst with *Tools < Extensions*. Make the dialog for Spatial Analyst with *View < Toolbar* and perform the calculation with *Spatial Analyst < Raster Calculator*. Make this new grid permanent by right-clicking the name of the layer and chose *Make Permanent*.
>
> Before the *Hydrology Modeling Extension* can be chosen beneath *Tools < Extensions*, it is necessary to register the extension DLL. Click on *Tools < Customize* and click the *Add from file* button. Navigate to ArcGis < Arcexe82 < ArcObjects Developer Kit < Samples < Spatial Analyst < Hydrology Modeling and chose esrihydrology_v2.dll, click *OK* and mark *Hydrology Modeling*.

Using hydrological modeling in ArcGis 8 require a DEM without local sinks. Sinks in a DEM are normally due to error in the data. Natural occurring sinks in a DEM with cell size larger than 10 metres are rare /Mark, 1988/, besides in areas with glaciers or karst. To fill a DEM with sinks should therefore sees as deleting unwanted errors in the DEM.

> The sinks are filled up with the function *Hydrology < Fill sinks...* and make the new DEM permanent by right-clicking the layers name.

Next step in the calculation of discharge is to make a new grid with flow directions for each cell using the filled DEM as input. ArcGis calculates the slope gradient direction using the elevation value in the cell and elevation values for eight adjacent cells. Hence, there are eight possible outcomes and are classified in the new grid with a value 1 for north, 2 for northeast, 4 for east (always a doubled value) etc to 128 for northwest /Jenson and Dominque, 1988/.

> The flow direction grid is made with *Hydrology < Flow Direction...* using the filled grid as input.

Using the flow direction grid it is possible to make a new grid showing for each cell the number of cells that are situated upstream the actual cell, i.e. the accumulated flow at each cell. High values indicate streams or discharge areas for ground water and low values indicate local topographical peaks or ridges.

> The accumulated flow is calculated with *Hydrology < Flow Accumulation...*, where the grid for flow direction is used as input.

Using the flow accumulation grid it is possible to calculate the average discharge in each cell using runoff data or data for precipitation and evapotranspiration. The simplest approach is to choose a constant value for specific runoff (dm^3 s^{-1} km^{-2}) for the whole catchments. The grid with flow accumulation values is multiplied with area of the cell and divided with 1,000,000 to get the results in km^{-2}. This new grid is multiplied with the specific runoff and divided by 1,000 to get the result in the unit m^3 s^{-1}.

The specific runoff for Vattholma catchment, situated west of Forsmark area, is 7.5 l s^{-1}km^{-2}. Due to the high east-west gradient in precipitation, with increasing values in the westerly direction, it is possible that the specific runoff for Norra Bassängen is lower than for Vattholma catchment. The specific runoff for Norra Bassängen was therefore set to 6.5 l s^{-1}km^{-2}.

The raster map showing water flow at each pixel in the model (m^3 s^{-1}) is named Flow-low in the GIS-database. The mean outflow from Norra Bassängen was calculated to 0.052 m^{3}s^{-1}.

2.4.5 Prediction of the groundwater surface level

The level of the ground water surface was predicted over the same area as the quaternary map using measurements of the levels in 34 ground water tubes (see Figure 2-6).

Only measurements for the months of April (high level) and August (low level) was used. Summary statistics for ground water levels are presented in Table 2-10.

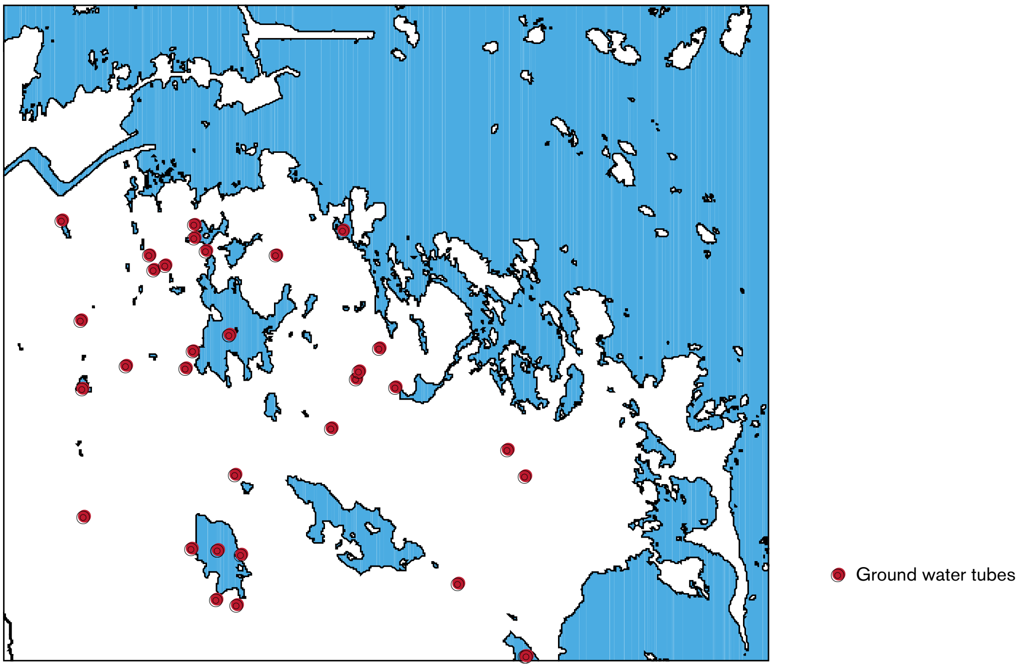


***Figure 2-6.** Positions of ground water tubes.*

Table 2-10. Ground water levels expressed as metre below ground surface (m).

	Difference April – August	April	August
Mean	0.58	0.95	1.63
Maximum	2.15	3.13	4.07
Minimum	–0.44	0.25	0.49
Variance	0.28	0.27	0.72

The ground water tubes were linked to soil-class using join-function in ArcGis. The idea was to check if ground water levels are higher in positions classified as "wet" in the soil map. The difference in ground water levels between different soil-classes was found to be low, but higher in soils classified as "wet" compared to "moist", and "moist" higher than soils classified as "fresh" (see Table 2-11).

Table 2-11. Soil classes and median ground water levels.

Soil-class	Median ground water level (m below ground)
"Wet"	1.00
"Moist"	1.15
"Fresh"	1.40

No ground water tube is placed on soil-class "Dry" (Bedrock), so the median ground water level was set to 3 metres for soil-class "Dry".

The soil map (vector format) was reclassified to a map describing ground water level below ground using values from Table 2-10. The ground water level for the sea was set to zero and ground water levels for the lakes was set to the lake surface elevation values. This map was converted to raster format with the same extension and cell resolution as the digital elevation model (DEM) and with a grid code for ground water level below ground. The DEM was subtracted with the rasterized ground water level map to create a DEM showing ground water levels (masl). This map is named GW masl in the GIS-database.

2.4.6 Predicting depths of quaternary deposits (soil depths).

Soil depths are measured at 48 sites in the Forsmark area (see Figure 2-7 and Table 2-12).

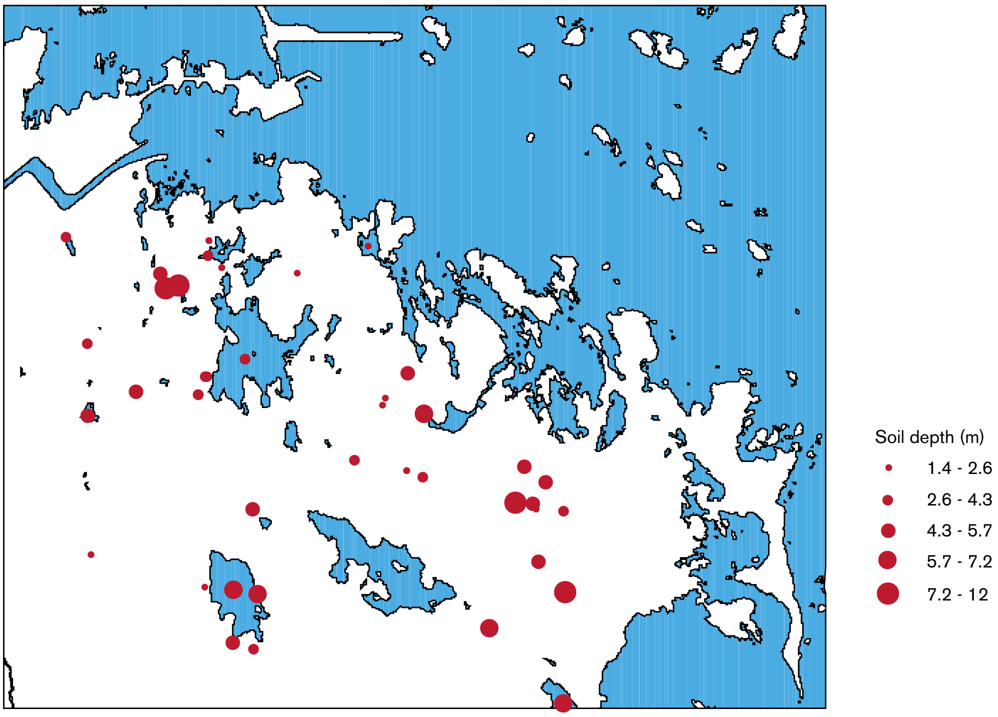


Figure 2-7. *Soil depths in the Forsmark area.*

Table 2-12. Different soil depths in the Forsmark area.

	Depth (m)
Median	4.2
Mean	4.6
Maximum	12.0
Minimum	1.4
Variance	6.3

An attempt was done to predict soil depths with the same technique as for ground water levels, i.e. join the ground water tubes to the quaternary map in ArcGis. The idea was to test if soil depths differ between different types of quaternary deposits. Unfortunately, no correlations were found between soil depths and types of quaternary deposits. So, a second attempt was to check correlation between soil depths and distance to regional or local major faults. Soil depths close to faults may be higher than distant from faults, due to that faults often coincide with valleys in the landscape. High soil depths were found close to faults but not at longer distance from faults. Unfortunately, shallow soils depths were also found close to faults (Figure 2-8).

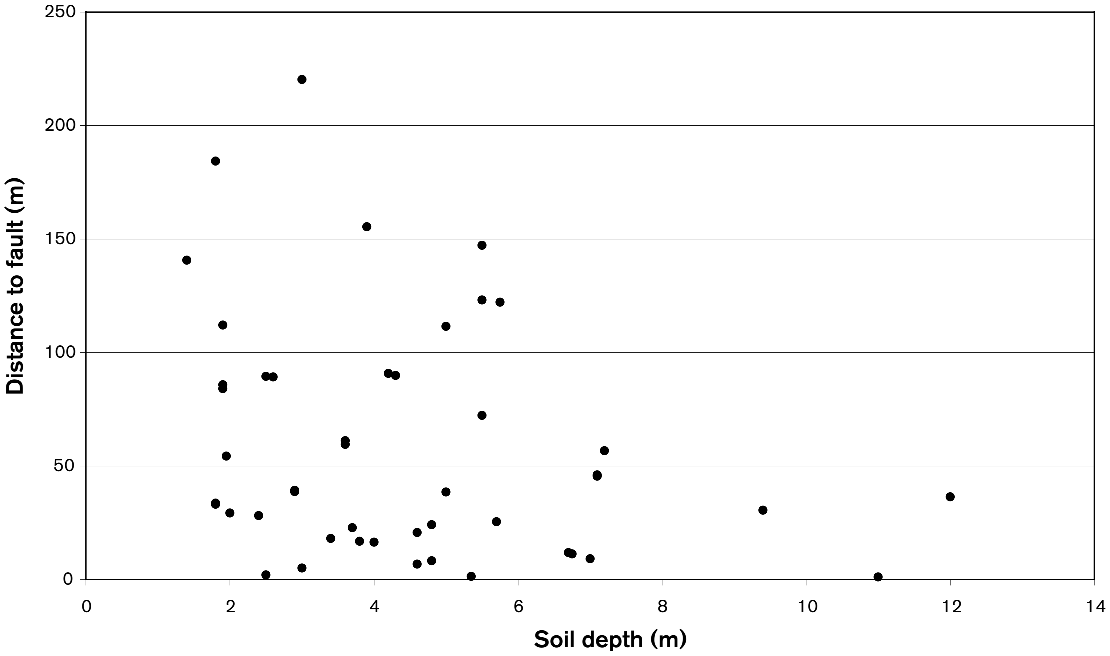


Figure 2-8. *Relationships between soil depths and shortest distance to faults.*

3 The limnic system

3.1 Geometry

The limnic system in this report is represented by Lake Eckarfjärden (Swedish Lake number 669723-163205) that is located 2 km south of Forsmark, near the coast of the province of Uppland, Sweden (60°22' N, 18°12' E). The lake is situated 6 m above sea level, which corresponds to an age of about 930 years /Brydsten, 1999/. The lake is small and very shallow /Brunberg and Blomqvist, 1998/ with a maximum depth of only 2.6 m and a mean depth of 1.5 metres. As a result the volume is small, 0.35 Mm^3 but the resident time is rather long, 383 days. The catchment is dominated by mature coniferous forest. Some characteristics for the lake and its catchment area is summarised in Table 3-1.

Table 3-1. Characteristics of Lake Eckarfjärden and its catchment /from Blomqvist et al. 2002/.

Catchment data		Lake morphometry	
Total area (km^2)	1.51	Lake area (km^2)	0.23
Forest (%)	73	Maximum depth (m)	2.6
Wetland (%)	7	Mean depth (m)	1.5
Pastures (%)	5	Volume (Mm^3)	0.35
Eckarfjärden (%)	15	Theoretical water residence time (days)	383

3.2 Primary producers

The major groups of primary producers present in the lake Eckarfjärden are the macrophytes, macroalgae *Chara* sp, microphytobenthos, phytoplankton, and epiphyte algae.

3.2.1 Species composition

The **macrophyte** taxa that contribute most to the macrophyte biomass in Eckarfjärden are *Phragmites australiensis* (reed) and *Typha* sp, but *Scirpus lacustris* and *Equisetum fluviatile* are also quite frequently occurring /Andersson et al. 2003/.

Since the macroalgae ***Chara sp*** differ greatly from macrophytes in terms of primary production rates as well as that they assimilate carbon from the water and not from the air, they have been treated as a separate group in the budget.

The **microphytobenthos** comprises mainly cyanobacteria and diatoms that belong to the functional group autotrophic non-flagellates /Blomqvist et al. 2002; Andersson et al. 2003/.

The major taxonomic groups of the **phytoplankton** taxa in the lake are *Crysophyceae*, *Cyanophyceae*, *Dinophyceae*, *Cryptophyceae*, *Euglenophyceae*, *Chlorophyceae* and *Bacillariophyceae* /Blomqvist et al. 2002; Andersson et al. 2003/. In the calculations they were combined to the functional groups autotrophic non-flagellates, autotrophic flagellates and mixotrophic flagellates and the total sum was used in the budget.

The fifth group of primary producers are the **epiphytic algae**, which are attached to the surfaces of macrophytes and Chara sp. At present, we have poor knowledge of the species composition of this group.

3.2.2 Habitat distribution

The habitat distribution of macrophytes in Lake Eckarfjärden is shown in Figure 3-1 and Table 3-2 /Brunberg et al. 2004/. *Phragmites australiensis* are the most common macrophyte, covering 31% of the lake area. /Andersson et al. 2003/ found that *Typha* sp is present within the outer reed belt and hence *Typha* sp covers 29% of the lake are. *Scoenoplectus lacustris*, *Equisetum fluviatile*, *Potamogeton natan*, *Potamogeton filiformis* and *Menyanthes trifoliate* are less common and cover only a few present of the lake area /Brunberg et al. 2004; Andersson et al. 2003/. *Chara* sp covers 50% of the lake area. Microphytobenthos are present over the whole lake area except for in the reed belt. Phytoplankton is assumed to be evenly present within the pelagial. The epiphytic algae are assumed to be present in the reed belt on straws of *P australinesis* and *Typha* sp. The substrate area was calculated from straw length submersed in water and straw diameter /Andersson, unpublished data/ and was 576 m^{-2} substrate per m^{-2} littoral. This is much lower than reported from other lakes /e.g. Allen and Ocevski, 1981; Meulemanns, 1988; Gessner et al. 1996/. However, much of the *Phragmites* belt has a water depth of 0 cm for large part of the year and hence a large part of the reed belt is unavailable for epiphytic growth. The epiphytic algae are most probably also present on the other macrophytes. However, as we have no values of the substrate area these macrophytes and the fact that they cover a much smaller area than the *P australiensis* and Typha sp, they have not been used in the calculations of substrate area. There is poor knowledge of epiphytes on the macroalgae *Chara* sp and hence, these epiphytes are assumed to be included in the biomass and production of *Chara* sp itself.

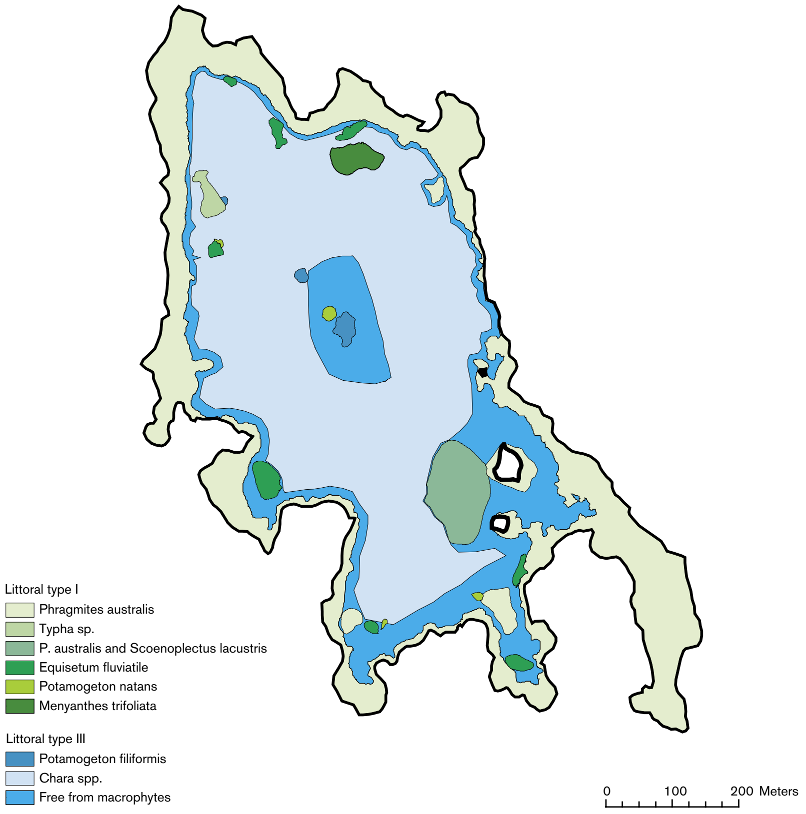


Figure 3-1. *Habitat distribution of macrophytes in Lake Eckarfjärden /from Brunberg et al. 2004/.*

Table 3-2. Habitat distribution and surfaces (m^2) or volumes (m^3) for macrophytes, *Chara* sp, microphytobenthos, phytoplankton, and epiphyte algae in Lake Eckarfjärden.

Functional group	Area in the lake	Size	Unit
Phytoplankton	Pelagial	257,000	m^3
Microphytobenthos	Bental	195,456	m^2
Chara sp	Specific chara algae area	142,330	m^2
Macrophytes	Specific area for:		
	Phragmites australiensis	88,424	m^2
	Typha sp	82,287	m^2
	Scirpus lacustris	7,267	m^2
	Equisetum fluviatile	3,511	m^2
Epiphytic algae*	Reed	88,424	m^2

* Note: The epiphytic algae biomass were normalised to the reed area.

3.2.3 Biomass

Biomasses of all primary producers are shown in Table 3-3. In terms of carbon biomass, macrophytes are by far the dominating primary producer (86%), followed by *Chara* sp (9%) and microphytobenthos (4%). Phytoplankton and epiphytic algae made up less than 1% of the carbon biomass of primary producers in Lake Eckarfjärden.

Initial data reported in other units than g C were converted with the aid of conversion factors /Kautsky, 1995/. Biomass estimates in g C were converted to g N and g P respectively by assuming a C:N:P-ratio for phytoplankton, microphytobenthos and epiphytic algae of [1:0.168:0.013], for Chara sp [1:0.084:0.008] and for macrophytes [1:0.051:0.005] /Kautsky, 1995/.

