Working Report 2010-36

Site and Regional Data for Biosphere Assessment BSA-2009

Supplement to Olkiluoto Biosphere Description 2009

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June 2010

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ABSTRACT

The safety case for a spent nuclear fuel repository at Olkiluoto includes a computational safety assessment. A site-specific biosphere assessment is an integral part of them both. In 2009 an assessment was conducted to demonstrate preparedness to apply for construction license to the repository in 2012. As a part of the biosphere assessment, the present conditions at the site are described in Olkiluoto biosphere description report for an analogue of the future conditions being simulated in the safety assessment. This report is a supplement to the biosphere description report of 2009 and documents the site and regional data used in the biosphere assessment "BSA-2009" with respective rationales.

Keywords: biosphere, safety assessment, parameter values.

Paikka- ja seutukohtaiset lähtötiedot biosfääriarviointiin BSA-2009; liite Olkiluodon biosfäärikuvaukseen 2009

TIIVISTELMÄ

Käytetyn ydinpolttoaineen loppusijoitus Olkiluodon kallioperään edellyttää turvallisuusperustelua, joka sisältää laskennallisen turvallisuusanalyysin. Paikkakohtainen biosfääriarviointi on olennainen osa kumpaakin. Vuonna 2009 koottiin turvallisuusperustelu osoittamaan valmiustaso jättää rakentamislupahakemus vuonna 2012. Osana biosfääriarviointia loppusijoituspaikan nykytilanne kuvataan Olkiluodon biosfäärin kuvaus -raportissa, ja se toimii analogiana turvallisuusanalyysissä simuloitaville tulevaisuuden olosuhteille. Tämä raportti on liite Olkiluodon biosfäärin kuvaus 2009 -raporttiin ja se dokumentoi biosfääriarvoinnissa "BSA-2009" käytetyt paikka- ja seutukohtaiset mallinnuksen lähtötiedot.

Avainsanat: biosfääri, turvallisuusanalyysi, parametriarvot.

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ABBREVIATIONS

BSA .... Biosphere assessment as entirety either regarding reporting or the assessment process (Fig. 1-4). Specifically, BSA-2009 refers to the biosphere assessment of 2009 (Hjerpe et al. 2010; Haapanen et al. 2009a, Helin et al. 2010, Ikonen et al. 2010, Karvonen 2009c, Hjerpe & Broed 2010).

BSD .... Biosphere description either as the process of analysing and integrating the site and regional data to the description of the present properties and transport processes of the site. Specifically, BSD-2006 refers to the report of (Haapanen et al. 2007) and BSD-2009 to the parent report of the one at hand (Haapanen et al. 2009a).

CR...................... Concentration ratio; concentration in e.g. part of a plant divided by the respective concentration in soil (or in a specific soil layer).

DTM .... Digital terrain model (of topography and bathygraphy).

FEH.................... A sampling plot, the FEH network is a sub-set of the FET grid.

FET .... Forest extensive-level monitoring plot, a basic unit of a systematic 100 x 100 m² environmental monitoring grid at Olkiluoto (App. D).

FIP .... Forest intensive(-level) monitoring plot, a part of the environmental monitoring network at Olkiluoto (App. D).

GIS..................... Geographical information system.

GM..................... Geometric mean.

GSD .... Geometric standard deviation.

Kd .... Solid/liquid distribution coefficient (partition coefficient, K_d) in soil, sediment or suspended matter of a water body.

LAI .... Leaf area index; half of the total green leaf area (i.e. one-sided area of broadleaves) in the plant canopy per unit ground area.

MAI .... Mean annual increment (of stem wood); stand volume divided by the stand age at a given time. In this report, usually based on 50- or 100-year rotation times (hardwood and other stands, respectively).

N .... Number of observations (data).

TESM .... Terrain and ecosystems development modelling as the process and in some occasions as the report. Specifically TESM-2009 refers to the effort and reporting within BSA-2009 (Ikonen et al. 2010), and TESM-2006 to the model version of 2006 (Ikonen 2007b).

STD.................... Standard deviation.

UNTAMO.......... A GIS toolbox customised for Posiva for terrain and ecosystems development modelling.

PREFACE

This has been compiled by experts from different organisations commissioned by Posiva Oy. On behalf of Posiva, the study has been supervised by Jani Helin and Ari T. K. Ikonen, who also edited the final version of the report. The following experts were primarily responsible for providing the data:

- Ari Ikonen (Posiva), project management and final editing;
- Lasse Aro (Finnish Forest Research Institute), forests and mires;
- Reija Haapanen (Haapanen Forest Consulting), editing of the Biosphere description report from which a lot of material was used here, data and literature review on reed colonies;
- Jani Helin (Posiva), maps, present housing data;
- Thomas Hjerpe (Saanio & Riekkola Oy): introduction, description of radionuclide transport and dose assessment modelling;
- Teija Kirkkala (Pyhäjärvi Institute), data on aquatic ecosystems;
- Sari Koivunen (Water and Environment Research of South-West Finland), monitoring data on aquatic ecosystems;
- Anne-Maj Lahdenperä (Pöyry Environment Oy), overburden data and geological expertise;
- Liisa Puhakka (Haapanen Forest Consulting), main data on birds and terrestrial fauna, life histories of typical terrestrial and avian fauna;
- Tapio Salo (Agrifood Research Finland), data on agriculture.

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- Tuomo Karvonen (WaterHope), description of surface and near-surface hydrological modelling and data;
- Merja Lusa and Mervi Söderlund (University of Helsinki, Laboratory of Radiochemistry), compilation of Kd database from the literature and the data from the on-going sorption study on Olkiluoto soils;
- Teea Penttinen (Pöyry Environment Oy), compilation of groundwater table data from Olkiluoto;
- Marketta Rinne, Jouni Nousiainen, Miia Kuisma and Eeva Lehtonen (Agrifood Research Finland), participation in collection of data on agriculture in Biosphere description 2009;
- Kristofer Stenberg (Facilia AB), fitting probability density functions to the housing data in section 3.3.8.

Several other experts have reviewed and provided useful comments on the report, and a number of experts have contributed to the data presented in the Biosphere description (Haapanen et al. 2009a) and further used here. The final draft of the report was reviewed by Steve Sheppard (ECOMatters Inc.), and parts included already in the Biosphere description (Haapanen et al. 2009a) also by Mike Thorne (Mike Thorne and Associates Ltd.) and Graham Smith (GMS Abington Ltd.). The authors wish to thank all who have contributed to reviewing and commenting on the report.

The following licences, permits or copyright arrangements apply to the figures in this report, in addition to those specifically mentioned in figure captions:

- Base maps: topographic database by the National Land Survey of Finland, permission 41/MML/09,
- Corine Land Cover 2000: Finnish Environment Institute. When producing this satellite image interpretation-based data, auxiliary data sources by the following organisations have been used: Finnish Environment Institute, National Land Survey, Ministry of Agriculture and Forestry/TIKE, Population Register Centre, Forest and Park Service and UPM Kymmene Oyj,
- Photograph of Hannu Vallas, Lentokuva Vallas Oy (Figure 1-2).

Unless otherwise mentioned, the maps are shown in the Finnish National Coordinate System, Zone 1 (KKJ1). The projection is Gauss-Krüger. The coordinate numbers (in metres) refer to this system.

1 INTRODUCTION

Posiva Oy (Posiva) is responsible for implementing a repository programme for spent nuclear fuel from the Finnish nuclear power reactors currently in operation and under construction. The spent nuclear fuel is planned to be disposed of in a deep repository to be constructed at a depth of between 400 and 600 metres in the crystalline bedrock at the Olkiluoto site. The Finnish Parliament ratified in 2001 the Government's favourable Decision in Principle on Posiva's application to locate a repository at Olkiluoto. This decision represents the milestone prior to entering the phase of confirming site characterisation.

Following the guidelines set forth by the Ministry of Trade and Industry (now the Ministry of Employment and Economy), Posiva is preparing for the next step of the nuclear licensing of the repository, which involves submitting the construction licence application for a spent fuel repository by the end of 2012.

1.1 Olkiluoto site

Olkiluoto is a large island (currently approximately 12 km^2), on the coast of the Baltic Sea, separated from the mainland by a narrow strait (Figures 1-1 and 1-2). The Olkiluoto nuclear power plant, with two reactors in operation, and a repository for low- and intermediate-level waste are located on the western part of the island. The construction of a new reactor unit (OL3) is underway at the site. The repository for spent fuel will be constructed in the central-eastern parts of the island after the construction licence procedures for a nuclear facility have been completed. The construction of an underground rock characterisation facility, called ONKALO, started in June 2004.

The site is located in an area of significant continuing postglacial land uplift (currently approximately 6–6.8 mm/y; Eronen et al. 1995, Kahma et al. 2001, Löfman 1999). This leads to new land areas continuously emerging. The effects of this process are accentuated by a rather flat topography and anthropogenic eutrophication of the Baltic Sea, which increases primary production, and consequently accumulation of organic matter especially in shallow bays. Common reed (*Phragmites australis*) is a key organism in this process, producing detritus, decreasing water flows and increasing silting. In the archipelago area south-southwest of Olkiluoto, relatively early emergence of smaller-scale lake and river systems is expected. Another important factor for the development of the landscape is a large river (Eurajoki), which has its outlet northeast of the island. It is expected that this river will flow north of the planned repository in the future. This will significantly affect the mass balances within the region arising from erosion and sedimentation processes.

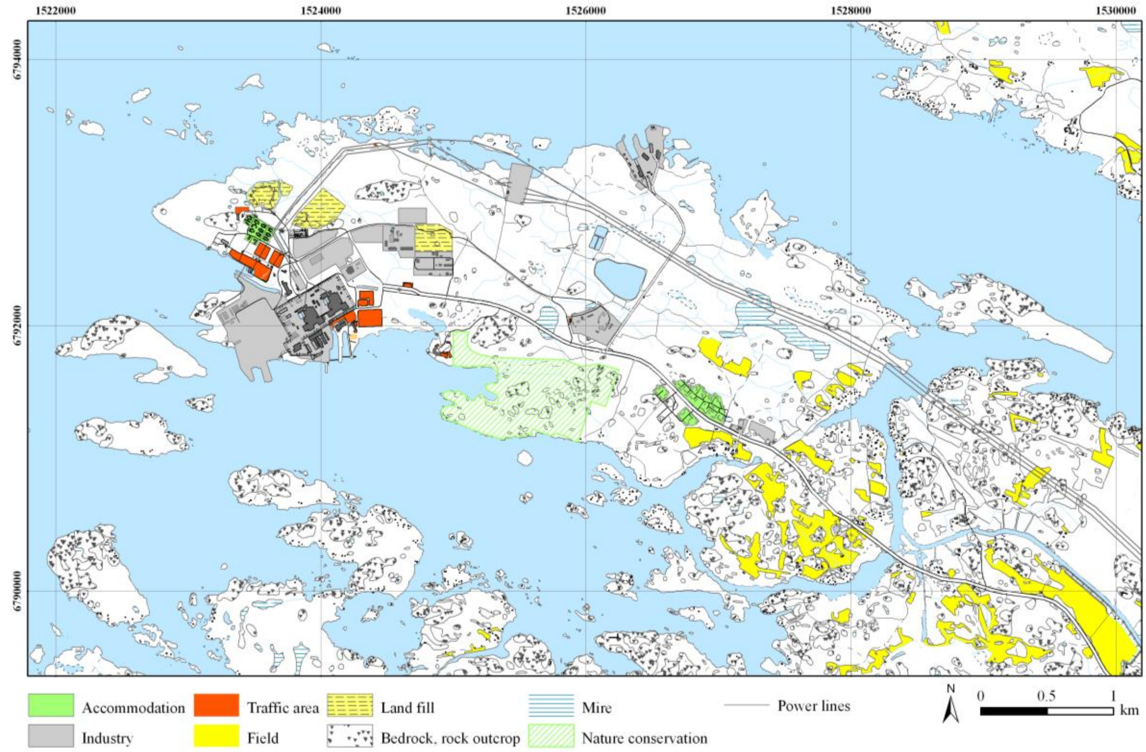

Figure 1-1. *An overview map of Olkiluoto. Topographic database by the National Land Survey of Finland, map layout by Jani Helin, Posiva Oy.*

Figure 1-2. *Olkiluoto Island and neighbouring mainland areas from the air on August 6, 2007 Photograph by Hannu Vallas, Lentokuva Vallas Oy.*

1.2 Safety case and biosphere assessment

Posiva is currently producing a safety case to support the construction licence application for a deep geological repository for spent nuclear fuel at the Olkiluoto site. A safety case is a synthesis of evidence, analyses and arguments that quantify and substantiate the safety, and the level of expert confidence in the safety, of a geological disposal facility for radioactive waste (IAEA 2006, NEA 2004). Posiva's plan for the safety case was initially prepared in 2004 (Vieno & Ikonen 2005), and has recently been revised (Posiva 2008). The first planning report introduced the Posiva Safety Case Portfolio as the documentation management approach, facilitating flexible and progressive development of the safety case; this approach is further developed in the present safety case plan.

1.2.1 Principles of the safety case

A safety case includes a quantitative safety assessment, which is defined as the process of systematically analysing the ability of the disposal facility to provide the safety functions and to meet technical requirements, and to evaluate the potential radiological hazards and compliance with the safety requirements.

The safety case broadens the scope of the safety assessment to include the compilation of a wide range of evidence and arguments that complement and support the reliability of the results of the quantitative analyses and demonstrate compliance with regulatory requirements. In concrete terms, a safety case includes all material presented by the repository implementer to the authorities and to other stakeholders in support of an application to site, construct, operate or close a disposal facility. The safety case is a key input to decision-making at several steps in the repository planning and implementation process. It becomes more comprehensive and rigorous as the programme progresses.

1.2.2 Safety case portfolio

Posiva’s safety case will be developed according to the plan published in 2008 (Posiva 2008), which updates the earlier plan published in 2005 (Vieno & Ikonen 2005). The safety case will be documented in a report portfolio (Figure 1-3). The Safety Case Report Portfolio is structured as follows.

The *Safety Case Plan 2008* located at the highest level refers to the report describing the plan (Posiva 2008). The *Description of the disposal system report* summarises the information on the waste form, the engineered barrier system and the Olkiluoto site. More detailed descriptions are given in technical and scientific reports on various components of the disposal system, including the site descriptive model of Olkiluoto and the description of biosphere conditions. Background analyses related to future climatic conditions will also be performed and reported. The features, events and processes (FEPs) affecting the evolution of the repository are described in the *Process report*. The evolution of the repository and the scenarios for analysis in the safety assessment are described in the *Formulation of scenarios report*. The most significant assumptions, models and data used in the safety case are documented in the *Models and*

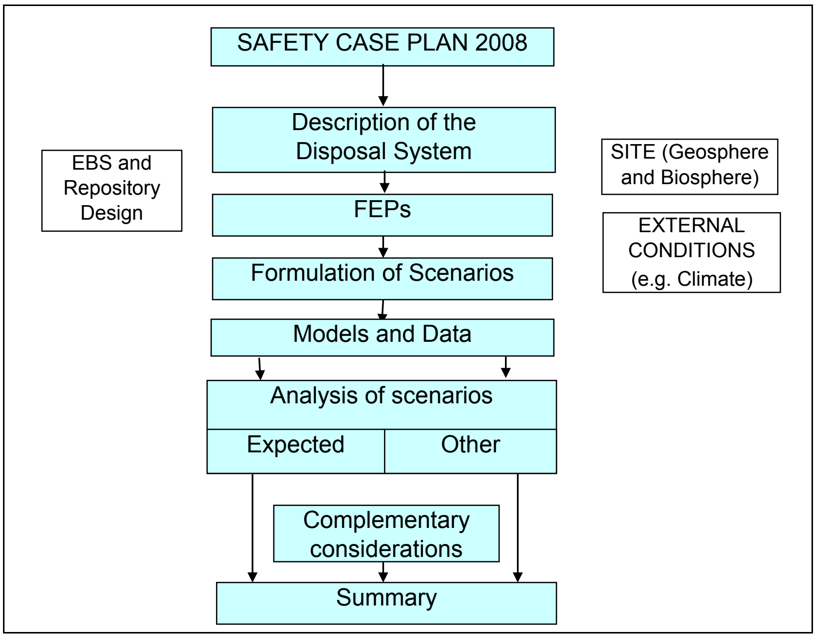

***Figure 1-3.** Main reports of the safety case portfolio (in blue) and the main input from supporting technical and scientific activities (in white), as presented in (Posiva 2008).*

data report. This serves as the main link between the safety case and the Olkiluoto site investigations and biosphere descriptions as well as between the safety case and the engineered barrier system (EBS) design and development. The quantitative assessment of the radiological consequences of scenarios leading to radionuclide releases is presented in the *Analysis of scenarios report*. The *Complementary considerations report* is carried over from the earlier *Safety Case Plan 2005* (Vieno & Ikonen 2005), where it was called the Complementary evaluations report. This provides additional evidence and arguments for long-term safety to promote confidence in the arguments, models and data used in, and results derived from, the quantitative safety assessment. Finally, the whole safety case, including the main results, will be described in a *Summary report*. This report will provide the main input to the Preliminary safety analysis report (PSAR) needed for the application for a repository construction licence.

The production of the safety case is divided into four main sub-processes. The *Conceptualisation & methodology sub-process* defines the framework for the assessment. The *Data handling and modelling sub-process* creates the main links between the safety case, the engineering design and planning of implementation processes, and the site characterisation process. The *Assessment sub-process* produces the Olkiluoto- and design-specific descriptions of the evolution of the disposal system in various scenarios, classified either as part of the expected evolution or as disruptive scenarios and analyses their potential consequences. The *Compliance & confidence sub-process* is responsible for the final evaluation of compliance of the assessment results with the regulatory criteria and for overall confidence in the safety case.

A vital component when producing the safety case is the biosphere assessment (BSA). In the present safety case plan (Posiva 2008), the biosphere assessment portfolio (as presented in Ikonen 2006) has been fully integrated into the main safety case portfolio and the safety case main sub-processes. However, the BSA component is retained for practical reasons, and will be compiled on the basis of several modelling and other reports documenting the assessment in detail (see Section 1.2.4).

1.2.3 Regulatory requirements and guidance for biosphere assessment

The basic regulatory requirements for the long-term safety of a geological repository in Finland are set out in the Government Decree on the safety of disposal of nuclear waste (GD 736/2008) and, in more detail, in the Radiation and Nuclear Safety Authority's (STUK) Guide YVL E.5 on disposal of nuclear waste. Guide YVL E.5 is expected to be issued in 2010 by the Finnish regulator and will supersede the earlier YVL 8.4 issued in 2001 (STUK 2001). GD 736/2008 and Guide YVL E.5 cover all aspects of the disposal of nuclear waste, including spent nuclear fuel. These aspects include radiation protection during the operation of the disposal facility and long-term safety. In an appendix to YVL E-5, guidance on regulatory expectations on the safety case will be provided. Guide YVL E.5 is quoted throughout the present document, based on an unofficial English translation of draft version 3 (STUK 2009).

The GD 736/2008 sets the criteria for the time window to be addressed in the biosphere assessment and the criteria for protection of humans within this time window:

"In any assessment period, during which the radiation exposure of humans can be assessed with sufficient reliability, and which shall extend at a minimum over several millennia:

1) *the annual dose[1] to the most exposed people shall remain below the value of 0.1 mSv, and*
2) *the average annual doses to other people shall remain insignificantly low.*"

After that period, the quantitative regulatory requirements are based on constraints on the activity release of long-lived radionuclides from the geosphere into the biosphere (YVL E.5). Consequently, the licence applicant does not have to present quantitative dose assessments for the period beyond which "the radiation exposure of humans can be assessed with sufficient reliability"; this period shall commence earliest after several millennia. However, biosphere features, events and processes (FEPs) may influence the assessed releases from the geosphere to the biosphere during the whole time frame.

The Guide YVL E.5 (STUK 2009) identifies the potential exposure environments and pathways to be considered. The dose assessment in general may assume that types of climate, human habits, nutritional needs, and metabolism remains unchanged, but needs to take account of reasonably predictable environmental changes, i.e. at least such as those that "arise from changes in ground level in relation to sea". At least the following exposure pathways shall be considered:

- Use of contaminated water as household water, as irrigation water and for watering animals
- Use of contaminated natural or agricultural products originating from terrestrial and aquatic environments

[1] *Annual dose* refers to the sum of the effective dose arising from external radiation within the period of one year, and the committed effective dose from the intake of radioactive substances within the same period of time (GD 736/2008). In this report "dose" refers

Based on these assumptions, the most exposed individuals are assumed to live in a self-sustaining family or small village community in the environs of the disposal site, where the highest radiation exposure arises via various pathways. In the living environment of this community, a small lake and shallow water well are assumed to exist. Larger groups of people for whom average doses are estimated are assumed to live at a regional lake or at a coastal site and are exposed to the radioactive substances transported into these watercourses. For the larger groups, no fixed dose constraint is set, but the acceptability of the doses depends on the number of exposed people, and they shall not exceed values from one hundredth to one tenth of the constraint for the most exposed individuals (STUK 2009).

The Guide YVL E.5 does not give any quantitative criteria for the protection of other living species. However, it is stating that:

"Disposal shall not affect detrimentally to species of flora and fauna, this shall be demonstrated by assessing typical radiation exposures of terrestrial and aquatic populations in the disposal site environments."

Present kinds of living populations may be assumed. No quantitative dose or exposure constraints are given for other living species. To demonstrate compliance with the regulatory criteria, the licence applicant shall assess the exposures and demonstrate that they are clearly below the levels which, on the basis of best available scientific knowledge, would cause decline in biodiversity or other significant detriment to any living population. In the compliance assessment in the current assessment, Posiva is comparing calculated typical dose rates to the screening values recommended by the PROTECT[2] project.

Furthermore, the Guide YVL E.5 provides guidance on regulatory expectations on the safety case. Here it is stated that a safety case shall include a description of the disposal system, including the natural environment at the disposal site.

1.2.4 Biosphere assessment

The overall aims of the biosphere assessment in the safety case are to describe the present, future and relevant past conditions at, and prevailing processes in, the surface systems of the Olkiluoto site, model the transport and fate of radionuclides hypothetically released from the repository through the geosphere to the surface environment, and assess possible radiological consequences to humans and other biota. From the view of assessing the dynamics of the biosphere in the given time window, there are two distinct periods:

1. Changes in the biosphere before the potential releases from the repository occur; this is in the time scale of millennia. During this period, the needed level of detail is that of relevance to determining possible environmental

[2] The EU EURATOM funded PROTECT project (FI6R-036425) is evaluating the different approaches to protection of the environment from ionising radiation and comparing these with the approaches used for non-radioactive contaminants. This will provide a scientific justification on which to propose numerical targets or standards for protection of the environment from ionising radiation.

conditions at the time the releases get into and are within the biosphere system.

2. Changes in the biosphere from the beginning of the releases until the end of the biosphere assessment time window; here the dynamics is relevant to the element cycling in the present-day environment. However, applying the information of the researchable environment of the present, it must be taken into account that the conditions may have changed during the period prior the releases arrived to the biosphere. According to the regulatory guidance, we can assume that the present-day conditions are still valid, except the consequences of the post-glacial land uplift.

Performing biosphere assessment can conceptually be described as a process (described in Figure 1-4). The biosphere assessment process can be divided into five main sub-processes, or components, briefly described as follows:

1. Conducting environmental studies and monitoring, and the compilation of a description of the present properties and on-going processes at the Olkiluoto site; this is the main activity in the *Biosphere description* process.
2. The description of the present conditions of the surface systems forms the basis for predicting the evolution of the topography, overburden, hydrology, flora and fauna at the site within the climate condition envelope provided in the scenario definitions by the overall safety case. This is called forecasting, is carried out by terrain and ecosystems development modelling (TESM) and is the main task in the *Terrain and ecosystems development* process.
3. Based on the forecasts, continuous and sufficiently homogeneous[3] segments of the modelled area, possibly receiving any radionuclides released from the repository, are identified (these are called *biosphere objects*). Each biosphere object is described by one ecosystem type and one set of data, and is associated with one radionuclide transport model. Connecting the biosphere objects, and also defining an adequately simplified release pattern based on the groundwater flow simulations, results in the landscape model. The landscape model is a site-specific state-of-the-art coupled time-dependent radionuclide transport model. Building the landscape model is the main task of the *Landscape model set-up* process, and involves both *forecasting* (of the connections in the landscape model) and *transport modelling* activities.
4. In the *Radionuclide transport modelling* process, resulting release rates of radionuclides to the biosphere from the geosphere modelling are assessed. A graded three-tiered approach will be applied. Tier 1 and 2 involve conducting generic evaluations to screen out radionuclides that have insignificant radiological consequences, using two levels of inherent pessimism, and Tier 3 is based on the landscape model. The main task of this process is to produce time-dependent radionuclide-specific spatial activity distributions in all biosphere objects.

[3] The homogeneity requires that within the segment, the variation in properties may not affect significantly to the parameter values of the respective object(s) in the radionuclide transport modelling and in the radionuclide consequence analysis, and that, on the other hand, the size is within the margins in which the inherently heterogeneous distribution of radionuclide concentration within the object becomes insignificant in the dose calculations as the exposure by an individual averages over these variations in the cause of the exposure (e.g. the size of a forest object is sufficient to produce only the annual food demand of about one person; to gain the maximal ingestion dose from edibles in a forest object, an individual must gather food all around the object, as is on the other hand required by the pessimism rules of the dose assessment).

5. The resulting activity concentrations from the radionuclide transport modelling constitute the basis for assessing potential radiological consequences to humans and other biota. Assessing these consequences and putting them into the context of regulatory requirements are the main tasks in the *Radionuclide consequence analysis* process.

The work performed within the BSA components (Figure 1-4) will contribute to the safety case, often to more than one of the main safety case reports (Figure 1-3). To illustrate the relationship between the BSA and the safety case, Table 1.1 indicates where the five major components of the BSA significantly contribute to the main safety case reports.

The biosphere assessment also contains other important features, complementary to the main components described above.

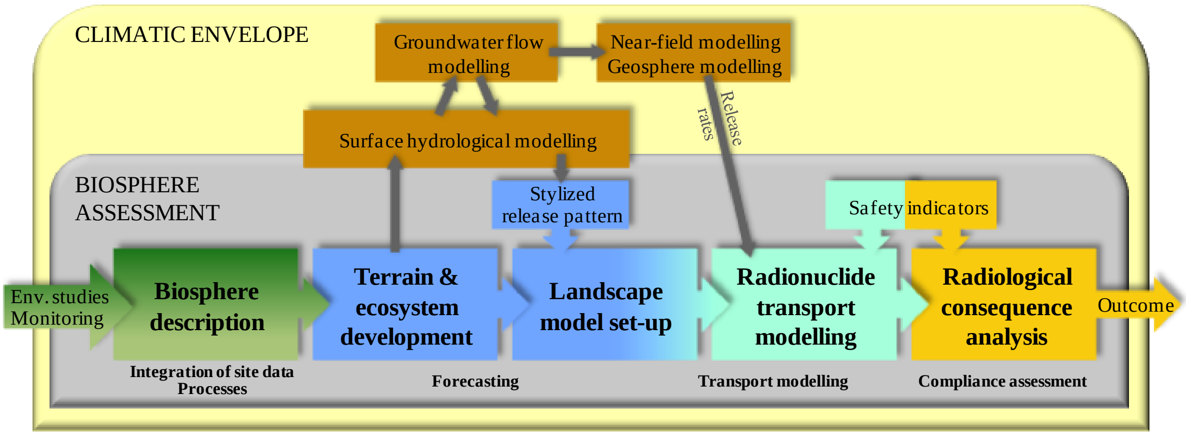

Figure 1-4. *Stylised illustration of the Biosphere assessment process. The five major components are marked in bold; the main activities (bold text under the components) are indicated by colours in the components. Selected key inputs and links are also included, especially regarding hydrological modelling.*

Table 1-1. *Main contributions from the five major components of the biosphere assessment to the main reports in the safety case.*

BSA component[(1)] / Safety case main report	BSD	TESM	LSM Set-up	RNT Modelling	RCA
Description of the disposal system	X				
Features, events and processes (FEP)	X				X
Formulation of scenarios		X			
Models and data	X	X	X	X	X
Analysis of scenarios		X	X	X	X
Complementary considerations				X	
Summary	X	X	X	X	X

[(1)] BSD (biosphere description), TESM (terrain and ecosystem development), LSM (landscape model), RNT (radionuclide transport) and RCA (radiological consequence analysis)

Biosphere calculation cases

Each component in Figure 1-4 contains sources of uncertainties. In order to assess the impact of main uncertainties, a set of biosphere calculation cases will be derived. The cases will be categorised according to variants of exposure pathways, based on identifying main uncertainties in the *forecasting* and *transport modelling* activities (Figure 1-4). Future human activities can be included or not in the build-up of exposure pathways. On top of this, uncertainties in selected parameter values in the radionuclide transport models will be explored. The propagation of uncertainties through the biosphere assessment is discussed also in the thematic considerations of Chapter 14.

Safety indicators

In addition to quantities of direct use in the compliance assessment, the biosphere assessment produces results relevant to building understanding of, and confidence in, the outcome of the analysis. These are called safety indicators and complementary safety indicators. Safety indicators have the main role of supporting the quantitative compliance assessment, and complementary safety indicators have the main role of increasing the confidence that the understanding of the behaviour of the biosphere is adequate.

Two safety indicators are derived, based on indicative stylised well scenarios: one for a drinking water well and one for an agricultural well. The drinking water well is similar to the applied well scenario in previous safety assessments (Vieno 1994, 1997, Vieno & Nordman 1996, 1999, Broed et. al 2007, Nykyri et al. 2008). The agricultural well is extended to also include watering cattle and irrigation of crops, and has earlier only been used in (Broed et al. 2007).

Other complementary safety indicators are also calculated, such as activity inventories, retained fractions and environmental activity concentrations for chronic releases.

Reporting the biosphere assessment

The Biosphere Assessment Portfolio was introduced in the Safety case planning report (Vieno & Ikonen 2005), and revised in Ikonen (2006). As discussed above, the biosphere assessment is now conceptually fully integrated into the safety case, but the biosphere assessment component has been retained for practical reasons. This means that the reporting of the biosphere assessment will continue to mainly follow the Biosphere Assessment Portfolio in Ikonen (2006), with a few modifications due to new features in the overall Safety Case Portfolio (Posiva 2008). The biosphere assessment in 2009 will produce four main reports, and several supporting reports, briefly described as follows:

Biosphere description report (BSD-2009). The BSD-2009 report documents the up-to-date scientific synthesis of the current state of the surface environment and the main features of the past evolution at the site. Furthermore, it provides conceptual ecosystem models and assessment data to support the subsequent biosphere assessment process components. The BSD-2009 (Haapanen et al. 2009a) is an update of Olkiluoto

Biosphere description report 2006 (Haapanen et al. 2007), and will be further updated in 2011.

Terrain and ecosystem development model report (TESM-2009). The TESM-2009 provides the up-to-date scientific synthesis of the expected evolution of the surface systems over the period for which the dose-based constraints apply. The TESM-2009 (Ikonen et al. 2009) is an update of TESM-2006 (Ikonen 2007b), and will be further updated in 2011.

Radionuclide transport and dose modelling in biosphere assessment in 2009. This report documents the conceptual and mathematical models and key data used in landscape modelling, radionuclide transport modelling, and radiological consequence analysis. The report also provides the basis for understanding the behaviour of the landscape model, by calculating results for stylized releases, such as chronic and pulse releases, into the biosphere. Key supporting reports are detailed model and modelling tools reports, such as Avila & Pröhl (2007), Avila & Bergström (2006) and Åstrand et al. (2005). This report (Hjerpe & Broed 2010) is an update, and extension, of the similar report of Broed (2007b), and will be further updated in 2012.

Biosphere assessment summary report (BSA-2009). This report presents the biosphere calculation cases and applies them to the relevant geosphere release rates from the RNT-2008 report (Nykyri et al. 2008). Furthermore, the fate of the hypothetically released radionuclides and the radiological consequences to humans and other biota are discussed. In addition, the BSA-2009 report summarises the three above-mentioned main biosphere assessment reports. The BSA-2009 report (Hjerpe et al. 2010) is an update, and extension, of the similar report of Broed et al. (2007), and will be further updated in 2012.

Biosphere assessment regarding operational safety and environmental impacts

The biosphere assessment considers mainly the so-called long-term safety, i.e., the performance of the repository and fate of possible releases from the emplaced disposal canisters in the time frame from the emplacement of the first canister to several millennia. However, the same characterisation activities, data and understanding of the ecosystems are useful also in the considerations of environmental impacts of the entire disposal programme and the so-called operational safety, i.e. radiological safety of the staff and public during the nuclear waste transport, encapsulation and final emplacement. These aspects, however, are not explicitly considered in this report but are left to the more appropriate context.

1.2.5 Ecosystems characterisation strategy

Ecosystems characterisation is an iterative process aiming to achieve an adequate site understanding, in order to evaluate the appropriateness of different models and of preliminary data to the site, and subsequently to provide data of sufficient scope and quality to underpin the safety case development. Due to the iterative nature of the safety case, not all needs can be known beforehand but they emerge also on the changes in the relative impact of the uncertainties both in the data and in the understanding of the system being analysed. At Olkiluoto, both the nuclear power plant and construction work within the repository programme also necessitate environmental monitoring that produces significant amounts of data, but due to different aims and purposes of these studies, not all these data can be fully used in the ecosystems characterisation, and even to a smaller degree in the assessment modelling.

Ideally, a totally exhaustive characterisation of the properties and processes of the ecosystems could be taken as the aim. However, with limited resources that can never be achieved, neither is it necessary to achieve to present a sufficient safety case. The extent of the ecosystem characterisation efforts needs to be in reasonable relation to the overall repository programme, the significance to the safety of the spent fuel disposal and the regulatory requirements. In practice, this means continuous improvement at a moderate level (i.e., reasonable in the context of overall repository programme) in ecosystems characterisation and other biosphere considerations, focusing on key issues that have significant safety relevance. Identification of key issues is not a straightforward task, but an iterative process, preferably done with feedback from the regulator and other stakeholders.

For gaining a basic understanding of the ecosystems and long-term transport processes usually relatively inexpensive survey methods provide a good basis. However, in the current stage of the repository programme, preparing for the construction licence application, the need for site-specific assessment data is pronounced. The main remaining data gaps are associated mostly with expensive and difficult methods of acquiring the site data, directly or indirectly (experiments, analogues). For successful planning of such campaigns, good site understanding is vital. Since the models will change conceptually based on new knowledge gained from the site, the data requirements will also change from time to time. Also, regulatory requirements and external data (such as dose factors) may change and cause change in priorities. Thus limiting the site work only to the essential would not be very long-sighted. Consequently, the planning and targeting of key issues is done for a few years at a time, and the scheduling of the most expensive work at the optimal stage of the repository programme is important in order to keep the costs at a reasonable level. In addition, in order for the ecosystems characterisation to contribute significant improvement in the subsequent assessment modelling, the data needs to be delivered well in time for the assessment.

The approach to ecosystems characterisation is, from the beginning, to target the studies on phenomena (processes) and factors that most affect the outcome from assessment models; the most important source of guidance in this targeting is the results from the uncertainty and sensitivity analyses of the radionuclide transport models included in the landscape model. This approach also means that the outcome from previous assessments, especially the radiological consequence analysis, provides guidance as to which radionuclides are most relevant for long-term safety; thus guiding the ecosystems characterisation regarding which elements and radionuclides to focus on in order to best improve the accuracy of, and confidence in, the outcome of the biosphere assessment. In practice, this biosphere description is based on the needs of modelling as improved based on the previous Biosphere description report, and the bulk of the new understanding gained during the present process can be digested into the subsequent models only after the 2009 assessment – although some of it has been already been conveyed to the most recent model development activities.

With the Olkiluoto site, there is the additional challenge of post-glacial land uplift continuously changing the landscape and conditions. Due to the ecologically very long time window for quantitative biosphere assessment, all the ecosystems characterisation has to be considered in the context of development from a coastal into an inland site. Given the land uplift development and the flat topography, terrestrial ecosystems play a significant role in the biosphere assessment and need to be characterised. Currently, mires, active agricultural areas and lakes are lacking from the site, and a larger Reference Area (Fig. 1-6) is needed to find suitable analogues for potential future conditions at the site. This work has been recently started through collating literature information, as summarised in this report on its part. Similarly, during the overall characterisation little data has been acquired in some key nuclides and their chemical analogues – the programme is currently shifting focus from the general characterisation to these assessment-driven key issues. In the interim, information from other programmes of similar sites (especially Forsmark in Sweden) or literature will be utilised. The issue of using site and generic data is discussed also as a thematic consideration in the concluding Chapter of this report.

1.3 This report

In order to demonstrate compliance with the regulatory long-term radiation protection requirements, as well as the suitability of the disposal method and site, the safety analysis shall include (STUK 2009):

- Description of the disposal system
- Functional description of the disposal system by means of conceptual and mathematical modelling and the determination of the input data needed in these models
- Analysis of the potential future evolutions of the disposal system
- Analysis of resulting doses radionuclides that enter to the biosphere

The Biosphere description report (Haapanen et al. 2009a), which is one of the main reports in the 2009 biosphere assessment, is an important document for the above-mentioned items to be included in the safety analysis. The Biosphere description report provides the description, also functional, of the biosphere component of the disposal site, by means of scientific synthesis of the current state of the surface environments and the main features of the past evolution at the site. It also increases the common understanding of the surface environments at the site.

This report is supplementary to the Biosphere description report (Figure 1-5), since due to the extensiveness of the site and regional data, all of it could not be included in the latter. This report also includes the key data and main features of the models presented in the Biosphere description report to form a comprehensive collection of data. In addition, more detailed data on specific datasets are provided in separate reports for the digital terrain model (Pohjola et al. 2009) and land uplift model (Vuorela et al. 2009).

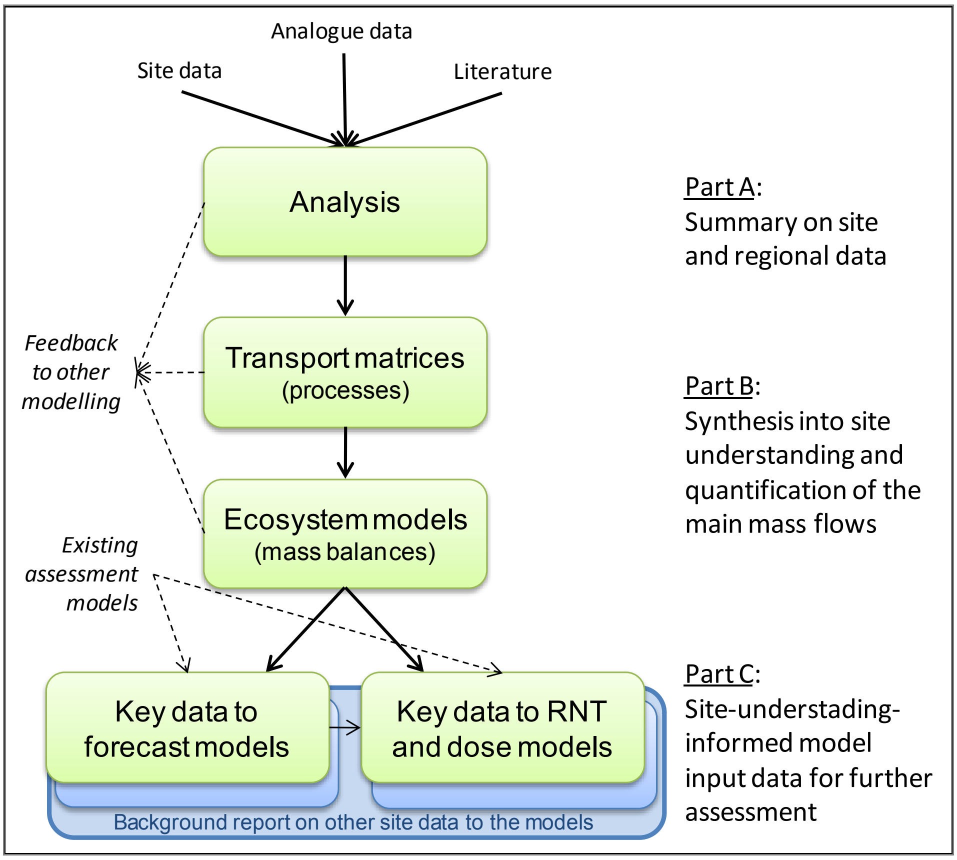

Figure 1-5. *Main structure of the Biosphere description report and the related process within the biosphere assessment. The report at hand is presented by the blue boxes supporting the Part C of the Biosphere description report.*

1.3.1 Model areas

The model area of terrain and ecosystems modelling, and subsequently radionuclide transport modelling, is shown in Fig. 1-8. Monitoring and investigations of terrestrial data have, however, been concentrated on Olkiluoto Island, and more specifically on the central parts the island. Concerning sea areas, there is a similar concentration of efforts on the close offshore of Olkiluoto. However, acoustic-seismic soundings of seabed sediments, as well as water quality measurements, exist from a broader area. Some objects (and data) are described beyond the biosphere model area, namely the rivers Eurajoki and Lapinjoki with their discharge areas, and a set of lakes and mires (Figs. 1-6 and 1-7) selected analogous to those expected to form at Olkiluoto site in the future (Haapanen et al. 2009b). Within the lake and mire project, a larger study area, the so-called Reference area, was delineated on the west coast of Finland (Fig. 1-6), and it is used for regional descriptions in this report. Also, large amount of generic GIS data have been acquired that cover variable range of areas.

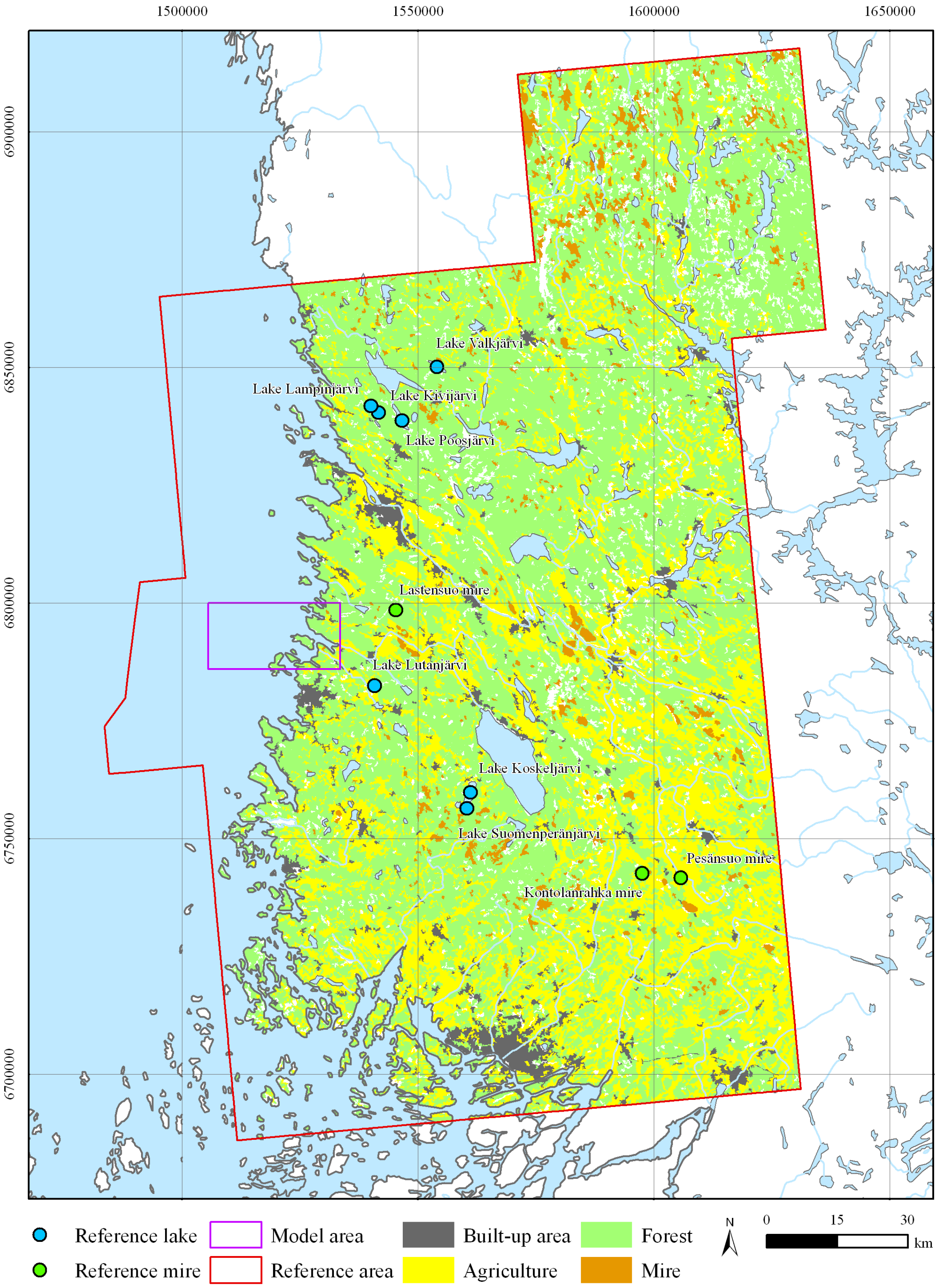

Figure 1-6. *Full Reference Area, with locations of lakes and mires selected as reference objects. CORINE Land Cover 2000 classification by Finnish Environment Institute. Map layout by Jani Helin, Posiva Oy.*

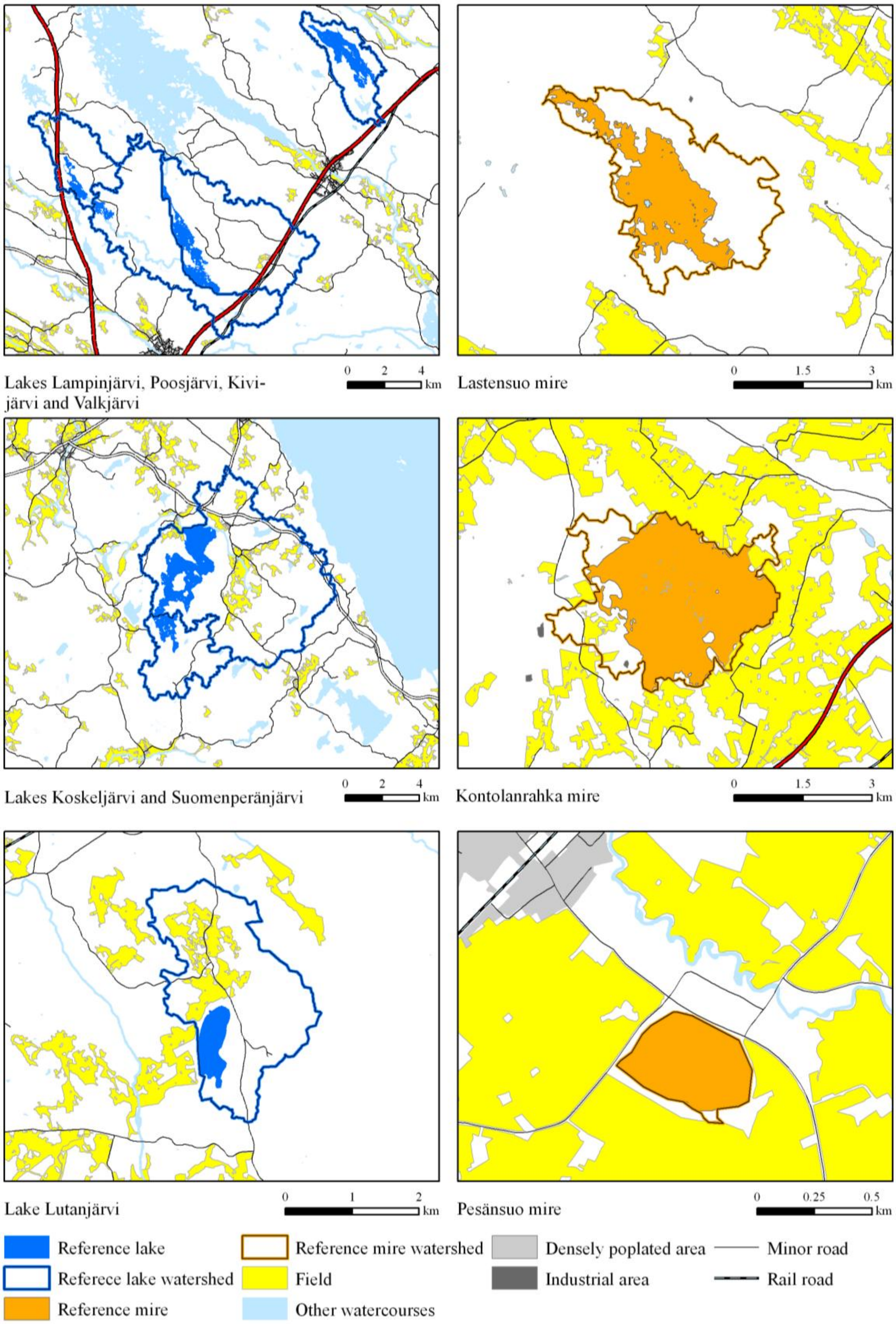

Figure 1-7. *Closer views to the lakes (left) and mires (right) selected as reference objects. Data source: topographic database by the National Land Survey of Finland. Watersheds have been delineated using the database, as well. Map layout by Jani Helin, Posiva Oy.*

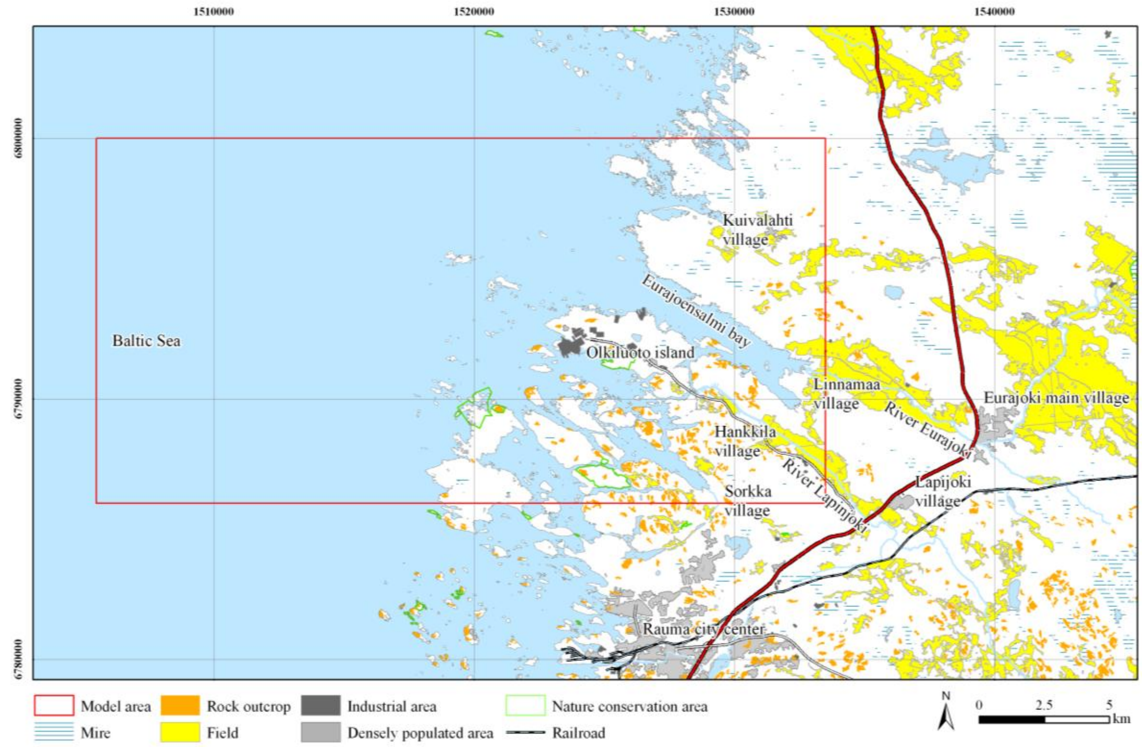

Figure 1-8. *Delineation of the Olkiluoto Biosphere modelling area. Topographic database by the National Land Survey of Finland, map layout by Jani Helin, Posiva Oy.*

2 PURPOSE OF DATA RECOMMENDATIONS

The overall aims of the biosphere assessment in the context of the safety case are to describe the present and future, and relevant past, conditions of and prevailing processes in the surface systems of the Olkiluoto site, to model the transport and fate of radionuclides hypothetically released from the repository through the geosphere to the surface environments, and to assess possible radiological consequences to humans and other biota. From a modelling point of view, the biosphere assessment process (Fig. 1-4 in section 1.2.4) can be divided into five main sub-processes, or components:

- *Biosphere description*, interpreting the data on the current features, processes and properties into ecosystem models (mass balances and fluxes) and providing site data for the rest of the biosphere assessment.
- *Terrain and ecosystems development modelling*, making forecasts of biosphere states in the future (including also the surface and near-surface hydrology).
- *Landscape model configuration process*, interpreting the forecasts and constructing a compartment model for the radionuclide transport modelling.
- *Radionuclide transport modelling*, assessing the transport and fate of radionuclides released from the bedrock to the biosphere with a graded three-tiered approach (see section 5.1.1 below).
- *Dose assessment*, analysing the radiological consequences of the radionuclide releases on humans and other biota based on the concentrations in the environmental media simulated by the radionuclide transport modelling.

There will be an overall modelling and data report for the entire safety case, of which biosphere is one part. Here only the site- and region-specific data are addressed. Even though values are provided here, they might be judged insufficient in evaluations for subsequent modelling phases (i.e. needing to be complemented by other data e.g. from literature). Here the ranking of the parameters by their importance is only tentative, since the initial site-specific database needs to be created, and based on earlier experience.

Even though specific values are provided here, they might need to be complemented by other data, for example, from the literature in order to cover the uncertainties. The final data used in the assessment is up to the respective reports (Hjerpe et al. 2010, Hjerpe & Broed 2010, Ikonen et al. 2010) to identify. For terrain and ecosystems development modelling more data are presented here than was possible to use in the 2009 assessment due to time schedules. However, they are utilised immediately after in the further development and testing of those tools not yet fully employed in assessment use.

2.1 Identification of key data and radionuclides

Following from the maturity of the earlier stages of Posiva's biosphere assessment, the ranking of parameters by their importance can be based only on the experience from recent assessments since the initial site-specific database needs to be created and comprehensive sensitivity and uncertainty analysis undertaken based on these more site relevant data. The identification of the key data here depends on the nature of the modelling:

- *Terrain and ecosystem development modelling and the structuring of the landscape model*: The prime focus is to make this stage as accurate and reliable as possible. The model and data needs are mainly driven by the identification of key processes in conjunction with expert judgment.
- *Radionuclide transport modelling*: A rather equal mix between the best available science, expert judgement and sensitivity assessment performed on the underlying sub-models in previous assessments and exercises. The main approach to identify key data is through sensitivity assessment, where the radionuclide composition of the release from the geosphere in the biosphere has the most central role.
- *Assessment of radiological consequences*: This is to a high degree driven by regulatory requirements and internationally recommended approaches. Selection of key data involves a combination of using internationally recommended data, sensitivity analysis and expert judgment.

The main focus in this report is on the radionuclides assigned top priority in the biosphere assessment: C-14, Cl-36 and I-129 (Table 2-1). The priority grouping of radionuclides is based on their expected relevance for long-term safety using a simple screening evaluation applied on the calculation cases analysed in earlier biosphere analysis of Broed et al. (2007) and the cases to be analysed from the RNT-2008 safety analyses (Nykyri et al. 2008).

The radionuclides are divided into five priority classes. Top priority (I) is given to radionuclides that are expected to dominate the dose in the most realistic calculation cases. High priority (II) radionuclides may contribute significantly, or even dominate the dose, in one or a few calculation cases with lower likelihood. Groups III and IV include radionuclides that may have a significant release from the geosphere for a few calculation cases, but are expected to have a minor contribution to the dose (less than a few percent), and the division between the medium priority and non-immediately handled nuclides is based on their potential to rise into a higher priority class due to improvements regarding knowledge of nuclides in a higher priority class. Low priority (V) nuclides include the rest of the radionuclides in the spent fuel inventory; these are not expected to result in any significant health consequences during the time window of biosphere assessment. However, it is not excluded that some priority V nuclides might need attention in the biosphere assessment in some calculation cases, but with lower expected potential, such as Ra-226, Pa-231, Pu-239 and Am-243.

The screening evaluation will be presented in detail in (Hjerpe & Broed 2010, Hjerpe et al. 2010); a preliminary grouping of radionuclides is presented in Table 2-1.

Table 2-1. *Priority classification of radionuclides, according to safety relevance for long-term safety (priority V nuclides are not included in the table).*

Priority I (top)	Priority II (high)	Priority III (medium)	Priority IV (non-immediate)
C-14 Cl-36 I-129	Mo-93 Nb-93m Nb-94 Cs-135	Ni-59 Se-79 Sr-90 Y-90	Pd-107 Sn-126 Sb-126

3 TERRAIN AND ECOSYSTEMS DEVELOPMENT MODEL

Terrain and ecosystems development is a major sub-process (Fig. 3-1) in the iterative biosphere assessment process. It predicts the development of the surface environments at the site given the climate scenarios envelope of possible conditions. The details of the modelling process and models are documented in the TESM-2009 report (Ikonen et al. 2010), and in several underlying supporting reports, and here only a concise description of the models are given to provide the framework for providing the site and regional data.

In this report more data are presented that was possible to use in the 2009 assessment due to the time schedule. However, they are utilised immediately after in the further development and testing of those tools not yet fully employed in assessment use. The models and data actually used to produce the forecasts used as an input to the subsequent steps in the biosphere assessment are documented in detail in the TESM-2009 report (Ikonen et al. 2010).

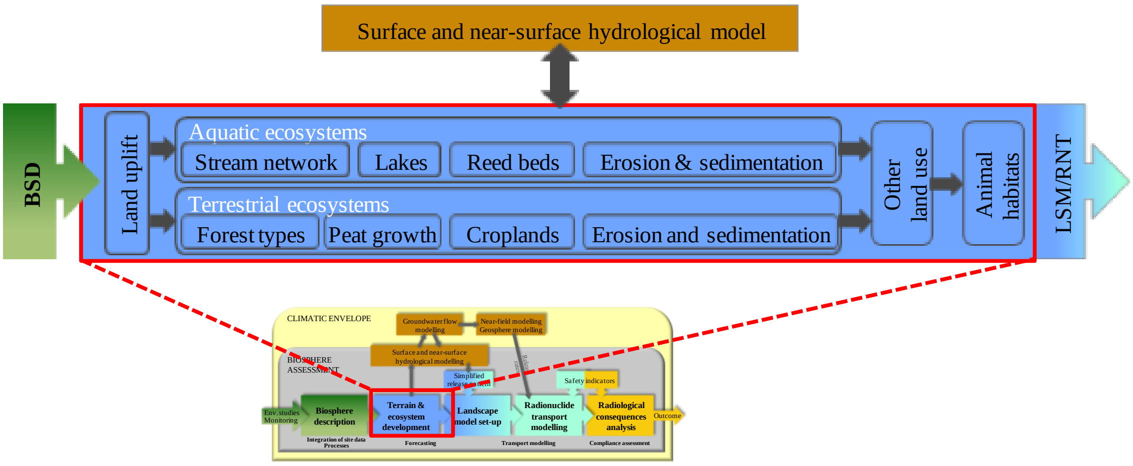

Figure 3-1. *Illustration of the TESM sub-process as part of biosphere assessment (Fig. 1-4). The interface to the surface and near-surface hydrological model is to nearly each component of the process. Some modelling stages are only at testing level in BSA-2009.*

3.1 Model description

For simulating the land uplift or other changes in the biosphere until and beyond the time when the potential releases would reach it, a GIS toolbox named UNTAMO has been developed for Posiva by Arbonaut Ltd. The tools and the simulation flow are documented in detail by Ikonen et al. (2010). Briefly, the toolbox consists of following main parts:

- Topographical and geological initial conditions,
- Land uplift and delineation of the sea area,
- Surface water bodies, runoff formation and flow rates,
- Terrestrial vegetation,
- Aquatic vegetation,

- Terrestrial erosion and sedimentation,
- Aquatic erosion and sedimentation,
- Fauna habitats,
- Land use, and
- Simulation control.

The simulation control part of the toolbox facilitates setting up, running and auditing a full or partial simulation. In the parameter value set-up dialogue box, there are access and synchronisation functionalities so that the validity of the parameters can be controlled in Posiva's Biosphere Assessment Database (BSAdb) including quality assurance and control scrutiny. The auditing functions keep track on the performance of the simulation and confirm whether the BSAdb data has been used or manipulated, or if the output files comply with the performance and setup log; a "fingerprint" code is included in all the results for verification.

The UNTAMO toolbox is used in the biosphere assessment together with the surface and near-surface hydrological model (Karvonen 2008, 2009a-c) presented in Chapter 4. The future terrain and ecosystems are forecast with UNTAMO and delivered as input data to simulate the groundwater flow and table in detail, further to be used as the groundwater head boundary condition in the deep groundwater flow modelling (e.g., Nykyri et al. 2008). Further in the safety assessment chain, the deep groundwater flow model is used to simulate potential release paths from the repository to the upper bedrock, which are then further continued in the surface and near-surface hydrology model to the rooting zone or to the surface water bodies. These release locations are then input to the UNTAMO for delineation of possibly contaminated, sufficently homogeneous[4] biosphere objects in a hydrologically valid chain downstream to the sea.

3.1.1 Topographical and geological initial conditions

As initial conditions, the topography (digital terrain model, DTM) and the overburden thickness are needed. In the latter, different soil and sediment layers are presented as a multiband raster where each band expresses the thickness of the respective layers. The order of the layers/bands is fixed and the respective list of overburden types is given as an input parameter for linking the other parameters to correct layers.

3.1.2 Land uplift and delineation of the sea area

During the last glaciation, the weight of the ice sheet caused the Fennoscandian crust to deform and down-warp several hundred metres. During and soon after the deglaciation, when the ice sheet melted and the load decreased and finally ceased, the initial uplift was rapid. Regionally the uplift rate can be presented in relation to download and inertia factors that depend on local conditions such as the ice-sheet thickness (stress) and the thickness and other properties of the crust, respectively (Vuorela et al. 2009).

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[4] The adequate homogeneity is determined by change of properties affecting to the parameter values in the biosphere radionuclide transport modelling (see data later in this chapter and in the background data report) and size related to validity of the compartment modelling in respect of reliability of predictions on the exposure to the contamination (variability/mixing within compartments), to be discussed in detail in other biosphere assessment reports.

Consistent with this, the land uplift module includes an implementation of Påsse's semi-empirical model (Påsse 1996, 1997, 2001, Påsse & Andersson 2005) as interpreted by Vuorela et al. (2009), who also provide most updated parameter data for the Olkiluoto site. In essence, the present and future land uplift is modelled using two s-curves for the isostatic rebound of the crust (*U*) and the eustatic sea level adjustment (*E*), respectively:

$$U = \frac{2}{\pi} \cdot A_S \cdot \left[\arctan\left(\frac{T_S}{B_S}\right) - \arctan\left(\frac{T_S - 1950 + t_{AD}}{B_S}\right) \right] \qquad \text{(Eq. 3-1)}$$

$$E = \frac{2}{\pi} \cdot 56 \cdot \left[\arctan\left(\frac{9500}{1350}\right) - \arctan\left(\frac{9500 - 1950 + t_{AD}}{1350}\right) \right] \qquad \text{(Eq. 3-2)}$$

where A_s is the download factor (m) relating to the ice-sheet thickness, B_s is the inertia factor (1/y) relating to the bedrock properties, T_s the timing factor of the maximum of the uplift rate (y) relating to the ice recession time, and t_{AD} is the time in the common calendar years (A.D.).

The effective sea-level change (*S*) is then

$$S = U - E \qquad \text{(Eq. 3-3)}$$

In the derivation of the parameters and in simulations of past situations, it needs to be noted, that these equations need to be complemented with so-called fast component before ca. 7600-6800 BC (Eronen et al. 1995, Ristaniemi & Glückert 1997) and Ancylus Lake water level corrections in about 8810-7150 BC (Vuorela et al. 2009). Equations for those corrections are given in (Vuorela et al. 2009) as well.

In addition, depending on the climate scenario envelope of the overall safety case, additional sea level change can be taken into account as a relative increase, or decrease, for each time step. This is modelled simply as a supplementary term to Eq. 3-3 ($S = U - E + \Delta$).

The delinearion of the sea identifies those areas below the sea level resulting from the land uplift or additional sea level changes, and removes such areas that do not have connection to the Baltic Sea, such as depressions and lake bottoms that may have an elevation value below the sea level, too.

3.1.3 Water bodies, runoff formation and flow rates

In identification and modelling the dimensions and water balance of surface water bodies, conventional methods are used as discussed below. To avoid inclusion of otherwise unnecessarily large area in the model, rivers having part of their catchment outside the model area can be taken into account by defining boundary conditions.

Identification of lakes and streams

Surface waterbodies are identified with conventional GIS analysis of flow accumulation: for each cell of the terrain model, a number of upstream cells is calculated (i.e. from how large area, in grid cell units, water is accumulated to a specific point by surface runoff). Those cells having a larger value are streams and rivers. Cells where all the other cells have a smaller value are bottoms of depressions, which are filled by water. A more detailed summary of the methodology is presented e.g. in chapter 5 of (Ojala et al. 2006).

Water flow rate

The runoff generation, or the flow rate as a function of precipitation on the watershed of a specific point in a stream, is modelled by a simplified concept of using a constant value for the fraction of precipitation appearing as the water flow in the rivers, but improvements based on a more detailed water balance analysis are planned to take also the soil type and land use into account.

Channel dimensions of streams

The cross-section dimensions of the rivers and smaller streams are calculated based on the open channel flow and usage of the Manning equation combined with the continuity equation as inferred in IAEA (2001) and used in the river model of Jonsson & Elert (2005). The water level in lakes will be modelled with the same approach in the next update of the toolbox.

In most cases discharge in open channel flow is calculated using the Manning equation combined with the continuity equation:

$$Q = \frac{1}{n} A R^{2/3} \sqrt{I} \qquad \text{(Eq. 3-4)}$$

where Q is the discharge (m^3/s), n the roughness coefficient (Manning coefficient, usually 0.03-0.04 in open channels), A the cross-sectional area of the flow (m^2), R the hydraulic radius of the cross-section (m), and I the energy slope (m/m), which is the driving force of the flow. The hydraulic radius can be defined as

$$R = A / P \qquad \text{(Eq. 3-5)}$$

where P is the wetted perimeter (m), i.e. the length of the cross-section that is in contact with the water.

The energy slope I is dependent on the discharge, longitudinal bottom slope of the river and shape of the cross-section of the river channel, further affected by the geological factors. In many cases the energy slope can be represented by the surface water slope in the longitudinal direction of the river; energy slope of 0.005 then means that the water surface drops 0.5 m per 100 m of the river length. In the UNTAMO implementation the energy slope is determined as the topographical slope of the ground surface along the stream channel (over a distance of one kilometre).

As for the rivers (streams) their location and topography, and thus the energy slope, are known, as well as the discharge calculated as presented above (runoff formation), only the cross-section remains to be solved. When the river width is given as a function of (or tabulated by) the discharge, the water depth in the channel can be calculated if the shape of the cross-section is defined (see section 3.3.2). The water flow cross-section area, however, is independent from the channel shape.

Water level of lakes

A lake can be formed only in a depression of terrain. With the conventional GIS analysis, the depressions are filled until the "water" is pouring out of the depression, i.e. to the lowest point still having flow direction towards the depression. This is however lower than the actual water level of the lake since the size of the outlet is again limiting the outflow according to Eq. 3-4, and since the lake cannot accumulate the runoff water unlimitedly - there has to be a balance of inflow and outflow. Figure 3-2 illustrates a simple situation: the water level rises until the water-filled cross-section of the outlet is large enough to convey the discharge to the lake (inflowing streams, runoff from the catchment area and possible minor contribution of groundwater discharging to the lake), meaning that the condition of Eq. 3-4 is satisfied.

In the future versions of the UNTAMO toolbox, the water level of lakes will be calculated iteratively as described just above, by rising the water level stepwise and recalculating the cross-section area from the terrain model. As the energy slope in lakes is usually very small, the lake water level is then taken as the filled level of the depression added with the depth of the outlet channel cross-section. In most cases, long-term average flow situations are simulated, but as for rivers, the same methodology applies to flooding occasions (shorter-term discharges) as well.