The biomass of the four dominating macrophyte taxa, *P australiensis*, *Typha* sp, *S lacustris* and *E fluviatile* were measured in the lake in the end of the summer of 2003 /Andersson et al. 2003/ and used as a total average biomass of macrophytes.

The *Chara* sp biomas has not been sampled in the lake Eckarfjärden but observation by eye indicates that the biomass is high. The figure used in the budget calculations were an average of the *Chara* sp biomass in several lakes reviewed by /Kufel and Kufel, 2002/.

Biomass of microphytobenthos and phytoplankton were measured in the lake in times series of approximately 12 samples a year from 2000 to 2002 /Blomqvist et al. 2002; Andersson et al. 2003/. In this budget average values for the whole period were used.

No measurements of biomass of epiphytes have been made in Lake Eckarfjärden. Instead literature values have been taken from a German oligotrophic lake having similar reed straw density as Lake Eckarfjärden /Meulemanns, 1988/.

Table 3-3. Biomass of phytoplankton, microphytobenthos, *Chara* sp, macrophytes and epiphyte algae in the lake Eckarfjärden (g CNP/m^2 or g CNP/m^3 and g CNP/lake).

Functional group	Biomass (carbon) (g C/m^2 or g C/m^3)	Biomass (nitrogen) (g N/m^2 or g N/m^3)	Biomass (phosphotous) (g P/m^2 or g P/m^3)
Phytoplankton	4.10E–02	6.89E–03	5.33E–04
Microphytobenthos	3.85E+00	6.46E–01	5.00E–02
Chara sp algae	1.23E+01	1.03E+00	9.83E–02
Macrophytes	2.25E+02	1.15E+01	1.12E+00
Epiphytic algae	3.09E–01	5.19E–02	4.02E–03
	(g C/lake)	**(g N/lake)**	**(g P/lake)**
Phytoplankton	1.06E+04	1.78E+03	1.38E+02
Microphytobenthos	7.52E+05	1.26E+05	9.78E+03
Chara sp algae	1.75E+06	1.47E+05	1.40E+04
Macrophytes	1.65E+07	8.42E+05	8.25E+04
Epiphytic algae	2.73E+04	4.58E+03	3.55E+02

3.2.4 Primary production

The primary production in Lake Eckarfjärden is presented in Table 3-4. The macroalgae *Chara* sp and macrophytes are the major primary producers and together contribute to almost 70% of the carbon fixation in the lake. The next largest primary producer is microphytobenthos making up 20% of the carbon fixation while phytoplankton and epiphytic algae make minor contribution to the carbon fixation.

Primary production estimates were converted to g N and g P respectively by assuming a C:N:P-ratio for phytoplankton, microphytobenthos and epiphytic algae of [1:0.168:0.013], for *Chara* sp [1:0.084:0.008] and for macrophytes [1:0.051:0.005] /Kautsky, 1995/.

The **macrophyte** production has not been measure in the lake. In the budget it was assumed that the production was as large as the standing crop could be sustained each year. This may be an underestimation of the production but probably smaller than 10% /Mason and Bryant 1975/. Although the macrophyte production could have been underestimated, it is still by far the largest primary producing component of the lake.

The *Chara* sp production has not been measured in the lake and generally there are few measurements of primary production of ***Chara sp*** reported in the literature. The productivity rates used in this budget was obtained from Pereya-Ramos /reviewed in Kufel and Kufel, 2002/. This productivity value is lower than productivities reported by /Kufel and Kufel, 2002/ and also somewhat lower than reported for the Baltic Sea /compiled in Kautsky, 1995/. The lower value was selected to ensure to not overestimate the production of *Chara* sp due to their abundance in the lake. Although the lower productivity values were used the *Chara* sp production was found to be one of the major primary producers in the lake. *Chara* sp has been shown to release as much as 10% of the fixed carbon as extra cellular organic carbon (EOC) /Sorell et al. 2001/, This figure for EOC was also used in the budget.

Primary production by **microphytobenthos** and **phytoplankton** were measured in the lake with ^{14}C-incorporations during 2001 and 2002 /Blomqvist et al. 2002; Andersson et al. 2003/. The release of EOC by phytoplankton varies between 5 and 80% /Camarero et al. 1999/. In this budget a release of 40% was assumed. Microphytobenthos has been shown to release more EOC than phytoplankton. Here, 70% of the carbon fixed by microphytobenthos was assumed to be released as EOC which somewhat higher than reported by /Smith and Underwood, 2000/, but about the same as has been reported by /Goto et al. 1999/.

Epiphytic primary production has not been measured in the lake. The figures used in the budget originate from an oligotrophic German lake /Meulemanns, 1988/. The carbon release (EOC) from the epiphytic algae was assumed to be the same as for phytoplankton, i.e. 40%.

Table 3-4. Primary production of phytoplankton, microphytobenthos, *Chara* sp, macrophytes and epiphyte algae in the lake Eckarfjärden (g CNP/m^2/yr or g CNP/m^3/yr and g CNP/lake/yr).

Functional group	Primary production (carbon) (g C/m^2/yr or g C/m^3/yr)	Primary production (nitogen) (g N/m^2/yr or g N/m^3/yr)	Primary production (phosphorous) (g P/m^2/yr or g P/m^3/yr)
Phytoplankton	1.85E+01	3.11E+00	2.41E–01
Microphytobenthos	5.57E+01	9.36E+00	7.24E–01
Chara sp	1.39E+02	1.17E+01	1.11E+00
Macrophytes	2.25E+02	1.15E+01	1.12E+00
Epiphytic algae	1.41E+01	2.31E+00	1.83E–01
	(g C/lake/yr)	**(g N/lake/yr)**	**(g P/lake/yr)**
Phytoplankton	4.76E+06	8.00E+05	6.19E+04
Microphytobenthos	1.09E+07	1.83E+06	1.41E+05
Chara sp	1.98E+07	1.66E+06	1.58E+05
Macrophytes	1.67E+07	8.42E+05	8.25E+04
Epiphytic algae	1.25E+06	2.10E+05	1.63E+04

3.2.5 Data origin for primary producers

The origin of the initial data for biomass and primary production of plants used the budget is summarised in Table 3-5.

Table 3-5. Summary of the origin of data for biomass and primary production data for phytoplankton, microphytobenthos, Chara sp, macrophytes and epiphyte algae used in the budget/model are obtained from.

Functional group	Biomass	Primary production	Source
Phytoplankton	Site-specific	Site-specific	/Blomqvist et al. 2002; Andersson et al 2003; Andersson and Brunberg, in print/
Microphytobenthos	Site-specific	Site-specific	/Blomqvist et al. 2002; Andersson et al. 2003/
Chara sp	Generic	Calculated	/Kufel and Kufel, 2002; Pereya-Ramos, 1981/
Macrophytes	Site-specific	Calculated	/Andersson et al. 2003; Brunberg et al. 2004/
Epiphytic algae	Generic	Calculated	/Meulemanns, 1988; Andersson, unpublished data/

3.3 Consumers

The consumers present in Eckarfjärden are bacteria, zooplankton, benthic fauna and fish. As a large part of the phytoplankton community is made up by mixotrophic species they could be treated as both primary producers and consumers. Therefore phytoplankton consumption and respiration will be presented below but otherwise they will be included in the primary producers.

3.3.1 Species composition

The species composition of the **bacteria** in the lake is not known and is not assumed to be of importance for the budget calculations for the lake. Because bacteria on different substrate are assumed to assimilate carbon from different carbon pools and be consumed by different predators at different rates, bacteria were divided into three groups: bacterioplankton, benthic bacteria and epiphytic bacteria.

Zooplankton was divided into three groups due to size and feeding preferences: ciliates, heterotrophic flagellates, and metazooplankton. Ciliates were not analysed into anymore detailed taxonomic level. The heterotrophic flagellates are mainly dominated by *Kateblepharis* and *Monosigales* /Blomqvist et al. 2002/. *Copepoda*, *Rotatoria* and *Cladocera* dominate the larger metazooplankton /Andersson et al. 2003/.

The taxa of **benthic fauna** found in the lake are: *Nematoda* (detrivore), *Oligochaeta* (detrivore), *Hirudinea* (carnivores), *Gastropoda* (grazers), *Pisididae* (filter feeders), *Isopoda* (detrivore), *Ostracoda* (detrivore), *Acarina* (carnivore), *Odonata* (carnivore), *Ephemoptera* (herbivore), *Coleoptera* (carnivore), *Trichoptera* (carnivore and herbivore), *Chironomidae* (carnivore and herbivore), *Ceratopogonidae* (carnivore) and *Chaoboridae* (carnivore) /Andersson et al. 2003/. They were combined into four functional groups: benthic carnivores, benthic herbivores, benthic filter feeders and benthic detrivores.

The **fish** species present in the lake are *Rutilus rutilus* (perch), *Perca fluviatilis* (roach), *Esox lucius* (pike), *Tinca tinca* ("tench"), and *Gymnocephalus cernua* (ruffe) /Borgiel, 2004/. The data on fish were combined into three functional food preferences groups; Zooplankton feeding fish (Z-fish), bottom fauna feeding fish (M-fish) and fish feeding fish (F-fish) due to the lengths and species of the individual fishes according to /Horppila et al. 2000/.

3.3.2 Habitat distribution

The habitat distributions of the fauna in the lake are shown in Table 3-6. Bacterioplankton, ciliates, heterotrophic flagellates, and metazooplankton were all assumed to be evenly present within the pelagial. Benthic bacteria were assumed to be present on the lake bottom of the whole lake, except for in the reed belt. The reason for this was that the abundance of benthic bacteria in the reed belt probably are much lower than in the thick microbial mat are present on the bottom of the rest of the lake. A large fraction of the benthic bacteria actually present in the reed belt is likely included in the epiphytic bacteria on the reed straws. Consequently, this underestimation is expected to be negligible. As for epiphytic algae, epiphytic bacteria and epiphytic fauna are assumed to be present in the reed belt on straws of *P australinesis* and *Typha* sp. The substrate area was, as described above, calculated from reed straw length submersed in water and straw diameter /Andersson, unpublished data/. The epiphytic bacteria and fauna are most probably also present on *S lacustris* and *E fluviatile*. However, as we have no values of the substrate area of these macrophytes and since they cover a much smaller area than the *P australiensis* and *Typha* sp, they have not been included in the calculations of substrate area.

Benthic fauna was assumed to be present on the lake bottom outside the reed belt. Benthic fauna is also present within the reed belt but this fauna is included in the epiphytic fauna.

Fish was assumed to be present within the whole lake area.

Table 3-6. Habitat distribution and surfaces (m^2) or volumes (m^3) of the habitats for bacterioplankton, ciliates, heterotrophic flagellates, metazoans, zooplankton feeding fish, bottom fauna feeding fish, predator fish, epiphytic bacteria, benthic bacteria, benthic carnivores, benthic detrivores, benthic filter feeders and benthic herbivores in Lake Eckarfjärden.

Functional group	Area	Size	Unit
Bacterioplankton	Pelagial	257,000	m^3
Ciliates	Pelagial	257,000	m^3
Heterotrophic flagellates	Pelagial	257,000	m^3
Metazooplankton	Pelagial	257,000	m^3
Z-fish	Lake area	283,952	m^2
M-fish	Lake area	283,952	m^2
F-fish	Lake area	283,952	m^2
Epiphytic bacteria	Specific area for reed	88,424	m^2
Epiphytic fauna	Specific area for reed	88,424	m^2
Benthic bacteria	Lake area	195,528	m^2
Benthic carnivores	Bental	283,952	m^2
Benthic detrivores	Bental	283,952	m^2
Benthic filter feeders	Bental	283,952	m^2
Benthic herbivores	Bental	283,952	m^2

3.3.3 Biomass

The biomass of consumers in Lake Eckarfjärden is presented in Table 3-7. The benthic bacteria are by far the largest functional group making up 62% of the consumer biomass. Other large functional groups in terms of carbon biomass are the benthic herbivores (9%) and benthic fauna feeding fish (8%).Initial data reported in other units than g C were converted with the aid of conversion factors /Kautsky, 1995/. Biomass estimates in g C were converted to g N and g P respectively by assuming a C:N:P-ratio for bacteria of [1:0.180:0.056] and for the rest of [1:0.257:0.018] /Kautsky ,1995/.

The biomass of **bacterioplankton** and **heterotrophic flagellates** in Lake Eckarfjärden has been measured monthly during 2000 to 2002 /Blomqvist et al. 2002; Andersson et al. 2003/. In this budget averages from the period were used. **Ciliates** and **Metazooplankton** have been measured during respectively 2000 and 2002 and averages were used /Blomqvist et al. 2002; Andersson et al. 2003/. The biomass of **epiphytic bacteria** was assumed to be the same as epiphytic algae. The biomass of epiphytic fauna was obtained from studies in the nearby Lake Erken /Erken report spring, 1998/.

Benthic bacteria in Lake Eckarfjärden have been measured on a monthly basis during 2000 to 2002 /Blomqvist et al. 2002; Andersson et al. 2003/. **Benthic fauna** biomass has only been sampled in the lake once (March 11, 2002) /Andersson et al. 2003/. The biomass of **benthic herbivores**, **benthic filter feeders**, **benthic detrivores** and **benthic carnivores** on macrophyte free bottom were low, 0.5, 0.2, 0.2, and 0.2 g C/m^2 respectively /Andersson et al. 2003/. However, densities of macroinvertebrates have been shown to correlate well with macrophyte coverage /van den Berg et al. 1997/. In this budget, estimates of the benthic fauna biomass on macroalgae bottom were obtained from a Chara sp meadow in the Baltic Sea /Fredriksson and Tobiasson, 2003/. These biomass values were about ten times higher than the biomass on the macrophyte free bottom but lower than reported by e.g. /Hargeby et al. 1994/ from the Chara dominated Lake Krankesjön in the south of Sweden.

Fish was sampled once (August 2003) /Borgiel, 2004/. The biomass data for fish presented as biomass per net was converted to biomass per m^2 with the conversion factor 33 gww/m^2 per gww/ha /Per Nyberg, pers comm/.

Table 3-7. Biomass of bacterioplankton, ciliates, heterotrophic flagellates, metazoans, zooplankton feeding fish, bottom fauna feeding fish, predator fish, epiphytic bacteria, benthic bacteria, benthic carnivores, benthic detrivores, benthic filter feeders and benthic herbivores in the lake Eckarfjärden (g CNP/m^2 or g CNP/m^3 and g CNP/lake).

Functional group	Biomass (carbon) (g C/m^2 or g C/m^3)	Biomass (nitrogen) (g N/m^2 or g N/m^3)	Biomass (phosphorous) (g P/m^2 or g P/m^3)
Bacterioplankton	5.24E–02	9.43E–03	2.93E–03
Ciliates	6.45E–03	1.66E–03	1.16E–04
Heterotrophic flagellates	1.66E–03	4.27E–04	2.99E–05
Metazoans	7.64E–02	1.96E–02	1.38E–03
Z-fish	8.60E–02	2.21E–03	1.55E–03
M-fish	3.44E–01	8.84E–02	6.19E–03
F-fish	1.62E–01	4.16E–02	2.91E–03
Epiphytic bacteria	3.09E–01	5.18E–03	1.61E–03
Epiphytic fuana	5.65E–03	1.45E–03	1.02E–04
Benthic bacteria	3.71E+00	6.67E–01	2.08E–01
Benthic carnivores *	1.93E–01	4.98E–02	3.48E–03
Benthic detrivores *	2.10E–01	5.40E–02	3.78E–03
Benthic filter feeders *	1.85E–01	4.74E–02	3.32E–03
Benthic herbivores *	5.12E–01	1.32E–01	9.22E–03
	(g C/lake)	**(g N/lake)**	**(g P/lake)**
Bacterioplankton	1.35E+04	2.42E+03	7.54E+02
Ciliates	1.74E+03	4.46E+02	3.12E+01
Heterotrophic flagellates	4.27E+02	1.10E+02	7.69E+00
Metazoans	1.96E+04	5.05E+03	3.54E+02
Z-fish	2.44E+04	6.28E+03	4.40E+02
M-fish	9.77E+04	2.51E+04	1.76E+03
F-fish	4.60E+04	1.18E+04	8.27E+02
Epiphytic bacteria	2.73E+04	4.91E+03	1.53E+03
Epiphytic fauna	4.99E+02	1.28E+02	8.99E+00
Benthic bacteria	7.25E+05	1.89E+05	5.90E+04
Benthic carnivores	3.78E+04	9.71E+03	6.80E+02
Benthic detrivores	4.11E+03	1.06E+04	7.40E+02
Benthic filter feeders	3.61E+04	9.27E+03	6.49E+02
Benthic herbivores	1.00E+05	2.57E+04	1.80E+03

* Note: The benthic fauna is different on macrophyte free and Chara sp bottom. The biomass value is a mean for the whole lake area.

3.3.4 Respiration and consumption

The respiration among the consumers was clearly dominated by bacterioplankton and benthic bacteria together making up 79% of the respiration (Table 3-8). Consequently, bacterioplankton and benthic bacteria also dominated the consumption (Table 3-9).

Initial data reported in other units than g C were converted with the aid of conversion factors /Kautsky, 1995/. Respiration and consumption estimates in g C were converted to g N and g P respectively by assuming a C:N:P-ratio for bacteria of [1:0.180:0.056] and for the rest of [1:0.257:0.018] /Kautsky, 1995/.

The respiration of bacterioplankton and epiphytic bacteria was assumed to be 3 times the production (assuming a growth efficiency of 25% which is the mean for bacterioplankton in freshwater. Productions of bacterioplankton have been measured in Lake Eckarfjärden with ^{3}H-thymidine incorporations during 2001 and 2002 /Andersson et al. 2003/. Production of epiphytic bacteria was taken from /Haines et al. 1987/. Production of benthic bacteria was measured in the lake. The respiration of **benthic bacteria** was estimated from their biomass, a biomass to respiration conversion factor /Kautsky ,1995/, and the temperature variation over the year /Blomqvist et al. 2002; Andersson et al. 2003/. Consumption of bacterioplankton, epiphytic bacteria and benthic bacteria was calculated as the sum of respiration and production.

The respiration data for the **zooplankton**, **fish** and **benthic fauna** groups were calculated from biomasses with the aid of conversions factors /Kautsky, 1995/ and temperature variation in the lake over the year /Blomqvist et al. 2002; Andersson et al. 2003/. For zooplankton and benthic fauna, the consumption was assumed to be three times the respiration whereas for fish the consumption was assumed to be 1.73 times the respiration.

The respiration of the mixotrophic phytoplankton was assumed to be 50% of consumption and 2/3 of their carbon demand was assumed to be incorporated from ingesting bacteria in proportion to their photosynthesis /Jansson et al. 1999a/. The mixotrophic phytoplankton community was assumed to fix carbon in proportion to their abundance of the total phytoplankton community. Hence, the mixotrophic consumption was calculated as twice the primary production of mixotrophic phytoplankton.

Table 3-8. Respiration of mixotrophic phytoplankton, bacterioplankton, ciliates, heterotrophic flagellates, metazoans, zooplankton feeding fish, bottom fauna feeding fish, predator fish, epiphytic bacteria, benthic bacteria, benthic carnivores, benthic detrivores, benthic filter feeders and benthic herbivores in the lake Eckarfjärden (g CNP/m^2/yr or g CNP/m^3/yr and g CNP/lake/yr).