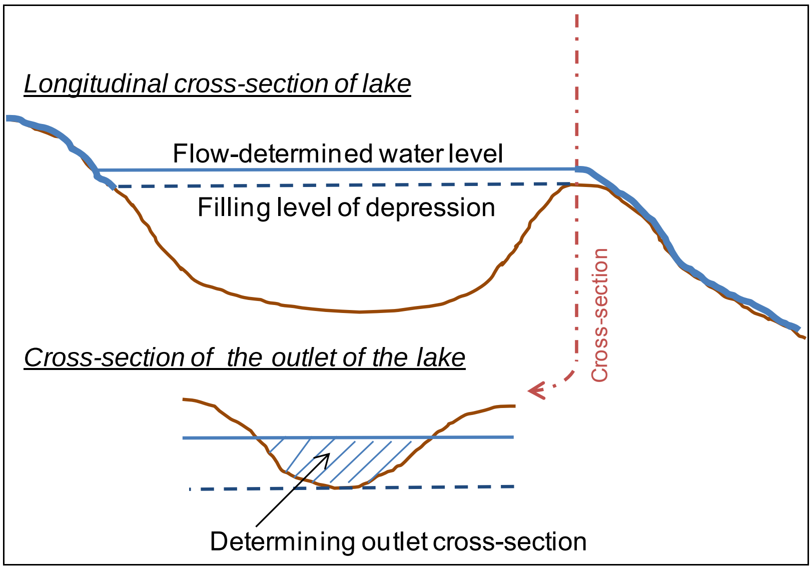

Figure 3-2. *Illustration of water level determination for lakes.*

3.1.4 Vegetation predictions

For the simulation of the development of terrestrial vegetation, there are two versions available in the UNTAMO toolbox: a Bayesian prediction based on direct application of site data (biomasses with respect to soil type, groundwater table and local solar conditions) and a simple vegetation type classification method.

Forest site classification

The site classification is for a vegetation prediction based on the growth site fertility, which is in essence determined by soil type. The classification is given as an input, and is presented in section 3.2.1 below (Table 3-4). It should be noted that the mires forming after the initial condition are determined using the peat growth model described in section 3.1.5 below.

Bayesian vegetation prediction

The Bayesian vegetation prediction model is based on similar principle as the simpler forest site classification, but applies more predicting variables resulting in higher apparent detail. It also produces direct biomass estimates specific to a grid cell instead of the plain classes. The model has been described in (Ikonen et al. 2008a) and only summarised here. It has been developed to predict terrestrial vegetation but can be applied also to aquatic vegetation if similar datasets become available.

Predicted vegetation types can be related to different soil and growth site properties (Table 3-1) using appropriate equations or e.g. logical relationships. Similarly as in the simpler forest site classification, the detailed phase in the cyclic vegetation succession is very difficult to predict due to uncertainties in the forest management and other drivers, and thus the vegetation is predicted probabilistically: in the long run the most probable species are likely to occupy the growth site for most of the time, taking the different management scenarios into account.

Based on this, parameter values are calculated for each vegetation class from the input data for each strata (Figure 3-3): surface soil type, soil thickness, groundwater table (same prediction tool as in the peat growth model, see section 3.1.5 below), and annual sum of solar radiation (affected by the slope and aspect of the local topography).

The Bayesian method (Tipping 2001) is used for each soil stratum to create relationships between the independent variables (soil properties, groundwater table, local solar effect) and the dependent, or predicted, variables for each of the survey plot in the input data set. The Bayesian predictor first searches the most similar plots on the basis of the given distance criteria for each grid cell. Then, a linear model is fitted between the dependent and independent variables, resulting in an individual model for each grid cell to be predicted[5].

[5] This is rather similar to the more classical approach of *k* nearest neighbours (kNN), but the discussion of the details is out of scope for the present report.

Table 3-1. *Properties of the terrain forecast used to predict vegetation types using the Bayesian approach (modified from Ikonen et al. 2008a).*

Property	Usage in vegetation prediction
Local effective temperature sum	Growth conditions and species composition
Altitude	Age of soil: stage in primary vegetation succession
Soil type	Site type: nutrient availability, organic matter content, stoniness
Humidity conditions (depth of groundwater table)	Water availability to plants
Prevailing vegetation	Available subsequent vegetation types, speed of succession
Thickness of organic matter layer	Fertility of the site, subsequent succession stages especially on younger sites

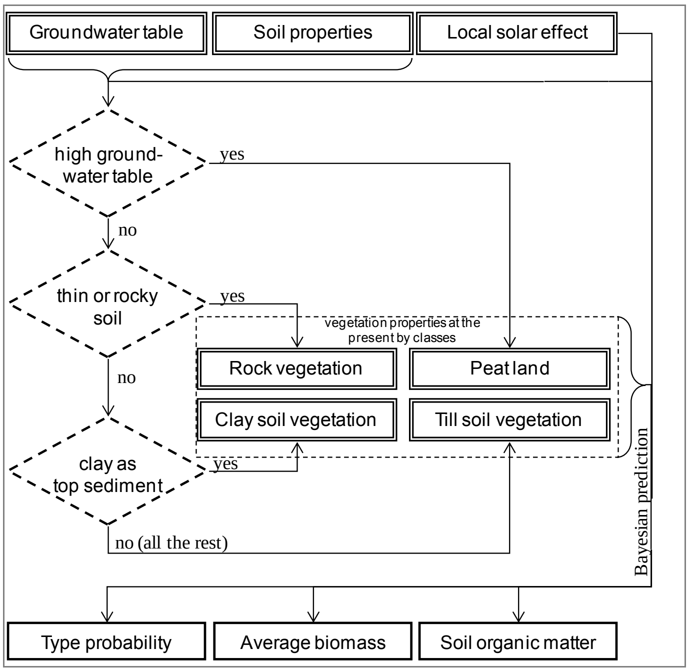

Figure 3-3. *Classification of soil strata by vegetation type (double-lined boxes) for the Bayesian vegetation prediction (Ikonen et al. 2008a). The predicted variables are presented in the lowest and the independent variables in the topmost row of boxes.*

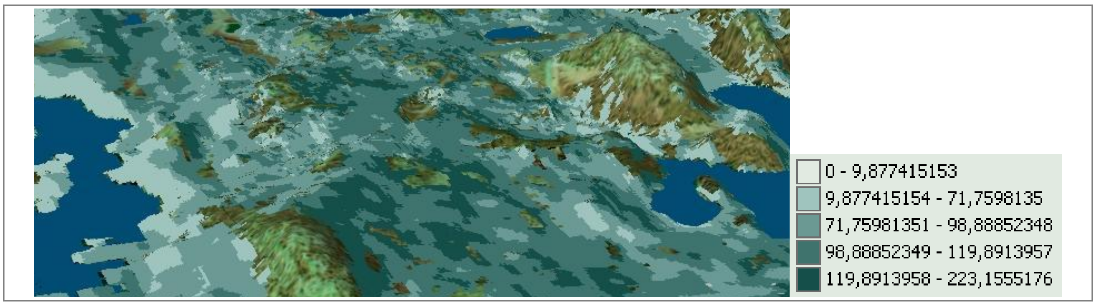

Figure 3-4. *Example of the results from the Bayesian vegetation prediction: distribution of biomass of coniferous trees (t/ha) from data of (Ikonen et al. 2008a). The vertical scale has been exaggerated to better present the effect of topography (solar conditions) and the accuracy in the numbers of the legend is arbitrarily too high. View is towards east-southeast.*

As a result, the amount of organic matter in the soil, the vegetation biomass, and the tree biomass separated for deciduous and coniferous species are estimated for each grid cell. Later, for selected object areas these data can be aggregated into patch-specific statistics to be used e.g. in the radionuclide transport modelling, whereas in the simpler site classification tool only the site class or proportion of site classes are produced and the biomass and other parameters need to be derived for these classes separately.

Aquatic vegetation

In the present model version, the aquatic vegetation includes only reed bed prediction. The existence of reed colonies is determined by a depth threshold and degree of exposure to waves (fetch analysis, similar as in the aquatic erosion and sedimentation model, see section 3.1.5 below) calibrated with site data. Basically, in shallow enough areas the extent of reed colonies is determined by the openness of the shore to wave action. Also threshold for flow rate can be applied for (almost) closed areas to take into account e.g. the exposure to river discharge to a narrow strait.

3.1.5 Erosion and sedimentation

Terrestrial erosion and sedimentation

On land, erosion is usually rather small (except on croplands) but it contributes to the suspended sediment load in the streams, lakes and coastal areas, making an input to the aquatic erosion and sedimentation model. In addition to erosion from land and subsequent deposition of soil particles, also accumulation of peat contributes to the terrestrial sedimentation. These two models are briefly presented below.

<u>Peat growth model</u>

The peat growth is simulated with the model of Clymo (1984); also applied to Finnish conditions by Clymo et al. (1998). In the model, peat growth is based on production-driven accumulation constrained by the hydrology (summer droughts) and the decay in deeper layers. In addition to these modules for organic material accumulation, thickness of the humus layer is predicted by the vegetation modules. The module produces an ellipsoidal bog if the base soil is totally horizontal and flat; in practical applications the actual peat thickness is that predicted by the model subtracted with the elevation difference between the point in question and the centre of the bog in the deepest point of the depression.

Basically the model can be condensed into a combination of equations 32 and 31 in (Clymo 1984):

$$H = \sqrt{\left(\frac{p_c}{\alpha_c \rho_c}\left(1 - e^{-\alpha_c t}\right)\right)^2 - \left(U/k\right)x^2} = \sqrt{H_m^2 - \left(U/k\right)x^2} \qquad \text{(Eq. 3-6)}$$

where

H peat thickness (m),

H_m peat thickness at the centre of the bog, i.e. at the focus of growth, (m),
x distance from the axis point (m),
t age of the bog (y),
p_c rate of matter passing to catotelm ($kg_{dw}/m^2/y$),
α_c peat decay rate in the catotelm (1/y),
ρ_c bulk density of peat (kg_{dw}/m^3),
U discharge from the bog ($m^3/m^2/y$; determined by the water balance),
k hydraulic conductivity of the peat (m/y).

As can be seen from the equation, the balance between the production on the bog (directly related to the rate of matter passing to the catotelm) and the decay of the plant remnants determines the peat thickness at the centre. The peat thickness in other points, or actually the extent of the bog in proportion to its height, is on its behalf determined solely by the hydrological conditions.

In addition to Clymo's original model, the implementation in UNTAMO includes also estimation of groundwater table since the growth of peat bog (location of foci) is determined based on a threshold of groundwater being close enough to the surface for peat-producing vegetation. Also, the growth focus and the age of the bog can be given for existing peat formations, and a wave effect buffer (distance from shoreline) can be specified to unable formation of peat on shoreline where wave action would remove it.

The prediction of groundwater table is implemented in the present version by a simple function of elevation from the closest water body as fitted to long-term average data from the Olkiluoto site (see section 3.4). As the groundwater table is usually more even than the topography, the prediction is filtered to a moving average of specified scale; only this way the model can produce wet areas in those depressions that are not filled by the surface runoff. It is acknowledged that this could be improved by deriving relationships to soil type and landuse from typical water balances, but on the other hand the prediction is used only to identify foci of peat bogs or areas of peatland vegetation in the Bayesian vegetation prediction; only delineation of areas of average groundwater table closer to ground surface than a threshold (typically around 10 cm) needed for mire vegetation does matter.

Terrestrial erosion-sedimentation model

The terrestrial erosion and redistribution of surface soils is simulated by applying the USPED/RUSLE model (Zaluski et al. 2004; www.iwr.msu.edu/rusle/) as such: the local net erosion is determined by the soil type, land cover and rain intensity (universal soil loss equation USLE; e.g., Tattari & Bärlund 2001), and the topography is then taken into account by slope analysis making the redistribution simulation in principle similar to the water flow accumulation.

In the first phase of the model, the net erosion (deposition) of soil is estimated for each grid cell based on product of values for factors of erosivity, soil erodibility, land cover and management and length and steepness of local slope. In the second phase the converging and diverging erosion flows are taken into account similarly as for surface runoff in the flow accumulation approach (section 3.1.3). To avoid unnaturally intense channelling of the erosion flow, the UNTAMO tool incorporates spatial filtering on the second phase.

The erosivity factor is related to the the intensity and duration of precipitation events and the resulting runoff and could be calculated from weather data as product of the total kinetic energy of the storm events times their maximum 30-minute intensity (http://www.iwr.msu.edu/rusle/rfactor.htm). However, the model has been found to be least sensitive to the variability of this parameter.

The cover and management factor, the most important to the prediction result, is used to reflect the effect of cropping and management practices on erosion rates. Its quantification is based on the concept of deviation from a standard, in this case an area under clean-tilled continuous-fallow conditions. The soil loss ratio is then the ratio of the soil loss under actual conditions to losses experienced under the reference conditions (http://www.iwr.msu.edu/rusle/cfactor.htm). Soil erodibility depends on the soil texture, structure, permeability and organic carbon content and represents both susceptibility of soil to erosion. It, too, is measured under the standard unit plot condition - past management or misuse of a soil e.g. by intensive cropping can increase its erodibility (http://www.iwr.msu.edu/rusle/kfactor.htm).

Aquatic erosion and sedimentation

For aquatic erosion and sedimentation processes accumulation of organic material in reed beds (identified using a model presented above in section 3.1.4) and overall sedimentation to lakes have been implemented and used in the 2009 biosphere assessment. For the overall erosion and sedimentation in all aquatic basins, a fetch-based model has been implemented but requires testing. These three models are briefly presented below.

Accumulation of gyttja in reed beds

In the present model, due to lack of more detailed data and model, gyttja accumulates at a constant rate thoughout the area of the simulated reed beds.

Simple sedimentation model for lakes

A simple correlation model for sedimentation in lakes has been presented in (Brydsten 2004, 2006) and further adjusted in (Ikonen 2007b): the sedimentation rate depends only on the lake water volume and thus decreases over time as the lake fills.

The model starts with a lake basin to form that exists before the wave-wash phase starts, i.e. a basin with a bottom consisting of till or postglacial clay. First, the basin fills up with 4 % of the initial volume by silty sand. Then, until at least 18 % of the former basin volume consists of fine-grained shallow gulf sediments, each year the basin is supplied with fine-grained inorganic sediments with a volume rate fitted to observation data as a function of the water volume (given as data in section 3.3.6). If the basin has bottom areas located below two meters water depth, all new sediments are placed there; otherwise the new sediments are spread evenly over the entire lake. The successive shallowing is calculated by dividing the sediment volume with the water area above the deposition locations.

As discussed in (Brydsten 2006), it is likely that the sedimentation rates should be different for the future lakes and for the other areas due to sedimentation, resuspension and erosion processes in different phases of the shoreline displacement. The original model of (Brydsten 2004) was applied already from the sea phases of each basin, whereas (Brydsten 2006) separates the sea and lake phases and treats them with different models, the latter being the same as in (Brydsten 2004), though. In the case of Olkiluoto, this would not make a significant difference, and furthemore, the model is intended to produce indicative results only since it is well known that the sedimentation rate would depend heavily on the suspended sediment load in the watercourse, which on its behalf depends on the land use in the catchment area. For example, the source of the sediment material is not considered; at the Olkiluoto site, the two main rivers (Eurajoki and Lapinjoki) bring large amounts of suspended matter to the area and their water stream acts also as an eroding force. Their catchment area and its land-use have a significant effect to the quality and the quantity of the suspended matter load. On the other hand, some future lakes are formed outside of the influence of these rivers, and those lakes also have relatively small catchment areas feeding water and suspended matter to them, likely resulting in more reduced sedimentation rate.

Fetch-based model for aquatic erosion and sedimentation

For aquatic erosion and sedimentation, a fetch approach (physical exposure by wind-induced effects; e.g., Ekebom et al. 2003) is has been implemented with shear stress conditions at the bottom (Huttula 1994, Shore protection manual 2001, Seuna & Vehviläinen 1986). The model requires testing before use in an assessment, though, and data are given in section 3.3.6 to facilitate this.

The model utilises concepts of fetch distance (i.e. distance over open water to the nearest land) and wind speed data to estimate shear stress at the bottom of the basin. When the shear stress exceeds a critical value, the sediment is eroded and remains suspended as long as the shear stress is again less than the critical shear stress for deposition.

The equations, mostly applied from (Huttula 1994) are presented in (Ikonen et al. 2010). The effective fetch is calculated as a mean fetch distance around the full circle, weighted by the wind probability in each direction, and similarly the mean wind speed is the probability-weighted average for every direction. As the main predicted variable is the change to the concentration of suspended solids in the water, in addition to the shear stress at the bottom, also the background concentration of suspended solids is required. It is calculated slightly differently for the different type of basins following from their hydrological characteristics: For rivers and lakes, the incoming sediment flow (from upstream and from the catchment by the terrestrial erosion-sediment model) is evenly distributed to the water volume, or practically calculated as the product of the sediment input in $kg/m^3/y$ and the retention time in years. Due to the high water exchange and narrow geometry the local changes in rivers are ignored. For coastal areas, a concentration raster or basin-specific value is provided as an input, and the contribution from the runoff from the catchment is considered negligible except for river mouths which should be taken into account in the input raster.

3.1.6 Fauna habitats

Identification of habitats of characteristic groups of animals has not been implemented in the toolbox yet, but at the current stage it would be based on identification of different ecosystems and their properties affecting the habitats as described in the Biosphere description report (Haapanen et al. 2009a). The module will be developed based on this information to compile information on the preferred, suitable and repulsive areas for the characteristic animal groups.

3.1.7 Land use

Cropland delineation

As land use types, at the moment only locations of croplands are identified. Their delinearion is based on the soil suitability and preference in the region at present (almost solely on clay or gyttja/mud soils; Ikonen 2007b). In addition, required soil thickness for the cropland management is taken into account.

In alternative, more advanced prediction, field delineation allows several attribute rasters such as the relative fertility of soil types, groundwater depth (see the peat growth model in section 3.1.5 above), terrain slope and soil thickness. The rasters are segmented into homogeneous compartments, and they are selected as croplands in order of best suitability until a given target value for the total cropland area has been reached. This target value is given as a scenario parameter, and is a surrogate of agricultural intensity of the community in the model area. This prediction model is similar to that used for predicting house locations, see below.

House prediction

The illustrative human settlement simulator is based on correlations of various factors affecting the housing density around the Olkiluoto site. Such factors are, for example, soil type and distances to the main road, nearest neighbour or a water body; a given number of houses are placed in the order of most preferable location. Two versions of the model have been outlined: a simpler one in production use, and a more advanced one being tested.

For the study of (Ikonen et al. 2008b), the house locations were placed randomly with a desirability index that was calculated as a product of weights based on:

- distance to shoreline of nearest river, lake or sea,
- distance to nearest field,
- distance to nearest existing house,
- distance to nearest main road,
- solar radiation index.

To calculate the above weights, present-day house locations within the model area were analysed for the weight rasters. The housing density (houses/km²) in the different classes were calculated (for the results, see section 3.3.8 below), and the densities were normalised to a common scale of 0 to 1 (inclusive). The houses in densely built areas and areas of scattered settlement were treated together, and the desirability index (W_{total}) was calculated as

$$W_{total} = W_{shore} \cdot W_{field} \cdot W_{house} \cdot W_{road} \cdot W_{solar} \qquad \text{(Eq. 3-7)}$$

where the multiplicands are, in respective order, the normalised housing density values for the criteria listed above. When sampling for the location of a new house, the distance to the nearest neighbor was calculated from the set of all the houses existing before and those already sampled for the location. Given areas can be excluded from the analysis, corresponding avoided or prohibited settlement areas. Croplands and water bodies are excluded by default.

To add an urbanisation effect, the house sampling tool can include point-wise data that represents the centerpoint, radius, number of houses and year of emergence of towns. When a town is to be created, the desired number of houses is placed, based on the weights above plus a weight of the distance to the centre. The additional weight is normally distributed around the center, with standard deviation equal to half of the radius; hence the weight at the perimeter is two standard deviations, implying that 98 % of added houses are within the town circle perimeter.

In the study of (Ikonen et al. 2008b), in lack of more detailed data and models, both roads and emerging towns we created manually to correspond to expected development. The roads included the existing main roads and for the emerging land the slope was used for guidance. An emerging town was placed at a convenient place (Fig. 3-5).

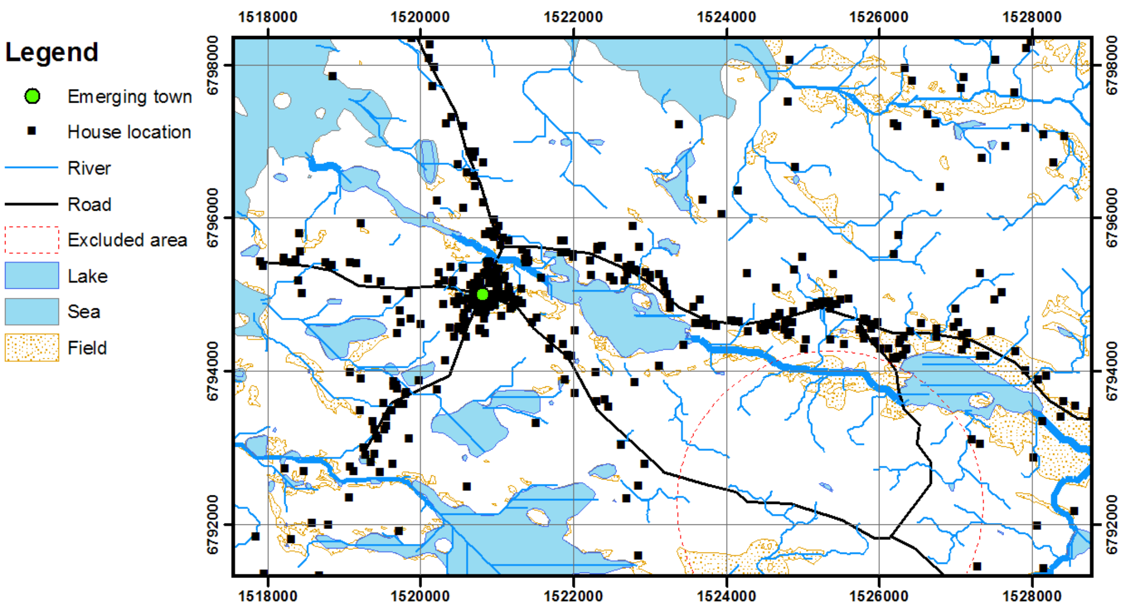

Figure 3-5. *Example on the result of the house prediction tool, redrawn from the simulation results of (Ikonen et al. 2008b). Map layout Martin Gunia, Arbonaut Ltd.*

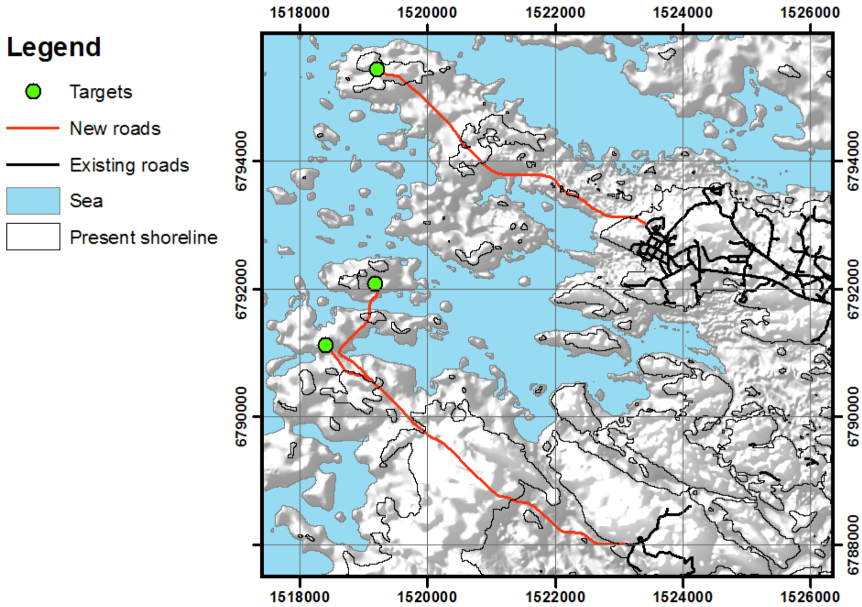

Figure 3-6. *Example prediction of main roads from the existing roads to three target points. Map layout Martin Gunia, Arbonaut Ltd.*

In the simpler tool, the same weights were used for both towns (village centres) and scattered settlement. The attraction factors are, however, likely to be different in densely built areas than elsewhere. In the more advanced version, the modelling area is split into urbanised and rural areas. Furthermore, the houses in both groups can be split into permanently inhabited and holiday houses.

The splitting into urbanised and rural areas is based on calculating housing densities in a larger grid, e.g. 250x250 m^2 and using a threshold value to identify the formation of area built densely enough. The required parameters additional to the simpler model are thus the grid size and the threshold density, intimately tied to the derivation of the desirability data (see section 3.3.8).

Road prediction

The main road network is simulated by minimising the costruction cost depending on the terrain type: the cost surface is composed of terrain slope classification and water body areas. In the present version of the model, the terrain slope is classified to five classed having a nominal construction cost value (see section 3.3.8), and then the water body area (lakes, rivers, sea) is superimposed on that using a constant cost value; building bridges becomes possible but costly, depending on the parameter values applied. The present main road network is used as an initial condition, and the predicted roads are following the least-cost path to the given target points.

This method optimises the road network only by avoiding steep cuts and crossing water bodies, but does not take into account e.g. the length of the path (realistic costs). This is rather unrealistic and effects are well visible in some cases (e.g. Fig. 3-6), but where the targets are close enough to each other, the predicted road network appears reasonable. If need arises, and suitable data are available, the cost surface can be constructed to take other factors into account as well, similarly to the housing prediction. However, since they both are intended only for illustrative use to support the formulation of dose assessment scenarios, no further effort was considered necessary for Biosphere assessment 2009.

Other land use

Considerations for other land use affecting the terrain or vegetation, e.g. draining a lake or building a dam, are left for manual manipulation of the respective interim files and stepwise simulation runs according to scenario or calculation case assumptions and data.

3.2 Key input data

For the development of the terrain and ecosystems, the initial terrain model and the land uplift model parameters are the most influential input data as they largely define the types of ecosystems developing in a place and the time scale of the change.

The other key data for the present model of the development of the ecosystems are the sea-level scenario adopted (a higher-level specification in the safety case), and parameters related to runoff formation and flow rates, sediment balance, accumulation of organic matter and the growth of forest and macrophyte vegetation, all providing the necessary data for forecasting the key parameters in the radionuclide transport models either directly or by classification (parameter values for each class are then assigned separately from the terrain and ecosystems development modelling process).

3.2.1 Initial topography and land uplift parameters

Terrain model

The terrain model describes the elevation of the ground and the depth of the sea-bottom surface, and it is a key input in land uplift and surface hydrological modelling, although it is difficult to point out which points within the model are of most importance except of course those addressed as contaminated areas in the radionuclide transport modelling. On the other hand, some other areas might get contaminated if the topography were slightly different for example resulting from a variation in a relatively small area where a river changes its course.

A high-resolution statistical terrain model of Olkiluoto Island and its surroundings has been derived by combining the existing data with the uncertainty information from various sources (Pohjola et al. 2009). Thin-plate-spline interpolation of the minimum energy surface was used for the creation of a 2.5-metre grid. Possibly erroneous data values were rejected from the model by using a spatial autocorrelation method. The error distribution of the model for each elevation point was calculated by Monte Carlo simulation of at least 2 000 realisations for each point, allowing point-wise probability distributions of the elevation value to be computed. To assess the impact of uncertainties by analysing alternative topographies realised from the probability distributions of grid cells, a project has been launched in 2009.

Land uplift

Considering the land uplift model, it is difficult to point out the key data affecting the Olkiluoto site and especially the radionuclide transport modelling and further the dose assessment. Firstly, the model is at the best regional, and results affecting the land uplift predictions at Olkiluoto depend on the values in the download and inertia factor rasters that are interpolated from data points scattered rather sparsely around Fenno-scandinavia. Naturally, data closest to Olkiluoto has a major effect, but into the direction it exists; for example to northeast and northwest other data tend to affect the shape of the raster surfaces. In addition, the average value at Olkiluoto as such affects only to the rate of the uplift (i.e., timing of stages in the shore-level displacement), but the variation of values in the modelling area might cause, for example, relocation of streams due to land tilting.

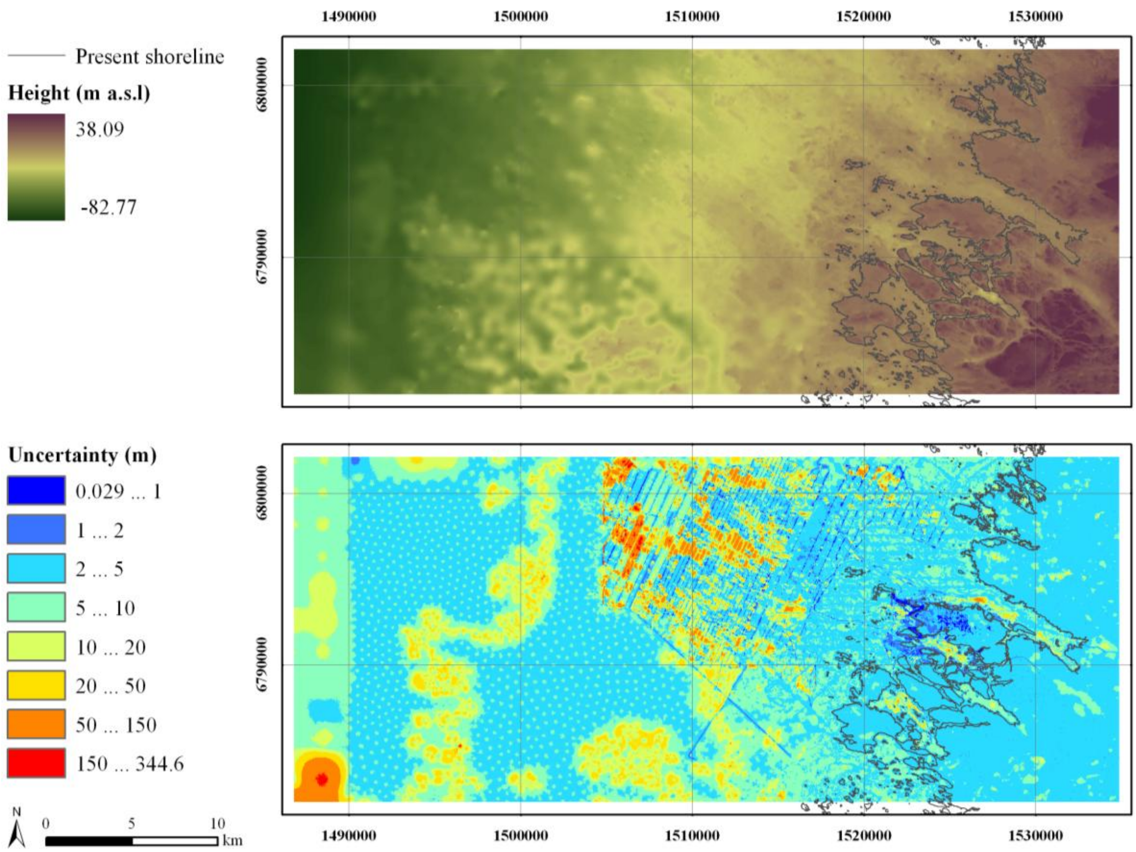

Figure 3-7. *Elevation (upper) and uncertainty estimates (lower) as differences of 5th and 95th percentile of elevation, data of (Pohjola et al. 2009) with present coastline from topographic database by the National Land Survey of Finland. Map layout by Jani Helin/Posiva Oy.*

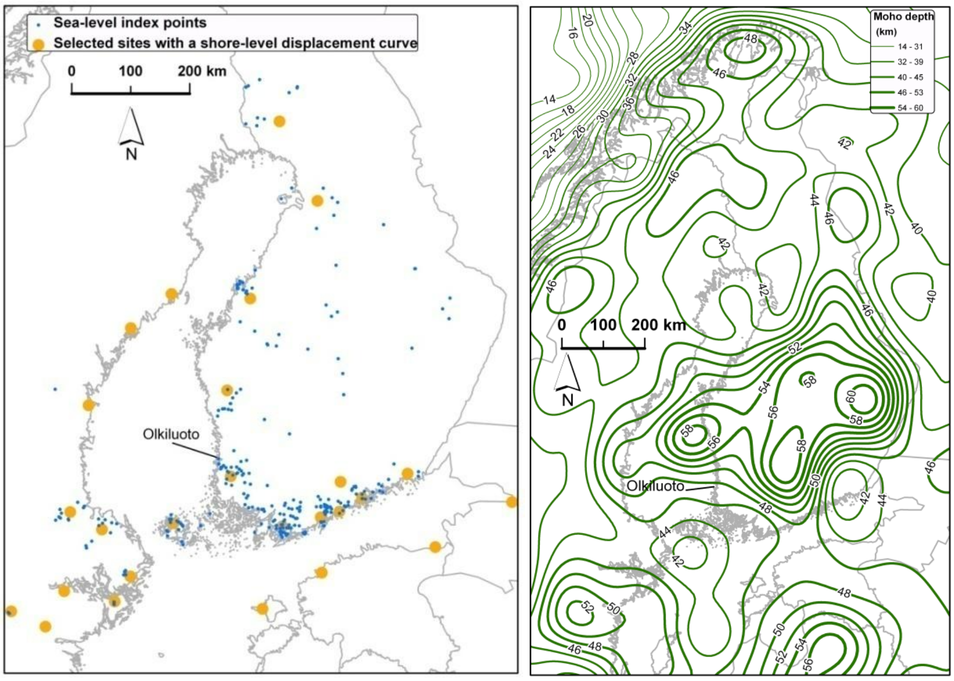

Figure 3-8. *On the left, locations of the local ancient shoreline and other dating points (blue) and regional sites (orange spots) where a shore-level displacement curve has been fitted to the local points (Vuorela et al. 2009). On the right, the crustal thickness (km ± about 10 %) by Grad & Tiira (2008, 2009). Map layout by Arto Vuorela/Pöyry Environment Oy.*

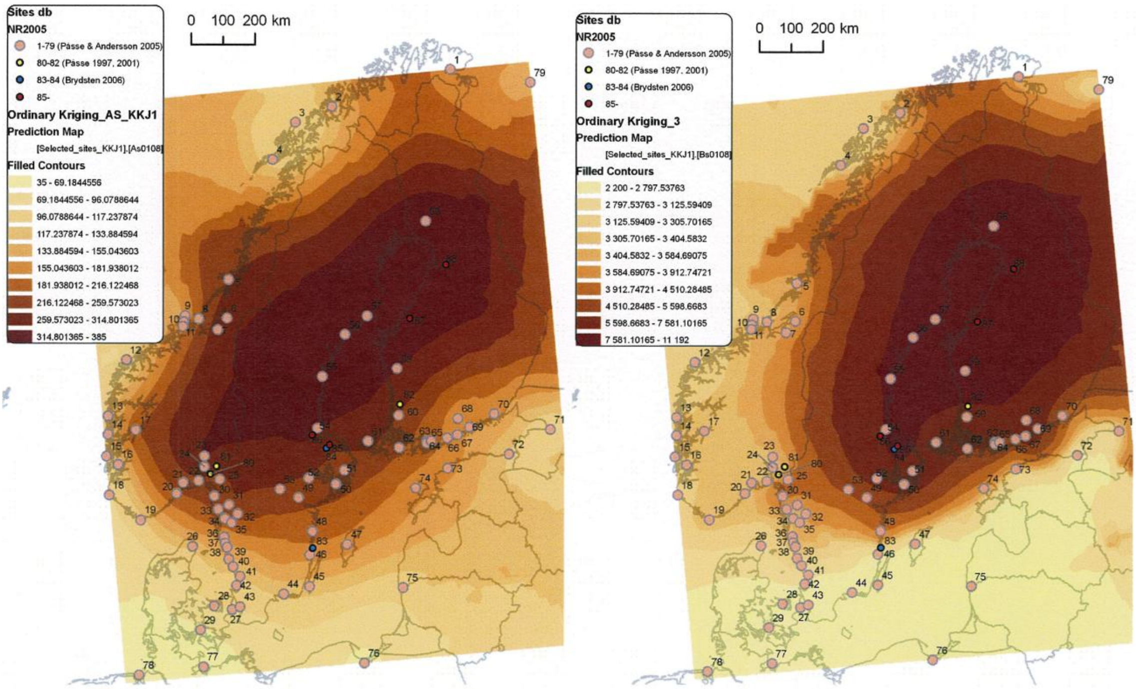

Figure 3-9. *Land uplift model parameters* A_s *(left) and* B_s *in Fennoscandian scale (Vuorela et al. 2009). Points indicate input data for the interpolation. Map layout by Arto Vuorela/Pöyry Environment Oy.*

Vuorela et al. (2009) have recently compiled the model input data that is used in the 2009 assessment. They have also studied the uncertainties with respect to the Olkiluoto site, and presented details on the spatial coverage of the data. For the UNTAMO simulations, rasters of the slow-phase download factor (A_s) and the inertia factor (B_s) are needed, as well as the timing parameter T_s, constant to the model area. Figure 3-8 presents the coverage of the input data for derivation of the raster parameters, and Figure 3-9 the actual rasters in larger scale. For T_s, value of 12 000 years (calibrated) is used.

3.2.2 Runoff formation, water levels and flow rates

For modelling the flow rates in the stream network at the future site, it is assumed that the runoff formation remains the same as at present in the neighbouring river catchments. The flow rate in the future streams is modelled by using specific runoff, i.e., the amount of annual precipitation falling on the catchment that reaches the running water in the river, calculated from the present-day situation in the rivers Eurajoki and Lapinjoki and their catchments. It is acknowledged that this is a rather simplistic approach, and, in the future modelling values depending, for example, on the soil type and land use are needed. For finding the value for the specific runoff parameter, the model is calibrated using the measured long-term precipitation (Ikonen 2002, 2005, 2007a, Haapanen 2008) and river discharge (Environmental information and spatial data service - OIVA portal, May 4, 2009) data presented in Table 3-2. The precipitation measured at Olkiluoto is used for the entire large catchment of the rivers to be consistent with the localisation of the weather data used in the other biosphere modelling. Regulation of the water level in Lake Pyhäjärvi, affecting the discharge to the River Eurajoki, is considered to follow the precipitation and to be implicitly taken into account in the application of the data. The discharge measurement point locations are presented in Table 3-3.

3.2.3 Forest site classification

In forests, the growth of vegetation is the main driver of radionuclides entering the biological cycle and possibly their further transmittal through the food web. The vegetation biomass also forms storage for radionuclides affecting the concentrations available for removal by runoff. In the terrain and ecosystems development model, the site classes for the vegetation (Table 3-4) are identified mainly based on the soil type and properties for the definition of corresponding parameter values in the radionuclide transport modelling and in the surface hydrology model. The classes have been derived by expert judgment on the basis of available literature and data, constrained by the limited possibilities of identifying future soil types and their properties from the present-day data on the sea bottom sediments and the conceptual classification of soil layers. It is acknowledged that the heterogeneity within the classes remains large, but, at the moment, no competing overall models are known. In the terrain and ecosystem modelling, only the forest site class is identified and the radionuclide transport and dose assessment parameters for each class are determined on that basis (for the data, see the sections below).

Table 3-2. *Annual discharges (m^3/s) in rivers in 1995-2007 (Environmental information and spatial data service - OIVA portal, May 4, 2009), the catchment areas (km^2) above the discharge measurement points (based on the topographic database of the National Land Survey of Finland) and annual precipitation (mm) at Olkiluoto (Ikonen 2002, 2005, 2007a, Haapanen 2008) in 1993-2007. MQ is the mean discharge (to be used in the model to present the annual total discharge), HQ and NQ highest and lowest daily discharges (m^3/s) occurring during the year.*

	Lapinjoki, Ylinenkoski			**Eurajoki, Pappilankoski**			**Precipitation, Olkiluoto**
	MQ	**HQ**	**NQ**	**MQ**	**HQ**	**NQ**	
Mean	**3.3**	19.9	0.03	**8.3**	37.5	0.9	**532**
Maximum	4.7	27.0	-	**12.5**	56.0	-	705
Minimum	1.3	-	0.01	**2.9**	-	0.0	316
Catchment area, km^2	**438**			**1 229**			

Table 3-3. *Coordinates of the measurement points of variables presented in Tables 3-2 and 3-6 (national KKJ1 coordinate system).*

	Northing	**Easting**
Pappilankoski, flow rate	6788430	1540680
Pappilankoski, suspended matter load	6788300	1539220
Ylinenkoski, flow rate	6785020	1536134
Ylinenkoski, suspended matter load	6784659	1536100
Olkiluoto weather mast	6792754	1523313

Table 3-4. *Site classes used in identifying the type and properties of future forests at Olkiluoto site.*

UNTAMO site class	**Soil type**	**Site type ***	**Main tree species**
1 Rocky forest	Rock (rock outcrops, weathered rock, stony and compact till), thin soils	Extremely infertile / barren (CIT) Dry / xeric (CT)	Treeless / pine
2 Heath forest	Washed till (coarse- / medium-grained)	Extremely infertile / barren (CIT) Dry / xeric (CT) Dryish /sub-xeric (VT)	Pine
		Fresh / mesic (MT)	(Pine) / spruce / birch
3 Herb-rich heath forest	Fine-textured mineral soil (fine till, sand, mixed glacio-aquatic sediment)	Grove-like (OMT)	Spruce / deciduous
4 Herb-rich forest **	Clay soils, recent mud/clay, gyttja	Grove (Lh)	Spruce / deciduous **
5 Peatland forest	Peat	Extremely infertile / barren (CIT) Dry / xeric (CT) Dryish / sub-xeric (VT)	Pine
		Fresh / mesic (MT)	(Pine) / spruce / birch
		Grove-like (OMT) Grove (Lh)	Spruce / deciduous

* The abbreviations of site types refer to the system widely used in Finland (Cajander 1949). The same site type abbreviations are used for corresponding peatland forests instead of mire site types for the main peatland categories (open fens and bogs, pine mires, hardwood-spruce mires and paludified forests).

** These areas are usually always used for agriculture in the region, and data on forest vegetation is scarce.

The thin soils are taken to be thinner than 30 cm, according to FAO classification (lithic leptosol and dystric leptosol). In the Olkiluoto forest plot data (Tamminen et al. 2007), there are 9 plots on lithic leptosol (0-9 cm soil), none on dystric leptosol (10-29 cm).

3.2.4 Reed bed extent

The reed colony model is based on assessing the fetch distance (degree of physical exposure) and assuming a maximum water depth and minimum flow rate for the vegetation to survive. Since the parameters are difficult to quantify in detail, the model is calibrated using data from a survey at the site (Haapanen & Lahdenperä 2009), see section 3.4.

3.2.5 Peat growth

The main parameters of the peat growth model, essentially as in Clymo (1984), have been taken from a survey covering whole Finland (Clymo et al. 1998; Table 3-5). As an exception, the average dry bulk density of peat is based on a database of 49 953 peat samples throughout Finland (Mäkilä 1994).

As comparison to the abovementioned data recommended for the assessment use, other literature values are presented in Figures 3-10 to 3-12.

Table 3-5. *Key parameters for accumulation of organic matter.*

Parameter	Unit	Value	Reference
Rate of matter passing to catotelm	$kg_{dw}/m^2/y$	0.0485	Clymo et al. (1998)
Decay rate of organic matter in catotelm	y^{-1}	3.7×10^{-5}	Clymo et al. (1998)
Bulk density of peat	kg_{dw}/m^3	91	Mäkilä (1994)

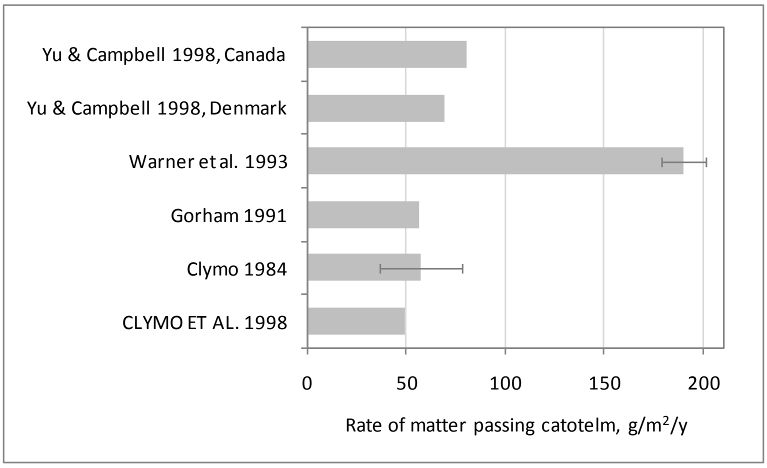

Figure 3-10. *Comparison of literature values for the rate of matter passing to catotelm. The selected value is the lowermost.*

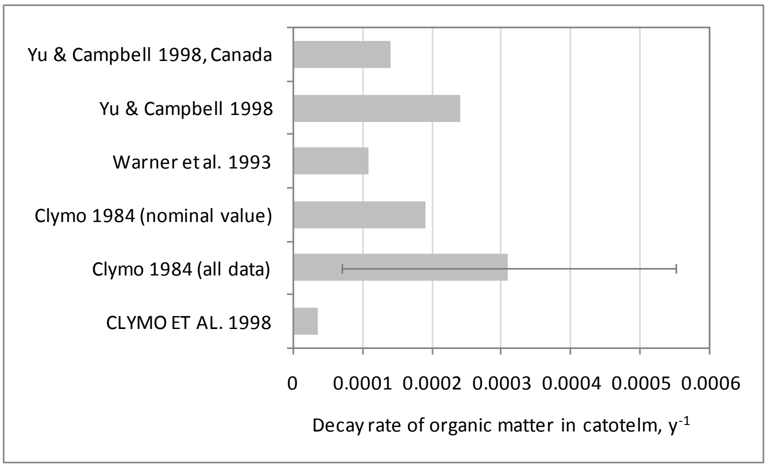

Figure 3-11. *Comparison of literature values for the decay rate of organic matter in catotelm. The selected value is the lowermost.*

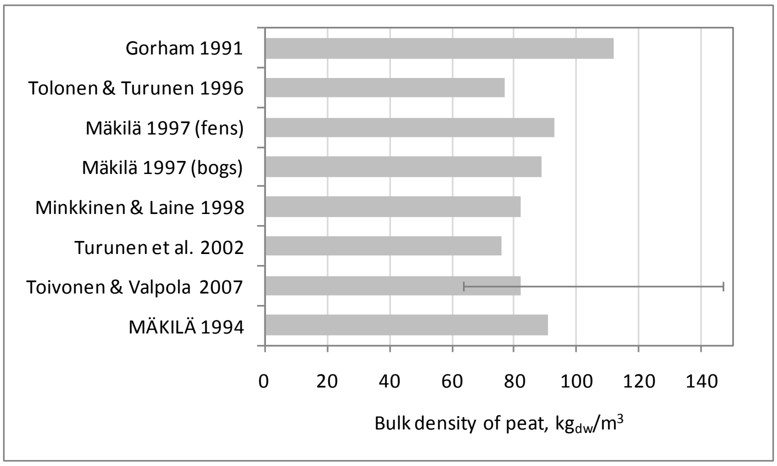

Figure 3-12. *Comparison of literature values for the bulk density of peat. The selected value is the lowermost.*

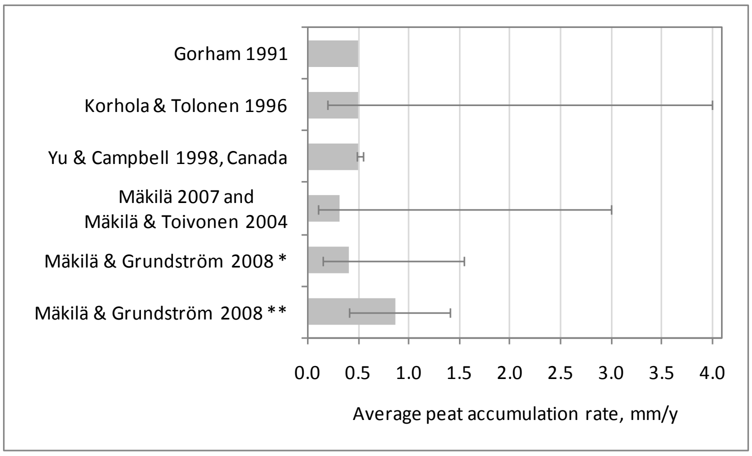

Figure 3-13. *Comparison of literature values for long-term average peat accumulation rates. * Pitkäsuo mire, rates during different stages of the mire; ** average rates of different mires in southwestern Finland.*

However, the literature review has been limited and was not focused specifically on the wetland types expected to form at the Olkiluoto site. Thus, the data should be taken as provisional, and the need for a further study and possibly field work is acknowledged. For a generic comparison basis, Figure 3-13 presents a compilation of literature data on long-term average peat accumulation rates (present peat depth divided by the basal age).

3.2.6 Accumulation of gyttja in reed beds

In the terrain and ecosystems development model, accumulation of gyttja occurs only in reed beds on the shoreline. The gyttja accumulation rate is assumed constant, and the value is derived from the data on Olkiluodonjärvi mire at the site (Leino 2001), because more comprehensive surveys are lacking. Based on an isolation date of common calendar years of 1491–1638 (Eronen et al. 1995, Vuorela et al. 2009), and a practically constant land uplift rate of 6 mm/y (Eronen et al. 1995) indicating that the start of reed colonisation (water depth 2 m, based on observations from the site) at the location presently 1.5 m a.s.l. (Leino 2001) was in the year 1418, the gyttja layer with a mean thickness of 0.6 m (calculated from sounding profile data points of Leino 2001) can be estimated to have been accumulating at an average speed of 2.7–8.2 mm/y. Some data exists from Lake Joutsijärvi (located in the Reference area, Fig. 1-6): while in the 1960s the accumulation of dry matter was approximately 2 500 g/m²/y, it has lowered to approximately 500 g/m²/y from the 1980s on; on average about 7 mm/y (Salonen et al. 2002). Organic matter accounts for about 10 % of these values, and the high values in the 1960s resulted from intensive forestry, mainly ditching of forests and mires (Salonen et al. 2002).

3.2.7 Fetch-based model for aquatic erosion and sedimentation

Similar to the effect of water flow on solutes, the sediment balance (erosion and deposition of sediments) regulates the transport of radionuclides sorbed in solid matter. For modelling the source of suspended solids in the stream water, the terrestrial sedimentation-erosion model is provided with specific parameter data considered to be applicable to the Olkiluoto site, and further calibrated by using the recorded suspended solid loads in the rivers Eurajoki and Lapinjoki (Environmental information and spatial data service - OIVA portal, May 4, 2009) provided in Table 3-6. The locations of the monitoring sites are presented in Table 3-3.

For details, it should be noted that the load of suspended matter has been monitored using somewhat different filters. From the Lapinjoki water the suspended matter has been separated earlier using 0.65-µm Sartorius filter and since 2006 using a GF/C filter. The water from Eurajoki has been filtered with Nuclepore. As the river water has been relatively low in the very fine fraction, there are likely no big differences, but this has not been confirmed by comparison tests.

For underwater erosion and sedimentation, a model based on the wind-direction-weighted fetch length is applied. For this, the key parameters are the wind speed and direction statistics and the critical shear stresses of sediment types that determine whether the material is eroded or whether the conditions are favourable for net sedimentation. The wind statistics were calculated from the weather data at Olkiluoto (Ikonen 2002, 2005, 2007a, Haapanen 2008, 2009), and presented in Table 3-7 and Figure 3-14. For the critical stresses only single literature values applicable for the Olkiluoto site are available (Table 3-8). They are expected to be valid, since the description of the sediment type corresponds to the properties of surface sediments in offshore Olkiluoto observed in sediment cores in 2008 (Ilmarinen et al. 2009, and a report on offshore sediment cores pending the chemical analysis results).

Table 3-6. *Annual flux of suspended matter (kg/y) in rivers in 1995-2007 (Environmental information and spatial data service - OIVA portal, May 4, 2009).*

	Lapinjoki, Ylinenkoski	Eurajoki, Pappilankoski
Mean	$1.20 x10^6$	$7.75 x10^6$
Maximum	$2.44 x10^6$	$11.64 x10^6$
Minimum	$0.19 x10^6$	$1.36 x10^6$

Table 3-7. *Probability (%) of hourly wind directions by speed class and mean and maximum hourly wind speeds (m/s) at Olkiluoto in 1993-2008 (Ikonen 2002, 2005, 2007a, Haapanen 2008, 2009). – denotes no observations in the class.*

	N	NE	E	SE	S	SW	W	NW	Any sector
Calm (0–1 m/s)	0.43	0.34	0.32	0.29	0.19	0.18	0.16	0.23	2.14
Weak (1–3)	5.66	4.70	5.23	8.28	6.87	4.45	3.65	4.73	43.57
Moderate (4–7)	6.75	3.39	3.71	6.28	11.12	7.38	3.85	4.96	47.43
Hard (8–13)	1.63	0.09	0.06	0.14	2.02	1.50	0.61	0.74	6.80
Gale (14–21)	0.05	–	–	–	0.00	0.00	0.00	0.00	0.07
Storm (>21)	–	–	–	–	–	–	–	–	–
Any speed class	14.5	8.5	9.3	15.0	20.2	13.5	8.3	10.7	100.0
Mean speed (m/s)	4.5	3.3	3.3	3.4	4.5	4.6	4.1	4.1	4.1
Max. speed (m/s)	16.8	12.4	10.6	10.3	14.6	14.3	14.4	14.6	16.8

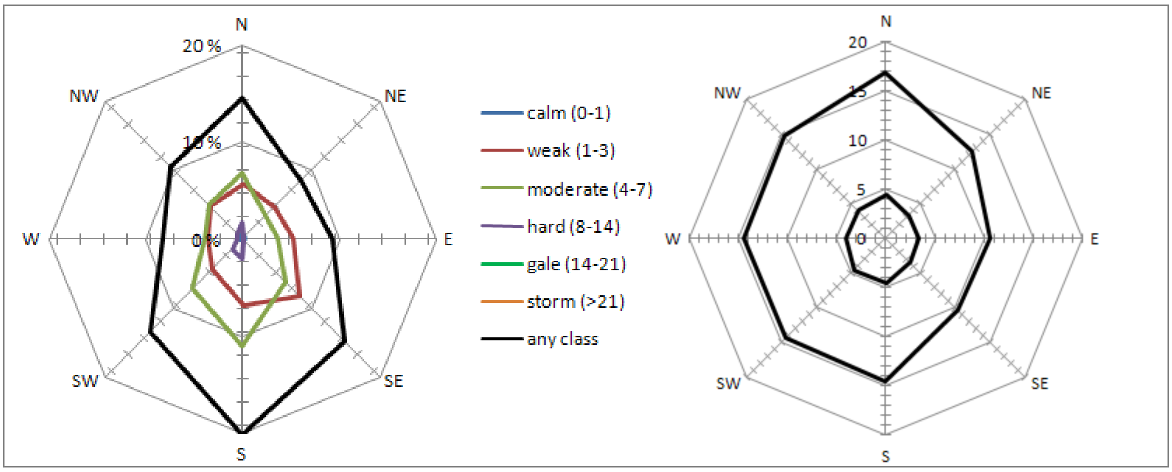

Figure 3-14. *Occurrence of wind speed classes (hourly average, m/s) and direction (left), and maximum and mean wind speed (m/s) by sector (wind blowing from, 45° sectors) (right) at Olkiluoto, 1992–2008 (Haapanen 2009).*

Table 3-8. *Critical shear stresses (N/m²).*

Sediment	Erosion	Sedimentation	Reference	Comments
Fine silt (fine-grained sand)	0.05	0.045	Huttula (1994) citing Podsetchine & Huttula (1994)	Found suitable for Lake Pyhäjärvi, represents the value for future lakes at Olkiluoto

3.3 Other site and regional input data

3.3.1 Initial overburden thickness

The development of the overburden 3D model has been initiated in 2009. As a major conceptual prerequisite to the overburden modelling and interpreting the various data, the assumed stratigraphical order is presented here in Figure 3-15. It is based on expert judgement and review of the relevant information, and has been further developed from that presented in Posiva (2003).

To combine different classifications to correspond the conceptual model, Table 3-9 has been compiled based on expert judgement and available documentation on the classifications used. The main assumptions have been:

- On dry land the tills have been categorised into gravelly, sandy and fine-textured, but corresponding data from the sea bottom is lacking and all these have been merged, although the sub-division should be applied where possible due to the different chemical properties.
- There are some observations of compact till from small-scale soil studies in Olkiluoto, but this class is lacking from surveys on larger areas.
- Glacioaquatic mixed sediment means material deposited near to glacier that could not be classified with the acoustic seismic equipment used (Rantataro & Kaskela 2010).
- In the sea-bottom clays glacial, Ancylus and Litorina types have been separated, but terrestrial classifications have only one type even though these types have different geotechnical and geochemical properties. When possible, these should be treated separately or at least divided into Litorina and Ancylus/glacial clay.

    - Glacial clays have been deposited in the melting phase of the glacier. They have a varved structure and are low in organic matter, sulphides and salts, and thus suitable e.g. for brick manufacturing unlike the post-glacial clays.
    - Ancylus and Litorina clays have been deposited in somewhat warmer climate and higher salinity than the glacial clays. In Ancylus clays the sulphide content is high, and in Litorina clays have higher content of organic matter.
- Gaseous sea-bottom sediments have been classified as mud/gyttja. These include sediments with methane of both biogenic and thermogenic origin and cannot be readily classified into decomposing layers and those receiving gaseous releases from bedrock fractures. In some closeby areas similar sounding results have been obtained from decomposing algae mats confirmed by diving.

In this report, no ready datasets on the overburden type and thickness are given; they are left for the further assessment as many judgements and assessment decisions are required to fill in lacking data. For the use, following datasets are recommended to be merged in the order of decreasing reliability for the purpose:

- soil sampling points, especially deep excavator pits (for summary, see respective sections in Haapanen et al. 2009)
- forest compartment and sampling plot surveys (Rautio et al. 2004, Tamminen et al. 2007),
- sea bottom acoustic-seismic sounding data (Rantataro 2001, 2002, Rantataro & Kaskela 2010),
- delineations of the geological investigation trenches in Olkiluoto (totally mixed soil),
- national soil map of Geological Survey of Finland,
- landscape database of National Land Survey (fields, constructed areas, uncovered bedrock outcrops),
- rather coarse data from the farther area lacking any other from the BALANCE project (Al-Hamdani et al. 2007).

Tillage/other man-made layer		Anthropogenic
Peat/humus		Organic layer
Recent mud/clay/gyttja		In water or moist base after the Litorina Sea stage
Litorina clay		Deposition during the Litorina Sea stage
Ancylus clay		Deposition during the Ancylus Lake stage
Glacial clay		Deposition during the melt of the glacier
Fine-grained till, sand, or mixed glacio-aquatic sediment		Glacio-fluvial; at the margin of the glacial ice sheet, or, effect of littoral forces and rivers
Washed (coarse/medium-grained) till		Glacier activity on or in the glacier, or at its margin
Compact till		Glacier activity under the glacier
Weathered rock		*In situ* weathered rock
Precambrian bedrock	Jotnian sandstone	
Stratum		**Notes on the origin**

Figure 3-15. *Interpreted standard stratification order of overburden at Olkiluoto. Not all layers are present in every point, and layers can be missing from between.*

***Table 3-9.** Soil and sediment type classifications in different datasets and the corresponding type in conceptual model applied in the biosphere assessment (based on expert judgement, see the text).*

Soil/sediment type in assessment	Sea bottom acoustic-seismic data		Forest surveys (Rautio et al. 2004, Tamminen et al. 2007)	Soil map of Geological Survey
	Rantataro 2001, 2002	Rantataro & Kaskela 2010		
Earthfill	-	Earthfill	-	Earthfill
Peat	-	-	Peat (sedge and sphagnum peat)	Peat (sedge and Sphagnum peat, peat harvest areas*)
Mud/gyttja	Recent gyttja clay/mud	Recent gyttja/clay/mud Gaseous sediment	-	Gyttja clay Mud
Litorina clay	Litorina clay	Litorina clay	Clay	Clay
Ancylus clay	Ancylus clay	Ancylus clay		
Glacial clay		Glacial clay		
Fine sand and silt	-	-	-	Medium fine sand Fine sand Very fine sand/silt
Sand and gravel	Sand and gravel Washed sand layers	Sand and gravel Washed sand layers	-	Gravel Sand
Fine till	Till Mixed glacio-aquatic sediment	Till Mixed glacio-aquatic sediment	Fine-textured till	Fine-textured till
			Sandy till	Sandy till
Washed till			Gravelly till	Gravelly till
Bedrock	Bedrock Sedimentary rock	Bedrock Sedimentary rock	Exposed bedrock	Bedrock Boulders Stones

* Usually some peat is left to remain to avoid mixing with the basement material in the harvest.

3.3.2 Water bodies, runoff formation and flow rates

Runoff formation and identification of lakes and streams

In lack of more hydrologically detailed model, the UNTAMO runoff formation model assumes that also in the future, the properties of the catchments of the rivers are similar than those of the two main river at present; this means that the land use, vegetation, soil types, and structure and water exchange in the upstream network should be about the same, as well as the climate. In the model, this is parameterised as applying effective rainfall constant, defined as the fraction of the annual rainfall into the catchment area appearing as the river mean discharge. These can be simply calculated from the data of Table 3-2 (section 3.2.2): On the part of the catchment area of Lapinjoki River that is above the discharge measurement point, 0.532 $m^3/y/m^2 \cdot 438\ km^2 = 233\,016\,000\ m^3/y$ of rain is falling. Of it, 3.3 $m^3/s = 104\,068\,800\ m^3/y$ is appearing as mean discharge of the river. Thus the effective rainfall constant for the Lapinjoki catchment is simply $(233\,016\,000\ m^3/y) / (104\,068\,800\ m^3/y) = 0.447$. Similarly, a value of 0.400 can be derived for Eurajoki River, but for the assessment use the value for Lapinjoki is preferred since its catchment resembles more those expected to form at the Olkiluoto site in the future.

On the basis of the topographical flow accumulation results and the conversion to river discharge, the stream network can be identified as cells having flow accumulation higher than a threshold value. This value depends on the needs of the interface to the surface hydrology model and to the radionuclide transport modelling: the former needs rather small-featured data whereas the latter has serious computational limitations as compartment models are needed to be formed from each stream segment. Thus, setting the value is best left as a practical assessment decision.

In order to take into account the catchment areas of rivers extending outside of the model area, boundary conditions are needed to be set for their mean discharge. This is of course specific the delineation of the model area - the area of the terrain model (Pohjola et al. 2009; section 3.2.1) is used here. Above, Table 3-2 presents data for the discharge of the two main rivers. As the measurement points are not at the model area boundary (Table 3-3), the values need to be adjusted to take into account the part of the catchment between the measurement points and the modelling area. This is done by scaling with the change in the catchment area, in practise the same approach as utilised to derive the effective rainfall constant value just above. The areas used here have been calculated on the basis of terrain model calculated to 10 m spatial resolution from the landscape database of National Land Survey. The results are presented in Table 3-10.

Table 3-10. *Mean annual discharge for Eurajoki and Lapinjoki Rivers scaled from data in Table 3-2 to correspond the full catchment area outside of the UNTAMO modelling area (see the text) with the respective coordinate points of the boundary condition (Finnish KKJ1 coordinate system).*

	Discharge		Catchment area *	Easting	Northing
	(m^3/y)	(m^3/s)	(km^2)		
Eurajoki	283 330 000	8.98	1 331.451	1534892	6790641
Lapinjoki	233 016 000	2.55	443.320	1534894	6785582

* Outside the model area; corresponding to the discharge values.

It should be noted that not all ditches and other smaller streams are identified with these parameters as more detailed simulation would be excessively heavy in computation. Thus care needs to be taken to adequately compare the UNTAMO simulations with the results of the surface and near-surface modelling. On the other hand, unmanaged ditches fill in with time, about 3 cm/year in the area of the Southwest Finland Forestry Centre (Silver & Joensuu 2005), which is not taken into account in the model.

The identification of lakes is parameterised to be done based on the minimum average water depth. This is best calibrated against the water bodies at present, utilising the base map information (section 3.4).

Width and cross-section type of streams

For determining the width of a river from its measured or modelled discharge, preferably for different cross-section types (i.e. bottom soil types), a map and aerial photo analysis was planned but not realised due to the limited resources available. This would improve the overall understanding of the relationship of the parameters, but is not essential from the view of radionuclide transport modelling which is the user of the predicted river width from the UNTAMO forecasts; the flow rate has far more effect to the radionuclide concentrations in the model.

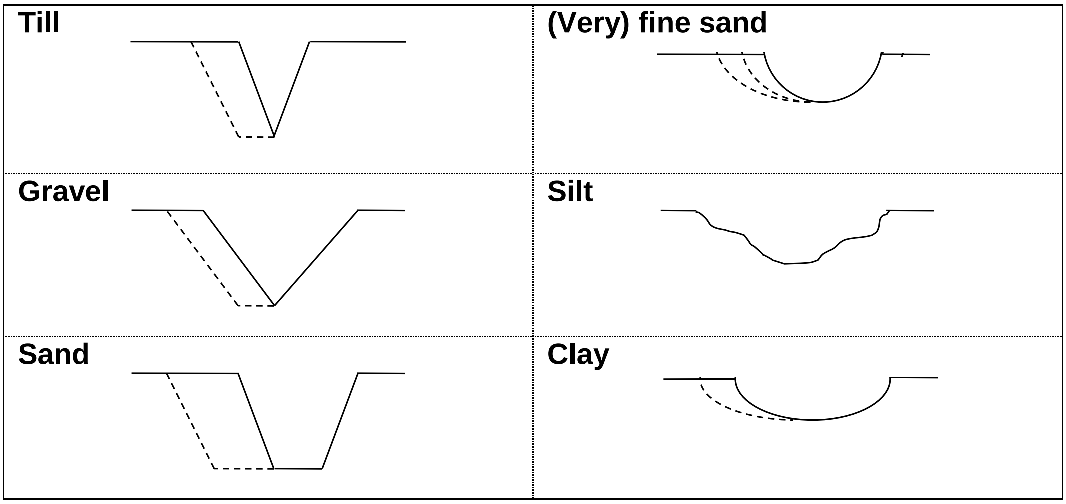

Figure 3-16. *River channel cross-section shapes and their enlargement types on different bed sediment types (redrawn from Aartolahti 1979).*

On the shapes on the stream cross sections, there are more data available. Generic text book examples are presented in Fig. 3-16. Also, in Laxemar, Sweden, stream cross-sections have been measured, ranging from triangular shapes to more circular or almost rectangular (fig. 2-1 in Jonsson & Elert 2006).

Different channel geometries result in different values on the hydraulic radius *R* and thus the radionuclide transfer rates (in model of Jonsson & Elert 2005, similar to the radionuclide transport models used by Posiva), but the variation due to the different cross-section shapes is most probably of minor importance in respect of the radionuclide transport modelling. However, the difference increases with increasing discharge.

On the future river channels at Olkiluoto, the cross-section is most likely trapezoidal on largest part of the area (mineral bottoms) and elliptical on thick enough clay deposits (organic bottoms); Fig. 3-16. Thin layers of finer sediments affect only to their thickness unless eroded away with shoreline displacement. On rock bottoms, the topography of the rock surface essentially determines the shape of the cross-section since the erosion is minor. Measurement data of cross sections of Eurajoki River, obtained from the Finnish Environment Institute rather late for this project, appear to support this view, even though detailed analysis has not yet been done.

Related to Eq. (3-4) above, the depth of the channel, *D* (m), on mineral bottoms is then

$$D = \frac{s}{2}\left(W + \sqrt{W^2 - \frac{4A}{s}}\right) \qquad \text{(Eq. 3-8)}$$

where *A* is the flow-determined cross-section area (m^2), *s* the slope of the immersed bank (m/m; drop per distance from shoreline) and *W* is the width of the river channel (m). Thus, also $D = sx$ where x is half of the difference between the channel width at the surface and at the bottom. For the organic bottoms, the depth is

$$D = \frac{2A}{\pi W} \qquad \text{(Eq. 3-9)}$$

Respectively, the wetted perimeter, P (length of the cross-section in contact with the water) for the mineral bottoms is as

$$P = 2\left(\sqrt{2} - 1\right)\frac{D}{s} + W \approx 0.8284\frac{D}{s} + W \qquad \text{(Eq. 3-10)}$$

and for organic bottoms, using the Ramanujan's approximation,

$$P = \frac{\pi}{2}\left[3\left(\frac{W}{2} + D\right) - \sqrt{\left(\frac{3W}{2} + D\right)\left(\frac{W}{2} + 3D\right)}\right] \qquad \text{(Eq. 3-11)}$$

The parameter s is usually somewhat difficult to determine, similarly to the $W - 2D/s$ (the width of the channel at bottom), especially since in the nature the bottom is not even and does not have a distinct, measurable width. However, the detailed dimensions of the channel seldom matter as much as the flow cross-section area - this is valid also to the radionuclide transport modelling - and thus some characteristic values for s are adequate. For slopes of earth piles, some generic estimates are available for the naturally stabile slope (friction angle), presented in Table 3-11. However, in many places, the roots of vegetation bind the soil, and practically upright river banks exist.