Functional group	Respiration (carbon) (g C/m^2/yr or g C/m^3/yr)	Respiration (nitrogen) (g N/m^2/yr or g N/m^3/yr)	Respiration (phosphorous) (g P/m^2/yr or g P/m^3/yr)
Mixotrophic phytopl	9.58E+00	1.61E+00	1.25E–01
Bacterioplankton	5.11E+01	9.19E+00	2.86E+00
Ciliates	1.41E–01	3.632E–02	2.54E–03
Heterotrophic flagellates	4.32E–02	1.11E–02	7.78E–04
Metazoans	8.53E–01	2.19E–01	1.54E–02
Z-fish	4.71E–01	1.21E–01	8.47E–03
M-fish	1.88E+00	4.848E–01	3.39E–02
F-fish	8.85E–01	2.28E–01	1.59E–02
Epiphytic bacteria	7.12E+00	1.28E+00	3.99E–01
Epiphytic fauna	2.08E–01	5.35E–02	3.75E–03
Benthic bacteria	4.12E+01	7.42E+00	2.31E+00
Benthic carnivores *	1.06E+00	2.72E–01	1.91E–02
Benthic detrivores *	1.13E+00	2.90E–01	2.03E–02
Benthic filter feeders *	8.55E–01	2.20E–01	1.54E–02
Benthic herbivores *	2.47E+00	6.36E–01	4.45E–02
	(g C/lake/yr)	**(g N/lake/yr)**	**(g P/lake/yr)**
Mixotrophic phytopl.	2.46E+06	4.14E+05	3.20E+04
Bacterioplankton	1.31E+07	2.36E+06	7.35E+05
Ciliates	3.63E+04	9.33E+03	6.53E+02
Heterotrophic flagellates	1.11E+04	2.86E+03	2.00E+02
Metazoans	2.19E+05	5.63E+04	3.94E+03
Z-fish	1.34E+05	5.43E+04	2.41E+03
M-fish	5.34E+05	1.37E+05	9.62E+03
F-fish	2.51E+05	6.46E+04	4.53E+03
Epiphytic bacteria	6.29E+05	1.13E+05	3.52E+04
Epiphytic fauna	1.84E+04	4.73E+03	3.31E+02
Benthic bacteria	8.06E+06	1.45E+06	4.51E+05
Benthic carnivores	2.07E+05	5.32E+04	3.73E+03
Benthic detrivores	2.21E+05	5.67E+04	3.97E+03
Benthic filter feeders	1.67E+05	4.30E+04	3.01E+032
Benthic herbivores	4.84E+05	1.24E+05	8.71E+03

* Note: The respiration for benthic fauna is different in the macrophyte free and in hte Chara sp bottom. The respiration per m^2 is a mean for the whole lake area.

Table 3-9. Consumption of mixotrophic phytoplankton, bacterioplankton, ciliates, heterotrophic flagellates, metazoans, zooplankton feeding fish, bottom fauna feeding fish, predator fish, epiphytic bacteria, epiphytic fauna, benthic bacteria, benthic carnivores, benthic detrivores, benthic filter feeders and benthic herbivores in the Lake Eckarfjärden (g CNP/m^2/yr or g CNP/m^3/yr and g CNP/lake/yr).

Functional group	**Consumption (carbon) (g C/m^2/yr or g C/m^3/yr)**	**Consumption (nitrogen) (g N/m^2/yr or g N/m^3/yr)**	**Consumption (phosphorous) (g P/m^2/yr or g P/m^3/yr)**
Mixotrophic phytopl.	1.92E+01	3.22E+00	2.49E–01
Bacterioplankton	6.81E+01	1.23E+01	3.81E+00
Ciliates	4.24E–01	1.09E–01	7.63E–03
Heterotrophic flagellates	1.30E–01	3.33E–02	2.34E–03
Metazoans	2.56E+00	6.57E–01	4.61E–02
Z-fish	8.14E–01	2.09E–01	1.47E–02
M-fish	3.26E+00	8.37E–01	5.86E–02
F-fish	1.53E+00	3.94E–01	2.76E–02
Epiphytic bacteria	1.42E+01	2.56E+00	7.97E–01
Epiphytic fauna	6.25E–01	1.61E–01	1.12E–02
Benthic bacteria	8.34E+01	1.50E+01	4.67E+00
Benthic carnivores	3.18E+00	8.16E–01	5.72E–02
Benthic detrivores	3.38E+00	8.70E–012	6.09E–02
Benthic filter feeders	2.57E+00	6.59E–01	4.62E–02
Benthic herbivores	7.42E+00	1.91E+00	1.34E–01
	(g C/lake/yr)	**(g N/lake/yr)**	**(g P/lake/yr)**
Mixotrophic phytopl.	4.93E+06	8.27E+05	6.40E+04
Bacterioplankton	1.75E+07	3.15E+06	9.80E+05
Ciliates	1.09E+05	2.80E+04	1.96E+03
Heterotrophic flagellates	3.33E+04	8.57E+03	6.00E+02
Metazoans	6.57E+05	1.69E+05	1.18E+04
Z-fish	2.31E+05	5.94E+04	4.16E+03
M-fish	9.24E+05	2.38E+05	1.66E+04
F-fish	4.35E+05	1.12E+05	7.83E+03
Epiphytic bacteria	1.26E+06	2.27E+05	7.05E+04
Epiphytic fauna	5.52E+04	1.42E+04	9.94E+02
Benthic bacteria	1.63E+07	2.97E+06	9.13E+05
Benthic carnivores	6.21E+05	1.60E+05	1.12E+04
Benthic detrivores	6.62E+05	1.70E+05	1.19E+04
Benthic filter feeders	5.02E+05	1.29E+05	9.03E+03
Benthic herbivores	1.45E+06	3.73E+05	2.61E+04

3.3.5 Data origin for consumers

The origin of the initial data for biomass, respiration and consumption of consumers used in the budget is summarised in Table 3-10.

Table 3-10. Summary of where the biomass, respiration and consumption data for phytoplankton (including mixotrophic phytoplankton), bacterioplankton, ciliates, heterotrophic flagellates, metazoans, zooplankton feeding fish, bottom fauna feeding fish, predator fish, epiphytic bacteria, benthic bacteria, benthic carnivores, benthic detrivores, benthic filter feeders and benthic herbivores used in the budget/model are obtained from.

Functional group	Biomass	Respiration and consumption	Source
Phytoplankton	Site-specific	Generic, Calculated	/Blomqvist et al. 2002; Andersson et al. 2003; Jansson et al. 1999a/
Bacterioplankton	Site-specific	Site-specific *, Generic, Calculated	/Blomqvist et al. 2002; Andersson et al. 2003/
Ciliates	Site-specific	Generic, Calculated	/Blomqvist et al. 2002; Andersson et al. 2003; Kautsky, 1995/
Heterotrophic flagellates	Site-specific	Generic, Calculated	/Blomqvist et al. 2002; Andersson et al. 2003; Kautsky, 1995/
Metazooplankton	Site-specific	Generic, Calculated	/Blomqvist et al. 2002; Andersson et al. 2003; Kautsky, 1995/
Z-fish	Site-specific	Generic, Calculated	
M-fish	Site-specific	Generic, Calculated	/Horppila et al. 2000/
F-Fish	Site-specific	Generic, Calculated	/Horppila et al. 2000/
Epiphytic bacteria	Generic	Generic, Calculated	/Haines et al. 1987/
Epiphytic fauna	Generic	Generic, Calculated	/Erken report spring, 1998/
Benthic bacteria	Site-specific	Site-specific *, Generic, calculated	/Blomqvist et al. 2002; Andersson et al. 2003/
Benthic carnivores	Site-specific	Generic, Calculated	/Andersson et al. 2003; Kautsky, 1995/
Benthic detrivores	Site-specific	Generic, Calculated	/Andersson et al. 2003; Kautsky, 1995/
Benthic filter feeders	Site-specific	Generic, Calculated	/Andersson et al. 2003; Kautsky, 1995/
Benthic herbivores	Site-specific	Generic, Calculated	/Andersson et al. 2003; Kautsky, 1995/

*Note: The bacteria production was measured on the site and the consumption was assumed to be respiration + production.

3.4 Food web interactions

There are two major pathways of carbon upwards in the food web in Lake Eckarfjärden. A large amount of carbon is consumed by bacterioplankton, which in turn are consumed by mixotrophic phytoplankton. Phytoplankton is grazed by metazooplankton and metazooplankton are grazed by Z-fish. There is a high predation pressure on Z-fish by predatory fish but the biomass of Z-fish is low and the F-fish is to a large extent dependent on M-fish. The other large flow of carbon upwards in the food web is through macroalgae and microphytobenthos into benthic herbivores. Benthic herbivores are to a large extent consumed by M-fish, and the M-fish is further preyed upon by piscivorous fish.

Figure 3-2 shows an illustration of the simplified food web for Eckarfjärden, which was used in the budget development. Processes that not are illustrated in the figure but were accounted for in the calculations are the flows from functional groups to dissolved inorganic matter (DIM), dissolved organic matter (DOM) and particulate organic matter (POM) as well as net flow to/from the lake. The distribution of the consumption from various food sources are shown in Table 3-11. The consumption of different food sources were obtained by identifying the food web relationships between the functional groups in the system, calculating the demand of food (total consumption) by each consumer group and the availability of their respective food items. For the consumers it was assumed that they eat in proportion to what is available of their food item/prey.

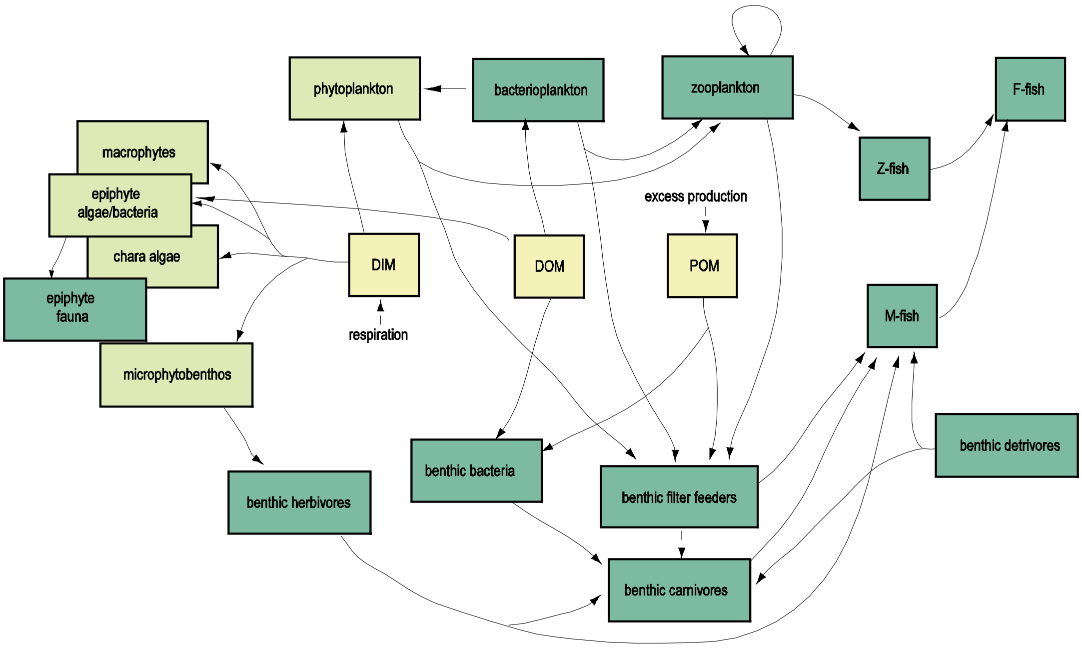


Figure 3-2. *Food web structure of the lake Eckarfjärden. DIM = dissolved inorganic matter, DOM = dissolved inorganic matter, POM = particulate organic matter. Excess carbon production from all groups lead to an increased POC pool.*

All carbon demand for primary production was assimilated from dissolved inorganic carbon (DIC). However, macrophytes consume their DIC from the air and do not influence the DIC pool in the water. Besides assimilating DIC, mixotrophic phytoplankton consumes bacteria both from the pelagial and the benthic microbial mat. Only 1% of the benthic bacteria were assumed to be available as a food source for mixotrophic phytoplankton as a large part of the bacteria are buried in the microbial mat.

Bacteria can assimilate both DOC and POC and **bacterioplankton** and **epiphytic bacteria** were therefore assumed to consume DOC and POC in proportion to the occurrence of the two fractions in the water, which resulted in a consumption of 98% DOC and 2% POC. **Benthic bacteria**, which have access to a large POC pool (sediment), were assumed to consume only POC.

Heterotrophic flagellates consume bacterioplankton and phytoplankton. However, in Lake Eckarfjärden the heterotrophic flagellates are small and the phytoplankton is too large to be grazed upon by the heterotrophic flagellates /Andersson, unpublished data/. Therefore, heterotrophic flagellates were assumed to only consume bacteria.

Ciliates are known to consume bacterioplankton, phytoplankton and heterotrophic flagellates. The assumption of consumption in proportion to what was available of the food source resulted in a diet of 55% bacterioplankton, 43% phytoplankton and 2% heterotrophic flagellates.

Metazooplankton consume phytoplankton, heterotrophic flagellates, ciliates and also small individuals within its own group. The zooplankton was divided into subgroups depending on food preferences /Bogdan and Gilbert, 1982; Pace et al. 1983; Browman et al. 1989; Bern, 1990; Boon and Shiel, 1990; Gilbert and Jack, 1993; Sarma, 1993; Ooms-Wilmns, 1997/. Thereafter the subgroups were assumed to eat in proportion to what was available of their food sources. The dominating food source for metazooplankton was assumed to be phytoplankton.

Zooplankton feeding fish (Z-fish) were assumed to 100% metazooplankton. **Benthic fauna feeding fish** (M-fish) were besides benthic fauna also assumed to feed on epiphytic algae and bacteria (selective feeding). Since there are no data on the distribution of their feeding preferences the M-fish were assumed to consume preys in proportion to what was available. As a result the diet was 41% benthic herbivores, 17% benthic detrivores, 15% benthic carnivores and 15% benthic filter feeders and 11% epiphytic algae.

Predatory fish (F-fish) was assumed to eat only fish. The shift from other food sources to fish will most likely not be complete but the F-fish was assumed to solely feed on fish in this budget which the distribution 58% M-fish, 27% F-fish and 15% Z-fish.

Epiphytic fauna was assumed to eat in proportion of what was available of epiphytic bacteria and epiphytic algae. This resulted in a consumption of 90% epiphytic algae and 10% epiphytic bacteria.

Benthic herbivores were believed to consume microphytobenthos and *Chara* sp. Benthic herbivores do not consume the macroalgae *Chara* sp in any larger extent but feed on the epiphytes on *Chara* sp /James et al. 2000/, which in this budget were included in the functional group macroalgae. The herbivores were assumed to graze in proportion of what was available, i.e. 30% microphytobenthos and 70% Chara sp These calculations were based on the biomass of *Chara* sp and may be an overestimation of the *Chara* sp consumption. On the other hand, the microphytobenthos to a large extent consists of inedible cyanobacteria.

Benthic filter feeders filter the overlaying water and the assumption of consumption in proportion to what was available lead to a diet of 76% POC, 11% metazooplankton, 7% bacterioplankton, 6% phytoplankton, 1% ciliates and 0.2% heterotrophic flagellates.

The **benthic detrivores** were assumed to mainly consume POC but also 20% of their food were assumed to be benthic bacteria as they probably are indistinguishable.

Benthic carnivores are assumed to eat in proportion of available benthic herbivores, filter feeders, detrivores and carnivores. All benthic fauna in these groups are most probably not available for benthic carnivores but as we have no data on feeding preferences we assume that all are available. The diet of benthic carnivores will with these assumptions be 47% benthic herbivores, 19% benthic detrivores and 18% benthic carnivores and 17% benthic filter feeders.

Table 3-11. Distribution (%) of carbon source of total consumption for the functional groups in the Lake Eckarfjärden.

Functional group	Distribution of carbon source in consumption
Phytoplankton (incl mixothrophic)	33% DIC, 67% bacteria
Microphytobenthos	100% DIC
Chara sp	100% DIC
Macrophytes	100% DIC
Epiphytic algae	100% DIC
Epiphytic bacteria	98% DOC; 2% POC
Bacterioplankton	98% DOC; 2% POC
Ciliates	55% bacterioplankton; 43% phytoplankton; 2% heterotrophic flagellates
Heterotrophic flagellates	100% bacterioplankton
Metazoa	76% phytoplankton; 12% ciliates; 9% bacterioplankton; 3% heterotrophic flagellates; 2% metazoa
Z-fish	100% metazoa
M-fish	41% benthic herbivores; 17% benthic detrivores; 17% benthic carnivores; 17% benthic filter feeders, 11% epiphytic alage, 1% epiphytic bacteria
F-fish	58% M-fish; 27%F-fish; 15% Z-fish
Benthic bacteria	100% POC
Benthic carnivores	47% benthic herbivores; 19% benthic detrivores; 18% benthic carnivores; 17% benthic filter feeders
Benthic detrivores	20% benthic bacteria; 80% POC
Benthic filter feeders	77% POC; 8% metazoa; 8% bacterioplankton; 6% phytoplankton; 1% ciliates; 0,2% heterotrophic flagellates
Benthic herbivores	30% microphytobenthos; 70% *Chara* sp

3.5 CNP budget

In Table 3-12, 3-13 and 3-14 whole lake budgets of carbon, nitrogen and phosphorous are summarised.

The carbon budget indicates that the total fixation of carbon in the primary production process is higher than the total consumption. The primary production is higher than the bacterial respiration indicating that the system is net autotrophic. That is, the system is self-sufficient on carbon and thus not dependent on carbon entering the system from the catchment. This is further emphasised by the higher outflow than inflow of DOC from lake.

Assuming the DOC exudation during primary production for different primary producers as above the DOC in the lake is not sufficient to support the bacterial production. However, DOC are not only released as exudates but are also released through senescence and by sloppy feeding by predators. The carbon pool not respired or consumed is high and sufficient to support the bacterial growth. In fact, it is much higher than the carbon needed for bacterial growth. The excess carbon is 3×10^7 g C/year and the DOC needed by bacteria not met by exudates from the primary producers is 8×10^6 g C/year. This leaves a large positive accumulation of POC each year in Lake Eckarfjärden. However, the macrophytes

Phragmites australis and Typha sp can be assumed to decompose within the littoral. This would result in the lake growing smaller from the sides, which is something that has to be further studied to evaluate if true. However, if the macrophytes are withdrawn from the net POC pool the resulting POC pool (8×10^6 g C/lake/year) match up fairly well with the measured sedimentation each year (6×10^6 g C/lake/year).

Table 3-12. Carbon budget for Lake Eckarfjärden.

Functional group	Biomass (g C/lake)	Primary production (g C/lake/yr)	Respiration (g C/lake/yr)	Consumption (g C/lake/yr)
Phytoplankton	1.06E+04	4.76E+06	2.46E+6	4.93E+06
Microphytobenthos	7.52E+05	1.09E+07	–	–
Chara sp	1.75E+06	1.98E+07	–	–
Macrophytes	1.65E+07	1.65E+07	–	–
Epiphytic algae	2.73E+04	1.25E+06	–	–
Bacterioplankton	1.35E+04	–	1.31E+07	1.75E+07
Ciliates	1.74E+03	–	3.63E+04	1.09E+05
Heterotrophic flagellates	4.27E+02	–	1.11E+04	3.33E+04
Metazoans	1.96E+04	–	2.19E+05	6.57E+05
Z-fish	2.44E+03	–	1.34E+05	2.31E+05
M-fish	9.77E+04	–	5.34E+05	9.24E+05
F-fish	4.60E+04	–	2.51E+05	4.35E+05
Epiphytic bacteria	2.73E+04	–	6.29E+05	1.26E+06
Epiphytic fauna	4.99E+02		1.84E+04	5.52E+04
Benthic bacteria	7.25E+05	–	8.06E+06	1.63E+07
Benthic carnivores	3.78E+04	–	2.07E+05	6.21E+05
Benthic detrivores	4.11E+04	–	2.21E+05	6.62E+05
Benthic filter feeders	3.61E+04	–	1.67E+05	5.02E+05
Benthic herbivores	1.00E+05	–	4.84E+05	1.45E+06
Total (biotic)	2.02E+07	5.33E+07	2.65E+07	4.56E+07
DIC	7.55E+06	–	–	–
DOC	6.16E+06	–	–	–
POC	1.33E+05	–	–	–
Total (abiotic)	1.38E+07	–	–	–

Table 3-13. Nitrogen budget for Lake Eckarfjärden.