Table 3-11. *Generic estimates of maximum stabile slopes for soil types in Finland.*

Soil type	Angle, °	Slope, m/m	Reference
Silty till	29 [a]	0.55	Korkiala-Tanttu et al. 2008
Sandy till	32 [a]	0.62	Korkiala-Tanttu et al. 2008
Gravelly till	34 [a]	0.67	Korkiala-Tanttu et al. 2008
Till	37 [b]	0.75	VTT 1999
Silt	27 [a]	0.51	RIL 1988
Sand	32 [a]	0.62	VTT 1999
Sand	30 [a]	0.58	RIL 1988
Sand (dry)	50	1.2 [c]	RIL 1988
Gravel	38 [b]	0.78	VTT 1999
Gravel	32 [a]	0.62	RIL 1988
Gravel (compact)	30	0.58 [c]	RIL 1988
Clay (dry)	40	0.84 [c]	RIL 1988
Clay (wet)	65	2.1 [c]	RIL 1988
Sandy clay	45	1.0 [c]	RIL 1988

a Loose material.
b Medium compactness.
c Reference value for ordinary excavation banking.

Till slopes start to loose their stability at 30-35° and finer sand at around 30°. Thus, a value of 0.6 m/m can be used for s in the context of the Olkiluoto site, dominated by fine and medium-grained tills.

3.3.3 Terrestrial vegetation

The data needed for the simpler forest site classification are given already above as key data in Table 3-4 (section 3.2.3). For the alternative model using the Bayesian vegetation prediction (section 3.1.4), the datasets of (Saramäki & Korhonen 2005) and (Tamminen et al. 2007) provide the needed input data for the teaching data (biomasses and soil types). For the groundwater table prediction, calibration data is presented later in section 3.4, and for the local solar intensity model no site-specific data is needed.

3.3.4 Aquatic vegetation

Reed bed extent is currently the only sub-model concerning aquatic vegetation. Its parameters are to be defined by calibration of the model to site data, see section 3.4.

3.3.5 Terrestrial erosion and sedimentation

In addition to the key data presented in section 3.2.5, other data are provided here for the peat growth model. The rather scarce data for the terrestrial erosion-sedimentation model are provided here as well.

Peat growth model

In order to sustain peat-producting vegetation the groundwater table should be around 0.1 m, by expert judgement. For the future assessments, the value should be established better by comparing groundwater table estimates to vegetation mapping. In water bodies no peat formation should be occurring.

For the hydraulic constraints in the model, the hydraulic conductivity of peat should be taken to be consistent with the surface and near-surface hydrological modelling, see section 4.2.2. The water discharge from the bog (parameter U) should be determined by water balance calculations, either for each bog separately or at least as a regional estimate for the model area. These simulations are out of the scope of this report.

In the model, existing peat bogs and their formation times also could be given as base points. However, such areas are few in the model area and practically absent where direct contamination is expected (by comparing the base map to results of (Karvonen 2009c). Thus no data are provided here. Minimum base area and length of the wave area buffer (distance from shoreline where peat formation cannot occur due to physical exposure) are left for assessment decisions, since the most appropriate values are dependent on the landscape model set-up and performance of the radionuclide transport simulations.

Terrestrial erosion-sedimentation model

Tattari & Bärlund (2001) have used soil erodability factors (K) from 0.15 to 0.30 in sensitivity analyses of a runoff model for Finnish conditions. Typical erosion processes in Finland are sheet, rill and tillage erosion. During and after the snowmelt, rill erosion is the dominant process (Tattari & Rekolainen 2006). Usually more than half of the erosion occurs during the winter, especially at snowmelt (Tattari & Bärlund 2001, Tattari & Rekolainen 2006), and thus the rill mode of the model is likely more applicable. No data on values for erosivity factor (*R*) or cover and management factor (*C*) applied to Finnish conditions were found, and the authors have no experience on the validity of generic literature values. The former, however, could be basically calculated from the meteorological observations, but the process (e.g. Johnson 1970, van Dijk et al. 2002, Davison et al. 2005) is rather complicated in respect of the significance of the parameter in the overall assessment.

For soil bulk density, there seems to be a general lack of directly suitable data; the only soil density data from Olkiluoto appears to be *particle densities* (Lintinen et al. 2003), which cannot be used for the present purpose without the porosity values, which were not measured at the time. The closest data are from the Forsmark site, Sweden (Lundin et al. 2004, Lindborg 2008 table 4-8 referring to Lundin et al. 2005), which have been complemented with literature data. However, obtaining bulk density values is rather straightforward and inexpensive, and thus sampling and measurements on soil types found in Olkiluoto has commenced.

The soil bulk density data found are presented in Table 3-13 together with respective data on soil carbon concentrations needed for radionuclide transport modelling (section 5.3.7), and the calculated statistics of soil bulk densities is presented in Table 3-12.

Table 3-12. *Statistics of soil bulk density (g/cm³) data presented in Table 3-13.*

Soil type	Mean	Min.	Max.	Std	N
Peat	0.082	0.064	0.148	0.016	26
Silt	*	1.7	2.0		
Fine sand	*	1.7	2.0		
Sand	1.6	1.4	2.0	0.25	5
Fine-grained till	1.8	1.2	2.3	0.35	39
Washed till	1.6	0.4	2.3	0.43	105

* Only minimum and maximum values available from handbook sources, see Table 3-12.

Table 3-13. *Soil bulk density and carbon concentration data collected from Olkiluoto (KK series), complemented with site-relevant literature values (f-g, fine-grained).*

Reported soil type	Sample, depth	Bulk density (g/cm^3)	Carbon conc. ($\%_{dw}$)	Reference
Peat				
Isokeidas	1.9 m	0.0776		Toivonen & Valpola 2007
Ruikusuo	1.2 m	0.0901		
Isoneva	2.6 m	0.0696		
Oravasuo	1.6 m	0.098		
Huhtainsuo	1.4 m	0.0845		
Levissuo	1.3 m	0.0946		
Kyläneva	1.4 m	0.0738		
Kiimasuo	1.6 m	0.0847		
Tervalamminneva	1.9 m	0.072		
Aukeakeidas	1.4 m	0.073		
Susihonganneva	1.5 m	0.0862		
Harjaneva	2.0 m	0.0759		
Heinäneva	2.1 m	0.0653		
Saarineva	2.4 m	0.0635		
Ympyriäiskeidas	2.1 m	0.0734		
Pänsäri	1.7 m	0.1477		
Mateenkeidas	1.2 m	0.0704		
Pomarkku, mean		0.082		
3670 bog sites		0.089		Mäkilä 1997
6 bog sites		0.072	51	
Fens		0.093		
548 bog sites		0.074	50	Tolonen & Turunen 1996
373 fen sites		0.081		
927 bog sites		0.074	50	Turunen et al. 2002
375 fen sites		0.081		
180 fen sites		0.082	53.9	Minkkinen & Laine 1998
3670 bog sites			50.5	Virtanen et al. 2003

Table 3-13 (contd'). Soil bulk density and carbon concentration data collected from Olkiluoto (KK series), complemented with site-relevant literature values (f-g, fine-grained).

Reported soil type	Sample, depth	Bulk density (g/cm^3)	Carbon conc. ($\%_{dw}$)	Reference
Clay				
Clay	KK14, 1.05-2.4 m		0.18	Lahdenperä 2009
Clay	KK15, 1.1-1.6 m		0.23	
Clay	KK18, 2-2.2 m		0.18	
Clay	KK19, 2-2.35 m		0.14	
Silt				
Silt		1.7-2.0		Korhonen 1963 *
Fine sand				
Fine sand		1.7-2.0		Katamäki et al. 1979
Fine sand		1.7-2.0		Korhonen 1963 *
Fine sand	KK15, 0.8-1.1 m		0.18	Lahdenperä 2009
Sand				
sand	KK15 0.07-0.5 m		0.22	Lahdenperä 2009
sand, coarse	KK16 0.1-0.3 m		0.64	
sand	KK16 0.3-0.5 m		0.14	
sand, mixed	KK16 0.5-1.1 m		0.13	
sand, gravelly		1.6		Lindborg 2008
sand, gravelly		2.0		
sand, Ancylus	225-232 cm	1.3-1.8	0.43	Ojala 2007
sand, Ancylus	442-448 cm	1.4	0.35	
sand, Yoldia	651-657 cm	1.38	0.46	
Fine-grained till				
sandy till	KK14 0.05-0.2 m		0.2	Lahdenperä 2009
sandy till	KK14 0.2-0.6 m		0.27	
sandy till	KK14 0.6-1.05 m		0.13	
f-g silty/clayish till	KK15 0.5-0.8 m		0.33	
sandy till	KK16 1.1-3 m		0.13	
sandy till	KK17 0.3-0.46 m		0.41	
sandy till	KK17 0.46-0.82 m		0.12	
f-g clayey till	KK18 0.2-2 m		0.07	
f-g clayey till	KK19 0.2-2 m		0.11	
fine-grained till, sand or mixed glacio-aquatic sediment	S1:3 0-10 cm	1.52		Lundin et al. 2004
	S1:3 10-20 cm	1.43		
	S1:3 20-30 cm	1.34		
	S1:3 30-40 cm	1.31		
	S1:3 40-50 cm	1.8		
	S1:3 50-60 cm	2.25		
	S1:7 0-10 cm	1.52		
	S1:7 10-20 cm	1.69		
	S1:7 20-30 cm	1.64		
	S1:7 30-40 cm	1.77		
	S1:7 40-50 cm	1.86		
	SS2:10 0-10 cm	2.25		
	SS2:10 10-20 cm	1.37		
	SS2:10 20-30 cm	1.15		
	SS2:10 30-40 cm	1.49		
	SS2:15 0-10 cm	1.75		
	SS2:15 10-20 cm	1.37		
	SS2:15 20-30 cm	1.34		
	SS2:15 30-40 cm	1.29		
	SS2:15 40-50 cm	1.23		
	SS2:15 50-60 cm	1.48		

* As cited in (Heiskanen 2003).

Table 3-13 (contd'). ***.*** *Soil bulk density and carbon concentration data collected from Olkiluoto (KK series), complemented with site-relevant literature values (f-g, fine-grained).*

Reported soil type	Sample, depth	Bulk density (g/cm³)	Carbon conc. ($\%_{dw}$)	Reference
Fine-grained till, cont'd				
sandy till		2.04		Lindborg 2008
sandy till		<2.3		
sandy/clayey till		2.1		
sandy till		1.6		
sandy till		1.9		
sandy till		2		
sandy till		2		
sandy till		1.9		
sandy/clayey till		2.1		
sandy till		2		
sandy till		1.9		
sandy till		2.1		
sandy till		2.2		
sandy till		2.2		
sandy/clayey/silty		2.2		
sandy till		2.1		
sandy till		2.1		
sandy till		2.2		
sandy till		2.3		
Washed till				
coarse sandy till	KK15 1.6-3 m		0.14	Lahdenperä 2009
coarse/medium-grained sediment	A1:1 0-10 cm	1.11		Lundin et al. 2004
	A1:1 10-20 cm	1.21		
	A1:1 20-30 cm	1.31		
	A1:1 30-40 cm	1.42		
	A1:1 40-50 cm	1.55		
	A1:1 50-60 cm	1.51		
	A1:14 0-10 cm	1.25		
	A1:14 10-20 cm	1.44		
	A1:14 20-30 cm	1.56		
	A1:14 30-40 cm	1.41		
	A1:14 40-50 cm	1.43		
	B2:1 10-20 cm	1.64		
	B2:1 20-30 cm	1.62		
	B2:1 30-40 cm	1.79		
	B2:1 40-50 cm	2.12		
	B2:1 50-60 cm	2.24		
	B2:5 10-20 cm	1.12		
	B2:5 20-30 cm	1.33		
	B2:5 30-40 cm	1.79		
	B2:5 40-50 cm	1.7		
	B2:5 50-60 cm	1.79		
	B3:1 0-10 cm	0.81		
	B3:1 40-50 cm	1.32		
	B3:1 50-60 cm	1.4		
	B3:2 0-10 cm	0.57		
	B3:2 10-20 cm	0.71		
	B3:2 30-40 cm	1.4		
	B3:2 40-50 cm	1.46		
	B3:2 50-60 cm	1.39		
	FG1:1 10-20 cm	1.64		
	FG1:1 20-30 cm	1.95		

Table 3-13 (contd'). Soil bulk density and carbon concentration data collected from Olkiluoto (KK series), complemented with site-relevant literature values (f-g, fine-grained).

Reported soil type	Sample, depth	Bulk density (g/cm³)	Carbon conc. (%$_{dw}$)	Reference
Washed till, cont'd				
coarse/medium-grained sediment	FG1:1 40-50 cm	2.05		Lundin et al. 2004
	FG1:1 50-60 cm	2.04		
	FG1:13 10-20 cm	1.99		
	FG1:13 20-30 cm	2.19		
	FG1:13 30-40 cm	2.1		
	FG1:13 40-50 cm	1.91		
	FG1:13 50-60 cm	2.3		
	FG2:1 20-30 cm	1.7		
	FG2:1 30-40 cm	1.69		
	FG2:6 0-10 cm	1.35		
	FG2:6 10-20 cm	1.44		
	FG2:6 20-30 cm	1.69		
	FG2:6 30-40 cm	1.56		
	FG2:6 40-50 cm	1.71		
	FL1:15 0-10 cm	0.58		
	FL1:15 20-30 cm	1.51		
	FL1:15 30-40 cm	1.88		
	FL1:15 40-50 cm	1.88		
	FL1:15 50-60 cm	1.86		
	FL1:6 0-10 cm	0.73		
	FL1:6 20-30 cm	1.76		
	FL1:6 30-40 cm	1.93		
	FL1:6 40-50 cm	2.07		
	FL1:6 50-60 cm	2.05		
	FL2:1 0-10 cm	1.01		
	FL2:1 10-20 cm	1.03		
	FL2:1 20-30 cm	1.52		
	FL2:1 30-40 cm	1.41		
	FL2:1 40-50 cm	1.2		
	FL2:13 0-10 cm	1.04		
	FL2:13 10-20 cm	1.19		
	FL2:13 20-30 cm	1.58		
	FL2:13 30-40 cm	1.55		
	FL2:13 40-50 cm	1.63		
	FL2:13 50-60 cm	1.66		
	R1:1 0-10 cm	0.42		
	R1:1 30-40 cm	1.65		
	R1:1 40-50 cm	1.46		
	R1:1 50-60 cm	1.36		
	R1:14 0-10 cm	0.35		
	R2:1 0-10 cm	0.6		
	R2:1 10-20 cm	1.82		
	R2:1 20-30 cm	1.72		
	R2:13 0-10 cm	0.46		
	R2:13 20-30 cm	1.41		
	R2:13 30-40 cm	1.5		
	R2:13 40-50 cm	1.78		
	S2:1 0-10 cm	1.28		
	S2:1 10-20 cm	1.78		
	S2:1 20-30 cm	1.81		
	S2:1 30-40 cm	2.1		
	S2:1 40-50 cm	2.03		

Table 3-13 (contd'). Soil bulk density and carbon concentration data collected from Olkiluoto (KK series), complemented with site-relevant literature values (f-g, fine-grained).

Reported soil type	Sample, depth	Bulk density (g/cm^3)	Carbon conc. ($\%_{dw}$)	Reference
Washed till, cont'd				
coarse/medium-grained sediment	S2:8 0-10 cm	1.3		Lundin et al. 2004
	S2:8 10-20 cm	1.48		
	S2:8 20-30 cm	1.31		
	S2:8 30-40 cm	1.89		
	S2:8 40-50 cm	1.9		
	S2:8 50-60 cm	2.03		
	SS1:1 0-10 cm	1.34		
	SS1:1 10-20 cm	1.52		
	SS1:1 20-30 cm	1.97		
	SS1:1 30-40 cm	1.97		
	SS1:1 40-50 cm	1.99		
	SS1:1 50-60 cm	1.76		
	SS1:11 0-10 cm	1.55		
	SS1:11 10-20 cm	1.99		
	SS1:11 20-30 cm	1.95		
	SS1:11 30-40 cm	1.99		
	SS1:11 40-50 cm	1.98		
	SS1:11 50-60 cm	1.99		
gravelly till		2.15		Lindborg 2008
		<2.2		
		2.1		
		2.2		

3.3.6 Aquatic erosion and sedimentation

Data for the accumulation rate of gyttja to reed beds have already been addressed as key data in section 3.2.6, and the key data for the fetch-based aquatic erosion-sedimentation model in section 3.2.7. In this section, data for the simple sedimentation model for lakes are provided.

As described in section 3.1.5 above, model begins with a coastal or a lake basin that exists before the wave-wash phase starts, i.e. a basin with a bottom consisting of till or postglacial clay. First, the basin fills up with 4 % of the initial volume by silty sand. Then, until at least 18 % of the former basin volume consists of fine-grained shallow gulf sediments, each year the basin is supplied with fine-grained inorganic sediments with a volume rate fitted to observation data as a function of the water volume, given here below. If the basin has bottom areas located below two meters water depth, all new sediments are placed there; otherwise the new sediments are spread evenly over the entire lake. The successive shallowing is calculated by dividing the sediment volume with the water area above the deposition locations.

The parameter values mentioned above are taken as generic values inherent to the model. The more site-specific part is the actual sedimentation rate function of water volume. In accordance to the intended use of the model as an indicative tool only, and as little new information has become available, the data and derivation in (Ikonen 2007b) are considered valid. Thus, the rate function is

$$SR = \begin{cases} 132.25 \times V - 4.6884 \times V^2 & , when \quad V < 14.1 \\ 35.288 \times V + 435.06 & \quad\quad\quad\quad V \geq 14.1 \end{cases} \quad \text{(Eq. 3-12)}$$

where *SR* is the sedimentation rate of the inorganic matter (m^3/y) and *V* the basin volume in Mm^3. The fitting has been done based on the data from (Brydsten 2004) complemented with rates derived from volumes of recent mud deposits calculated from data of (Rantataro 2001) assuming 3500 years of depositing time and the corresponding to basin volumes near Olkiluoto calculated from the terrain model (Ikonen 2007b).

3.3.7 Fauna habitats

As there are no specific models yet for delineating habitats of typical fauna, no detailed data are given either. For development of such models, the discussion in the relevant sections of (Haapanen et al. 2009a) should be taken into account. Furthermore, life history profiles (habits, diet, life cycle) of typical terrestrial and avian fauna have been compied into App. C.

3.3.8 Land use

For the land use, data for delineation of croplands are given, as well as for house predictions. For simulating the formation of main road network, no site or other relevant data are available to define the relative costs of different slope categories or crossing water bodies; these are left as assessment or scenario decisions. However, if the model is tested against the present road network, it should be born in mind that the main roads in the derivation of the housing density data were taken as the road class IIIb or better[6] in the landscape database of the National Land Survey.

Cropland prediction

Croplands are usually established on fine-textured soils containing plenty of nutrients and few stones. The soil thickness must be at least half a metre to secure proper root growth and water availability to plants (Haapanen et al. 2009a, p. 224). Thus, the threshold of minimum soil thickness should be set to 0.5 m.

Suitability of soil types to cultivation of different crops depends on the nutrient and water availability from the soil (Table 3-14; Haapanen et al. 2009a). (Ikonen 2007b) found a good agreement between the present croplands in the Olkiluoto-Eurajoki area and suitability classification of Table 3-15, and section 2.5 of (Haapanen et al. 2009a) provide support to it from a historical perspective of taking land into agricultural use. As there will be large clay areas emerging from the sea especially along the future river valley of Eurajoki while sandy areas remain few and small (Ikonen 2007b, Ikonen et al. 2009a), likely the croplands will be almost solely on clay or gyttja/mud soils, in addition to those available at present.

[6] Class codes LUOKKA 12111, 12112, 12121, 12122, 12131, 12132 in the shapefiles.

Table 3-14. *Soil types and prevailing conditions that are suitable for different crops (re-arranged from table 8-1 in Haapanen et al. 2009a).*

Crop	Soil type	Other conditions
Winter cereals	Clay, sand	Small slope, no water ponds in autumn and winter
Oilseed	Clay, sand	Mineral soils warm enough to ensure maturation
Sugar beet	Clay, sand	Good nutrient levels
Cabbages	Clay, sand	Rich in nutrients and good water availability
Other vegetables	Sand	Rich in nutrients and good water availability
Potato	Sand	pH (5–6), good nutrient levels and water availability
Carrot	Sand, organic	Loose soil, warm enough for late carrot cultivars
Barley	All	Soil pH >6, satisfactory soil P level
Oats	All	Grows also in low pH (5–6) and on cool organic soils
Grass	All	Tolerant for most soil conditions

Table 3-15. *Suitability of some soil types for different uses (Ikonen 2007b). Applied and cropped from (Haavisto-Hyvärinen & Kutvonen 2007, GSF 2005). 0 = unsuitable, 1 = poor, 2 = medium, 3 = good.*

Soil type	Agriculture			Infrastructure	
	Cereals	Root crops	Grassland, pasture	Building	Construction materials
rock	0	0	0	3	1
till	0	0	0	3	0
gravel	0	0	0	3	3
fine till	1	2	2	3	0
sand	1	1	1	2	1
clay	3	3	3	1	2
gyttja	3	1	2	0	0
Carex peat	1	2	2	0	0
Sphagnum peat	0	0	0	0	0

For the advanced version of cropland prediction, several other inputs such as relative fertility of soil types, groundwater depth and terrain slope could be used to refine the prediction, together with the target value of the area of croplands to be delineated. However, this approach is not used in BSA-2009 since the simpler method produces adequately realistic results; the advanced version is more useful in alternative land-use scenarios where the agricultural intensity is needed to be controlled as a scenario parameter.

House prediction

To test the simpler version of the house prediction tool, Ikonen et al. (2008b) derived weighting distributions of housing density from the present dry land in their modelling area of 908 existing houses based on the landscape database of National Land Survey. The results are presented in Fig. 3-17. Even though the area is rather small, 184 km², these are judged to represent the area around the Olkiluoto site well enough.

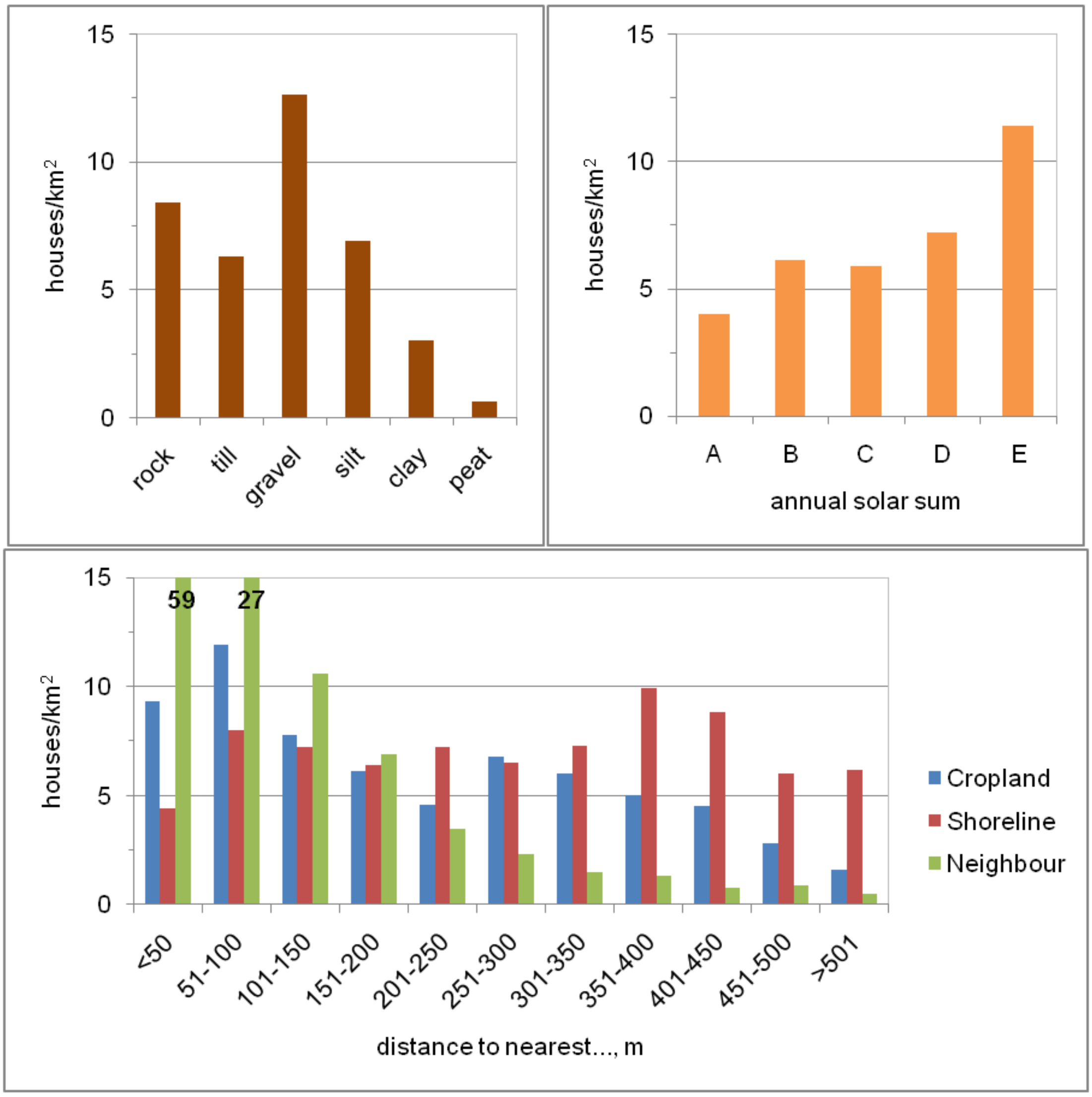

Figure 3-17. *Weighting distributions of housing density (houses/km²) derived from present land areas nearby the Olkiluoto site (Ikonen et al. 2008b). Annual solar sum is presented as classes with increments of 20 000, with class A being <784 410 and class E >844 411 index units.*

As an improvement, data have been compiled to produce separate weighting distributions for dense and scattered housing, and permanent and holiday housing within them. The input data for the study are

- residential building database of Population Register Centre,
- topographic database of National Land Survey (license no. 41/MYY/10) for roads and areas excluded from residential buildings (see below),
- protected areas and protection programme areas of Finnish Environment Institute, and
- grid database of population density of Statistics Finland only as a visual aid.

First, areas of untypical housing structure were excluded from the analysis. They include

- protection area around the Olkiluoto nuclear power plant, and other non-residential areas in the February 2008 draft of component master plan of Olkiluoto,
- nature protection areas and shooting ranges marked on the base maps of National Land Survey,
- protected areas and protection programme areas of Finnish Environment Institute, such as nature reserves and areas under shore protection programmes.

After that, densely built areas were delineated by visual interpretation first aided by the grid database of Statistics Finland and then more detailed with help of the base map data. Cropland areas were excluded from the analysis due to the preference of cultivation of best soils. Also all water bodies (sea, lakes larger than 1 ha [7], rivers broader than 5 m) were excluded. The delineation of the areas resulted in

- densely built area of 4 km^2 having 676 permanently settled and 4 holiday houses,
- area of scattered settlement of 166 km^2 having 568 permanent and 29 holiday residential buildings,
- excluded area of 104 km^2, mainly water bodies and fields.

The derived weighting distributions are presented in Table 3-16. The distributions were fitted to the data by the Kolmogorov Smirnov (KS) quality statistic method and have already been normalised so that the value represents the probability (fractional number of houses) for a house to be located on a grid cell having the specified property. Roads in this analysis correspond to the level IIIb or better in the base map database of National Land Survey.

To analyse the difference in housing density between the densely built and scattered areas, a 250x250 m^2 grid was established and number of houses in each were calculated (Fig. 3-18). There is an overlap, but distinctively in the scatteredly inhabited area there are no cells with 5 permanent houses or more per grid cell. As the parameters of the grid size and the threshold density are intimately tied to the derivation of the desirability data, a town (village centre) should form when the number of permanently inhabited houses exceeds 5 per a 250x250 m^2 grid cell.

[7] Smaller lakes are unlikely to accommodate more than single house.

Table 3-16. *Normalised weighting distributions (the full integral equals 1) derived from the present housing pattern in Eurajoki, around the Olkiluoto site.*

Dependency	Distribution type	Distribution parameters	Truncation limits	N
Permanently inhabited houses in areas of scattered housing				
UNTAMO solar index	Weibull	α = 5.6711 β = 1.0378x10^6	2.5x10^5; 1.3x10^6	568
Distance to nearest neighbour * (m)	lognormal	μ = 4.77 σ = 0.77	10; ∞	536
Distance to nearest cropland (m)	lognormal	μ = 3.6027 σ = 1.0704	10; ∞	568
Distance to nearest main road (m)	lognormal	μ = 4.4126 σ = 1.1456	0; ∞	568
Distance to nearest ** densely built area (m)	gamma	μ = 1.7481 σ = 967.02	0; ∞	568
Distance to nearest water course (m)	Weibull	α = 1.1789 β = 515.45	0; ∞	568
Permanently inhabited houses in densely built areas				
UNTAMO solar index	beta	α_1 = 4.6195, α_2 = 0.70794 lower = 4.3437x10^5 upper = 1.2201x10^6	2.5x10^5; 1.3x10^6	676
Distance to nearest neighbour * (m)	lognormal	μ = 3.6937 σ = 0.38799	0; ∞	676
Holiday houses in areas of scattered housing				
UNTAMO solar index	triangular	a = 5.7691x10^5 mode = 1.0889x10^6 b = 1.1424x10^6	2.5x10^5; 1.3x10^6	29
Distance to nearest neighbour * (m)	exponential	μ = 250.63	10; ∞	27
Distance to nearest cropland (m)	lognormal	μ = 4.0929 σ = 1.1276	10; ∞	29
Distance to nearest main road (m)	Weibull	α = 0.87184 β = 291.69	0; ∞	29
Distance to nearest ** densely built area (m)	lognormal	μ = 7.641 σ = 0.75216	0; ∞	29
Distance to nearest water course (m)	lognormal	μ = 5.1185 σ = 1.3075	0; ∞	29

* Any house existing or placed just earlier.
** To the perimeter of the densely built area.

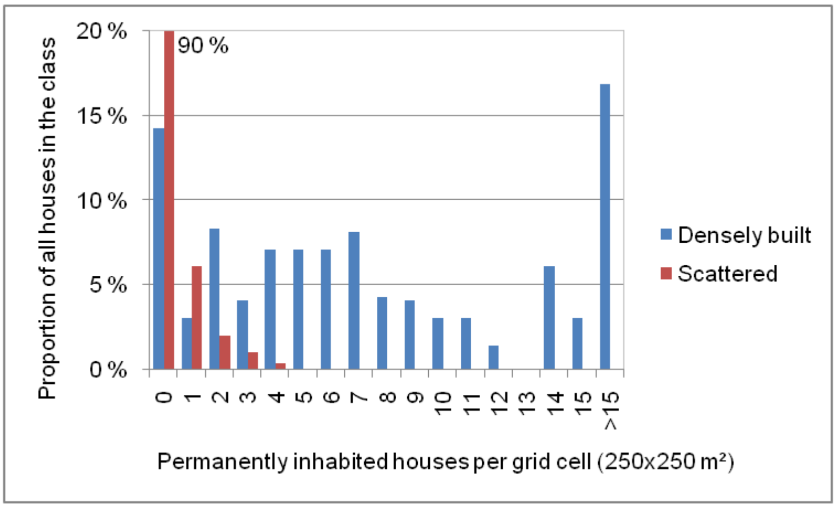

Figure 3-18. *Share of 250x250 m² grid cells having a specified number of houses per cell.*

3.4 Data for model calibration and testing

In this section, various datasets for calibration or testing of the UNTAMO models are presented. Performing and analysing the results of the tests are left for the subsequent assessment steps, though.

Stream network and lakes

Correlating the river discharge with the width of the river channel on different bed sediment types was already touched on in section 3.3.2: by extracting the width of the water filled area in base map or preferably from aerial photographs and measuring or estimating the respective discharge, the correlation could be established.

The discharge threshold for streams to be included in the analysis can be derived also by comparing the interim results of UNTAMO (those giving the discharge or flow accumulation values) to the base map or known type of streams at the present. Alternative approach would be to define the watershed of the smallest brooks to be included in the final results and to estimate the respective discharge using the concept of effective rainfall constant (see section 3.3.2).

Defining the criteria for minimum size of lakes, results from several input data values should be compared to the base map and other information on the present area. Likely no definite values can be derived due to issues related to the spatial and vertical accuracy of the topographical model in respect of smaller ditches or dams, but this would result in best conceivable result.

Sedimentation and suspended matter in coastal areas

For testing data on the sedimentation conditions and suspended matter content in the coastal areas near Olkiluoto, see the data presented in sections 7.1.2, 7.1.3 and 7.3.1 in (Haapanen et al. 2009a). There are data on the present sea bottom sediments (e.g. deposits of gyttja or recent mud), on the suspended solid concentration in some measurement points, a water quality mapping and hydrodynamical modelling results available, at least.

Sedimentation and resuspension in lakes

Comprehensive data on sedimentation and resuspension in two lakes has been collected by Niemistö (2008). The lakes have rather similar morphometry (Fig. 3-19) as those expected to form near Olkiluoto in the future (Ikonen 2007b, Ikonen et al. 2010). In addition, Huttula (1994) has reported measurements and modelling results on the resuspension conditions in Lake Pyhäjärvi, which is in the catchment of Eurajoki River discharging next to Olkiluoto Island.

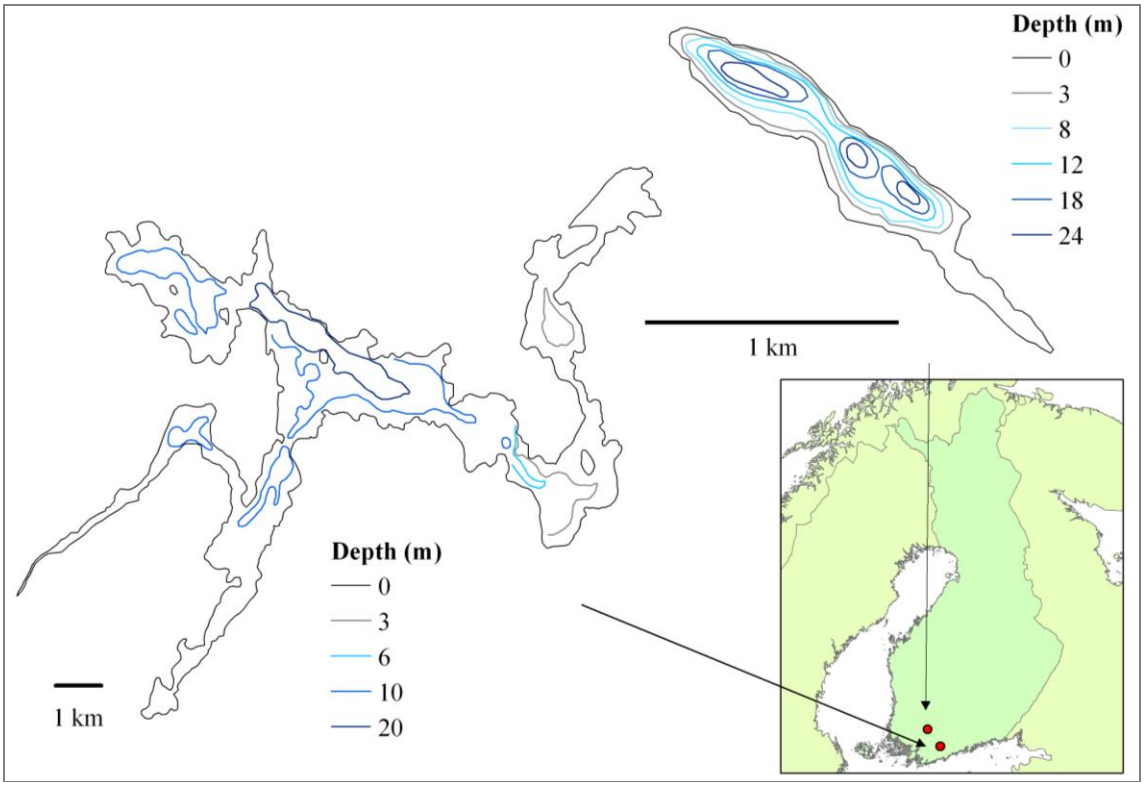

Figure 3-19. *Morphometry of Lake Hiidenvesi (left) and Lake Rehtijärvi (right) studied in (Niemistö 2008). Redrawn from the original publication by Jani Helin/Posiva Oy.*

Reed bed extent

On the shorelines, the existence or lack of macrophyte vegetation (reed colonies) determines whether a gyttja layer accumulates. The reed colony model is based on assessing the fetch distance (degree of physical exposure) and assuming a maximum water depth and minimum flow rate for the vegetation to survive. Since the parameters are difficult to quantify in detail, the model is calibrated using data from a survey at the site (Haapanen & Lahdenperä 2009).

The extent of the reed colonies were recorded at selected locations along the margin of the colony using a GPS device, and observations were also made of the bottom type and water depth (Haapanen & Lahdenperä 2009). The surveyed routes were photographed as well, allowing delineation of the reed polygons from aerial photographs.

Reed avoids locations with heavy flow, but also ice has a decisive effect on controlling the reed expansion: exposed, shallow shores may be reed-free both in inland water shores and in sea shores (Toivonen 1981, Munsterhjelm 2005).

The dynamic development of reed (*Phragmites australis*) vegetation is a decisive factor affecting development and distribution of the vegetation of shallow open bays and flads (Munsterhjelm 2005). In the innermost parts of the archipelago, reed colonises most of the shorelines and reaches its deepest limit of 2.1-2.2 (max. 2.25) m depth (Luther

1951a). It also colonises a considerable part of the soft-bottom shorelines in the inner archipelago zone.

Further out in the archipelago, the reed colonises mainly the most sheltered bays in the outer archipelago zone. Here it does not completely cover the shores and extends to depths between 1 and 1.5 m (Luther 1951a). In sheltered inner archipelago zone coves and bays and in the juvenile flad stages it may reach approx. 1.5-2 m in depth (Luther 1951a), and occasionally its deepest limit. During flad development it expands towards greater depths, mostly reaching its deepest limit in flads.

It can be asked why these flads and later stages, where large bottom areas are shallower than 2.25 m, are not overgrown by reeds? In the flads, reed exhibits an elevation of its deepest limit towards the most sheltered shores, a process that may already begin in the outer stages. In sheltered bays and juvenile flads, reed-free ice-pressed glades in the reed belt (Luther 1951a, 1951b) are formed at approx. 0.5-0.8 m depths. These reed-free areas develop mainly on soft gyttja bottoms. Here the rhizomes of the reed lose their hold on bottoms eroded by the ice. During every growth season reeds attempt to colonise the shallow bottoms in a horisontal zone up to several metres, but is every winter torn up from the bottom by the ice. Finally, as the critical depth becomes free from reed, inner and an outer reed belts may be formed. The deep limit of the inner belt will finally withdraw to 0.2-0.3 m depth. The outer belt will disappear at the latest when its bottom has risen to the critical level. The effect of this process increases with the rising of the bottoms and becomes more prominent towards later stages in the flad development. Thus, the flad stages will not primarily become overgrown by reeds.

The total colonisation of reeds does not occur until the locality has become shallow enough for the movements of the ice to decrease, i.e. less than 0.2-0.3 m. Of course there is a shrinking of the area of the entire locality as the shore-line gradually moves towards the middle. Forming belts and reed-turf, giving shelter from winds and water movements, and filtering and accumulating material the reed substantially participates in creation of the flad environment (Häyrén 1902, Munsterhjelm 2005).

In limnic waters, reedbeds and rush colonies dominate areas that reach 0.5-1.5 m depths at the shoreline, measured from the mean water level. Reed colonies tolerate mesotrophic to eutrophic conditions (Eurola 1962), whereas oligotrophic the colonies are minor or absent (Toivonen 1981).

Groundwater table

For the simple estimation of the groundwater table, the monitoring data from the Olkiluoto site can be used. The groundwater table has been recorded with varying intervals (from 10 minutes to a week) or in campaigns from a large set of various boreholes, groundwater tubes and drill holes. The monitoring holes and tubes included in the analysis, and the time periods of the monitoring data used, are listed in App. E together with an example on the level of detail of the data.

To update the earlier simplistic relationship between the elevation and the long-term groundwater head (Löfman 1999, Ikonen 2007b), these data were combined with the ground-level elevation of each monitoring hole/tube (Fig. 3-20). A linear fitting was done to the observed mean values.

Using the method, there is limitation firstly in the elevation range. Also application to the future (extrapolation and interpretation of the zero level in case of the catchment area is discharging to a large enough lake instead of the sea) is far from being free of assumptions. As the surface and near-surface hydrological model is available (Karvonen 2008, 2009a-c), it should be used to simulate typical future catchments and derive similar simplified relationships applicable to them to avoid too demanding iteration between UNTAMO and the surface hydrological model. Cerainly, the surface and near-surface hydrological model needs to be validated to the data of the present, including those utilised here.

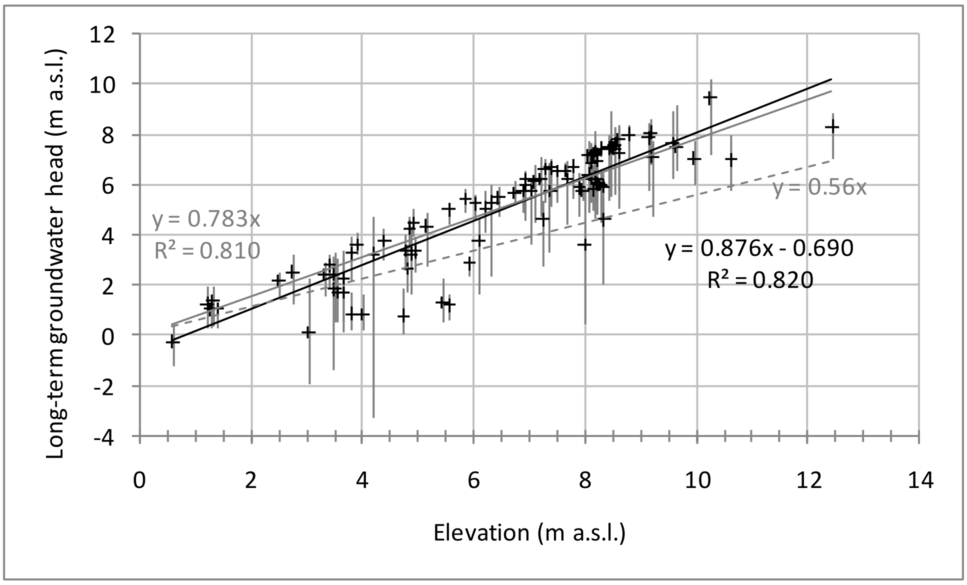

Figure 3-20. *Relationship between average long-term groundwater table and ground surface elevation of observation holes in Olkiluoto, nominally 2001-2008. Error bars represent the observed minimum and maximum head values. Linear fitting to the mean values are presented for the best fit and one forced to positive values above the sea level. Also the coarse estimate used in earlier deep groundwater flow simulations (y = 0.56x; e.g. Löfman 1999, Löfman & Poteri 2008) is presented for reference with a dashed line.*

4 SURFACE AND NEAR-SURFACE HYDROLOGICAL MODEL

Surface and near-surface hydrological model (Karvonen 2008, 2009a-c) is used firstly to provide the deeper groundwater flow model with groundwater pressure head boundary conditions, where the land uplift and other terrain and ecosystem development processes have been taken into account (in practise, based on the TESM modelling results), and secondly to continue the release paths from the repository to the upper bedrock all their way through the overburden to rooting zone and surface water bodies and to calculate water balance of the contaminated biosphere objects (again based on the TESM modelling results, and the outcome of the deeper groundwater flow modelling).

In this chapter, the model is first described, and the identified key site data are provided. However, a number of parameters and assumptions are internal to the model and left for the respective reports (e.g. Karvonen 2008, 2009b,c) to be discussed. Also, the bedrock data are left for the Site Description process (e.g. Posiva 2009a).

4.1 Model description

For estimating the movements and storages of water in the ecosystem models and in the radionuclide transport models of agricultural and forest ecosystems, horizontal and vertical water fluxes in the overburden and on the ground are modelled in a 3D grid with various types of spatial and temporal conceptualisations linking the unsaturated and saturated soil water in the overburden and groundwater in bedrock to a continuous pressure system.

The model has been calibrated for the present-day conditions (Karvonen 2008, 2009a,b), but the parameterisation of soil layers, land use and vegetation was done in such a way that the model can later be used for description of the past evolution of the overburden hydrology at the site, as well as the hydrological evolution of the overburden in the future (Karvonen 2008, 2009c). The effect of land uplift on surface hydrology is taken into account by using the ground surface elevation as an input value. Influence of different type of climate scenarios on water-balance components (surface and subsurface runoff, interception, transpiration, flux at overburden-bedrock interface) can be taken into account by manipulating the meteorological inputs.

4.2 Key input data

Three different types of data are needed in the surface and near-surface hydrological model: 1) spatio-temporal data, 2) spatial data and 3) parameter values for the different sub-models. The most important temporally and to an extent also spatially varying data are meteorological data – precipitation, air temperature, radiation, relative humidity, wind speed – needed as input values for the model. Moreover, measured groundwater levels, pressure heads in shallow bedrock tubes and discharges in overflow weirs are needed in the calibration of the model, but are not within the scope of this report (but of e.g. Posiva 2009a).

The key spatial data are terrain model, overburden thickness model, surface ditch network, land use type, vegetation type and soil type. For the model of future surface hydrology, all these are simulated in the terrain and ecosystem development model and transferred to the inputs of the surface hydrology model.

The most important model parameters are related to vegetation and soil. The key vegetation parameters are those influencing interception and transpiration. These, however, cannot be readily provided for the full spatial extent, but instead the model is calibrated using site and literature data as discussed in sections 4.4 and 4.1, respectively.

4.2.1 Meteorological data

The meteorological data comprise of hourly time series of precipitation, air temperature and wind speed (from as close evaporating surface as possible). They have been measured and reported since 1992 from the nuclear power plant weather station and from 2004 from a forest intensive monitoring plot OL-FIP4 (Ikonen 2002, 2005, 2007a, Haapanen 2008, 2009). Furthermore, precipitation and air temperature have been measured since 2005 and 2007 from the other two forest intensive monitoring plots, OL-FIP10 and OL-FIP11 (reported in the same reports). Figure 4-1 and Table 4-1 present a summary of the meteorological observations. Wind conditions have been summarised earlier in Table 3-7 and Fig. 3-14 above.

For the meteorological data of the future conditions, climate scenarios will be outlined as the climatic envelope of all assessment scenarios (Posiva 2008). The climate scenarios will provide pseudo time series modified from the present time series to correspond to the climatic parameters derived from global or regional climate simulations. This work is currently on-going at Finnish Meteorological Institute, and from early 2010 it should provide with the time series data for the subsequent modelling.

4.2.2 Saturated hydraulic conductivity

Saturated hydraulic conductivity values were taken from the results of the slug tests carried out on the Olkiluoto Island (Tammisto et al. 2005) and complemented for the other soil types with literature data (Table 4-2).

Table 4-1. *Long-term average temperature, annual precipitation and average wind speed at the Olkiluoto weather mast (1993–2008; Haapanen 2009).*

	Olkiluoto 1993-2008
Average annual temperature	6.0ºC
- coldest month	-4.2ºC (Feb)
- warmest month	17.1ºC (Jul)
Annual precipitation	542 mm
Prevailing wind direction (from)	S
Average wind speed	4.1 m/s

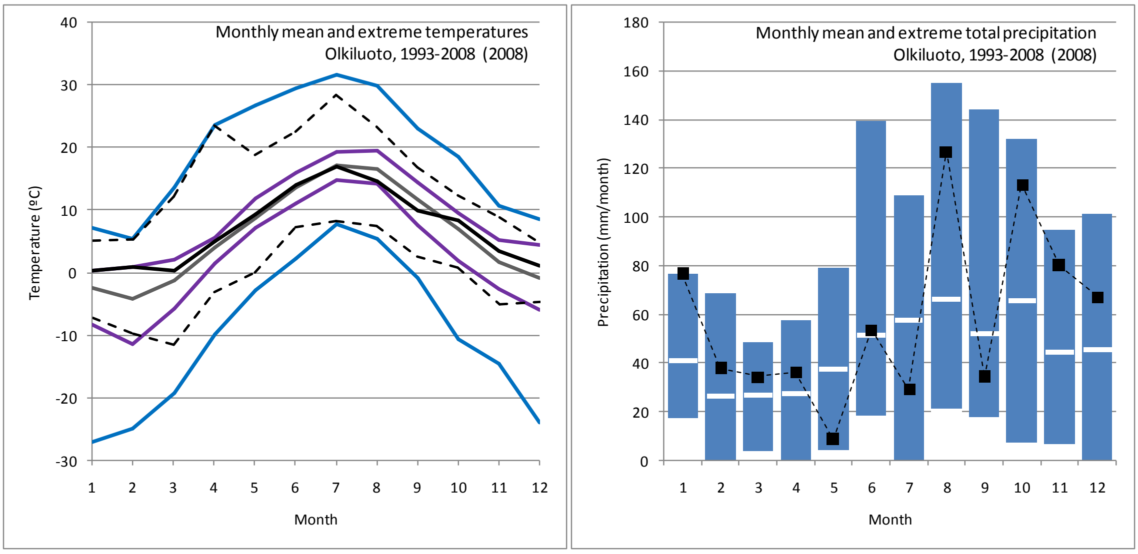

Figure 4-1. *Monthly mean and extreme temperatures (left) and monthly total precipitation (right) at Olkiluoto for the period of 1993–2008 (Haapanen 2009). The black lines represent the monthly mean temperature and total precipitation in 2008; dashed black is the month's lowest and highest temperature in 2008; the gray line is the long-term monthly mean; the purple lines the long-term mean low/high; the blue lines long-term low/high; the bars lowest and highest monthly precipitation recorded; and the white cuts in the bars the long-term monthly mean precipitation.*

Table 4-2. *Saturated hydraulic conductivity (m/s) of soil types applied in the surface hydrology model.*

Soil type	K (m/s)	Reference
Future site (forecast)		
Peat	2.3E-6	Päivänen (1973)
Clay, gyttja	4.5E-7	Estimated from present Olkiluoto
Fine-grained till/sand	5.2E-6	Estimated from present Olkiluoto; Tammisto et al. (2005); Tammisto & Lehtinen (2006)
Washed till	7.7E-6	
Compact till	2.5E-6	Keskitalo & Lindgren (2007); Keskitalo (2008)
Present Olkiluoto		
Gravelly till	5.8E-5	Tammisto et al. (2005); Tammisto & Lehtinen (2006)
Sandy till	1.6E-5	Keskitalo & Lindgren (2007); Keskitalo (2008)
Fine-textured till	6.8E-6	Keskitalo & Lindgren (2007); Keskitalo (2008)
Gravel	6.4E-5	Keskitalo & Lindgren (2007); Keskitalo (2008)
Coarse sand	9.3E-6	Keskitalo & Lindgren (2007); Keskitalo (2008)
Coarse fine sand	5.8E-6	Keskitalo & Lindgren (2007); Keskitalo (2008)
Fine sand	4.6E-6	Keskitalo & Lindgren (2007); Keskitalo (2008)
Very fine sand	2.7E-6	Keskitalo & Lindgren (2007); Keskitalo (2008)
Clay	4.5E-7	Keskitalo & Lindgren (2007); Keskitalo (2008)
Sedge peat	3.5E-6	Päivänen (1973)
Sphagnum peat	3.8E-6	Päivänen (1973)
Mull	6.9E-6	Calibration: Karvonen (2009a)
Exposed bedrock	1.0E-8	Posiva (2009)
Stone field	2.3E-5	Keskitalo (2008); Keskitalo & Lindgren (2007)
Both for present and forecast		
Tillage	3.5E-5	Calibration: Karvonen (2009a)
Weathered rock	1.0E-8	Posiva (2009)
Sea bottom mud/gyttja	4.5E-7	Estimated from present Olkiluoto
Sea bottom clay	7.5E-7	Estimated from present Olkiluoto
Sea bottom till	2.5E-6	Estimated from present Olkiluoto

4.3 Data for model calibration and testing

As the surface and near-surface hydrological model covers rather large area, and in practise the measurements can be done only in relatively few locations, most of the use of the site data is for calibrating and testing the model.

Maximum stomatal conductance (Karvonen 2009b) needed in the transpiration model is calibrated using the sap flow measurements from forest intensive monitoring plots (FIP) (Haapanen 2008, 2009; p. 83-84 in Haapanen et al. 2009a). Rainfall and snowfall interception capacities were calibrated using the FIP data and that from wet deposition monitoring plots (Haapanen 2005, 2006, 2007, 2008, 2009). The former are automatic measurements with hourly time series and the latter are mainly based on continuous sampling with two to four weeks between changing the sampling bags.

Similarly for calibrating the ground temperature profile and snow cover sub-models, ground frost and snow depth (weekly measurements across Olkiluoto Island) and soil temperature at different depths (hourly time series from the three FIPs) have been measured (Ikonen 2002, 2005, 2007a, Haapanen 2008, 2009) and utilised in the modelling. Furthermore, earlier weekly manual and more recent automatic measurements of discharge in main ditches (e.g. Haapanen 2009) have been used in model testing and calibration.

For the simulation of the behaviour of the groundwater table, the same data applied earlier in section 3.4 and summarised in App. E is used. Initial values for the soil water retention curve parameters have been obtained from measured particle size distribution curves (Jauhiainen 2004) and calibration was used to find the final values used in the model (Karvonen 2008, 2009a).

5 RADIONUCLIDE TRANSPORT MODELLING

In this chapter, first the radionuclide transport models are briefly presented; for more elaborate description, see (Hjerpe et al. 2010) or (Hjerpe & Broed 2010). After that, the site and regional data for the identified key parameters and Priority I elements (Table 2-1) are discussed with some complementary comments to the text already given in chapter 11 of (Haapanen et al. 2009a). Thereafter, the available site and regional data for the other parameters of the radionuclide transport models are provided.

It needs to be noted, that the data are to be complemented for the future assessment, and the element- or nuclide-specific data needs be complemented with other data sources (generic literature, handbook values etc.) already for the biosphere assessment of 2009. To maintain as clear difference between site and regional data and those from literature, the latter is reported separately in (Helin et al. 2010).

5.1 Model description

The radionuclide transport modelling process includes the traditional ecosystem-specific compartment models underlying the landscape model, and the screening models introduced in the 2009 biosphere assessment. To increase clarity, the radiological consequence analysis (dose assessment) is not separated here from the transport modelling for safety indicators.

5.1.1 Graded approach to radionuclide transport modelling

In the 2009 biosphere assessment, a graded approach to radionuclide transport modelling is implemented with three tiers (Fig. 5-1), compatible with international experience and guidance (IAEA 2006, ICRP 2007). The common denominator in tiered approaches is that the complexity and realism increases at the higher tiers. The first two tiers are screening evaluations based mainly on literature data, using two levels of inherent pessimism in the applied screening models. The third tier involves a site-specific coupled time-dependent ecosystem-specific radionuclide transport model, in conjunction with a dose assessment based on the most recent international recommendations (ICRP 2007). The landscape modelling described below is that undertaken at Tier 3 due to its requirement for site-specific data, whereas both Tier 1 and 2 are based on a pre-selected screening value for the annual effective dose to humans and a screening environmental media radioactivity concentration for other biota.

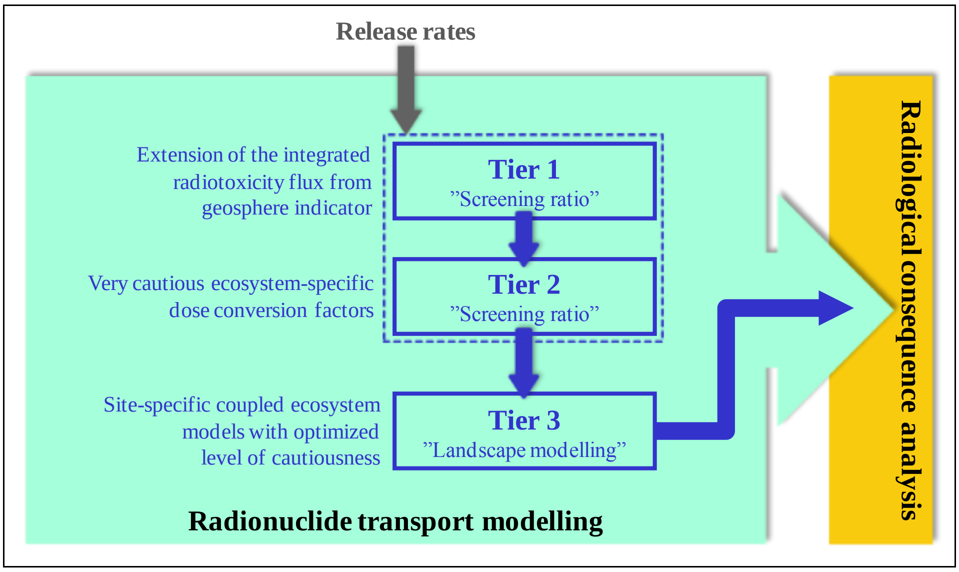

Figure 5-1. *Simplified illustration of how the graded approach is applied in the radionuclide transport modelling component in the biosphere assessment process. The dashed line indicates that both tiers are always performed on the full release rate data sets. Tier 3 is assessing only selected radionuclides, and following from the formulation of the graded approach, the site data are needed only there.*

5.1.2 Biosphere objects used in the landscape modelling

The biosphere object models have recently been updated, based on a sensitivity analysis (Broed 2007a, 2007b), and internal auditing against available site-specific data and best scientific knowledge; these updated models are used in the 2009 biosphere assessment. A great improvement in the models is that they are consistent at a conceptual level, meaning that the structure of compartments is similar in all models. This will facilitate coupling between ecosystems existing at the same time, and the transition between ecosystem types due to the evolution of the biosphere, for example, when new terrestrial ecosystems are formed from the sea due to land uplift. All included ecosystem-specific models (forest, wetland, agricultural land, lakes, rivers, sea) could, in principle, be illustrated in one generic model. However, for clarity, the models are divided into a generic terrestrial and a generic aquatic model; these are presented in Figures 5-2 and 5-3.

For C-14, a specific activity model (Avila & Pröhl 2007) is applied as the conceptual models above. Thus, unlike for the transfer factor models for other nuclides, no concentration ratio data are applicable.

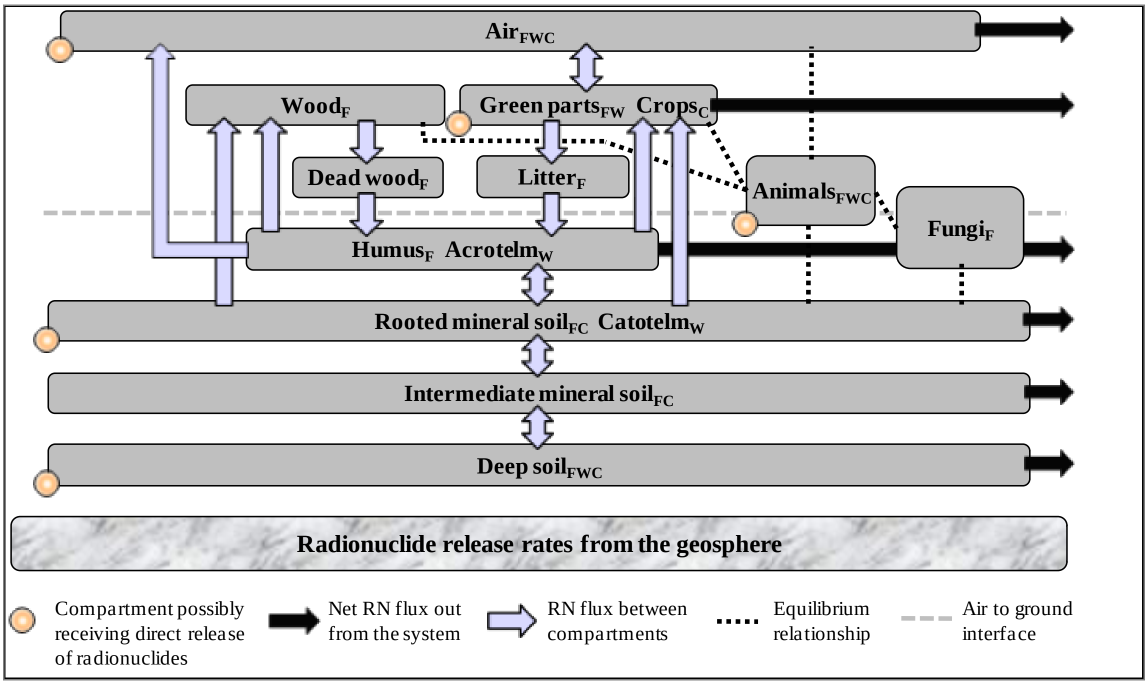

Figure 5-2. *Conceptual radionuclide transport model for terrestrial ecosystems in the landscape model, forest (F), wetland (W) and cropland (C). The indices in the compartment names define for which ecosystem(s) they are valid.*

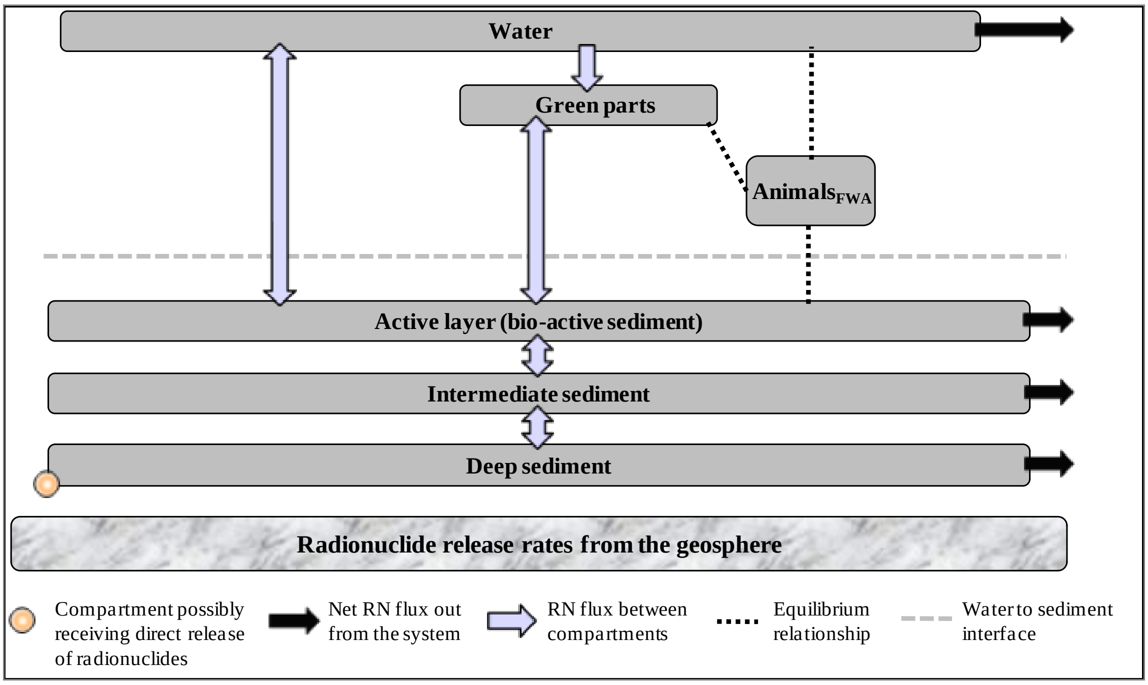

Figure 5-3. *Conceptual radionuclide transport model for aquatic ecosystems in the landscape model (lake, river, sea and coastal areas).*

5.1.3 Derivation of soil-to-plant concentration ratios from site data

Following the compartment division in the revised models discussed above, site-specific concentration ratio values are calculated for the transport from the humus layer and from the rooted mineral soil using the fine root biomass distribution (data in section 5.2.1) as a weighting factor; it is assumed that the uptake from the two compartments hosting the roots is proportional to the amount of roots in them:

$$f_i C_j = CR_{i,j} C_i \qquad \text{(Eq. 5-1)}$$

$$C_j = \Sigma_i \, CR_{i,j} C_i = CR_{eff} C_s \qquad \text{(Eq. 5-2)}$$

where f_i is the proportion of fine root biomass in soil layer i, C_j is the concentration in the recipient compartment (e.g. wood or foliage), $CR_{i,j}$ is the soil layer-specific concentration ratio from soil layer i to compartment j, and C_i is the radionuclide concentration in soil layer i. To calculate the concentration in the recipient compartment using the conventional concentration ratio (CR_{eff}), the corresponding average concentration in the soil layers relevant to the root uptake (C_s) shall be used, although from the site studies at Olkiluoto it is rarely available as such, since data are lacking on some layers. However, if needed, the effective concentration ratios can be calculated from the site data as:

$$CR_{eff} = C_j \, / \, [\, (\Sigma d_i \rho_i C_i)/(\Sigma d_i \rho_i) \,] \qquad \text{(Eq. 5-3)}$$

where d_i is thickness of a considered soil layer and ρ_i the respective density of soil (for default values see sections 5.2.1 and 5.3.1 (Table 5-20)).

For appropriate concentration ratios, care should be taken in the use of soil concentration data from various digestion methods in the chemical analyses. Unfortunately, this information is often lacking from the literature data. Especially in the case of the data from Olkiluoto, wet digestion (H_2O_2 + HNO_3) of the soil is preferred as it possibly overestimates[8] the concentration ratio and thus bioavailability of the contaminants.

5.1.4 Input data from other sources

In addition to the site and regional data, a bulk of inputs to the radionuclide transport modelling are from other sources. Most of them are from earlier modelling stages in the assessment and are affected by the site data, as described above for the terrain and ecosystems development modelling (TESM) and the surface and near-surface hydrological model.

The TESM provides with the geometrical properties of the biosphere objects and the soil and sediment thickesses. Forest type classification is assigned in the TESM, and the

[8] Wet digestion breaks organic matter for analysing concentrations of nutrients available to plants via decomposition. In mineral soils this underestimates the amount of all bioavailable nutrients (and thus overestimates the concentration ratio). More appropriate methods mimic the ion exchange processes in the soil, such as $BaCl_2$ or NH_4Ac extractions, but less data is available for these. Of course, the selection of the digestion method should be in accordance with the soil concentration on which the concentration ratios are applied in the model, and thus closely tied to the details of determination of the solid/liquid distribution factor (Kd).

vegetation-related parameters such as biomasses and annual productions are then calculated as area-weighted averages for each object from the class-specific data given in this chapter. The TESM also provides the river discharges and water exchange rates of lakes, and in the future version also the suspended particulate matter and sedimentation rates, as well as the erosion rates for each biosphere object.

The surface and near-surface hydrological model is used, based on the results of TESM, to provide the radionuclide transport models with water balance data: precipitation and evapotranspiration rate, intercepted fraction of the rainfall, and both horizontal and vertical water flows from a compartment to another within and between the biosphere objects.

5.2 Key input data

In the case of aquatic objects, the geometry and retention time (flow rates) are the most important parameters for radionuclide transport due to the rapid water exchange. The former is derived within the terrain development model, as is the latter for lakes and rivers. For coastal objects, the retention time is somewhat based on expert judgment in cases where water mass balance does not give a conclusive answer (two-directional flow across an interface between coastal objects) and is thus a matter of an assessment decision (assumption).

In the biosphere assessment of 2009, the currently available site data will be used to the fullest possible extent. However, some key data will have to be taken from the literature, for example the solid-liquid distribution coefficients (Kd) in soils and sediments and most of the concentration ratios to biota. These data are currently under acquisition and site-specific values will be provided for the next round of assessments. Furthermore, a significant amount of site data are conveyed to the radionuclide transport modelling though the surface hydrology model and the terrain and ecosystem development models, as discussed above; the data provided in the previous sections affect the radionuclide transport models as do the directly used site data provided in this section.

Following from the discussion in section 2.1, the key input data here is further limited to the Priority I nuclides (C-14, I-129, Cl-36) and the respective and analogue elements.