Functional group	Biomass (g N/lake)	Primary production (g N/lake/yr)	Respiration (g N/lake/yr)	Consumption (g N/lake/yr)
Phytoplankton	1.78E+03	8.00E+05	4.14E+05	8.27E+05
Microphytobenthos	1.26E+05	1.83E+06	–	–
Chara sp	1.47E+05	1.66E+06	–	–
Macrophytes	8.42E+05	8.42E+05	–	–
Epiphytic algae	4.58E+03	2.10E+05	–	–
Bacterioplankton	2.42E+03	–	2.36E+06	3.15E+06
Ciliates	4.46E+02	–	9.33E+03	2.80E+04
Heterotrophic flagellates	1.10E+02	–	2.86E+03	8.57E+03
Metazoans	5.05E+03	–	5.63E+04	1.69E+05
Z-fish	6.28E+03	–	3.43E+04	5.94E+04
M-fish	2.51E+04	–	1.37E+05	2.38E+05
F-fish	1.18E+04	–	6.46E+04	1.12E+05
Epiphytic bacteria	4.91E+03	–	1.13E+05	2.27E+05
Epiphytic fauna	1.28E+02	–	4.73E+03	1.42E+04
Benthic bacteria	1.31E+05	–	1.45E+06	2.15E+06
Benthic carnivores	9.71E+03	–	8.83E+03	2.93E+06
Benthic detrivores	1.06E+04	–	5.67E+04	1.70E+05
Benthic filter feeders	9.27E+03	–	4.30E+04	1.29E+05
Benthic herbivores	2.57E+04	–	1.24E+05	3.73E+05
Total (biotic)	1.36E+06	5.34E+06	4.93E+06	8.60 E+06
DIN	6.88E+04	–	–	–
DON	–	–	–	–
PON	–	–	–	–
Total (abiotic)	6.88E+04	–	–	–

Table 3-14. Phosphorous budget for Lake Eckarfjärden.

Functional group	Biomass (g P/lake)	Primary production (g P/lake/yr)	Respiration (g P/lake/yr)	Consumption (g P/lake/yr)
Phytoplankton	1.38E+02	6.19E+04	3.20E+04	6.40E+04
Microphytobenthos	9.78E+03	1.41E+05	–	–
Chara sp	1.40E+04	1.58E+05	–	–
Macrophytes	8.25E+04	8.25E+04	–	–
Epiphytic algae	3.55E+02	1.63E+04	–	–
Bacterioplankton	7.54E+02	–	7.35E+05	9.80E+05
Ciliates	3.12E+01	–	6.35E+02	1.96E+03
Heterotrophic flagellates	7.69E+00	–	2.00E+02	6.00E+02
Metazoans	3.54E+02	–	3.94E+03	1.18E+04
Z-fish	4.40E+02	–	2.41E+03	4.16E+03
M-fish	1.76E+03	–	9.62E+03	1.66E+04
F-fish	8.27E+02	–	4.53E+03	7.83E+03
Epiphytic bacteria	1.53E+03	–	3.52E+04	7.05E+04
Epiphytic fauna	8.99E+00	–	3.31E+02	9.94E+02
Benthic bacteria	4.06E+04	–	4.51E+05	9.13E+05
Benthic carnivores	6.80E+02	–	3.73E+03	1.12E+04
Benthic detrivores	7.40E+02	–	3.97E+03	1.19E+04
Benthic filter feeders	6.49E+02	–	3.01E+03	9.03E+03
Benthic herbivores	1.80E+03	–	8.71E+03	2.61E+04
Total (biotic)	1.57E+05	4.60E+05	1.29E+06	2.31E+06
DIP	5.09E+02	–	–	–
DOP	–	–	–	–
POP	–	–	–	–
Total (abiotic)	5.09E+02	–	–	–

4 The terrestrial system

4.1 Geometry

The terrestrial model area is defined with regard to the shoreline documented in the cadastral map from the 1950ies. A digital altitude model constructed by /Brydsten, 2004/ is used to delimit Bolundsfjärdens catchment area /Brunberg et al. 2004/, see Figure 1-1. The terrestrial system has been divided in sub-areas based on vegetation type /Boresjö Bronge and Wester, 2003/, and also the abiotic properties have been classified.

In general, the catchment area of Bolundsfjärden has a relatively low relief, making the boarders between certain geometrical properties unclear, e.g. watershed. Differences in altitude also affect the biotic boarders in the area resulting in fast changes during, for example, high water flows (Figure 4-1).

Figure 4-1. *Picture showing Bolundsfjärden area. Photo by Alf Sevastik, SKB.*

4.2 Primary producers

The vegetation constitutes a major part of living biomass and comprises the main primary producers in terrestrial ecosystems. The biomass and necromass will therefore be an important measure of how much carbon that may be accumulated in a specific ecosystem. Similarly, the net primary production will be an estimate of how much carbon (and other elements) that is incorporated in living tissue. Thus, combining net primary production and decomposition rates will give a rough estimate of the carbon turnover in the ecosystem.

The plant biomass in an area consists of a number of different components that all have to be measured or estimated to correctly estimate the total biomass (/Chapin et al. 2002/, Figure 4-2). Some of these components are well studied while others only are poorly investigated which make total biomass difficult to estimate. There are several reasons for the differences in knowledge. Some of the components are extremely labour intensive to study, e.g. root turnover, but in these cases generic data are available. In the case of mycorrhizae there are nearly no data existing. This component has not been included in biomass calculations until quite recently and is thus at present omitted from biomass calculations.

Photosynthesis provides the carbon and the energy that are essential for many important processes in ecosystems. Photosynthesis directly supports plant growth and produces organic matter that is consumed by animals and soil microbes. The photosynthesis at an ecosystem level is termed gross primary production (GPP). Approximately half of the GPP is respired by plants to provide the energy that supports the growth and maintenance of biomass /Chapin et al. 2002/. The net carbon gain is termed net primary production (NPP) and is the difference between GPP and plant respiration. However, GPP can not be measured directly and total respiration is difficult to measure, especially in multi-species forests /Gower et al. 1999; Gower at al. 2001/.

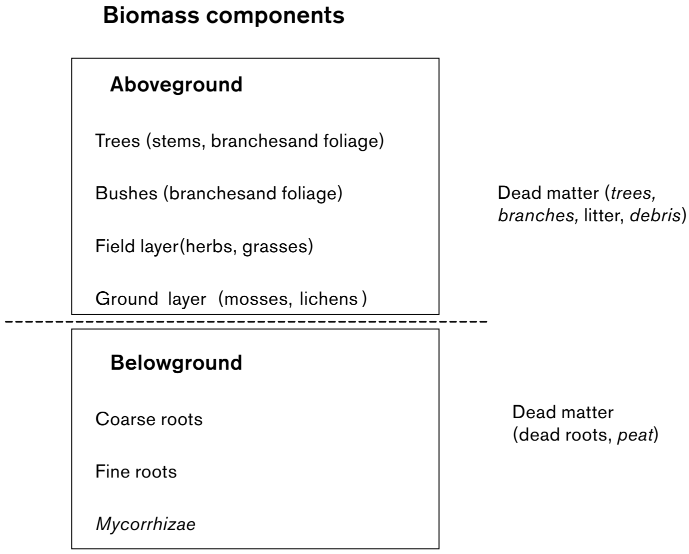


***Figure 4-2.** The different components of biomass in a forest. Components in italic are omitted in the calculations of biomass. See text for explanation.*

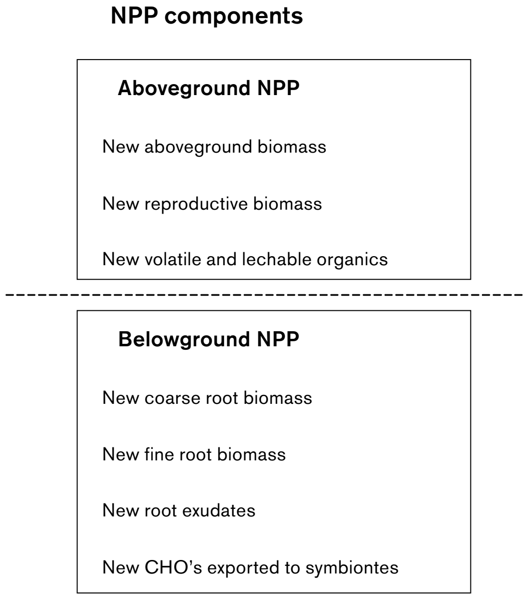


Figure 4-3. *The changes in biomass components that together constitutes the NPP during a specific time interval /after Clark et al. 2001/. Components in italic are omitted in the calculations of NPP. See text for explanation.*

The different components, constituting the NPP for a certain ecosystem may be measured separately (/Clark et al. 2001/, Figure 2). NPP can then be calculated directly using eq (x):

$$\text{NPP} = \sum P_i + H \qquad (3)$$

where P is the net production of dry biomass for each of the plant tissues (i), including wood, foliage, reproductive tissue, roots (including mycorrhizae) and H is the consumption of organic matter by herbivory. In this report we have omitted a number of components that so far are considered to be less important. Studies concerning volatile and lechable components above ground suggest that these components constitute an insignificant loss of the forest NPP /Clark et al. 2001/. Root exudates and transport to symbiontes are poor studied fields but some studies have shown that the loss may be significant at the individual level with up to 30% of the NPP. No estimates of root exudates and transport to symbiontes are known at the forest stand level. A general review of herbivory showed that herbivory generally is less than 10% of NPP in forests except during insects outbreaks when it can be up to 50% of NPP /Schowalter et al. 1986/. Herbivory on Scots Pine (*Pinus sylvestris*) was estimated to be 0.7% of the total needle biomass and 2.5% of the total needle production during one year /Larsson and Tenow, 1980/, while root consumption by phytophagous nematodes was estimated to 0.3% of the annual production of fine roots /Magnusson and Sohlenius, 1980/. Herbivory is, due to the low documented effect on NPP in boreal systems, excluded from the calculations of NPP. The carbon stock of dead plant tissue, e.g. logs and debris, was not included due to lack of site specific data.

Below we present a method to calculate biomass and primary production for a specific area. This method is under development and will be further refined to fulfil its goal to give an accurate description of biomass and primary production patterns in the landscape.

4.2.1 Habitat distribution and species composition

In order to calculate figures of biomass and production values of the terrestrial vegetation at Bolundsfjärden, a number of vegetation types were defined. Table 4-1 shows the distribution of the major land types in Bolundsfjärden. The forest was divided into different forest types defined by the tree species and age, and further separated into the functional layers; tree, bush, field and ground layers.

Table 4-1. Major land types of Bolundsfjärden. Data calculated from the vegetation map /Boresjö Bronge and Wester, 2003/.

Type of land	m^2	%	% excl water
Arable land	13,049	0.15	0.17
Grassland	117,503	1.36	1.50
Forest	6,789,168	78.32	86.73
Developed	–	–	–
Other	907,769	10.47	11.60
Water	840,751	9.70	10.74
Total	8,668,240	100.00	–

The young forests dominate when studying 30-year class intervals, the 0–29 class constitutes more than 40% of the forest area (Table 4-2).

Table 4-2. Age distribution in 30-year class intervals. Data calculated from the forestry management plan /Sveaskog, 1999/.

Age classes	Distribution (%)
0–29	40.73
30–59	7.72
60–89	20.14
90–115	31.41

4.2.2 Biomass

As far as possible, site specific data was used for modelling. However, since essential site specific data has not yet been measured, generic data was used for calculations and conversions of site specific data into units necessary for the study. The different sources of information used in the calculations are presented in Table 4-3.

Table 4-3. The data sources used to assign values to the different habitat categories in the calculations of biomass and primary production in the Bolundsfjärden catchment area.

Variable group	Variable	Data source
Biomass	Tree layer	Forestry management plan /Sveaskog, 1999/.
	Other layers	In situ studies of standing crop from bush, field, and ground layers, /Fridriksson and Öhr, 2003/.
	All layers	Generic data on dry weight and carbon content of biota, SKB R-01-09.
Primary production	Tree layer	Data obtained from the plots of the National Forest Survey.
	Other layers	In situ studies of standing crop from bush, field, and ground layers, /Fridriksson and Öhr, 2003/.
	All layers	Generic data on dry weight and carbon content of biota, /Jerling et al. 2001/.

4.2.3 Tree layer

The biomass of Bolundsfjärden tree layer was calculated using information from the Forestry Management Plan, where data on standing crop (given as m^{3}sk/ha) was available. The basis for the geometrical resolution was the vegetation map of the area.

Biomass data was not available for all the different vegetation types as given in the vegetation map. Therefore, the vegetation classes in the vegetation map were divided into five different types: old (> 30 yr) coniferous forests, young (≤ 30 yr) coniferous forests, deciduous (> 70% deciduous trees) forests, no forests and water bodies. The latter two classes have no tree layer. The first three types were assigned values of biomass, calculated from the local Forestry Management Plan. This value only gives the biomass of the stems, and therefore the biomass of bark, pins, needles and roots had to be added. Such calculations were made using data from the National Forest Survey (cf /Berggren and Kyläkorpi, 2002/). These calculations showed that the stem weight in old coniferous trees and deciduous trees in this area is 64% of the total above-ground weight and the corresponding value for young coniferous trees is 60%. Hereafter, the weight of the root system was added, and the above-ground part of trees on was average weigh 85% of their total weight.

After these calculations the data on total tree weight was complete. This weight was then converted into dry weight by using the factor 0.42 /Jerling et al. 2001/ and thereafter to carbon content by using the factor 0.5 /Jerling et al. 2001/.

4.2.4 Shrub, field and ground layers

Biomass of the shrub-, field- and ground layers in the area was calculated using data from /Fridriksson and Öhr, 2003/. In their study the actual amount of carbon was measured in six different vegetation types; harvested areas, grazed grasslands, sea shores, wetlands, Pinus dominated areas and Picea dominated areas. For each of these vegetation types, six sample plots were assessed and measured with regards to carbon content.

The basis for geometrical resolution was the vegetation map and, again, data from the Terrain Type Classification was used to fill the gaps. The vegetation was divided into the six types studied in /Fridriksson and Öhr, 2003/. The average values of biomass dry weight in the different layers were calculated. These weight values were then translated to carbon content using the factor 0.453 in accordance with /Fridriksson and Öhr, 2003/.

For the categories arable land, mixed forest and deciduous forest, no in situ measurements of biomass have been conducted. Therefore, the deciduous forest was assigned the same value as grazed grassland and the mixed forest was assigned the same value as Picea forest. The biomass of the arable land was calculated based on the standard yield figures of barley, which is the main crop cultivated in the area /Berggren and Kyläkorpi, 2002/. To the standard yield of 312.5 g barley/m^2 /Berggren and Kyläkorpi, 2002/ was added generic values of treshing loss, straw yield and root production. The total figure was then translated to carbon content using the factor 0.453 in accordance with /Fridriksson and Öhr, 2003/. The biomass value for the map classes bare rock, water and hard surfaces were set to zero: i.e. no terrestrial biomass was assumed to exist here.

Table 4-4. Biomass and primary production estimates for the different habitat categories in the catchment area of Bolundsfjärden using site-specific data.

	Vegetation type	Biomass (kg C/m^2)	Production (kg C/m^2/yr)
Tree layer	Old coniferous forest	7.89	0.24
	Young coniferous forest	0.67	0.08
	Deciduous forest	3.60	0.24
	No forest layer	0.00	0.00
	Surface water	0.00	0.00
Other layers	Harvested area	0.69	1.13
	Grazing area	0.19	0.35
	Sea shore	0.25	0.25
	Wetlands	0.57	0.61
	Pinus forest	0.73	0.73
	Picea forest	0.59	1.04
	Arable land	0.30	0.30
	Mixed forest	0.59	1.04
	Deciduous forest	0.19	0.35
	Rocky area	0.00	0.00
	Surface water	0.00	0.00
	Hard surface area	0.00	0.00

Table 4-5. Total biomass and primary production estimates for the catchment area of Bolundsfjärden using site-specific data.

	Total biomass (kg C)	Total production (kg C/yr)	Av biomass (kg C/m^2)	Av production (kg C/m^2/yr)
Tree layer	32,058,178	1,152,553,148	4.096	0.147
Other layers	4,917,337	7,036,810,008	0.628	0.899
Total	36,975,515	8,189,363,156	4.724	1.046

4.3 Primary production

Tree layer

Production of the tree layer was calculated using data from the National Forest Survey (Table 4-3). A previous cut-out of 520 sample sites covering a relatively large area including and surrounding the model area /Berggren and Kyläkorpi, 2002/ was used in order to obtain mean values with an acceptable level of statistical certainty.

In the present estimation of production, stem growth was calculated for the same plots as described above. We used average values for the five different classes; old (> 30 yr) coniferous forests, young (≤ 30 yr) coniferous forests, deciduous (> 70% deciduous trees) forests, no forests and water bodies. In addition to stem growth, we added bark, pin, needle and root growth as described above, assuming that all parts of the trees have linear growth.

4.3.1 Shrub, field and ground layers

For the six different vegetation types studied in /Fridriksson and Öhr, 2003/, data on dry weight was divided into green and non-green production. We assumed that all green vegetation fractions in general constitute the yearly production. However, as stated in /Chapin et al. 2002/, the green biomass only reflects 40% of the total production, so we used this value to increase the green fraction figure. These weight values were then translated to carbon content using the factor 0.453 in accordance with /Fridriksson and Öhr, 2003/.

For the vegetation types arable land, mixed forest and deciduous forest, no in situ measurements of biomass have been conducted. Therefore, the deciduous forest was assigned the same value as grazed grassland and the mixed forest was assigned the same value as Picea forest. The production of the arable land was assumed to be the same as the standing crop biomass, i.e. the calculations were performed the same way as described above. The production in the map classes bare rock, water and hard surfaces were set to zero, i.e. no terrestrial production occurs here.

4.4 Biomass consumers

Data concerning consumers are only documented for mammals. Data are based on inventories of the whole Forsmark region, and thus not site specific for Bolundsfjärdens catchment area. However, since many large mammals move over large areas, the mean value for population densities based on the entire Forsmark region represent a good estimate of the actual occurrence.

4.4.1 Moose

Data concerning moose population density in the whole Forsmark area were estimated by two methods during 2002; aerial survey and pellet sampling /Cederlund et al. 2003/. The results for these two studies were very different and therefore both values have been used. In the aerial survey the proportion of females, males and calves were recorded. These proportions did not vary much between the three different areas surveyed. The weight values used were slaughter weights from the sampling of moose in the Saxmarken area, just north of Forsmark. A general carbon value of 10% of the fresh weight has been used for the calculation of carbon weight per unit area.

Table 4-6. A population estimate of moose population, transformed into kg/C/km^2, in the Forsmark region based on two different methods /Cederlund et al. 2003/.

	Population density (ind/km^2)	Average carbon weight of moose (kg C/km^2)
Moose, pellet counting	0.83	10.41
Moose, aerial survey	0.24	3.01

Table 4-7. Avarage moose weight (kg) for the population in the Forsmark region divided into male, cow and calf /Cederlund et al. 2003/.

	Average weight (kg)	Proportion (%)
Moose males (Saxmarken)	161	17.4
Moose cows (Saxmarken)	146	52.2
Moose calves (Saxmarken)	70	30.4
Average weight moose	125	

4.4.2 Roe deer

Data concerning the roe deer population density in the whole Forsmark area were estimated by pellet counting during 2002 /Cederlund et al. 2003/. The proportions between males and females have not been estimated, but since the weights do not differ much this has not been taken into account. According to statistics /Miliander et al. 2004/ the proportion of calves hunted is about 30% and this value has been used as the proportion of calves within the population, despite the uncertainty in data. The weight values used were slaughter weights from /Miliander et al. 2004/. A general carbon value of 10% of the fresh weight has been used for the calculation of carbon weight per unit area. The population density (ind/km^2) was 5.9 and the average carbon weight was 12.59 kg C/km^2. The average weight (kg) for the roe deer population separated into calves and adults was 14 kg for calves and 24.5 for adults and 21.35 in average for the whole population.

4.4.3 Forest and field hare

Data concerning the population densities of forest hare and field hare in the whole Forsmark area were estimated by pellet counting during 2002 /Cederlund et al. 2003/. No difference between the sexes has been documented. The weight values used were slaughter weights from /Miliander et al. 2004/. A general carbon value of 10% of the fresh weight has been used for the calculation of carbon weight per unit area.

Table 4-8. Population density (ind/km^2), weight (kg/ind) and average carbon weight (kg C/km^2) for the roe dear population in the Forsmark area /Cederlund et al. 2003/.

	Population density (ind/km^2)	Weight (kg/ind)	Average carbon weight (kg C/km^2)
Forest hare	0.44	5	0.18
Field hare	0.32	4	0.16

4.4.4 Marten and lynx

Data concerning the population densities of marten and lynx in the whole Forsmark area were estimated by inspecting tracks on snow during 2002 /Cederlund et al. 2003/. No other density data is available and therefore these two species represent the carnivores in this area. A general carbon value of 10% of the fresh weight has been used for the calculation of carbon weight per area.