5.2.1 Forests

For elemental circulation in forests, according to our models, the most important parameters are the annual production of wood, foliage and understorey (determining the biological storage) and concentration ratios (CR) from soil to understorey and foliage (determining the uptake). However, for the latter, not much site data are available yet, and thus only some values for iodine can be given. These will be complemented by literature data in subsequent reports. Furthermore, the biomasses of the forest compartments determine the concentrations and the transport implied by the CRs. The hydrological balance that greatly affects the circulation is simulated by the surface hydrology model, and thus transpiration and the intercepted fraction of precipitation by the canopy are not discussed here.

The carbon content of vegetation can be assumed to be 50 % of dry mass (Hakkila 1989, Nurmi 1993, Bolin et al. 2000, Prentice et al. 2001), although Olkiluoto-specific data were available for tree foliage and ground vegetation species based on the plot measurements in 2005 and 2006 (C content 51–55 % in foliage and 47–52 % in ground vegetation, respectively; Tamminen et al. 2007).

Annual production of tree wood, foliage and understorey

Annual production of wood is given as a mean annual increment of stem wood (MAI, bark included), which is estimated by dividing stand volume by stand age at a given time. MAI reflects the site fertility, and it naturally depends on tree species and the developmental stage of the stand (Fig. 5-4). Here, derivation of MAI is based on the results published by Kuusela (1977) and Ilvessalo & Ilvessalo (1975), using a rotation period of 100 years. If possible, MAIs were derived appropriate to western Finland. MAI calculations were also based on measurements at the site (Saramäki & Korhonen 2005) by dividing the current stand volume by the age of dominant trees. Natural and harvesting removals were excluded. Best estimate value for MAI was chosen as a mean value of MAIs from Ilvessalo & Ilvessalo (1975) and Kuusela (1977) matched to the intensively studied FET plots by UNTAMO site classes. Minimum and maximum values represent the variability between the different methods and source data. Minimum values were, in most cases, derived from Kuusela (1977) and maximum values from Ilvessalo & Ilvessalo (1975). If Olkiluoto site-specific values for MAI were used, they mostly provided the minimum and maximum values (Table 5-1).

Annual production of tree foliage was estimated to approximate 82.1 % of the annual stem wood production (Mälkönen 1974), and this proportion was used in calculations of tree foliage production based on the MAI for a 100-year rotation length.

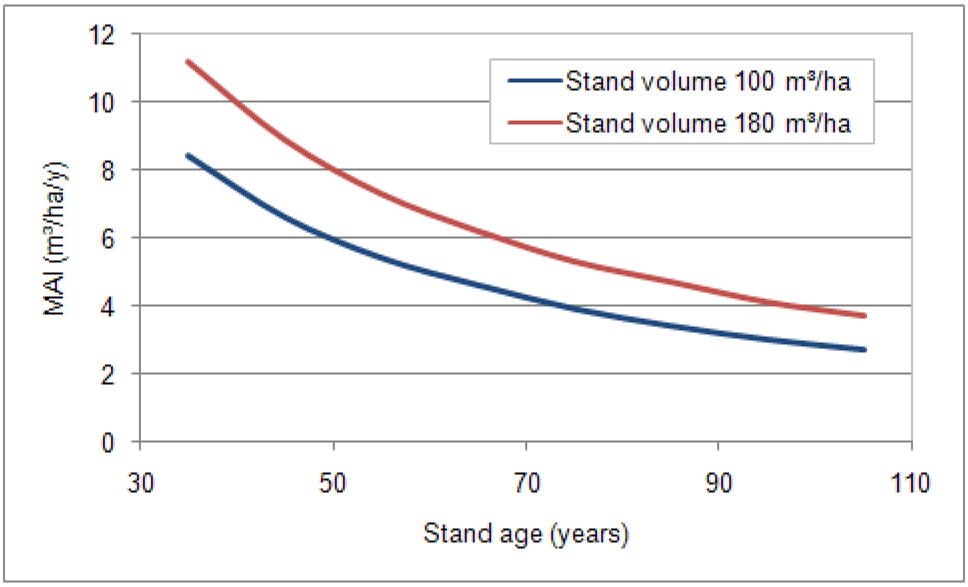

Figure 5-4. *An example of the dependency of mean annual increment of stem wood (MAI) on growing stand volume and stand age; data of (Nyyssönen & Mielikäinen 1978) on Scots pine on* Vaccinium myrtillus *site type (MT) in southwestern Finland.*

Table 5-1. *Mean annual increment of stem wood (MAI, m³/ha/y) derived from literature (Ilvessalo & Ilvessalo 1975, Kuusela 1977) and measurements on Olkiluoto (Olkiluoto incl.) for a 100-year rotation time. Note: best estimate and maximum values for peatland forest based on literature are overestimated.*

UNTAMO site class	MAI (m^3/ha/y)					
	Based on literature			Olkiluoto data included		
	B.E	Min.	Max.	B.E.	Min.	Max.
1 Rocky forest	2.6	1.6	2.9	1.9	0.4	2.9
2 Heath forest	5.6	3.7	7.7	4.9	0.8	8.5
3 Herb-rich heath for.	6.7	5.8	7.7	6.0	0.1	11.2
5 Peatland forest	6.7	1.8 *	7.7	3.9	0.2	11.2

* Using the same data originating from (Ilvessalo & Ilvessalo 1975) as for the best estimate and maximum, the minimum would be 5.8

Table 5-2. *Generic data on wood density by species (Saranpää 1997) and calculated species-weighted averages for forest classes applied.*

Species	Density (kg_{dw}/m^3)
Pine	420
Spruce	380
Birch	480
Other deciduous	460

UNTAMO site class	Average wood density (kg_{dw}/m^3)
1 Rocky forest	413
2 Heath forest	417
3 Herb-rich heath for.	424
5 Peatland forest	425

Table 5-3. *Mean annual above-ground production of understorey vegetation ($g_{dw}/m^2/y$) derived from Mälkönen (1974) for site class 2 and measurements on FIP plots on Olkiluoto for site class 3 (Haapanen 2009) for a 100-year rotation time.*

UNTAMO site class	Above-ground production ($g_{dw}/m^2/y$)					
	Understorey			Shrub-layer		
	B.E.	Min.	Max.	B.E.	Min.	Max.
1 Rocky forest	-	-	-	-	-	-
2 Heath forest	96.3	80.0	121.5	-	-	-
3 Herb-rich heath for.	62.6	41.8	75.3	-	-	-
5 Peatland forest	-	28 *	346 *	-	-	-

\- Data not available
* Minimum and maximum values from Reinikainen et al. (1984); some of forested peatlands being under amelioration measures and some of extremely high fertility. Due to a communication error in data compilation phase, the respective values of 136 and 1370 $g_{dw}/m^2/y$, including both trees and understorey, were propagated to the further assessment.

For conversion from MAI in m³ to kg_{dw} units, generic data of (Saranpää 1997) has been used: first average stand volumes (m³/ha) by tree species have been calculated for each UNTAMO site class from the sampling plot data (Saramäki & Korhonen 2005), and these have been utilised in calculation of volumetrically species-weighted average of wood density. Both the values of (Saranpää 1997) and those calculated for the UNTAMO site classes are presented in Table 5-2.

Annual production of understorey (above-ground parts) for UNTAMO site class 3 was derived from measurements on the forest intensive monitoring plots (FIP) in 2008 (Haapanen 2009). Annual production was determined by six functional plant groups which were:

1. *Vaccinium vitis-idaea* (lingonberry - an evergreen dwarf shrub)
2. *Vaccinium myrtillus* (bilberry - a deciduous dwarf shrub)
3. Lower herbs: *Maianthemum bifolium, Oxalis acetosella, Trientalis europaea* (shoots die every year)

4. Ferns: *Equisetum sylvaticum*, *Dryopetris cathusiana*, *Gymnocarpium dryopteris*, *Pteridium aquilinum* (shoots/leaves die every year)
5. Grasses (both perennial and annual leaves)
6. Mosses (lower parts die gradually)

For dwarf shrubs the annual aboveground biomass production was calculated as the sum of leaves and stems grown in 2008. In lower herbs and ferns the whole shoot corresponds the growth in 2008. The data basis will be improved as longer data series are obtained from the Olkiluoto monitoring programme. In *Linnaea borealis*, *Deschampsia flexuosa* and *Luzula pilosa*, whose leaves are perennial, the annual growth was estimated by dividing the shoot biomass by three (subjective estimation of the age) and in biennial *Rubus idaeus* by two. In mosses the annual growth was estimated by dividing the biomass of the upper part by 2.5, which was the average number of the annual growth segments according to observations done on the plots. Results for different functional groups were summed up and are presented in Table 5-3.

For UNTAMO site class 2, values were derived from Mälkönen (1974). They represent mesic and sub-xeric mineral soil forests. For this UNTAMO site class, the annual production of understorey is a rough estimate if used as a mean value for the 100-year rotation time. However, values for UNTAMO site class 3 represent quite well different developmental stages of forests, since there were growing about 10–15, 40–45 and 100-years-old trees on the intensive monitoring plots FIP11, FIP4 and FIP10, respectively.

Site class 4 (herb-rich forest) is not considered here since such sites fall into the agricultural land category in the biosphere base case; majority of these forests have been cleared for fields in earlier times, as well (Haapanen et al. 2009a). They are at the present extremely scarce in the region, and mainly found by shorelines, being subject to ongoing succession of soil and vegetation properties.

Average biomass of tree wood, foliage and understorey

The mean value of tree biomass (below and above-ground, all trees) for rotation periods of 100 years for conifers and 50 years for deciduous trees are based on forest sample plot (FET) measurements (Saramäki & Korhonen 2005). The biomasses were derived using Swedish models (Marklund 1988), except for fine roots, whose biomass was calculated according to Helmisaari et al. (2007), and for leaves, the biomass of which was estimated using models by Repola (2008). The biomass of coarse roots and stumps of deciduous trees were estimated using the same models as for pine (Marklund 1988). The best estimate of average above-ground tree biomass was derived from stands of different ages representing different developmental stages of those stands. For heath forests and peatlands, minimum and maximum values reflected site type: the better the site type, the higher the average tree biomass (kg_C/m^2) during a 100-year rotation period. For herb-rich heath forests, minimum and maximum values reflected tree species: the highest average above-ground tree biomasses were in Norway spruce-dominated stands, and the lowest in birch-dominated stands. Stands over 100 years of age were excluded. If the number of stands in certain UNTAMO class was too small, or stand ages were not distributed “evenly” across the 100-year rotation period, minimum and maximum values were not estimated.

Table 5-4. *Above-ground biomass (kg_C/m^2) derived from Olkiluoto for a 100-year rotation period.*

UNTAMO site class	Above-ground biomass (kg_C/m^2)					
	Trees			Other vegetation		
	B.E.	Min.	Max.	B.E.	Min.	Max.
1 Rocky forest	1.291	-	-	0.123	-	-
2 Heath forest	3.519	1.820	3.842	0.059 (0.203*)	0.141*	0.270*
3 Herb-rich heath for.	4.927	2.971	6.453	0.053	0.033	0.123
5 Peatland forest	3.396	2.045	3.679	0.078	-	-

- Data not available
* Source: Ilvesniemi et al. (2009).

Mean value of biomass of other vegetation (below and above-ground, shrub-layer excluded) were derived from biomass estimates for forest compartments based on models by Muukkonen & Mäkipää (2006). For herb-rich heath forests, the minimum value was estimated in deciduous stands and the maximum in Scots pine-dominated stands.

No suitable data or generic models were available to determine biomass in shrub-layer on Olkiluoto. However, the biomass of shrub-layer in Finnish forests is relatively small when compared to the total biomass of forests (e.g., Mälkönen 1974). The annual production of shrub-layer is also small. For example, Mälkönen (1974) estimated values of 5–15 kg_{dw}/ha/y for shrub-layer, whereas corresponding figures for other vegetation ranged between 805 and 1 215 kg_{dw}/ha/y. In addition, trees being more than 1.3 m in height have been included in the tree layer.

Site class 4 (herb-rich forest) is not considered here since such sites fall into the agricultural land category in the biosphere base case, and they are at the present extremely scarce in the region (lack of data). Results are presented in Table 5-4.

To divide the biomass of trees into the compartments of wood and foliage used in the model, it was estimated that the wood comprises of 65 % of the biomass and the foliage the remaining 35 %. The estimate is based on the measurements of 22 801 trees in Olkiluoto (Saramäki & Korhonen 2005) and average over tree species and sizes, since all trees that had gained the breast height (1.3 m) were included in the inventory[9]. The average biomass of tree stems was calculated to be 36 kg_{dw} (range 0.15-1545 kg_{dw}) and biomass of the tree crown respectively 19 kg_{dw} (0-572 kg_{dw}). Here, the crown branches are included in the foliage, which is consistent with the conceptualisation of understorey but should be taken into account e.g. in derivation of concentration ratios for the foliage compartment if enough data were available.

Site-specific concentration ratios from soil to wood, foliage and understorey

At the present phase of the programme, only some site-specific values for iodine can be given concerning the Priority I elements identified in section 2.1 (for the elements on a lower priority, see section 5.3.1). This data need to be complemented by literature to cover the uncertainties. The principle of calculations and definitions are presented section 5.1.3.

[9] Smaller trees are classified to belong to the shrub layer, which was unfortunately not measured as the protocol of National Forest Inventory was followed.

First, root biomass distribution is needed to calculate the concentration ratios specific to the soil layers as well as for the effective concentration ratios. Table 5-5 summarises the fine root biomass distribution data from the Olkiluoto site together with available literature data.

To apply these to specific sampling plots, biomass distributions have been derived for stands of the main tree species, and then these are applied as an average weighted by proportions of main and side tree species at the plot (Saramäki & Korhonen 2005). The root biomass proportions applied are presented in Table 5-6. The mineral soil layers of depths 0-10 and 10-20 cm are first treated separately, taking the depth of rooting layer into account, and then a thickness-weighted average has been calculated for the determination of the concentration ratio from the rooted mineral soil compartment respective to the radionuclide transport model conceptualisation.

Table 5-5. *Distribution of fine root biomass (%, on dry-weight basis) in modelled soil compartments (mineral soil 0–30 cm). Site data from Helmisaari et al. (2009b) and literature data from Helmisaari et al. (2007, 2009a).*

Studied plant group	Humus	Min. soil
Site data		
Pine	38	62
Shrubs in pine stand	85	15
Grasses in pine stand	89	11
Spruce	59	41
Grasses in spruce stand	99	1
Birch (seedlings)	71	29
Shrubs in birch seedling stand	63	37
Grasses in birch seedling stand	76	24
Mosses and lichens	100 *	0 *
Literature data for comparison		
Dwarf shrubs, grasses	67±19	33
Pine	59±8.5 36±11 **	41 64 **
Spruce	61±7.2 63±16 **	39 37 **

* Expert judgement
** Based on ectomycorrhizal root tips assumed to correlate with the fine root biomass (supported by Helmisaari et al. 2009a)

Table 5-6. *Fine root biomass proportions (%) for stands of most common tree species as applied from the data of (Helmisaari et al. 2009b) summarised in Table 5-5.*

Stand type	Humus layer	Min. soil 0-10 cm	Min. soil 10-20 cm
Trees			
Pine	38.3	57.0	4.8
Spruce	59.3	40.7	0
Birch (deciduous)	70.6	29.4	0
Shrubs			
Pine	84.7	15.3	0.2
Spruce	84.7	15.3	0.2
Birch (deciduous)	62.6	37.4	0
Grasses and herbs			
Pine	88.2	11.0	0.8
Spruce	98.9	1.1	0
Birch (deciduous)	75.9	24.1	0

For the soil bulk densities of the humus and mineral soil layer, values of 1.1 and 2 g_{dw}/cm^3 have been used. The former represents the denser end of peat in the generic data of (Korhonen 1963) and the latter is the mean value for fine-grained till (Korhonen 1963); soil type at all plots fine-textured till (Rautio et al. 2004). It should be noted, that only the relative values affect to the calculation of the effective concentration ratio (Eq. 5-3), and improving the site database for better quantification of soil bulk densities is rather easy, although not yet done.

Based on samples from three monitoring plots at Olkiluoto (Haapanen 2009), a Scots pine, a Norway spruce and a black alder stand, concentration ratios for iodine can be then calculated (Table 5-7). The available samples of understorey plants have been grouped into two groups: Grasses and herbs include narrow-buckler fern (*Dryopteris carthusiana*), tufted hair-grass (*Deschampsia cespitosa*) and wood sorrel (*Oxalis acetosella*) and leaves of raspberry (*Rubus idaeus*). Dwarf shrubs include leaves of bilberry (*Vaccinium myrtillus*) and lingonberry (*Vaccinium vitis-idaea*), both stems and current-year (C) leaves.

Table 5-7. *Site-specific concentration ratios to understorey plants and tree foliage for iodine (kg_{dw}/kg_{dw}). Values are given separately from humus layer and rooted mineral soil (0–30 cm), as well as effective CR and the conventional concentration ratio (ratio of concentration in the plant part and in the humus layer).*

	CR_{humus}			$CR_{mineral\ soil}$			$CR_{effective}$		
	GM	GSD	N	GM	GSD	N	GM	GSD	N
Trees									
Buds	0.06		1	0.12		1	0.19		1
Alder buds	<0.02			<0.06			<0.13		
Pine buds	0.06		1	0.12		1	0.19		1
Branches (current-year)	<0.04			<0.08			<0.13		
Alder branches	<0.02			<0.06			<0.13		
Pine branches	<0.04			<0.08			<0.13		
Spruce branches	<0.02			<0.08			<0.12		
Foliage (current-year)	0.05		1	0.14		1	0.29		1
all leaves	0.05		1	0.14		1	0.29		1
all needles	<0.04			<0.08			<0.13		
Alder leaves	0.05		1	0.14		1	0.29		1
Pine needles	<0.04			<0.08			<0.13		
Spruce needles	<0.02			<0.08			<0.12		
Understorey									
Grasses & herbs	0.09	1.7	5	0.02	5.4	5	0.28	1.2	5
Narrow-buckler fern	0.13	1.9	2	0.01	4.5	2	0.28	1.1	2
Tufted hair-grass	0.05		1	0.11		1	0.27		1
Wood sorrel	0.07		1	0.00		1	0.22		1
Raspberry leaves	0.07		1	0.13		1	0.34		1
Dwarf shrubs, stems	<0.09			<0.02			<0.13		
Bilberry stems	<0.09			<0.02			<0.13		
Lingonberry stems	<0.09			<0.02			<0.13		
Dwarf shrubs, leaves (C)	0.07	2.0	2	0.03	1.2	2	0.16	1.1	2
Bilberry leaves	0.07	2.0	2	0.03	1.2	2	0.16	1.1	2
Lingonberry leaves	<0.09			<0.02			<0.13		
All understorey (leaves)	0.08	1.7	7	0.03	4.0	7	0.23	1.4	7

5.2.2 Croplands

For radionuclide transport in croplands, the irrigation rate (amount and frequency; the source term) and leaf area index (LAI; capacity to capture contaminants from the irrigation water, defined as half of the total green leaf area, i.e. one-sided area of broadleaves, in the plant canopy per unit ground area) have been found to be the most important parameters.

In case of an irrigation event, there must be available water sources and irrigation must be profitable for the farmer. In Table 5-8, average values of irrigation rates and frequencies for the most common crops in Finland are given as estimates from the irrigation recommendations (Maatalouskeskusten liitto 1979), a review of current practise (Pajula & Triipponen 2003) and studies where leaf area index development is documented (Table 5-8).

The various crops are not cultivated at the same time. Thus, a characteristically pessimistic value, with respect to the dose assessment, has been chosen for the use in the assessment.

Table 5-8. *Irrigation rate (Maatalouskeskusten liitto 1979, Pajula & Triipponen 2003) and leaf area index data for crops at Olkiluoto region.*

Crop type	Irrigation amount (m^3/m^2/event)	Irrigation frequency (1/y)	Leaf area index (m^2/m^2)	References for leaf area index
Cereals	0.030	1	1.5	Ilola et al. (1988)
Grassland	0.030	1	1	Virkajärvi (2003), Virkajärvi & Järvenranta (2001), Sahramaa (2003)
Sugar beet	0.030	1	2	Expert judgment
Potato	0.020	2	2	Mustonen (1999 , 2004).
Peas	0.025	1	2.5	Mäkelä et al. (1997)
Field vegetables	0.025	3	2	Salo & Suoja-Ahlfors (unpubl.)
Berries and fruit	0.015	3	1	Salo & Hoppula (unpubl.)
In assessment:	0.025	3	2.5 (1–2.5)	

5.2.3 C-14 modelling

Due to its nature, C-14 is modelled separately from the other nuclides using an application (Hjerpe & Broed 2010) of a specific activity model (Avila & Pröhl 2007). There are four modelling situations:

1. a lake, a coastal area or a river (an aquatic object),
2. a forest,
3. an irrigated cropland, and
4. a forest or a cropland forming from an aquatic object, for example, due to land uplift or drying/draining of a lake.

Since the geometrical properties have the strongest effect on the mixing volume and the water exchange, and thus on the doses, the most pessimistic aquatic object is a small lake (Avila & Pröhl 2007). Thus, here the data are presented, in addition to the terrestrial cases, only for lakes, and those for rivers and coastal areas are left for the background data report. It should be noted that an important process of CO_2 release from water body surface to the atmosphere (BIOMOVS 1996) is omitted from the model as a pessimistic assumption (Avila & Pröhl 2007).

Wind speed and mixing height

Wind speed determines in the model, together with the mixing height, the mixing volume for the C-14 release from the soil to the air – the pathway to assimilation by plants in the terrestrial systems. Thus, both these two parameters are significant in the terrestrial cases. For the wind speed, see Table 3-7 above (section 3.2.7). The mixing height, or the height needed to supply the canopy with its CO_2 demand, is basically dependent on the vegetation height and biomass: a well-developed canopy, which is able to assimilate daily 2–3 g CO_2/m^2 soil in a sunny summer day during photosynthesis (Avila & Pröhl 2007 citing Geisler 1980), requires the CO_2 that is contained in a 20-m layer from the ground surface. However, on sunny days, the effective mixing height could be much higher since the insolation causes a convective boundary layer. Also, due to the photosynthesis, the canopy is an effective CO_2 sink that causes a permanent flux of CO_2 from upper atmosphere layers to the ground. Therefore, assigning a vegetation-dependent mixing height value is not feasible at the moment, and the values of 20 m and 10 m are chosen for forests and croplands in the assessment, respectively, as proposed in the model description report (Avila & Pröhl 2007).

Net primary production

Primary production is the production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis. Gross primary production is the rate at which an ecosystem's producers capture and store a given amount of chemical energy as biomass in a given length of time. Some fraction of this fixed energy is used by primary producers for cellular respiration and maintenance of existing tissues. The remaining fixed energy is referred to as net primary production. It is the rate at which all the plants in an ecosystem produce net useful chemical energy; it is equal to the difference between the rate at which the plants in an ecosystem produce useful chemical energy (the gross primary production) and the rate at which they use some of that energy through cellular respiration. Some net primary production goes toward growth and reproduction of primary producers, while some is consumed by herbivores.

In the C-14 model implementations for forests and lakes, the net primary production is also a key parameter. For croplands, it has less of an effect on the model results due to the differences in contamination pathways; irrigation is more important for crops.

Forests

In Table 5-9, net primary production values for forests (UNTAMO site classes) are given. Site class 4 (herb-rich forest) is not considered here, since these sites fall into agricultural land in the biosphere base case, and they are at the present extremely scarce in the region (lack of data). For further discussion on possible values for peatlands, see section 5.3.7.

Table 5-9. *Net primary production ($g_C/m^2/y$) of forest vegetation by site class (Haapanen et al. 2007).*

UNTAMO site class	Best estimate	Min	Max
1 Rocky forest	140	114 *	223 *
2 Heath forest	249	90	422
3 Herb-rich heath forest	349	245	427
5 Peatland forest	not available **		

* Minimum and maximum values based on individual compartment-wise data (Rautio et al. 2004) instead of being averages of calculated minima and maxima by tree species and site types

** Reliable data not available due to scarce research (see e.g. Wieder 2006)

Lakes

For different kinds of lakes (oligotrophic, mesotrophic and eutrophic) in Finland, generic net primary production values are given by Eloranta (1996). The future lakes in Olkiluoto area will probably be shallow and mesotrophic, for which the values of 0.037-0.091 $kg_C/m^2/y$ can be assumed. For oligotrophic lakes the respective values would be 0.018–0.037 and for eutrophic ones 0.091–0.37 (Eloranta 1996). As the doses to humans in the model increase with decreasing net primary production (Avila & Pröhl 2007), the minimum for a mesotrophic lake is chosen for the best estimate value.

Irrigation

For croplands, the irrigation amount and frequency are key parameters also in respect of C-14 transport. For their values, see Table 5-8 above (section 5.2.2).

Dissolved inorganic carbon in lakes

The data of DIC concentrations in lakes of Southern Finland are deficient: only one value was found in the literature. According to Arvola et al. (1996) DIC concentration in the humic, mesotrophic Lake Pääjärvi was 3 mg/L. More data exist of TOC (total organic carbon) concentrations, which varied between 7.5–10 mg/L in 1991–1995 in the same lake (Environmental information and spatial data service - OIVA portal, May 4, 2009).

Sedimentation rate in lakes

As the DIC concentration regulates the mixing and availability of C-14 releases, sedimentation is a removal effect, mainly controlled by the sedimentation rate parameter. Sedimentation rates depend on winds, currents, upwelling and the production of system. In the Lake Joutsijärvi, located in the Reference area (Fig. 1-6), the net sedimentation rate has been 640 $g_{dw}/m^2/y$ during the 1990s, and ranged 500–2 300 $g_{dw}/m^2/y$ in 1950–1998 (Fig. 5-5). About 10% of the material is organic (Salonen et al. 2000). The value of the latest decade has been taken as the best estimate, since the other values have been reported to be associated to changes in the land use in the catchment area (Salonen et al. 2000); however the range is useful in the biosphere assessment to cover the potential occurrence of such changes.

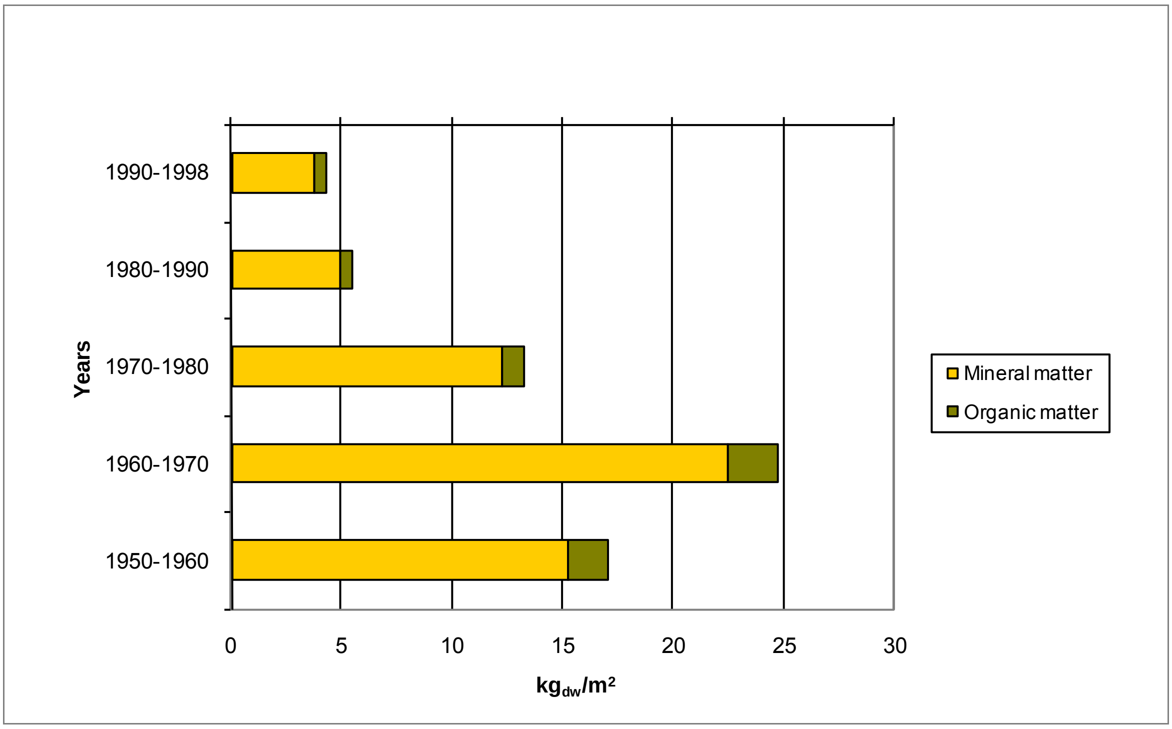

Figure 5-5. *Temporal variation in the net sedimentation rate in Lake Joutsijärvi, reproduced from the data of (Salonen et al. 2000) by Teea Penttinen / Pöyry Environment Oy.*

Table 5-10. *Gross sedimentation rates measured 1 m above the bottom, and resuspension rates in different lake basins (Niemistö 2008).*

	Area, km²	Mean depth, m	Max. depth, m	Gross sedimentation rate, $g_{dw}/m^2/d$	Resuspension, %
Lake Hiidenvesi					
Kirkkojärvi	1.6	1.1	3.5		
Mustionselkä	2.7	1.7	4.5	3.2-10.5	16-84
Nummelanselkä	3.8	2.5	7		
Kiihkelyksenselkä	10.5	11.2	33		
Kuninkaanlahti	-	-	28	3.2-5.2	51-95
Sirkkoonselkä	0.8	3.4	15		
Lake Rehtijärvi					
shallow areas	0.4	9.2	25	6-27	72-96
deep areas				4.1-23.6	20-106

A comprehensive study on sedimentation and resuspension in two lakes in southern Finland (Table 5-10; Niemistö 2008) was found after the compilation of the Biosphere description 2009 (Haapanen et al. 2009a). The morphometry of the lakes (Fig. 3-19 in section 3.4) corresponds well to those expected to form at Olkiluoto site in the future (Ikonen 2007b, Ikonen et al. 2010), and furthermore the bottom of Lake Hiidenvesi is mainly clay (Niemistö 2008) as the prevailing bottom type of the future Olkiluoto lakes.

In the data of Table 5-10, the resuspension (R) has been calculated according to Gasith (1975), as cited in (Niemistö 2008):

$$R = S\,\frac{f_S - f_T}{f_R - f_T} \qquad \text{(Eq. 5-4)}$$

where S is gross sedimentation rate ($g_{dw}/m^2/d$) and f_i organic fraction of gross sedimentation (S), surface sediment (R) and suspended matter (T). The method is applicable to shallow water bodies and based on the assumption that the organic matter content in the bottom sediment differs from that in the suspended matter (Blomqvist & Håkanson 1981 cited by Niemistö 2008).

Morphometrically, the area of Kiihtelyksenselkä in the study of Niemistö (2008) is most similar to the Joutsijärvi Lake sampling point. If average of the minimum and maximum, 73 % is used, the gross sedimentation rate in Joutsijärvi would become 1100 $g_{dw}/m^2/y$, or 3.0 $g_{dw}/m^2/d$.

To further compare the available data, net sedimentation rates in mm/y from literature have been collected to Table 5-11 and converted to mass units assuming a sediment bulk density of 170 kg_{dw}/m^3 (mean of all lake sediment samples of Ilus et al. 1993, see section 5.3.4). However, it should be noted that the growth of sediment thickness includes also the compression of the sediment (Lindholm 2005), unlike the direct mass rate estimates given above for Joutsijärvi, Hiidenvesi and Rehtijärvi lakes, and thus the values given in Table 5-11 are likely underestimates of the true net sedimentation rate; by using the same average resedimentation rate as above, the values in Table 5-11 would turn into gross sedimentation rates of 0.03-2.0 $g_{dw}/m^2/y$. However, this gives an impression on the available data and variability of sedimentation conditions in lakes.

For the BSA-2009, a nominal value of 3.0 $g_{dw}/m^2/d$ for gross sedimentation is adopted, as derived with some assumptions from the Joutsijärvi study (Salonen et al. 2000), and the range to extend from 1 to 30 (an expert judgement based on the data in Tables 5-10 and 5-11). Based on the study of Niemistö (2008) and the parallelism above, 73 % is taken as the nominal value and 15-110 % as the range for the resuspension rate. The case of resuspension rate exceeding the gross sedimentation rate means effective erosion of the bottom and cannot be excluded in the light of the expected evolution of the site.

Table 5-11. *Reported net sedimentation rates in Finnish lakes. Those given in $g_{dw}/m^2/y$ have been converted assuming a bulk density of 170 kg_{dw}/m^3 (see the text).*

Lake	mm/y	$g_{dw}/m^2/y$	Notes	Reference
"Natural rate" for lakes in general	1-3	0.2-0.5	Eutrophication can increase the rate 5-10 fold	Alasaarela & Rantala 1990
Oligotrophic lake	0.1	0.02		Särkkä 1996
Eutrophic lake	5	0.9		Särkkä 1996
Perholampi	0.62	0.11	Pristine, shallow, silty	Virkanen & Tikkanen 1998
	6.5	1.1	After ditching	
Vihtamojärvi	4.1	0.70	After ditching	Lindholm 2005
Mustalampi	6.7	1.1	During years after ditching	
Kalliojärvi	4.3	0.73		
Autiojärvi	4.5	0.77		

Decomposition rate of exposed sediment

Decomposition rate of organic matter in newly formed terrestrial object (relict) determines the rate on which the inherited radioactivity inventory is released. Gisi (1990) gives a value of 0.03 y^{-1} of soil organic matter amount, with a normal distribution of 0.03; 0.01 (mean; standard deviation). This is used further given the lack of better data; studies at the site or in analogous lakes and mires will be done in the programme period of 2010-2012. Also, due to the lack of data, the model uses a simple constant decomposition rate, even though it is acknowledged that there are, in reality, components with different degrees of resistance to decomposition.

5.3 Other site and regional data

In this section, site and regional data are provided to the other parameters and elements than those classified as key data and addressed already in section 5.2.

5.3.1 Forests

Transfer from tree foliage to litter

For biomass fluxes (biomass shed annually, or turnover rate), Lehtonen (2005) has compiled data for Finnish conditions. For spruce he gives a rate of 0.10 y^{-1} and for pine 0.21 y^{-1}. For broadleaved trees he estimates a value of 0.78 y^{-1} based on information that the leaves become 22 % lighter during the yellowing process in autumn (Viro 1955); even though practically all leaves fall every autumn, the turnover rate remains below 1 y^{-1} in the biomass units.