Table 4-9. Population density (ind/km^2), weight (kg/ind) and average carbon weight (kg C/km^2) for the marten and lynx populations in the Forsmark area. Data from /Jägareförbundet, 2004/.

	Population density (ind/km^2)	Weight (kg/ind)	Average carbon weight (kg C/km^2)
Marten	0.24	1.2	0.028
Lynx	0.02	19.0	0.038

4.4.5 Rodents

Data concerning the population densities of different kinds of rodents in the Forsmark area were estimated by trapping in June and October 2003 /Cederlund et al. 2004/. The weight values used were average values estimated from data found on the web site of the Gothenburg natural history museum. A general carbon content of 10% of the fresh weight has been used for the calculation of carbon weight.

Table 4-10. Population density (ind/km^2), weight (kg/ind) and average carbon weight (kg C/km^2) for the rodents populations in the Forsmark area. Data from /Göteborgs naturhistoriska museum, 2004/.

	Population density (ind/km^2)	Weight (kg/ind)	Average carbon weight (kg C/km^2)
shrew	2,913	0.02	4.37
“mice”, June	3,040	0.03	7.60
“mice”, October	5,486		13.71
Average “mice”		0.03	10.66
Water vole, June	900	0.23	20.25
Water vole, October	1,150	0.23	25.88
Average water vole			23.06
Field vole, June	694	0.03	2.08
Field vole, October	831	0.03	2.49
Average field vole			2.29
Bank vole, June	4,618	0.03	12.70
Bank vole, October	5,635	0.03	15.50
Average bank vole			14.10

4.5 Production consumers

No site specific production data is available for the area, and thus the following assumptions concerning the production in the area have been used /Cederlund, pers comm/:

Moose: 30% of biomass.
Roe deer: 50% of biomass.
Hare: 30% of biomass.
Marten and *lynx*: 30% of biomass (high value, predators
generally have lower production values than herbivores).
Rodents: 10 generations per year (10 times biomass).

Table 4-11. Production values for different species and functional groups within the Bolundsfjärden.

	Kg C tot/year
Moose	15.76
Roe deer	49.30
Hare	0.39
Rodents	4,264.02
Sum herbivores	4,329.47
Marten	0.07
Lynx	0.09
Sum carnivores	0.15

4.5.1 Consumption

As no site specific consumption data were available, data for the different animals were sought on the web.

Moose

Consumption rates of 10–20 kg/day in winter and up to 50 kg/day at summer were stated at www.boraszoo.se. An average value of 30 kg/day was used.

Roe deer

Consumption rates of 1.5–2 kg/day were stated at www.jarvzoo.se. An average value of 1.75 kg/day was used.

Hare

A consumption rate of 0.5 kg/day were stated at www.jagareforbundet.se. This value has been used.

Rodents

No data have been found.

Table 4-12. Consumption data for grazing mammals found in the Forsmark area.

	Moose	Roe deer	Hare	Rodents	Sum Herbivores
Number of individuals	4.19	46.18	2.97	110,289.33	–
Consumption (Kg C/ind day)	3.00	0.18	0.05	no data	3.23
Consumption (Kg C/ind year)	1,095.00	63.88	18.25	no data	1,177.13
Consumption (Kg C/area, year)	4,585.54	2,949.89	54.28	no data	7,589.71

4.5.2 Marten and lynx

An adult lynx eats about 1 kg fresh weight/day (www.jarvzoo.se). For marten, no data were found, but an assumption that their consumption per weight is approximately the same as lynx, which is also a predator. The average weight used for marten is about 0.06 of the weight used for lynx. The consumption rate for marten was therefore set to 0.06 of the consumption rate of lynx.

Table 4-13. Consumption data for lynx and martens calculated for the Forsamark area and Bolundsfjärden.

	Kg C/ind per day	Kg C/ind per year	Kg C/year (Bolundsfjärden)
Lynx	0.1	36.5	5.7
Marten	0.0	2.2	4.1
Sum carnivores			9.8

Table 4-14. Hunted wild birds, statistics from "Jägarförbundet" for Bolundsfjärden catchment area. Few weight values were found, therefore approximations have been used.

	Individuals (n)	Weight (kg C/year)
Skogsfågel	1.2	0.27
Sjöfågel	0.5	0.54

4.5.3 Fishing

In August 2003 fish sampling was performed in Lake Eckarfjärden and Lake Bolundsfjärden (/Borgiel, 2004/. Forsmark site investigation. Sampling of fresh water fish. SKB P-04-06). The catches are here expressed as weight per unit effort. In general, 1 kg CPU is about equal to 30 kg fish biomass (Per Nyberg, Fiskeriverket 2004-03-18). According to Per Nyberg, Fiskeriverket 2004-03-18, a reasonable fish biomass in the Forsmark area is about 50 kg/ha.

Table 4-15. Weight per unit effort calculated for different fish species in Bolundsfjärden and Eckarfjärden.

Species	Perch	Ruffe	Pike	Roach	Crucian carp	Tench	Total
Bolundsfjärden	0.67	0.02	0.04	0.47	0.23	1.00	2.44
Eckarfjärden	0.92	0.00	0.45	0.79	0.00	1.47	3.64

4.6 Food web interactions

One of the purposes for documenting and calculating the production and consumption in the terrestrial systems of Forsmark is to identify the major pathways of carbon in the system. So far, the major functional groups have been identified, but not the food web interactions as a whole. Figure 4-4 present a first draft to the complete food web interaction and carbon flow. A more developed interaction model will be presented in the SurfaceNet report.

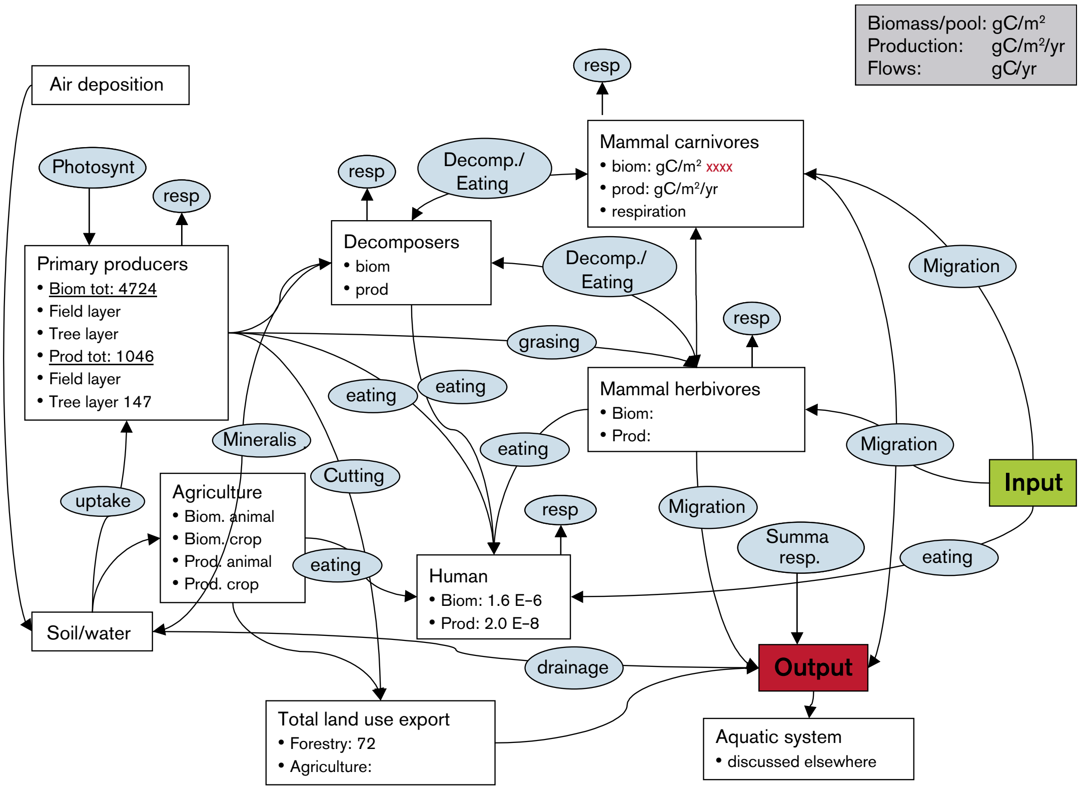


Figure 4-4. A first draft showing the food web interactions and carbon flow in the terrestrial ecosystem in Forsmark. The values for production are calculated based on sites specific data from Bolundsfjärdens catchment area presented in this report.

5 Humans

5.1 Population

There are no inhabitants within Bolundsfjärden today. There are however three holiday houses within the area, which indicates that there is a small holiday population /Miliander et al. 2004/. According to Statistics Sweden (SCB) there are in average three persons per holiday house for 60 days per year, when calculating the water use /SCB, 2003/.

When modelling flows in the biosphere we can apply the population density in the main drainage area (54/55) to Bolundsfjärden. The population density is 0.2 inhabitants/km^2 in 2002, which gives a population of 1.7 within Bolundsfjärden.

A theoretical population can be estimated based on a figure given by /LivsmedelsSverige, 2004/, showing that each person needs 3,000 m^2 (0.3 hectare) to be self-sufficient. At least half of that amount is needed for fodder production. The total area of grassland and arable land in Bolundsfjärden is 130,550 m^2. An area of that amount could feed 43.5 persons. According to /Rubio Lind, 2004/ a vegetarian only need 550 m^2 to be self-sufficient. This appears to be a very low figure. It ought to be approximately 1,500 m^2, as no fodder production is needed.

Scenarios

1. If the inhabitants were vegetarians with a land area of 550 m^2 or 1,500 m^2 per person, the grassland and arable area in Bolundsfjärden would be able to feed 237 or 87 persons instead of 43.5.
2. If we in the future would use the forest for grazing during the summer season (six months) the area that are needed for grazing and fodder production per person could be reduced with 50%. Each person would only need 2,250 m^2 and the grassland and arable area in Bolundsfjärden could feed 54 persons instead of 43.5.
3. If we assume that all the smaller lakes (except Eckarfjärden, Gällsboträsket and Bolundsfjärden) in the future would become wetlands that could be drained and used for agriculture, we would gain 332,032 m^2 according to /Rubio Lind, 2004/. This area could then support 111 additional persons if we calculate with 3,000 m^2 per person.

According to /Naturvårdsverket and Boverket, 2000/, the ecological footprint is 6–7 hectare per person in Sweden. An ecological footprint represents the productive area needed to produce everything consumed by an individual and to absorb the emissions that result from this consumption. The footprint includes forest and water area. The arable land accounts for approximately 2 ha. This is a considerably higher figure; the grassland and arable area in Bolundsfjärden could in that case only support 6.5 persons.

5.2 Human land use

Human land use, here separated into forestry and agriculture, is an important factor both as affecting dispersal and accumulation processes in the landscape, but also as a direct estimation of exposure to dose. Forestry may radically affect the run-off volume and the chemical composition of the run-off water. However, forestry is less likely direct source of exposure of dose to humans compare to agriculture and hunting. Below we present calculations of forestry, agriculture and hunting activities.

5.2.1 Forestry in Bolundsfjärden

Forestry has in recent time replaced fire as the most important factor affecting and structuring the CNP budgets in forests over longer time scales. The removal of biomass by the forest industry is described in this section, whereas the accumulation of CNP as biomass is described under "Primary producers".

Bolundsfjärden is dominated by forests and nearly 87% of the land area is forested (see Table 4-1 under primary production). The forested area is dominated by coniferous forests (92%) and only app 8% of the tree layer has a significant deciduous share /calculated from Boresjö Bronge and Wester, 2003/. The forestry carbon removal is here calculated as the part of the stem used by the forestry and does not include other parts (e.g. branches), which here are supposed to be left at the deforested area. The following calculations were made:

The average volume in mature forest of the area (hkl 40) is 233.1 m^3sk/ha according to the forestry management plan /Sveaskog, 1999/.

18.31% of the forest is 0–9 years old = 115.2 ha.

Tot volume: 233.1×115.2 = 26,853.12 m^3sk = 5,639,155 kg C.

Divided by 10 years = 563,916 kg C/yr is exported. Divided by the land area = 72 g C/m^2/yr.

Table 5-1. Biomass production in the forests of Bolundsfjärdens catchment area. All values in the table are based on site specific data.

	Total biomass (kg C)	Total production (kg C/yr)	Av biomass (kg C/m^2)	Av production (kg C/m^2/yr)
Tree layer	5,129,802.740	174,092.360	4.765	0.162
Other layers	685,640.779	911,141.336	0.637	0.846
Total	5,815,443.519	757,222.815	5.402	0.703

5.2.2 Agriculture

The area classified as grassland or arable land in Bolundsfjärden is in total 130,550 m^2 (see Table 4-1 under Primary production). However, no agricultural activities are currently existing in this area.

5.2.3 Scenario of potential land use and agriculture production in Bolundsfjärden

According to /LivsmedelsSverige, 2004/ the need of land area for self-sufficiency is 3,000 m^2 per person, of which approximately 50% are needed for fodder production. Assuming that two persons live in Bolundsfjärden, they would need 3,000 m^2 altogether for crop production.

Based on the fact that a cow needs 1.8–3.0 hectares for fodder production and grazing /SLU, 2001/, we may estimate that the remaining arable land and grassland in Bolundsfjärden (127,000 m^2) can feed 5.3 cows. For example, a potential land use in Bolundsfjärden sustaining two humans has an area for agriculture of 130,550 m^2, crop production of 3,000 m^2 and grassland and fodder production of 127,000 m^2.

One dairy cow produces in average 7.735 tonnes of milk per year. An average dairy cow is slaughtered at the age of five years after given birth to three calves. One calf per year would have to be kept for breeding. The utilized carcass weight for an old calf (age six months) is 82.3 kg. /Miliander et al. 2004/.

The only crop that is produced in Forsmark perish is barley /Miliander et al. 2004/. The crop production in Bolundsfjärden, is therefore assumed to be barley. The production is based on the standard yield in SKO-area 0322, where Bolundsfjärden is located.

The amount of carbon has been estimated as 10% in slaughtered calves and 2% in milk. The amount of carbon in crop is estimated as 45.3% of the dry weight. The dry weight is 85% of the fresh weight according to /Jordbruksverket, 2003/.

Table 5-2. An estimated agricultural production in Bolundsfjärden.

Meat production					
Number of cows	**Calves per cow and lifetime (5 y)**	**Calves/year**	**Calves for slaught**	**Slaughtered calves (kg)**	**Slaughtered calves (kg C)**
5	3	3	2	164.6	16.5
Milk production					
Number of cows	**Milk per cow and year (kg)**	**Milkproduction total (kg)**	**Milkproduction (kg C)**		
4	7,735	30,940	618.8		
Crop production					
Area (ha)	**Standard yield (kg/ha) Barley**	**Yield (kg)**	**Yield (kg dw)**	**Yield (kg C)**	
0.3	2,834	850.2	722.7	327.4	

5.2.4 Outdoor life

Current and potential picking of wild berries

The calculations are based on the approximate average amount that is picked in Sweden as demonstrated in /Berggren and Kyläkorpi, 2002/. That is 23.0 millions litres in Sweden in 1997. The forest area in Sweden is approximately 230,000 km^2 /SCB, 2004/, giving in average 100 litres/km^2 (approximately 100 kg/km^2).

The total available amount of wild berries can be calculated based on the fact that 5–7% of the available amount was picked in 1977, which was 75.3 millions litres /Berggren and Kyläkorpi, 2002/. That gives a total amount of 1,255 millions litres. The amount per unit area forest is thus 5,450 litres/km^2, which approximately is 5,450 kg/ km^2.

Approximately 10% of the fresh weight is assumed to be carbon. The forest area in Bolundsfjärden is 6,789,168 m^2 (GIS).

Current and potential picking of fungi

According to /Berggren and Kyläkorpi, 2002/ the amount of fungi that can be consumed is approximately 40 kg/ha, while the amount of attractive fungi for consumption is 1.5 kg/ha. Some 5–7% of the fungies were picked in 1977, but the picking has been reduced since then. If we assume that the picking is 3% today, the picked amount of attractive fungi would be 4.5 kg/km^2. If we want to calculate the risk of exposure based on a critical group, one may assume that all the consumable fungi are picked.

The forest area in Bolundsfjärden is 6,789,168 m^2 (GIS). A fungi is assumed to contain 1.2% carbon.

Table 5-3. Available and potential picking of fungi and wild berries in the Bolundsfjärden catchment area.

	Available amount (kg C/km^2)	Available amount in Bolundsfjärden (kg C)	Picked amount (kg C/km^2)	Picked amount (kg C/km^2) in Bolundsfjärden
Wild berries	48	326	0.1	2.4
Fungi	545	3,700	10	68

5.2.5 Hunting

The species that are hunted for consumption are mainly moose, roe deer and hare. Länsstyrelsen i Uppsala keeps statistics concerning the moose hunting, while Jägareförbundet keeps statistics concerning other wildlife. The average harvest of moose in Forsmark perish and the average harvest of roe deer and hare in Östhammars jaktvårdskrets that are demonstrated in /Miliander et al. 2004/ are appliable Bolundsfjärden.

The carcass weights are calculated according to /Miliander et al. 2004/. The amount of carbon is assumed to be 10% of the carcass weight.

Table 5-4. Carcass weight (kg) for wild mammals in the Forsmark area.

Species	Harvest ind/km^2	Carcass weight (kg)	Carcass weight (kg/km^2)	Carcass weight (kg C)	Carcass weight (kg C/km^2)
Moose					
mean value 99-03	0,53	547	64	54,7	6,4
Roe deer					
mean value 97-01	1,9	192	22	19,2	1,92
Alpine hare					
mean value 97-01	0,13	2,5	0,29	0,25	0,029
Common hare					
mean value 97-01	0,28	6,7	0,78	0,67	0,078

6 The drainage area model

The major aim with constructing a drainage area model is to describe transport and accumulation processes of carbon, nitrogen and phosphorus (CNP) in a landscape. Such a description requires a deep understanding of the importance of a number of different processes affecting the budgets of CNP. This description will serve as the base for understanding and predicting transport and accumulation of CNP and other substances with similar chemical properties by connecting information from the different scientific fields and identify the processes of prime interest. The model is not aiming to be a general model. Instead the aim is to incorporate as many site-specific data and processes as possible using state of the art data from as many scientific fields as possible. In the end this will of course not rule out the possibility that this model may be applied on other areas of interest. In a first step processes have to be identified for each scientific field separately by constructing a descriptive model /see Löfgren and Lindborg, 2003/. This report presents data from the catchment area Bolundsfjärden and the large recipient Eckarfjärden covering a number of different scientific fields.

The overall drainage model will serve as a knowledge base for the TERRA model (see chapter 8.7) and modelling of dose to humans, and will not be subject to simulations. However, some fields such as surface hydrology, considered to be the most important driving variable for transport and accumulation processes /Blomqvist et al. 2000/, will be subjected to quantitative modelling and simulation using site specific data in order to understand vertical and horizontal movement of surface water. This information will be connected to budget calculations describing the flows of matter at the level of catchment area and used to estimate leakage into running water, lakes and the final recipient; the sea. Measurements of matter transport in streams give an estimation of the leakage from the terrestrial systems in their sub catchment areas (Figure 6-1).

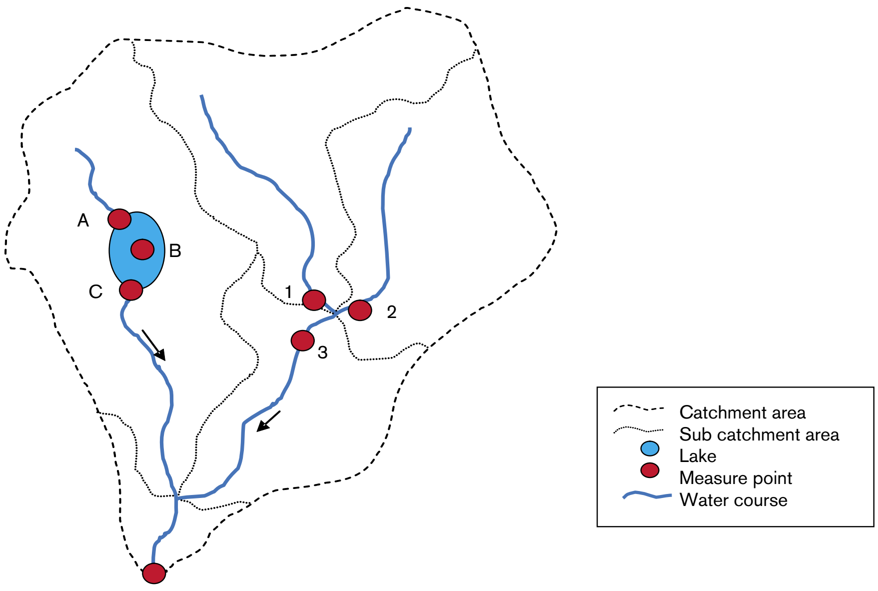


Figure 6-1. The picture illustrates a catchment area containing a lake and running water, and the sub catchment areas for these. The red points illustrates where field measurements of water chemistry are taken to be able to follow transport and accumulation of matter within the catchment area.

This makes it possible to validate estimated leakage and actual leakage from terrestrial systems. It will also be possible to crosscheck by using sums (e.g. 1+2 = 3 in Figure 6-1). Consequently, there will be several possibilities to fine-tune the descriptive model in means of actual leakage of a number of chemical elements and substances into the running water using terrestrial information such as vegetation, soil type and size of the catchment area. The aquatic systems are not only important for transport, but also for accumulation of matter in the lake or the sea bed /Blomqvist et al. 2000/. It will therefore be possible to identify important factors related to sources and sinks of matter in the ecosystem. By describing the CNP budgets and transfer in the drainage area we will be able to describe the pathways for other substances with similar chemical properties as CNP, such as some radionuclides. This task will be a crucial step in the coming safety analysis.

The drainage area model will also function as a knowledge base for understanding the drainage area in a temporal context providing information on how to predict future changes and succession of the emerging landmasses due to land upheaval. Moreover, these workshops covering terrestrial and aquatic systems generated insight in where the potential difficulties are (e.g. linking data and processes from different scientific fields) and what parameters are lacking or need better estimates (e.g. soil respiration) which should be collected in field campaigns.

6.1 Dose model

A dose assessment model was designed in order to estimate dose conversion factors to an adult for unit releases of radionuclides of interest for safety analyses of spent fuel to lake Eckarfjärden. Forests are dominating ecosystem in the drainage are 60%, while only 1% consists of arable land /Brunberg et al. 2004/ However, this area is large enough to feed a number of persons TBD and in addition the amount of fish for consumption is large enough 350 kg to lover the annual consumption for some persons. The internal exposure pathways to be considered were therefore, drinking water, consumption of fish, vegetables, root crops, milk and meat. The latter are supposed to contaminate by cows intake of lake water. In addition external exposure from ground and inhalation of resuspended soil particles were included.

It was determined to use the lake module applied for the safety analyses of SFR /Karlsson et al. 2001/ for the transport calculations while the expressions for exposure pathways were taken from SR 97 /Bergström et al. 1999/.

Therefore we first identified those parameters in that module which need site specific information for calculation of concentrations in radionuclides in the compartments. For all these parameters except for the concentration of suspended matter in the lake values were obtained from the siting programme, see Table 8.1 below. All other parameter values were taken from SR 97.

Table 6-1. Site specific data units.

Parameter	Unit	Value
Lake area	m^2	282,400
Mean depth	m	0.91
Water retention time	days	328
Depth of upper sediment	m	0.05
Annual average runoff	M3	9.1 10–3

The transport module was implemented in Simulink and dose conversion factors for 17 radionulides of interest in safety analyses were obtained. These factors were briefly compared to those used in SR 97. The factors for the lake Eckarfjärden were about two orders of magnitude higher than those from SR 97. This was expected as lake Eckarfjärden has a smaller water volume and longer retention time of water than the lake used in SR 97. Comparisons of percentage contribution to EDF for various exposure pathways showed also good agreement, however bearing in mind that the EDF's from SR 97 were obtained with initial generation of input parameter values.

6.1.1 Activity modelling by using hydro- and primary production data

A model for dilution of radionuclide contaminated ground water and uptake of radionuclide in vegetation was developed using the discharge grid, the flow direction grid and primary production data.

The model starts at a ground water discharge point and ends up in the nearest downstream lake. The route for the contaminated ground water from the discharge point to the lake is calculated with the "rain drop" tool in the ArcGis Hydrological modeling extension. The "rain drop" toll creates a line. This line is converted to points with 5 metres increments along the line. The points are converted to circular polygons with 10 metre diameter with the "buffer tool". Using these circular polygons the maximum discharge for each polygon is calculated using "Zonal statistics" in ArcGis. With this method the route is divided into 10 metre long segments with discharge data for each segment.

The "zonal statistics" tool is also used to get vegetation data to each segment. The vegetation type with the largest area in each circular polygon is chosen to represent the whole line segment. Calculated primary production values for each vegetation type are then joined to the table. Now the table has the following variables:

X	X-coordinate for the start point of the line segment.
Y	Y-coordinate for the start point of the line segment.
D	Distance from discharge point (m).
Q	Discharge (m^3 year^{-1}).
PP	Primary production (kg C m^{-2} year^{-1}).

The statistical table from "zonal statistics" is opened in Excel where the final dilution model is developed.

On top of the worksheet four constants are set by the user of the model:

Q_RN	Discharge of radio nuclides.	(Bq year^{-1})
L	Length of line segment (m).	
W	Width of "route" (m).	
E	Evapotranspiration (m^3 s^{-1} km^{-2}).	

The E-constant is converted to m^3 year^{-1} using the constants L and W and number of seconds per year (E_year).

The first row in the model represents the first ten metres from the discharge point along the route. In first column the concentration of radio nuclides in water is calculated with:

$RN\_conc = Q\_RN / Q$ (Bq m^{-3})

In the second column the amount of radio nuclides in water is calculated with:

$RN\_amount = RN\_conc \times Q$ (Bq)

In the next column to the right the amount of radio nuclides stored in the biomass is calculated with:

$Bio\_uptake = E\_year \times RN\_conc$ (Bq)

In the last column the concentration of radio nuclides is calculated with:

$Bio\_conc = B\_uptake / (PP \times L \times W)$ (Bq kg C^{-1})

The next row represents the line segment 10–20 metres from the discharge point. First the amount of Bq (RN_amount) is calculated as RN_amount in the segment upstream minus the amount stored in the biomass (B_uptake) in the same segment with:

$RN\_amount_{(Seg2)} = RN\_amount_{(Seg1)} - B\_uptake_{(Seg1)}$ (Bq)

The next step is to calculate the concentration of radio nuclides in segment two with:

$RN\_conc_{(Seg2)} = RN\_amount_{(Seg2)} / Q_{(Seg2)}$ (Bq m^{-3})

The rest of the equations in row 2 are the same as for row 1. The equations in row 2 were then copied down to the last segment.

6.1.2 The activity model applied to the Eckarfjärden catchments

A hypothetic ground water discharge point was randomly selected within the Eckarfjärden catchments. The route from the discharge point to Eckarfjärden was found to be 760 metres. The discharge of radio nuclides was chosen to 1 Bq $year^{-1}$ and the evapotranspiration was set to the yearly average value 0.0133 (dm^3 s^{-1} km^{-2}) (see Table 5).

The primary production along the route varied between 0.22–0.66 Bq kg C^{-1} m^{-2} $year^{-1}$. Figure 1 shows the drop in the amount of radio nuclides along the rote depending on the chosen route width. The figure shows an exponentially decrease which level out at approximately 250 metres. The reason for this is a strong increase in discharge at this point along the route. It can also be seen in the figure that the chosen width of the route have a great influence of the amount of radio nuclides that reach the lake.

Because of the strong dilution of the contaminated ground water at the 250 metre point, the uptake to biota occur mainly along the first 250 metres of the route (see Figure 6-3), and hence the highest concentration of radio nuclides in biota is also found in this area (see Figure 6-4).

If the most likely route width is chosen to 1 metre, approximately 85% of the radio nuclide discharge will reach the lake Eckarfjärden and 15% will be stored in the biota, mainly along the first 100 metres of the route. If the discharge of radio nuclides will continue for a long period of time, a "Hot spot" close to the discharge point will probably occur.

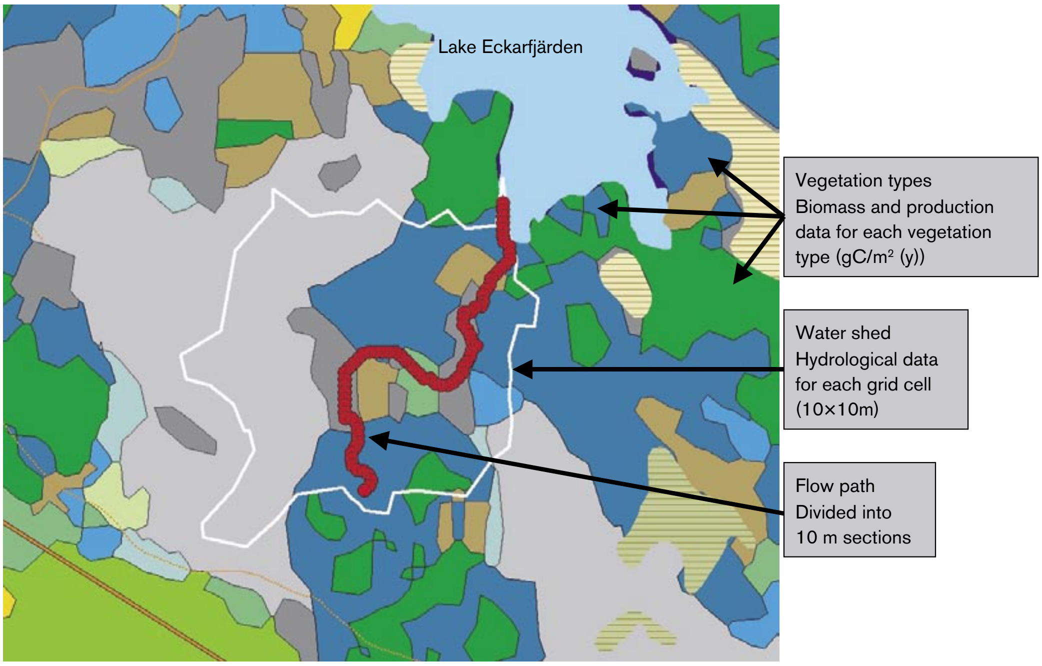


***Figure 6-2.** A flow path through different vegetation types from a randomly selected discharge point, marked in red dots. Drainage area for the outlet marked with a white line.*

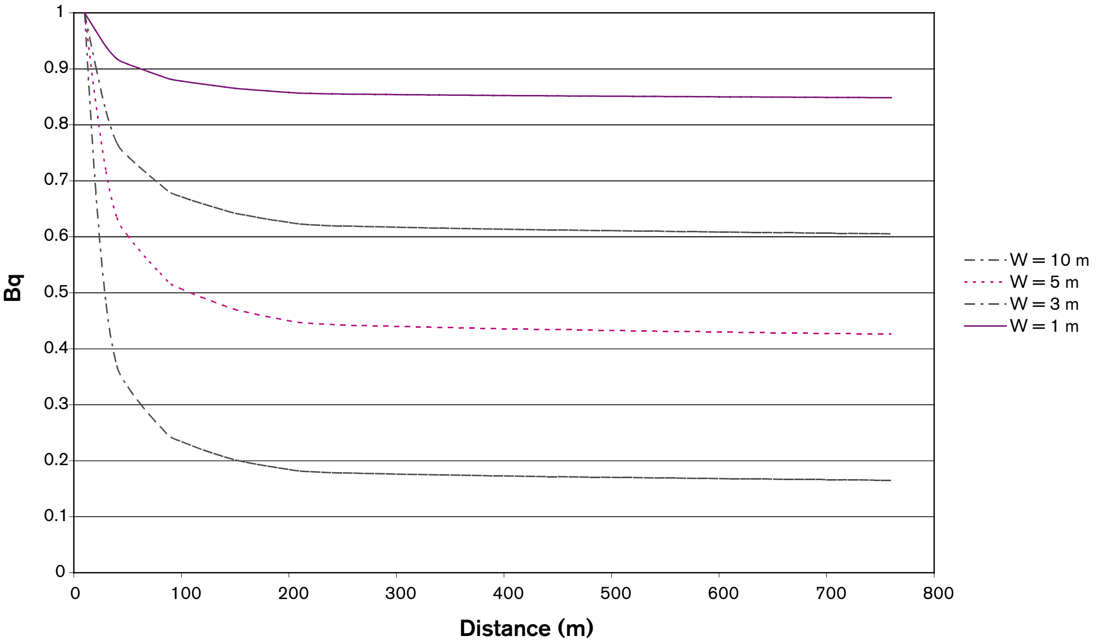


***Figure 6-3.** The amount of radio nuclides (Bq) in water along the route depending on the chosen route width.*

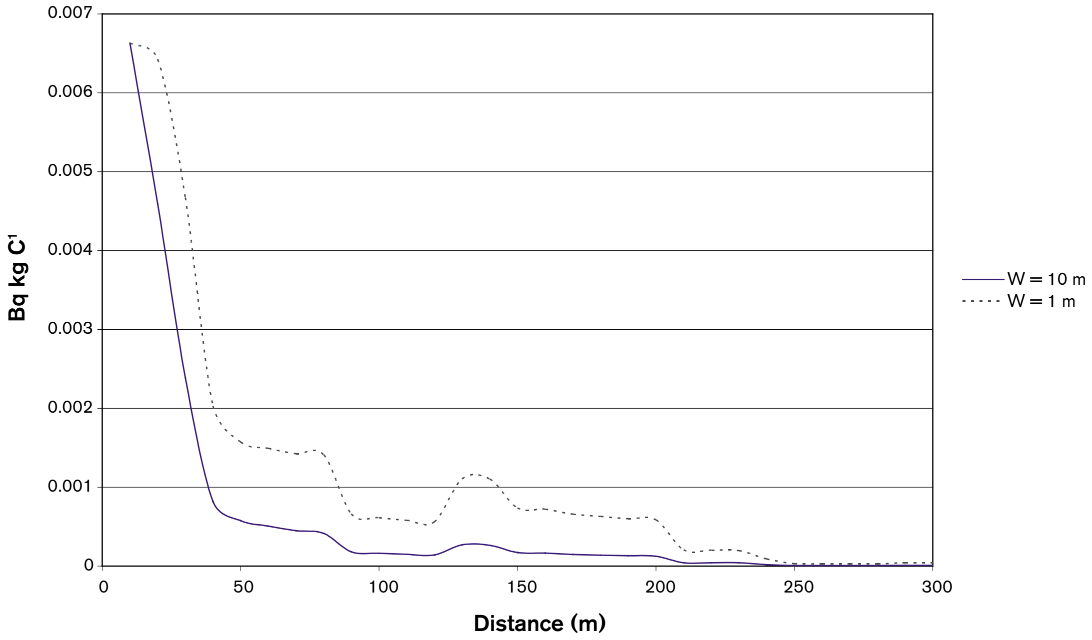


Figure 6-4. *The concentration of radio nuclides in biota (Bq kg C^{-1}) depending on the chosen route width.*

6.2 Description of CoupModel

A number of ecosystem process oriented models have been developed, like the 3-PG model by /Landsberg and Waring, 1997/, the Sim-CYCLE model by /Ito and Oikawa, 2002/ and the CoupModel by /Jansson and Karlberg, 2004/. An overview of the Swedish CoupModel will be presented below. These types of models have many things in common but they often differ with respect to their use and how the site specific applications are made. Typical for these models are that they represent the soil, the plant and the atmosphere. They have normally a full mass balance for water and carbon. Together with water and carbon, also heat and nitrogen are sometimes included. External forcing of the models are sunshine and meteorological conditions and rate regulating parameters represents typical properties of the ecosystems. The models may have quite different resolutions of areal and temporal scales. Typical scales are daily resolution of input/output variables covering areas from 10 to 100,000 m^2.

The Coupmodel is general enough to include water and heat processes in any soil independent of plant cover in a soil-plant-atmosphere system. The strength of the CoupModel is that it is more developed to account for interaction between the climate, tree stand and soil temperature /see e.g. Gustafsson et al. 2004/. However, the 3-PG model has been tested for many more sites around the world and represents a good starting point for comparison with other ecosystems /see Landsberg et al. 2003/, whereas the CoupModel has more application to the Nordic countries. The CoupModel will account for how different stand development (= leaf area index, degree of cover) will influence both snow and energy balance within the tree stands so that the feedback from soil and climate to canopy processes can be described /Gustafsson et al. 2004/.

6.2.1 Description of components

The model consists of two main parts, the water and heat part and the nitrogen and carbon part. A complete budget and description of all major fluxes and storages of water, heat, nitrogen and carbon is made. The model has previously been used to estimate carbon and nitrogen fluxes for forest ecosystems. In these cases a daily time resolution was a driving condition for the nitrogen/carbon processes. This restricts the use to systems where the physical characteristics are known or the physical characteristics are independent of the nitrogen/carbon processes. To enable simulations of the influence of present climate on both carbon assimilation and carbon release from all major regions of Sweden, an approach with feedback between abiotic processes and the turnover of carbon in the entire soil-plant system is needed.

The model will be briefly described below, and some of the key parameter values will be presented for the simulations. A detailed description of the model is given by /Jansson and Karlberg, 2004/, and a review on the software has been presented by /Jansson and Moon, 2001/. A detailed review of the model and how it has been used to simulate water, heat and nitrogen conditions for arable land and forests in the Nordic countries has been made by /Jansson et al. 1999b/. A more general review on the physical processes as described in the model was given by /Jansson, 2003/.

6.2.2 Plant growth

Input of carbon to the system (carbon assimilation rate) was simulated by an empirical function based on a light use efficiency. Total plant growth, $C_{Atm\rightarrow a}$, was proportional to the global radiation absorbed by canopy ($R_{s,pl}$) but limited by unfavourable temperature $f(T_a)$, nitrogen $f(CN_{leaf})$and water $f(E_{ta}/E_{tp})$conditions represented by functions ranging between zero and unity as:

$$C_{Atm\rightarrow a} = \varepsilon_L f(T_{Air}) f(CN_{leaf}) f(E_{ta}/E_{tp}) R_{s,pl} \qquad (4)$$

where ε_L is a parameter. The light use efficiency value was1.7 g Dw/MJ. Only maintenance respiration was accounted for. Also the different response function for air temperature and leaf C/N ratio was considered as a linear function with values that were slightly modified. Carbon allocation to the different components of the vegetation was made by using empirical functions based on a subdivision of plant into: leaves (needles), stem and roots. The roots were assumed to obtain 20% of total net primary production (NPP) and the same value was used for the leaves. Roots and leaves were assumed to have a turnover rate that was based on the fine root fraction or on the green active part of leaves. All remaining biomass was represented by the stem pool (including twigs, branches, stumps and coarse roots).

The nitrogen uptake by the plant roots was driven by the carbon assimilation rate and assumed C/N ratios for the different components of the plant. A certain fraction of the mineral N in the soil was assumed to be easily available for uptake every day. The demand of the vegetation was fulfilled with the highest priority for the roots, followed by the stem and finally the leaves. In case of nitrogen deficiency, i.e. when estimated uptake was less than the estimated demand, a supplementary mechanism was assumed by allowing nitrogen to be assimilated in organic form. This possible organic uptake was assumed to be proportional with different coefficients to the actual total storage of litter and humus in the soil. Consequently, nitrogen uptake was dependent on both mineral N composition in the soil and the amount of organic N storage in the soil. Nitrogen was also assumed to be retained in the plant in a mobile pool of N and C that was used in the spring to start the development of new leaves.

6.2.3 Soil pools and fluxes

The soil organic material was represented in different ways depending on the purpose of the simulation. Soil organisms, such as microorganisms, decompose the organic matter, and their activity, therefore, accounts for the fluxes between different organic pools in the soil. Microbial biomass can optionally be explicitly or implicitly represented. To account for differences in substrate, the model has a minimum representation of two organic pools independent of soil horizon. One of these is named *Litter* and has a high turnover rate. The other one is *Humus* and represents a low turnover rate.

The decomposition rate of the litter pool, C_{Decomp}, was calculated as a first order rate process:

$$C_{Decomp} = k_l f(T) f(\theta) C_{Litter} \tag{5}$$

where k_l is a parameter. The same first order rate equation was applied for humus, by using the parameters k_h. We assumed k_l to 5.10^{-3} and k_h to 1.10^{-5} (day^{-1}) based on the range of decomposition rates found for the LUSTRA CFS sites.

The products of decomposition are CO_2 (respiration), humus and, conceptually, microbial biomass and metabolites. Since the microbes are implicitly included in the litter pools, the synthesis of microbial biomass and metabolites constitute an internal cycling i.e. $C_{Litter \rightarrow Litter}$, eq 0.5. The relative amounts of decomposition products formed from the litter pool decomposition are:

$$C_{Litter \rightarrow CO_2} = (1 - f_{e,l}) \cdot C_{Decomp} \tag{6}$$

$$C_{Litter \rightarrow Humus} = f_{e,l} f_{h,l} C_{Decomp} \tag{7}$$

$$C_{Litter \rightarrow Litter} = f_{e,l} (1 - f_{h,l}) \cdot C_{Decomp} \tag{8}$$

where $f_{e,l}$ and $f_{h,l}$ are parameters.

The humus pool always has an efficiency parameter, $f_{e,h}$, equal to zero, resulting in a respiration from the humus pool, $C_{Humus \rightarrow CO2}$, equal to the total decomposition products from the humus pool. Consequently this is the only flow from the humus pool.

Organic matter in the soil organic pools described above is considered to be vertically immobile. However, the soil water in the profile normally contains an amount of dissolved organic matter originating from litter, humus or microbes. Consequently this organic matter can be passively transported vertically by water flows.

In a similar way also the carbon in the soils was assigned to represent a distribution that was similar to data from the National Survey of Forest Soils and Vegetation.

6.2.4 Common response functions

Two response functions, the response functions for temperature and soil moisture were used in many procedures. These two functions are described in detail in this section.

Based on the experience from a number of investigations the response function for temperature was based on the Ratkowsky function. The function states, *f(T)* is based on a squared relationship:

$$f(T) = \left(\frac{T - t_{\min}}{t_{\max} - t_{\min}} \right)^2 \tag{9}$$

where t_{min} and t_{max} were assigned to –7 and 25°C.

The soil moisture response function, $f(\theta)$, is a simple functions that is related to three different regions of the soil moisture retention curve. The actvitiy is reduced both depending on too low and too high water contents. At saturation, a fixed degree of the optimum activity is assumed. In the intermediate range from saturation to the wilting point the acitivity was calculated as:

$$f(\theta) = \min\left(\left(\frac{\theta_s - \theta}{p_{\theta Upp}}\right)^{p_{\theta p}} \left(1 - p_{\theta satact}\right) + p_{\theta satact}, \left(\frac{\theta - \theta_{wilt}}{p_{\theta Low}}\right)^{p_{\theta p}}\right) \tag{10}$$

where $p_{\theta Upp}$, $p_{\theta Low}$ and $p_{\theta p}$ are parameters and the variables, θ_s,θ_{wilt} and θ are the soil moisture content at saturation, at the wilting point and at the actual soil moisture content respectively.

6.2.5 Physical processes and feed back

The simulations of soil temperature, soil moisture conditions and the soil water flows were based on the physical equations. The most important interaction between the carbon turnover and the physical conditions is governed by the leaf area index and the ratio between actual and potential transpiration. Both will in turn influence the input of carbon to the system and both are strongly related to the temperature and the moisture.

The leaf area index is simply estimated directly in proportional to the simulated amount of biomass of the leaf compartment. The leaf area will in turn determine both the amount of radiation that will be adsorbed for possible carbon assimilation, the potential canopy resistance and the amount of net radiation that will be available for estimation the potential transpiration.

Transpiration is defined as a potential rate when neither soil water deficits nor low soil temperatures influence the water loss. The potential transpiration, E_{tp}, is calculated from Penman's combination equation in the form given by /Monteith, 1965/:

$$L_\upsilon E_{tp} = \frac{\Delta R_n + \rho_a c_p \dfrac{(e_s - e)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)} \tag{11}$$

where R_n is net radiation available for transpiration, e_s is the vapour pressure at saturation, e is the actual vapour pressure, ρ_a is air density, c_p is the specific heat of air at constant pressure, L_v is the latent heat of vaporisation, Δ is the slope of saturated vapour pressure versus temperature curve, γ is the psychrometer "constant", r_s is an "effective" surface resistance and r_a is the aerodynamic resistance.

The actual transpiration is given as:

$$E_{ta} = E_{ta}^{*} + f_{umov} \cdot (E_{tp}^{*} - E_{ta}^{*}) \tag{12}$$

where f_{umov} is the degree of compensation, E_{ta}^{*} is the uptake without any account for compensatory uptake and E_{tp}^{*} is the potential transpiration with eventual reduction due to interception evaporation. The compensatory uptake is distributed to the layers where no water stress occurs and in accordance with the relative fraction of the roots in these layers. In a first step the E_{ta}^{*} is calculated as the result of possible stresses at each depth and finally integrated as:

$$E_{ta}^{*} = E_{tp}^{*} \int_{z_r}^{0} f_\psi(z) f_T(z) r(z) \tag{13}$$

where *r(z)* is the relative root density distribution, z_r is root depth and f_ψ, and f_T are response functions for soil water potential and soil temperature. These functions were used according to previously defined default values for the model.

6.3 Parameterisation of the model for the Forsmark area

In general data was assumed from the work by /Jansson et al. 2002/, representing typical forest sites in Sweden. Some site specific considerations for the Forsmark area is described below.

Driving data

Climate data to run the model were taken from a time series using data from Uppsala using the years (1960–1999). These data were used because of their high quality and completeness with respect to all driving variables (air temperature, air humidity, wind speed, cloudiness and precipitation).

Soil data

No complete information of water retention curves from Forsmark was available so a similar soil was selected from Norunda that is about 40 km SW from the area (Figure 6-5)

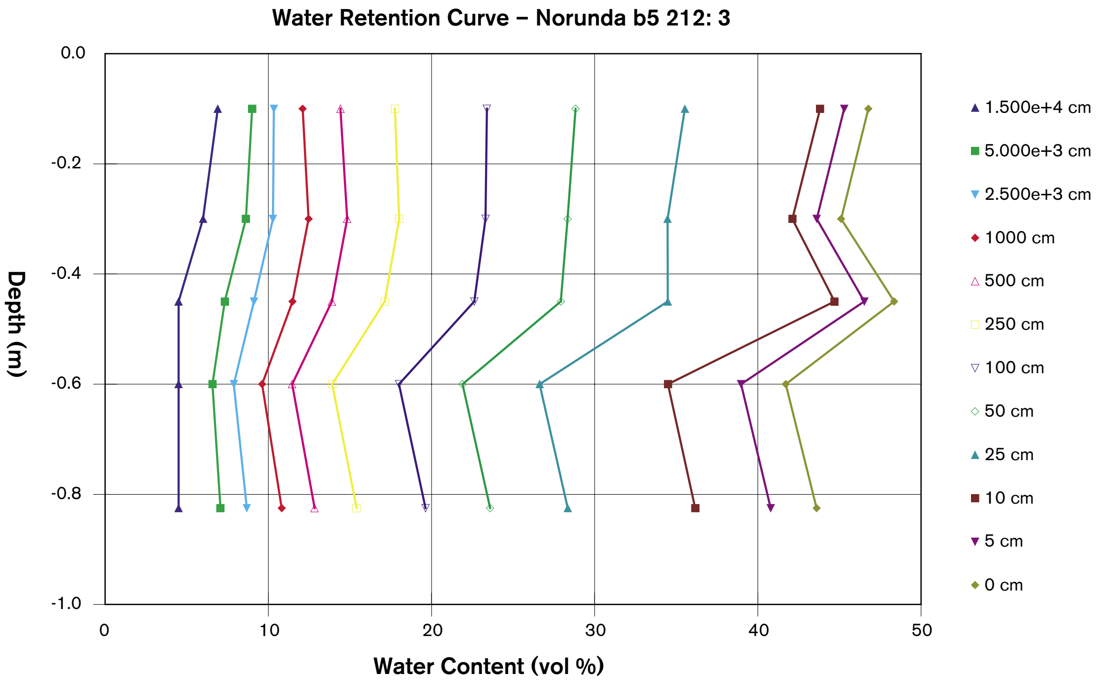


Figure 6-5. *Water retention for a till soil used in model.*

Vegetation data

The growth and development of the stand was assumed to follow the dynamics that recently have been estimated for another site, Knottåsen within the LUSTRA project, located some 100 km NW from the Forsmark area.

6.4 Results

The results represent a first possible description of the water and carbon balance for a forest ecosystem during a 80-year-period in the Forsmark area. The water balance is demonstrated during a selected sub-period of 9 years from which the typical seasonal patterns for runoff and evapotranspiration is identified (Figure 6-6). Corresponding variation for the ground water variation (Figure 6-7) was assumed reasonable.

The carbon budget during a normal rotation time for forests in the area demonstrates a system close to steady state with respect to the total carbon pool (Figure 6-8).

The initial conditions in the simulation represented a 40-year old stand according to data available from the area where clear cutting with harvest was done in the middle of the simulation period. The soil organic pools showed a rapid increase after the clear cutting because of residues left on the ground and litter input from the root system. However, a substantial part of the litter was decomposed after 10 year following clear cutting and instead a slow steady increase of the humus pool was initiated.

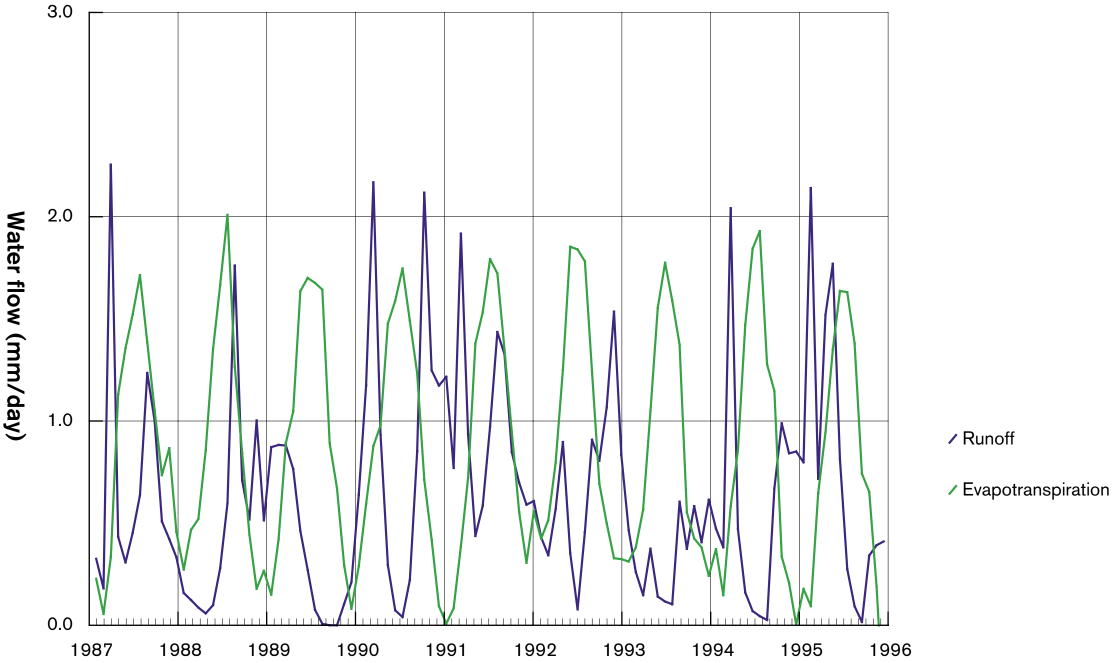


Figure 6-6. Simulated runoff and evapotranspiration as monthly mean values during a selected 9 year period.

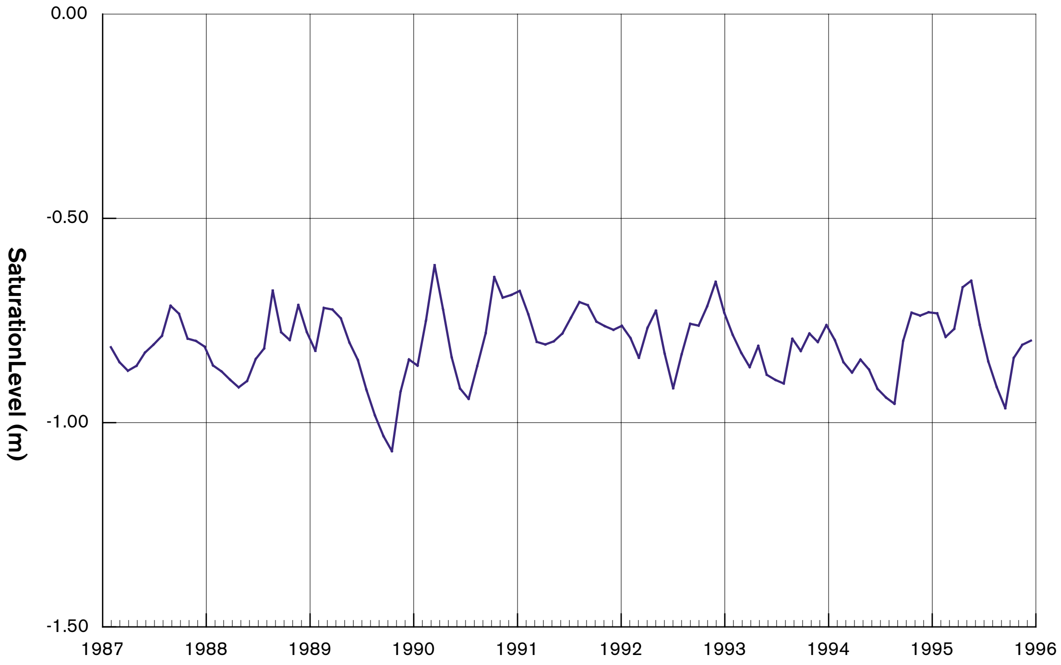


***Figure 6-7.** Simulated ground water levels during the same selected 9 year period as in Figure 6-6.*

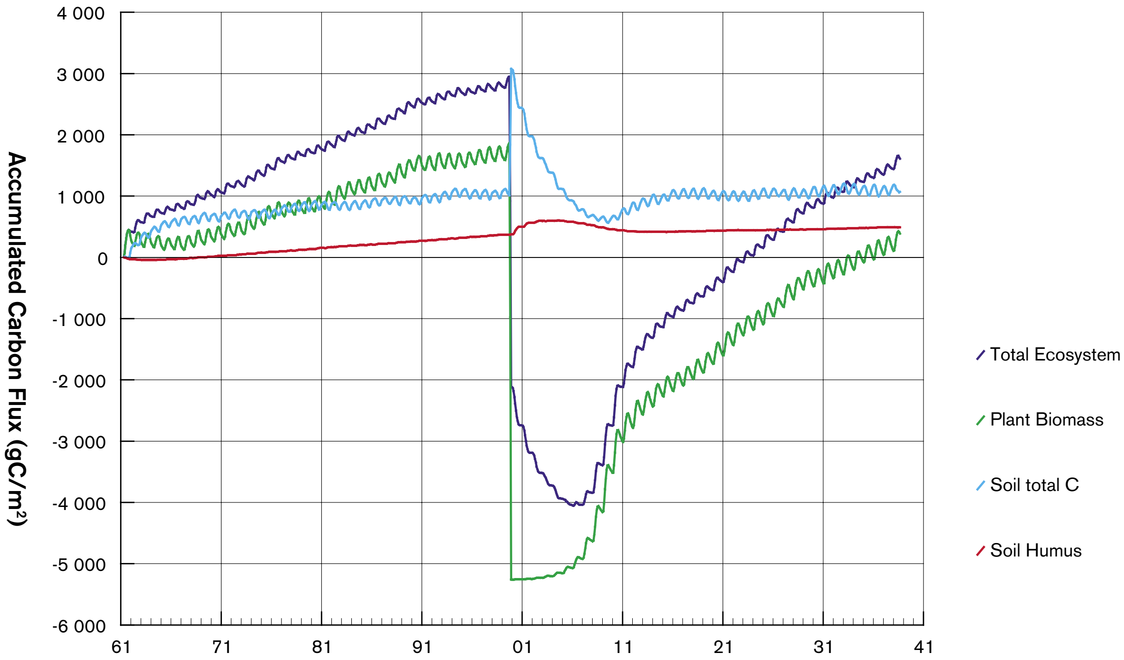


***Figure 6-8.** The simulated change of Carbon plant and soil during an 80 year period.*

6.5 Conclusions

The water and carbon simulations made during the workshop represent a test of possible model use and not a precise method to represent the Forsmark area. The work was made partly as a group work, which initiated many discussions on both specific information from the area and on general aspects of using ecosystem related models. It would be valuable to make sure that the model could represent the present conditions within the area with respect to forest stands, soil texture, groundwater conditions and hydrology. We were not successful to make the model to work with multiple canopies and more advanced dynamics of competition between tree canopy and forest understorey.

The hydrological parts of the model could be improved by using more site specific data on meteorological data, soil physical data and actual ground water measurements. However, we believe that it would be of highest interest to test the water balance components of evapotranspiration using eddy flux techniques. The major advantage is the larger areal representation and the high temporal resolution compared to conventional runoff data and ground water levels. Such eddy flux data should also include the total ecosystem flux of carbon for the ecosystem. The carbon flux is the other main interest for understanding the dynamics of the forest. It should be possible to make use of data available on carbon storage in the soil and in the biomass. Moreover, Eddy flux data may be useful to quantify the decomposition of organic material and the connection between the decomposition and the hydrological conditions.

6.6 Tensit implementation of lake model

At the workshop at Marholmen the lake model from /Karlsson et al. 2001/ was implemented. This was done as an exercise using Tensit, a newly developed simulation tool /Jones et al. 2004/. Since this model is already well documented and not of primary interest at this stage its details including parameters, equations and results are not presented here. The most important to point out is that we now are using our new tool in practice. A short introduction of its benefits follows below.

The Tensit tool can handle transport and decay of radio nuclides and is capable of both deterministic and probabilistic simulations. A major benefit is that it provides a standard for how simulations are setup and particularly easy to connect different ecosystems. This makes the model more easily overviewed, and in the end also more reliable than if all models would use their own standard.

Tensit utilises and connects two separate commercial softwares. The equation solving capability and model building is derived from the Matlab/Simulink software environment to which Tensit adds a library of interconnectable building blocks. Probabilistic simulations are currently provided through probabilistic software (@Risk) that communicates with Matlab/Simulink.

6.7 Description of the model TERRA

A radioecological model for terrestrial biotopes, TERRA, was developed during the workshop as a first approximation of a model based on site specific data. The model describes the upward transport of radionuclides from groundwater leading to their accumulation in soil and the transfer to vegetation and animals. TERRA is structured to handle any kind of terrestrial biotope, such as forested areas, grassland and agricultural fields. However, the parameter values in this specific case were chosen as representative of forests of the study area.

6.7.1 Conceptual model

The TERRA conceptual model is shown schematically in Figure 6-9. The uptake of radionuclides by vegetation from soil is modeled with a function of the vegetation growth using soil-to-plant concentration ratios as described in /Garten, 1999/. The transport of radionuclides from the groundwater layer to the topsoil is modeled with the same compartment model that was used in SR 97 /Bergström et al. 1999/ to model the upward transport of radionuclides in agricultural lands. The characteristics of the regolith in the region were used to define the geometry of the compartments. A direct transfer of radionuclides from groundwater to tree woods and leafs was also considered to account for the uptake of radionuclides with transpired water. It was assumed that all water consumed by trees (water demand) comes directly from the saturated zone. At the same time, the pool of radionuclides taken up from the soil includes also radionuclides that are taken up with water. Hence, in some circumstances the above assumptions may lead to overestimation of the total uptake of radionuclides by trees and the subsequent accumulation of radionuclides in the top soil.

The growth of vegetation was described using average growth rates for the studied area. To estimate activity concentrations in the vegetation average biomass values recorded in the area were used. For the moment, the model considers an average tree during the whole simulation period. Losses from the system due to tree cutting were neglected.

The transfer of radionuclides to wild herbivores (herbivorous mammals) was described with an allometric relationship between the concentration of radionuclides in the animal diet and the animal body derived using a kinetic-allometric approach /FASSET, 2003/.

6.7.2 Mathematical formulation

The model is formulated as a system of ordinary differential equations corresponding to each of the compartments represented in Figure 6-9. Below we present the equations used to represent the transfer between different compartments. The model was implemented in Simulink using the Tensit library /Jones et al. 2004/.

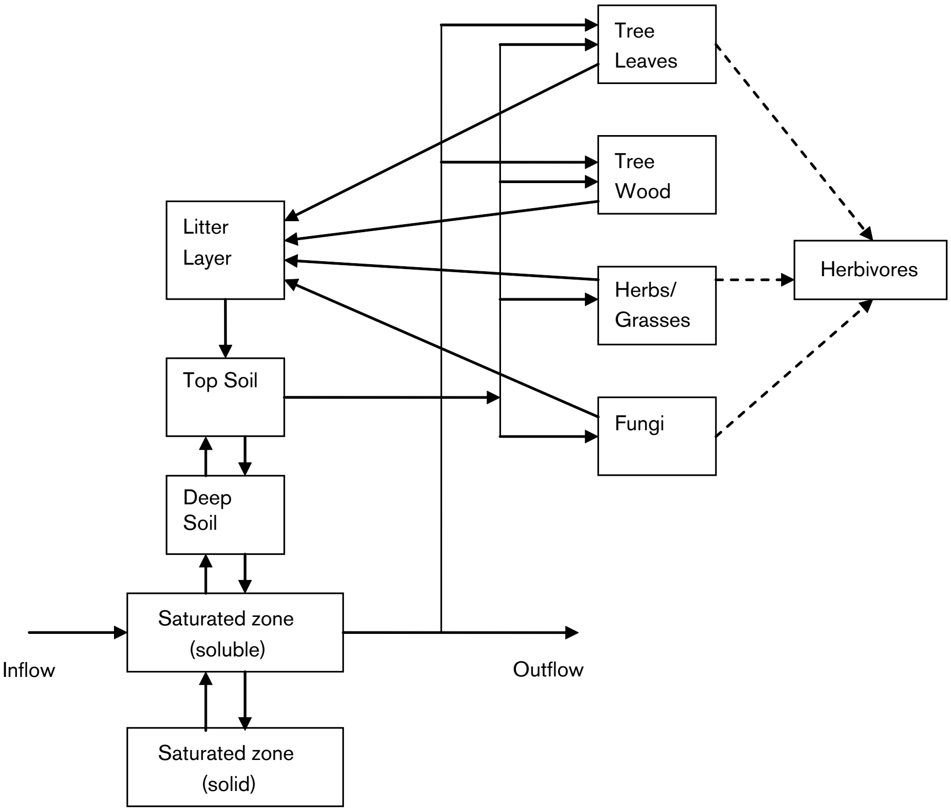


Figure 6-9. *Schematic representation of the TERRA conceptual model. The boxes correspond to compartments and the filled arrows to fluxes between compartments. Dotted arrows indicate that equilibrium between the connected compartments is assumed.*

Vertical and horizontal transport of radionuclides

The same equations as for agricultural land module in /Bergström et al. 1999/ were used to describe the vertical and horizontal transport of radionuclides in soil and are therefore not presented here.

Uptake of radionuclides by vegetation from groundwater

The rate constant in 1/y, transfer coefficient ($TC_{water,wood}$ and $TC_{water,leaves}$), of radionuclides from the ground water to the vegetation was calculated with equation (1).

$$TC_{water,wood} = \frac{WDem_{tree} * F_{wood}}{Depth_{water}}$$

$$TC_{water,leaves} = \frac{WDem_{tree} * F_{leaves}}{Depth_{water}} \qquad (14)$$

where,

$WDem_{tree}$ is the tree water demand [$m^3/m^2/y$],
F_{wood} is the fraction of radionuclides taken up with water that is transferred to the tree wood [unitless],
F_{leaves} is the fraction of radionuclides taken up with water that is transferred to the tree leaves [unitless],
$Depth_{water}$ is the depth of the groundwater table [m].

The model currently does not address explicitly the transfer of radionuclides to the roots with water followed by translocation to leaves and wood. These processes will be considered explicitly in future versions of the model.

Uptake of radionuclides by vegetation from the top soil

The transfer of radionuclides from the top soil to vegetation was assumed proportional to the yearly biomass production and the concentration of the radionuclide in the newly produced biomass. The corresponding transfer coefficients ($TC_{soil,herbs}$, $TC_{soil,\ fungi}$, $TC_{soil,\ wood}$, $TC_{soil,\ leaves}$) in 1/y are represented with equation (2).

$$TC_{soil,vegetation} = \frac{VP * CR_{soil,vegetation}}{\rho_{topsoil} * H_{topsoil}} \qquad (15)$$

where,

VP is the yearly production of vegetation, i.e. tree wood (WP), tree leaves (LP), herbs/grasses (HP) and fungi (FP) [kg/m^2/y],
$CR_{soil,vegetation}$ is the concentration ratio of the radionuclide from soil to different kinds of vegetation [unitless],
$\rho_{topsoil}$ is the bulk density of the top soil [kg/m^3],
$H_{topsoil}$ is the top soil thickness [m].

Transfer of radionuclides from vegetation to the litter layer

The model assumes that the radionuclides are transferred from the vegetation to the litter layer together with the biomass that falls to the ground. The transfer rate is obtained by multiplying the current inventory in vegetation with a parameter corresponding to the yearly fractional loss from vegetation expressed in 1/y. Releases to litter due to weathering processes were neglected.

Transfer from the litter layer to the top soil

The transfer of radionuclides from the litter layer to the top soil, as a consequence of litter decomposition, was accounted for by multiplying the current inventory in litter with a parameter corresponding to the yearly fractional loss from vegetation expressed in 1/y.

Calculation of concentration in herbivores

The activity concentration in the herbivore mammal expressed in Bq/kg wet weight was calculated by multiplying the concentration of radionuclides in the animal diet by a concentration ratio, which was derived using a kinetic model in combination with known allometric relationships /FASSET, 2003/:

$$C_{Herbivore} = (\sum_{i} C_{veg,i} * F_{diet,i}) * a * W^{b} * f_{gut} \qquad (16)$$

where,

$C_{veg,i}$ is the concentration of radionuclides in different types of vegetation eaten by the herbivore [Bq/kg dry weight],
$F_{diet,i}$ is the fraction of the i-th vegetation type in the diet of the herbivore [unitless],
a is the multiplication constant in the allometric (weight dependent) relationship for the concentration ratio between the concentration in the diet of the animal and in the animal body [the value includes appropriate unit conversions],

b is the exponent in the allometric relationship for the concentration ratio between the animal diet and the animal body [unitless],
f_{gut} is the fractional gut uptake of the radionuclide for the herbivore [unitless],
W is the weight of the herbivore [kg fresh weight].

6.7.3 Parameter values

Vertical and horizontal transport of radionuclides

The parameter values used in the equations describing the vertical and horizontal transport of radionuclides are shown in Table 6-2. The depth of the top soil (the layer where most active roots are located) was assumed to vary between 0.4 and 0.5 m. The depth of the deep soil (soil layer from the root zone to the groundwater table) was estimated to vary between 0 and 0.7 m with a mean value of 0.4 m by subtracting the assumed depth of the top soil from the distance from the soil surface to the groundwater table (height of the groundwater table) obtained from field data. The minimum value of the height of the groundwater table (0.9 m) was estimated from measurements in boreholes drilled in April and the maximum value (1.6 m) from measurements in boreholes drilled in August. An annual average based on these calculations of 1.3 m was used. The depth of the groundwater table was obtained by subtracting the total soil depth from the height of the groundwater table.

Runoff was obtained from estimations (see calculation of discharge in each cell in a rasterized Eckarfjärden catchments) of the specific runoff in the area (6.5 10^{-3} $m^3/km^2/s$). Data on soil porosity was obtained as follows: texture composition of about 40 soil profiles in combination with a rough classification of the soil were compared to similar soils for which data are available in the database of the CoupModel. The outcome of that investigation lead to a set of values for different soil-types and depths. Based on these values an average value of 0.45 was assumed as best estimate for the two soil layers and a value of 0.25 for the saturated zone.

Table 6-2. Values of parameters used in equations describing the vertical and horizontal transport of the radionuclides.

Parameter	Mean	Min	Max
Runoff ($m^3/m^2/y$) [RUNOFF]	0.2	0.1	0.3
Saturated zone depth (m) [DEPTHSAT]	4	1	16
Deep soil depth (m) [DEPTHDS]	0.4	0	0.7
Saturated zone porosity (–) [POROSITYSAT]	0.25		
Top soil depth (m) [DEPTHTS]	0.5	0.4	0.5

The water flow from saturated zone to deep soil and the distribution coefficients (Table 6-3) reported in SR 97 were used. It was considered that erosion in forests is very low and therefore this process was neglected. As the rate of bioturbation for the study area was not available and knowing that bioturbation is lower in forests than in agricultural lands, the values were assumed equal to 1/10 of the ones used in SR 97.

Table 6-3. Distribution coefficient (m^3/kg) between liquid and solid phase used for different radionuclides

	Cl36	Tc99	Np237	I129	Ni59	Cs135	Pu239	Ra226
BE	1.00E–03	5.00E–03	1.00E–01	3.00E–01	5.00E–01	1.00E+00	5.00E+00	5.00E–01
Min	1.00E–04	1.00E–03	1.00E–02	1.00E–01	5.00E–02	1.00E–01	1.00E–01	1.00E–02
Max	1.00E–02	1.00E–02	1.00E+00	1.00E+00	5.00E+00	1.00E+01	1.00E+01	1.00E+00

Uptake of radionuclides by vegetation from groundwater

The water demand of trees ($WDem_{tree}$) was assumed equal to 169.7 m^3/m^2/y. Further, it was assumed that equal fractions (50%) are transferred to the tree wood and leaves. The depth of the groundwater table (saturated zone) presented in Table 1 was used.

Uptake of radionuclides by vegetation from the top soil

The biomass and production rates of wood, leaves, litter, herbs/grasses and fungi shown in Table 3 were used to obtain the corresponding TC and to calculate activity concentrations. The values were obtained from the currently developed vegetation model /Preliminary Site Description SKB R-04-15/ by dividing total biomasses by the total area of the drainage region. All these values are based on calculations using the forested area (6,789,168 m^2) which is a smaller area than the total drainage area (7,827,490 m^2).

Table 6-4. Biomass and annual production of vegetation (dry weight) values from /Preliminary Site Description SKB R-04-15/ together with information retrieved from /Skogssverige, 2004/ that the pins (here categorized under leaves) of an average Swedish spruce weigh approximately 5% of its total biomass.

Parameter	Value
Leaves production (kg dw/m^2/y)	0.08
Leaves biomass (kg/m^2)	0.5
Wood production (kg/m^2/y)	0.18
Wood Biomass (kg dw/m^2)	5.1
Herbs/grasses production (kg/m^2/y)	1.54
Herbs/grasses biomass (kg/m^2)	0.92
Fungi production (kg/m^2/y)	0.01
Fungi biomass (kg/m^2)	0.01

The bulk density of the top soil was estimated by multiplying the soil density (assumed equal to 2,400 kg/m^3) by the soil porosity (Table 6-2). The values used for the soil to plant concentration ratios are shown in Table 6-5. For herbs and tree leaves values compiled by /Karlsson et al. 2001/ for pasture were used. The same values, but divided by 10, were used for tree wood. For fungi values compiled by /Avila, in preparation/ were used.

Table 6-5. Soil-to-plant concentration ratios used for different types of vegetation.

Vegetation		Cl36	Tc99	Np237	I129	Ni59	Cs135	Pu239	Ra226
Leaves	BE	3.00E+01	8.00E+00	7.00E–02	6.00E–01	2.00E–01	2.00E–01	4.00E–04	8.00E–02
	Min	1.00E+01	8.00E–01	7.00E–03	6.00E–02	2.00E–02	2.00E–02	5.00E–05	2.00E–02
	Max	1.00E+02	8.00E+01	7.00E–01	6.00E+00	2.00E+00	2.00E+00	7.00E–01	4.00E–01
Wood	BE	3.00E+00	8.00E–01	7.00E–03	6.00E–02	2.00E–02	2.00E–02	4.00E–05	8.00E–03
	Min	1.00E+00	8.00E–02	7.00E–04	6.00E–03	2.00E–03	2.00E–03	5.00E–06	2.00E–03
	Max	1.00E+01	8.00E+00	7.00E–02	6.00E–01	2.00E–01	2.00E–01	7.00E–02	4.00E–02
Herbs	BE	3.00E+01	8.00E+00	7.00E–02	6.00E–01	2.00E–01	2.00E–01	4.00E–04	8.00E–02
	Min	1.00E+01	8.00E–01	7.00E–03	6.00E–02	2.00E–02	2.00E–02	5.00E–05	2.00E–02
	Max	1.00E+02	8.00E+01	7.00E–01	6.00E+00	2.00E+00	2.00E+00	7.00E–01	4.00E–01
Fungi	BE	3.00E+01	8.00E+00	5.00E–03	6.00E–01	1.30E–01	1.00E+00	5.00E–03	3.00E–02
	Min	1.00E+01	8.00E–01	2.00E–03	6.00E–02	1.00E–01	3.00E–01	2.00E–03	1.00E–02
	Max	1.00E+02	8.00E+01	1.00E–02	6.00E+00	1.70E–01	1.60E+01	1.00E–02	5.00E–02

Transfer of radionuclides from vegetation to the litter layer

The yearly fractional loss from herbs and fungi was set equal to 1, i.e. a total biomass loss to the litter layer was assumed. The fractional loss from leaves was estimated equal to 0.25 per year. This value was obtained by assuming that for deciduous trees all leaves fall each year, while needles have a turnover rate of about 5 years. As coniferous forests are dominating in the area (92%), a weighted average will be about 0.25 per year. The fractional loss from wood was taken equal to 0.004 per year from /Garten, 1999/.

Transfer from the litter layer to the top soil

The fractional loss from the litter layer to the top soil was assumed equal to 0.16 per year /Garten, 1999/.

Parameters needed for calculation of concentration in herbivores

The weight of the considered herbivore, in this case moose, was estimated from observed slaughter weights in the study area, which are 146 and 161 for female and male respectively /Cederlund et al. 2003/. A ratio of 0.55 between total slaughter and living weight was assumed. Hence, assuming that the same number of males and females are slaughtered, an average living weight of 270 kg is obtained. The animal diet was assumed to consist of 80% herbs, 15% of tree leaves and 5% of fungi. These are approximate values observed in summer-autumn seasons in middle Sweden /Avila, 1998/.

The values of the fractional gut uptake (Table 6-6) reported in /FASSET, 2003/ were used. For the parameters of the allometric relationship (a and b) values reported in /Avila, in preparation/ were adopted.

Table 6-6. Radionuclide dependent parameters used in the calculation of the radionuclide concentration in herbivores.

Parameter	Cl36	Tc99	Np237	I129	Ni59	Cs135	Pu239	Ra226
f_{gut}	1	0.1	0.001	1	0.05	1	0.0005	0.2
a	0.207	0.42	19.6	1.45	22	1.15	19.6	14.5
b	0.0113	0.16	0.136	–0.11	0.11	0	0.136	0.08

6.7.4 Results of test simulation with the model

The model was simulated for 10^6 years for the case of a continuous unit input of 1 Bq/year to the groundwater compartment (saturated zone water) using the parameter values presented above. Doses to man via ingestion of moose at the rate 2 kg/y were calculated using dose conversion factors from SR 97. The results show (Figure 6-10) that the doses to man, expressed in Sv/y per Bq/y, level out with time for all studied radionuclides. Equilibrium is however obtained at different times for the different radionuclides. Some radionuclides, like Ra226 and I129, need a very long time to reach equilibrium, and therefore they require a more detailed consideration regarding effects of environmental changes.

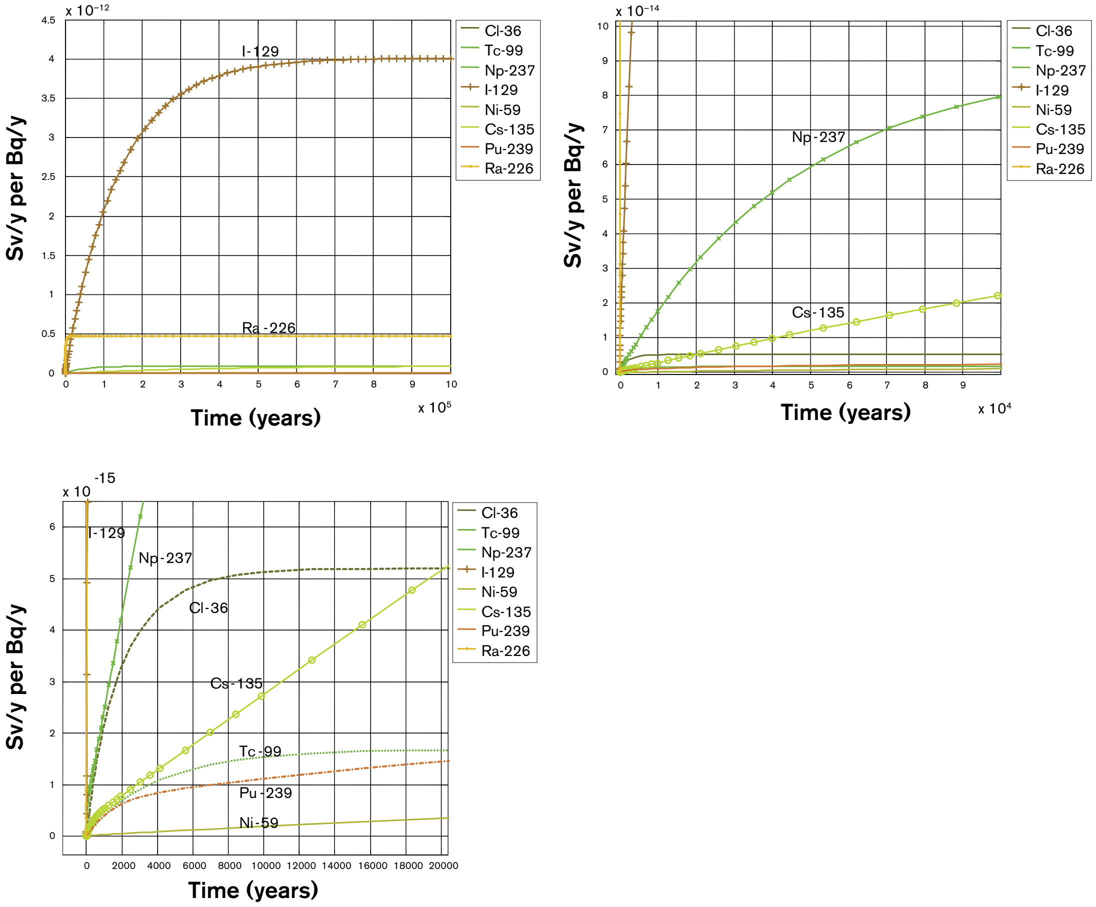


Figure 6-10. *Dose rates (in Sv/year per 1 Bq/y) obtained for the studied radionuclides from a test simulation with the TERRA model. Values are shown at three different time intervals in order to clearly show the dynamics for all simulated nuclides.*

6.7.5 Discussion

Site specific data was difficult to obtain for many of the parameters used in this version of the TERRA model. For some of these parameters we used preliminary values taken from the literature and for some it was only possible to make a guess. Hence, the results presented here should be seen only as a preliminary estimation made to test the functioning of the model and to illustrate possible outcomes.

It should be noted that the model TERRA is still in an early stage of development and that the objective in this workshop was to illuminate to what extend the data being collected during the site investigation program could be of use for the model. Hence, the focus was put on covering as much as possible the transfer processes going on in the system, although using in some cases a very simplified representation. The next step in the development will be to refine the representation of the transfer processes and in particular those describing the vertical redistribution of the radionuclides in the system.

For some of the parameters used in the current version of the model TERRA it will be difficult to obtain data. This concerns mainly radionuclide dependent parameters, such as the soil-to-plant concentration ratios, which encompass several processes and are therefore highly variable and at the same time difficult to assign heuristically a value, even if this was a conservative one. A possible strategy to solve this problem would be to use the approach used by /Kumblad et al. 2003 and 2004/ for aquatic environments, and being developed within the EC project BORIS /Avila et al. 2001/ for terrestrial environments. This method will be adopted in TERRA for disaggregating some of the radionuclide dependent parameters as functions of the carbon, water and nutrient fluxes in the system. It is foreseen that a more detailed conceptual structure of the model will be required to properly implement the above mentioned approaches.

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