To derive average values for the UNTAMO site classes (Table 3-4, section 3.2.3), first the tree volumes on each sampling plot (Saramäki & Korhonen 2005) are converted to biomass using the average wood densities for tree species (section 5.2.1) and the volumetric proportions of main and side tree species. As it is assumed that the foliage comprises 35 % of the tree biomass (section 5.2.1), the calculated biomasses can be used as such to estimate the average biomass proportion of each tree species within an UNTAMO class (Table 5-12). The average transfer rates from foliage to litter (Table 5-12) can then be estimated simply by taking the average of the turnover rates above weighted by the biomass proportions of the tree species.

For a range of the foliage-to-litter transfer rate, the case of spruce (0.11 y^{-1}) can be taken as a minimum (although this might be an overestimate of minimal needle fall) and 1 y^{-1} as maximum, which would correspond to the case of broadleaved trees without no internal circulation of nutrients[10].

[10] This might be the case with some elements; the process is not known well enough. For the mass pool modelling of elements and radionuclides, this may be even more relevant than the overall-biomass approach - the pools and fluxes should actually be radionuclide-specific if adequately data were available.

Table 5-12. *Average biomass proportion of tree species in UNTAMO site classes, and estimated average biomass transfer rates from tree foliage to litter (see the text).*

UNTAMO site class	Spruce (biomass-%)	Pine (biomass-%)	Broadleaves (biomass-%)	Transfer rate foliage-litter (1/y)
1 Rocky forest	19	77	3	0.21
2 Heath forest	42	31	27	0.32
3 Herb-rich heath for.	47	21	32	0.34
5 Peatland forest	18	45	37	0.40

Transfer from trees to dead wood

Lehtonen (2005) provides turnover rates also for branches, branches and roots and reproductive organs and stem bark (Table 5-13). To apply these in the biosphere assessment, average biomasses of respective compartments in each UNTAMO site class are needed.

In the Biosphere description of 2006 (Haapanen et al. 2007), it was calculated that on average, the stem with bark accounted for 43, branches for 22, foliage for 15, stump for 5 and roots for 15 % of the total tree biomass on sampling plots at Olkiluoto (site data complemented with biomass expansion factors (BEF) and biomass models; Lehtonen et al. 2004, Parviainen 1999, Ilomäki et al. 2003, Muukkonen & Mäkipää 2006, Marklund 1988, Helmisaari et al. 2007, Repola et al. 2007.

Table 5-13. *Literature data on turnover rates (y^{-1}) from branches and bark in Finland (Lehtonen 2005).*

	Spruce	Pine	Broadleaves
Branches and roots [a]	0.0125	function of age	0.0135
Branches [b]	0.0125	0.027	
Reproductive organs and stem bark [a]	0.0027	0.0052	0.0029

a Lehtonen 2005, table 4, Southern Finland.
b Lehtonen 2005, p. 29.

Table 5-14. *Estimated fluxes and corresponding turnover rates from tree wood to dead wood (see the text).*

UNTAMO site class	Biomass flux ($kg_{dw}/m^2/y$)	Turnover rate (1/y in biomass)
1 Rocky forest	1.28	0.0013
2 Heath forest	2.72	0.0028
3 Herb-rich heath forest	3.35	0.0031
5 Peatland forest	2.58	0.0012

***Table 5-15.** Literature data for turnover rates (y^{-1}) of understorey plants to litter (Lehtonen 2005) and respective average biomasses (kg_{dw}/m^2) at Olkiluoto (Huhta & Korpela 2006).*

	Turnover rate (1/y)	Reference	Biomass (kg_{dw}/m^2)			
			Class 1	Class 2	Class 3	Class 5
Mosses (bryophytes)	0.33 [b]	Tamm 1953, Kellomäki et al. 1977, Havas & Kubin 1983, Nakatsubo et al. 1997	71	33	34	42
Lichens	0.1 [b]	Longton 1992, Kumpula et al. 2000	16	1.9	3.6	0
Dwarf shrubs [a]	0.25 [b]	Mork 1946, Mälkönen 1974, Havas & Kubin 1983	30	11	13	22
Herbs and grasses [a]	1 [c]	Lehtonen 2005	5.9	7.8	7.6	14

a Above-ground parts
b Equals annual biomass production
c Assumes that above-ground parts fall completely to the litter at the end of the growing season

In respect of the above-ground parts only, these become 66.2 % for stem and bark and 33.8 % of the tree wood biomass for branches. By assuming that respective proportion of 1.2 % is bark (and thus 65 % the stem), we can calculate average biomasses for branches and bark[11] based on the average tree biomasses (Saramäki & Korhonen 2005) for each site class. Further, these can be converted into removal flux in $kg_{dw}/m^2/y$ by applying the turnover rates for branches (the average turnover rate of branches and roots for broadleaves) and stem bark to the biomasses. Adding these two mass fluxes together, and further by diving with the respective compartment biomasses, turnover rates can be estimated (Table 5-14).

Transfer from understorey to litter

Estimating the litterfall fluxes for the understorey within an UNTAMO site class is done similarly as for the tree litter: estimates of the biomass by each plant group (Huhta & Korpela 2006) are calculated into site class averages, and these are used together with the data provided in (Lehtonen 2005) to calculate biomass-weighted average turnover rates. The data presented in Table 5-15 results in turnover rates 0.31, 0.40, 0.38 and 0.43 y^{-1} in site classes 1, 2, 3 and 5, respecitively.

For the extremes, it can be assumed that only mosses grow on the site or that all understorey are annual grasses and herbs (0.33 and 1 y^{-1}, respectively, see Table 5-15), except at minimum only lichen is present in the rocky class (0.1 y^{-1}).

Biomass of litter and dead wood

Some litter biomasses from few plots in Finland have been presented by Peltoniemi et al. (2004), see Table 5-16. As their plot types correspond to the forest classes 2 (subxeric) and 2 (mesic) of Table 3-4 (section 3.2.3), their averages could be used to give an estimate for class 2. The litter layer would then have on average 0.29 kg_C/m^2 of which 0.042 kg_C/m^2 is coarse woody and 0.25 kg_C/m^2 other litter. By assuming the generic 50 % carbon content of dry plant matter, these would translate into 0.58, 0.083 and 0.50 kg_{dw}/m^2, respectively.

[11] Loss of stem wood is considered to be included in the harvest (see below), including also snags.

Table 5-16. *Litter biomasses in some Finnish forest plots (Peltoniemi et al. 2004).*

Site type	Litter total	Coarse woody litter		Other woody litter	
	kg_C/m^2	kg_C/m^2	%	kg_C/m^2	%
Subxeric Scots pine 1	0.260	0.074	28	0.19	72
Subxeric Scots pine 2	0.253	0.033	13	0.22	87
Subxeric Scots pine 3	0.294	0.043	15	0.25	85
Mesic Scots pine 1	0.280	0.040	14	0.24	86
Mesic Scots pine 2	0.285	0.040	14	0.25	86
Mesic Scots pine 3	0.305	0.047	15	0.26	85
Mesic Norway spruce 1	0.290	0.025	9	0.27	91
Mesic Norway spruce 2	0.335	0.030	9	0.31	91

No direct measurements on the biomass of dead wood were found, but (Saramäki & Korhonen 2005) give estimates of volume of dead wood on forest and scrub land in Olkiluoto with an overall mean of 6.24 m^3/ha and standard error of 0.78 m^3/ha. The respective number on Southwest Finland Forestry Centre is 1.82 ±0.12 m^3/ha. They also provide data on the distribution of dead wood into species and appearance (degree of decomposition), but these are not directly usable; the utilisation of the original measurements should be investigated.

Mäkinen et al. (2006) provide data from which an average density of 254 kg_{dw}/m^3 for dead wood can be derived, as well as 51 % for the respective carbon content. Using this density value, the estimates for Olkiluoto and Southwest Finland become 0.158 and 0.046 kg_{dw}/m^2, respectively. In carbon units, these become 0.081 and 0.024 kg_C/m^2, which are in good agreement with those presented for coarse woody litter in Table 5-16.

Decomposition rate of litter and dead wood

The Biosphere description of 2006 (Haapanen et al. 2007) presented a general assumption of decomposition that 95 % of litter will decompose in 100 years and the remaining 5 % will form slowly decomposing humus. Assumption was based on Yasso simulations made in national inventory report (Greenhouse... 2006) of Finland under the UNFCCC (United Nations Framework Convention on Climate Change). The initial phase of decomposition, e.g. when lignin, cellulose, hemicelluloses and extractives decompose, is likely responsible of this faster phase, but the further decomposition is less known and harder to quantify (Lehtonen 2005). From the numbers above, assuming a constant decay rate, a decomposition rate of 0.030 y^{-1} can be calculated for the litter.

In a study with the Yasso model, branches and needles were simulated to lose more than 90 % of their initial carbon during the first 20 years, whereas stumps and roots decomposed more slowly (Palosuo 2008). This would impy a constant decay rate of 0.11 y^{-1}. In the same study, within a 100-year rotation, the average carbon stock of branches and needles left in the forest as harvest residues was simulated to be 11 % of their original carbon amount (Palosuo 2008), yielding a constant decay by 0.022 y^{-1}. These, of course, are for the carbon content, differentiating somewhat from the biomass-based numbers presented above.

For peat bogs, no specific studies were found. However, (Clymo 1984) gives an estimate for a decay rate of acrotelm for Kunnonniemensuo, southern Finland, as only available data for the parameter. This value is given as 0.054 y^{-1} with a standard deviation of the same value.

For the decomposition of dead wood there seems to be a lack of data, but one Finnish study was found (Mäkinen et al. 2006). They provide data on remaining mass after specified years after death of the tree from field experiments. If we assume a constant decay rate as above for litter, their data for logs would result on average in 0.054 y^{-1}, with a range of 0.016-0.12 depending on tree species and degree of decay. In comparison to the values derived for litter, this appears to be plausible, although the real variation can be higher.

However, these studies usually include the uncertainty of how long a tree stays as a snag before felling down into a log when a faster decay begins. Mäkinen et al. (2006) have characterised this well, but still these estimates include the variability of time spent as snag. They also present data to support other than constant or exponential decay to accommodate the various phases in the decomposition process.

Average lifetime of trees

The average lifetime of trees is dependent on the forest management scenario, and should be consistent with the mean annual increment (MAI) calculations (section 5.2.1) - a nominal value of 100 years is used throughout this report.

The nominal value overestimates the life span of deciduous trees and slightly underestimates that of coniferous species. According to the present forest management practise, rotation time of deciduous stands is around 50 years and that of conifers 70-100 years. Based on literature, partial decay of European alder (*Alnus incana*) increases at the age of 50 years (Salmi 1977), and the life time of common/black alder (*Alnus glutinosa*) is usually less than 120 years (Valkonen 1996). Biological deterioration of downy birch (*Betula pubscens*) starts at the age of 60-70 years, and of silver birch (*Betula pendula*) in 10-15 years older trees (Niemistö et al. 2008). Of conifers, Scots pine reaches its full age in 100-150 years and in medium-fertile forests of southern Finland it becomes overaged at 200-250 years, but can live 500-600 years or even longer in some cases (Sarvas 1964). Norway spruce is in full age at 250-350 years (Sarvas 1964) and seldom lives over 400 years (Salmi 1983).

Harvested fraction of tree biomass

In the harvest, on average 53.6 % of the fellings is left in the forest (0.062 $kg_C/m^2/y$, whereas biomass removed from the forest was 0.060 $kg_C/m^2/y$; Lehtonen 2005, fig. 14). This apparently includes the trunk, branches and the foliage. If the foliage is taken as 35 % of the biomass (section 5.2.1), this would imply that 11.4 % of the wood biomass (=65-53.6) is left to the forest if we assume none of the foliage is harvested. This coincides well with the earlier estimate that 34 % of the wood biomass would be branches (section 5.2.1; Haapanen et al. 2007), meaning that $^2/_3$ of the branches, the bigger ones, are harvested. However, these figures should be taken as coarse estimates, since depending on the forest management and markets for the products, different shares of trunk, branches (especially domestic firewood), and foliage and even stumps (biofuel) would be harvested.

Bioturbation

Total bioturbation of forest top soil (defined here as annual mass exchange between the two topmost soil layers due to activity of fauna) resulting from the activity of earthworms and ants was estimated to be on average 0.19-15.9 $kg_{dw}/m^2/y$ in mesic spruce, alder and deciduous, abandoned field and mixed coniferous sites at Forsmark. At Oskarshamn, the corresponding numbers were 0.03-24.7 $kg_{dw}/m^2/y$ at oak, grazed pasture, alder, pine and spruce sites (Table 5-17). According to the authors, two main factors seemed to be responsible for the discrepancies: soil pH and groundwater table (Persson et al. 2006).

In the lack of detailed analysis to combine the data of (Persson et al. 2006) and the recent ant, snail and earthworm inventories at Olkiluoto in 2008-2009 (Nieminen et al. 2009), their data were applied to the forest classes adopted (Table 3-4) as described in Table 5-17. The data from the both Swedish sites was included to cover in the variation the possible bias caused by the calcerous soils at Forsmark not encountered at Olkiluoto. The statistics of the bioturbation values for the classes are presented in Table 5-18 and Figure 5-6, where also data for pasture and cropland are included for reference.

Table 5-17. *Estimated bioturbation rates ($kg_{dw}/m^2/y$) in Forsmark and Oskarshamn, Sweden, according to the study of (Persson et al. 2006), and the applied classification to the system used in Posiva's biosphere assessment 2009.*

Site	Bioturbation, $kg_{dw}/m^2/y$	Description of site (Persson et al. 2006)	Application of site type to Olkiluoto	Applied forest class
Oskarshamn				
AG1	9.81	Moist/wet alder forest	MT/OMT/Lh/peatland	3, 5, (4)
AG2	3.06	Moist/wet alder forest	MT/OMT/Lh/peatland	3, 5, (4)
QR1	7.41	Oak forest near shoreline	untypical tree species	none
QR2	42.46	Oak stand in a gentle slope	untypical tree species	none
GP1	4.75	Sheep-grazed pasture	pasture	pasture
GP2	11.07	Sheep-grazed pasture	pasture	pasture
PA1	0.01	Spruce on drained peatland	peatland	5
PA2	0.04	Spruce on drained peatland	peatland	5
PS1	0.64	Open pine forest	less fertile pine forest	2, 1
PS2	0.28	Open pine forest	less fertile pine forest	2, 1
Forsmark				
B2A	0.14	Mixed coniferous plot	VT/MT/OMT	2, 3
FG1	20.71	Mesic spruce plot	MT	2
FG2	10.83	Mesic spruce plot	MT	2
FL1	2.63	Mesic decid. forest (alder, ash)	untypical tree species	none
FL2	17.16	Mesic deciduous forest (maple, ash)	untypical tree species	none
SS1	13.77	Moist/wet alder forest, swamp forest	peatland	5
SS2	10.18	Moist/wet alder forest, swamp forest	peatland	5
A1	4.75	Abandoned field (high groundwater table)	exceptionally wet field	none
A2	1.56	Abandoned field (drier than A1)	field	cropland

Table 5-18. *Statistics of bioturbation data ($kg_{dw}/m^2/y$) from Table 5-17 organised by the forest class. Some data are used for several classes to cover the variability in bioturbation rate and due to the different classifications. Pasture and cropland data are included for reference.*

Class	Mean	Min.	Max.	Std	N
1 Rocky	0.5	0.3	0.6	0.3	2
2 Heath	6.5	0.1	20.7	9.1	5
3 Herb-rich heath	4.3	0.1	9.8	5.0	3
5 Peatland	6.1	0.01	13.8	5.9	6
Cropland	1.6	-	-	-	1
Pasture	7.9	4.7	11.1	4.5	2

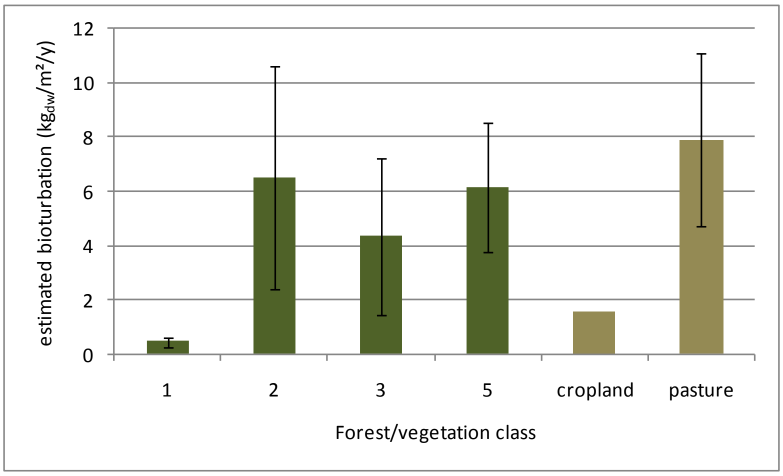

Figure 5-6. *Estimated bioturbation rates ($kg_{dw}/m^2/y$, mean ± standard error) as re-grouped from (Persson et al. 2006) to correspond the simplified forest type classification Posiva's biosphere assessment 2009. Pasture and cropland data are included for reference.*

Thickness, density and carbon content of humus layer

Thickness and density of humus layer has been determined from the forest sampling plots at Olkiluoto (Tamminen et al. 2007). The data are summarised for UNTAMO site classes 1-3 in Table A-5 (App. A).

Soil bulk density

Soil bulk densities were derived for the use of the terrain and ecosystems development modelling in section 3.3.5. These values (Table 3-12) should be applied for consistency also in the radionuclide transport modelling.

Distribution coefficient (Kd) in forest soil

The solid/liquid distribution coefficient is an aggregated parameter that describes the sorption in soil (and sediments) to solids. Three sources have been found reporting Kd for till from Olkiluoto or close vicinity (Kohtala & Holttinen 1979, Miettinen et al. 1981, Nikula & Pinnioja 1981) from where data for Cs, Sr and Ni (and Co, Zn) can be obtained for till soils (Table 5-19). These are complemented with literature data in (Helin et al. 2010) for the assessment use, and a project has been started to acquire more Kd data for soils in Olkiluoto (Lusa et al. 2009).

Table 5-19. *Distribution coefficient (Kd) data for till sampled from Olkiluoto and its vicinity.*

Soil type	Kd (L/kg)		Location	Reference
Strontium (Sr-85)				
till	7.7	±0.1	Olkiluoto (KK1, sorption)	Nikula & Pinnioja 1981
	9.8	±0.1	Olkiluoto (KK1, desorption)	
	13	±1	Olkiluoto (KK2, sorption)	
	16	±2	Olkiluoto (KK2, desorption)	
	17	±2	Olkiluoto (KK4, sorption)	
	20	±2	Olkiluoto (KK4, desorption)	
till	13-24		Olkiluoto	Miettinen et al. 1981
till	3.5-11		Olkiluoto	Kohtala & Holttinen 1979
Cesium (Cs-134)				
till	1500	±20	Olkiluoto (KK1, sorption)	Nikula & Pinnioja 1981
	1100	±70	Olkiluoto (KK1, desorption)	
	3000	±50	Olkiluoto (KK2, sorption)	
	3200	±1200	Olkiluoto (KK2, desorption)	
	1200	±300	Olkiluoto (KK4, sorption)	
	1000	±400	Olkiluoto (KK4, desorption)	
till	510-2100		Olkiluoto	Miettinen et al. 1981
till	62-510		Olkiluoto	Kohtala & Holttinen 1979
Nickel (Ni-63)				
till	1500	±70	Olkiluoto (KK1, sorption)	Nikula & Pinnioja 1981
	2800	±200	Olkiluoto (KK1, desorption)	
	1300	±300	Olkiluoto (KK2, sorption)	
	2800	±400	Olkiluoto (KK2, desorption)	
	1100	±20	Olkiluoto (KK4, sorption)	
	1900	±200	Olkiluoto (KK4, desorption)	

Concentration ratios from soil to wood, foliage and understorey

Site-specific data for calculating concentration ratios from soil to plants are mainly from the forest sampling campaign (Tamminen et al. 2007), which was recently complemented to acquire initial site data on iodine and selenium (Haapanen 2009). All the available data have been utilised to calculate concentration ratios from soil to tree wood, to foliage of trees and to different types of understorey plants. The calculation method is presented in section 5.1.3.

As above for iodine, first, root biomass distribution is needed to calculate the concentration ratios specific to the soil layers as well as for the effective concentration ratios. Table 5-5 summarises the fine root biomass distribution data from the Olkiluoto site together with available literature data.

To apply these to specific sampling plots, biomass distributions have been derived for stands of the main tree species, and then these are applied as an average weighted by proportions of main and side tree species at the plot (Saramäki & Korhonen 2005). The root biomass proportions applied are presented in Table 5-6. The mineral soil layers of depths 0-10 and 10-20 cm are first treated separately, taking the depth of rooting layer into account, and then a thickness-weighted average has been calculated for the determination of the concentration ratio from the rooted mineral soil compartment respective to the radionuclide transport model conceptualisation.

As the forest sampling campaign data do not include element concentrations in mineral soil since it was carried out solely by applying the generic methodology of National Forest Inventory, data have been taken from other soil analyses to be able to calculate also the conventional concentration ratios. The soil type on the forest sampling has been determined from the grain size distribution analysed from the samples (Tamminen et al. 2007), and the corresponding average concentrations in the mineral soil have been assigned as presented in Table 5-20. It should be noted, that only the relative values affect to the calculation of the effective concentration ratio (Eq. 5-3), and improving the site database for better quantification of soil bulk densities is rather easy, although not yet done. On peatland plots the concentrations and bulk density in the sampled peat layer (Tamminen et al. 2007) has been used throughout the soil data for the calculation of concentration ratios.

In case of the concentration data of selenium (and iodine) in plants from the complementary campaign (Haapanen 2009), all data were utilised even though the result was below the limit of quantification (LOQ). The average of the two samples of each plant compartment was used if both values were above the LOQ. If another one was over the limit, the single value was used as such. In case of both samples resulting in concentration below the LOQ, the numerical value of LOQ was used as such to overestimate the concentration ratio. Respectively, where needed[12] for the concentration in soil a value of LOQ/2 was used, again to overestimate the bioavailability.

Table 5-20. *Concentration data used to fill gaps in the forest sampling plot data (Tamminen et al. 2007), derived from excavator pit sampling (OL-KK12-13: Lintinen & Kahelin 2003; OL-KK14-17: Lahdenperä 2009), and bulk densities of soil types based on literature (Korhonen 1963 cited by Heiskanen 2003).*

Soil type	Soil samples used in calculation of conc.	Calculated average concentrations (mg/kg$_{dw}$)					Density [a] (g/cm³)
		Ca	Cr	K	Mg	Ni	
Gravel (Sr)	OL-KK12 0-0.8 m OL-KK13 0-0.4 m	377 [b]	0.05 [c]	28.0 [b]	42.6 [b]	0.25 [c]	1.8 (1.6-2.0)
Sand (Hk, Hs, Ht)	OL-KK15 0-0.43 m OL-KK16 0-0.2 m OL-KK16 0.2-0.4 m [d]	379	0.275	24.8	47.5	0.25 [c]	1.7 (1.5-2.0[e])
Fine till (HtMr)	OL-KK18 0-1.8 m OL-KK19 0-1.8 m	957	0.05 [c]	27.1	24.9	0.25 [c]	2.1 (1.9-2.2)
Sandy till (HkMr)	OL-KK14 0-0.15 m OL-KK14 0.15-0.55 m OL-KK17 0-0.16 m OL-KK17 0.16-0.52 m	553	0.105	33.8	67.4	0.015 [c]	2.0 (1.8-2.2)
Coarse till (SrMr)	OL-KK15 1.53-2.9 m [f]	1340	0.05 [c]	59.7	105	0.51	2.2 [g]

a Value assigned by judgement and the range given in the literature.
b Only synthetic rainwater leach data available, scaled to correspond the NH_4-Ac digestion by calculating ratio of concentrations in the NH_4-Ac leach (OL-KK14 0.55-1 m, OL-KK15 1.53-2.93 m, OL-KK16 1-2.9 m) to the water leach (OL-KK6...OL-KK13, layers deeper than 0.5 m): Ca 3.22, K 3.19, Mg 14.4.
c Concentrations below limit of quantification (LOQ), a value of LOQ/2 is used since this results in higher concentration ratios than using merely the LOQ as such.
d To avoid underestimation of concentration ratios, layers OL-KK15 0.75-1 m and OL-KK16 0.4-1 m were not included even though they represent similar soil type, since they are from deeper layers than the rooting depth and exhibit lower concentrations (except for Cr) than the shallower layers.
e Range for sands is 1.5-1.9 and for fine sands 1.7-2.0.
f Only sample corresponding the grain size at the forest sampling plots, although from a rather deep layer.
g In lack of data in the same source as for the others, this value has been taken from Lindborg 2008, mean for gravelly till.

[12] In case of iodine in all samples of deeper mineral soil layer (10-30 cm) and for selenium in all mineral soil samples except on plot FIP10 for the other top soil sample (0-10 cm).

For lichens and mosses, no layer-specific concentration ratios from the mineral soil were calculated, since in their case the concentration ratio from the humus layer alone corresponds the effective concentration ratio; these organisms take most of their nutrients from the air.

The results for Ni, Cr (chemical analogue to Mo) and Se are given in Tables 5-21 to 5-23. The data for I have been presented already in Table 5-7 above. For some of the elements there are less plant species due to the lack of respective sample material.

Table 5-21. *Site-specific concentration ratio for nickel data derived from the samples of (Tamminen et al. 2007) and (Haapanen 2009, p. 53). Layer-specific concentration ratios are given for humus and mineral soil, together with the effective concentration ratio from the whole soil column (see section 5.1.3). Data for all understorey plants excludes stems of dwarf shrubs and mosses.*

Nickel	From humus			From mineral soil			CR_{eff}		
	GM	GSD	N	GM	GSD	N	GM	GSD	N
Trees									
Buds	0.21	2.2	2	0.24	1.6	2	0.50	1.1	2
Alder buds	0.12		1	0.18		1	0.46		1
Pine buds	0.35		1	0.33		1	0.55		1
Branches (current-year)	0.062	1.6	3	0.084	1.1	3	0.17	1.1	3
Alder branches	0.051		1	0.075		1	0.20		1
Pine branches	0.10		1	0.096		1	0.16		1
Spruce branches	0.045		1	0.081		1	0.16		1
Foliage (current-year)	0.070	1.7	93	12	8.5	83	3.1	4.8	93
Leaves	0.13	1.6	22	2.8	17	22	3.4	5.8	22
Alder leaves	0.12	1.7	16	2.6	19	16	2.0	5.6	16
Birch leaves	0.15	1.5	6	3.6	18	6	3.7	6.6	6
Needles	0.058	1.5	71	21	4.6	61	3.4	4.5	71
Pine needles	0.050	1.4	31	32	4.7	22	2.1	6.7	31
Spruce needles	0.065	1.4	40	17	4.4	39	4.9	2.7	40
Understorey									
Grasses and herbs	0.15	1.7	130	3.0	13	127	5.2	4.7	130
Herbs	0.15	1.8	69	2.4	14	69	4.7	4.8	69
Narrow-buckler fern	0.45	2.7	2	0.021	5.3	2	0.53	1.2	2
Wood sorrel	0.064		1	0.002		1	0.14		1
Raspberry leaves	0.088		1	0.10		1	0.31		1
Grasses	0.15	1.7	61	3.8	11	58	5.9	4.5	61
Tufted hair-grass	0.12		1	0.14		1	0.44		1
Stems of dwarf shrubs	0.10	1.6	3	0.017	1.5	3	0.11	1.3	3
Bilberry stems	0.085	1.7	2	0.019	1.7	2	0.11	1.4	2
Lingonberry stems	0.14		1	0.015		1	0.10		1
Dwarf shrubs (current-year)	0.060	1.6	118	3.6	7.2	104	3.1	3.4	118
Bilberry leaves	0.071	1.5	60	5.2	6.3	56	3.8	2.9	60
Lingonberry leaves	0.077		1	0.008		1	0.054		1
Evergreen plants	0.050	1.6	57	2.6	6.7	47	2.6	3.5	57
All understorey plants	0.10	2.0	248	3.2	9.9	231	4.1	4.1	248
Mosses	0.38	1.6	87	-		-	0.38	1.6	87

__Table 5-22.__ Site-specific concentration ratio data for selenium derived from the samples of (Haapanen 2009, p. 53). Layer-specific concentration ratios are given for humus and mineral soil, together with the effective concentration ratio from the whole soil column (see section 5.1.3). Data for all understorey plants excludes stems of dwarf shrubs and mosses.

Selenium	From humus			From mineral soil			CR_{eff}		
	GM	GSD	N	GM	GSD	N	GM	GSD	N
Trees									
Buds	<0.02			<0.14			<0.16		
Alder buds	<0.02			<0.12			<0.14		
Pine buds	<0.02			<0.14			<0.16		
Branches (current-year)	0.02	1.4	3	0.16	1.3	3	0.15	1.4	3
Alder branches	0.02		1	0.16		1	0.19		1
Pine branches	0.01		1	0.16		1	0.17		1
Spruce branches	<0.01			<0.16			<0.10		
Foliage (current-year)	0.02	1.6	3	0.20	1.2	3	0.18	1.7	3
Leaves	0.03		1	0.20		1	0.24		1
Alder leaves	0.03		1	0.20		1	0.24		1
Needles	0.02	1.4	2	0.19	1.3	2	0.16	1.9	2
Pine needles	0.02		1	0.23		1	0.25		1
Spruce needles	<0.01			<0.16			<0.10		
Understorey									
Grasses and herbs	0.06	1.4	5	0.06	5.2	5	0.34	1.5	5
Herbs	0.06	1.5	4	0.04	5.3	4	0.34	1.6	4
Narrow-buckler fern	0.08	1.4	2	0.04	4.1	2	0.40	1.5	2
Wood sorrel	0.04		1	0.01		1	0.19		1
Raspberry leaves	0.06		1	0.29		1	0.43		1
Grasses	0.05		1	0.23		1	0.34		1
Tufted hair-grass	0.05		1	0.23		1	0.34		1
Stems of dwarf shrubs	0.04	1.6	2	0.05	1.6	2	0.23	1.6	2
Bilberry stems	0.03		1	0.04		1	0.16		1
Lingonberry stems	0.06		1	0.08		1	0.33		1
Dwarf shrubs (current-year)	0.05	1.6	3	0.09	2.1	3	0.28	1.6	3
Bilberry leaves	0.06	1.4	2	0.13	1.4	2	0.35	1.4	2
Lingonberry leaves	0.03		1	0.04		1	0.17		1
All understorey plants	0.05	1.5	8	0.07	3.7	8	0.32	1.5	8
Mosses	-		0	-		-	-		0

Table 5-23. *Site-specific concentration ratio data for chromium (chemical analogue to molybdenum) derived from the samples of (Tamminen et al. 2007) and (Haapanen 2009, p. 53). Layer-specific concentration ratios are given for humus and mineral soil, together with the effective concentration ratio from the whole soil column (see section 5.1.3). Data for all understorey plants excludes stems of dwarf shrubs and mosses.*

Chromium	From humus			From mineral soil			CR_{eff}		
	GM	GSD	N	GM	GSD	N	GM	GSD	N
Trees									
Buds	<0.008			<0.001			<0.004		
Alder buds	<0.004			<0.001			<0.004		
Pine buds	<0.008			<0.001			<0.002		
Branches (current-year)	0.011	2.2	2	0.002	1.6	2	0.0050	1.1	2
Alder branches	0.006		1	0.001		1	0.0052		1
Pine branches	0.019		1	0.003		1	0.0048		1
Spruce branches	<0.010			<0.002			<0.005		
Foliage (current-year)	0.028	2.0	90	1.5	5.4	81	1.6	3.5	155
Leaves	0.022	2.1	21	0.27	11	21	1.2	4.2	95
Needles	0.030	1.9	69	2.8	2.1	60	2.3	2.0	60
Alder leaves	0.023	2.0	15	0.2	12	15	0.32	6.1	15
Birch leaves	0.021	2.6	6	0.3	9.2	6	1.5	3.4	80
Pine needles	0.027	2.1	30	5.4	1.7	22	2.9	2.2	22
Spruce needles	0.033	1.8	39	2.0	1.7	38	2.1	1.8	38
Understorey									
Grasses and herbs	0.12	2.5	129	0.66	9.4	127	3.0	5.4	127
Herbs	0.079	2.3	68	0.33	10	68	1.8	5.4	68
Narrow-buckler fern	0.055	1.6	2	0.0003	4.4	2	0.010	1.3	2
Wood sorrel	0.037		1	0.0001		1	0.011		1
Raspberry leaves	0.028		1	0.0050		1	0.022		1
Grasses	0.198	2.1	61	1.5	6.9	59	5.6	4.4	59
Tufted hair-grass	0.013		1	0.0023		1	0.010		1
Stems of dwarf shrubs	0.052	1.0	2	0.0009	1.0	2	0.0061	1.0	2
Bilberry stems	0.051		1	0.0009		1	0.0060		1
Lingonberry stems	0.053		1	0.0009		1	0.0063		1
Dwarf shrubs (current-year)	0.056	2.1	101	0.84	5.2	92	1.8	4.2	92
Bilberry leaves	0.059	2.0	60	1.0	4.9	57	2.1	4.0	57
Lingonberry leaves	0.019		1	0.0003		1	0.0022		1
Evergreen plants	0.052	2.2	40	0.80	3.1	34	1.7	2.8	34
All understorey plants	0.087	2.5	230	0.73	7.5	219	2.4	5.0	219
Mosses	0.52	2.0	87	-		-	0.52	2.0	87

5.3.2 Croplands

Soil properties

In the cultivated fields around the Olkiluoto site, the bulk density of undisturbed top soil (0-25 cm) is typically 1200 kg_{dw}/m^3, with a range of 1000-1500 (expert knowledge of the region). The high organic matter content of Finnish soils, compared to many other European countries, causes the relatively low densities.

In the deeper layers soil bulk density increases, see Table 3-12 in section 3.3.5. The densities of the other clay soils are higher than those presented above for cultivated soils: ploughing and other soil management of croplands increases the porosity - the other values are likely for rather tight soils.

Table 5-24. *Maximum standing biomass, annual production and net primary production (NPP) of crop types in the region around the Olkiluoto site, with data on the respective edible portions (dry-weight basis like the harvested fraction, too).*

	Standing biomass		Production		NPP	Harvested
	kg_{dw}/m^2	edible	$kg_{dw}/m^2/y$	edible	$kg_C/m^2/y$	biomass
Cereals	0.425	60 %	0.45	57 %	0.18	57 %
Grassland	0.500	80 %	1.0	80 %	0.40	80 %
Sugar beet	1.20	15 %	1.3	14 %	0.52	14 %
Potato	1.00	60 %	1.1	55 %	0.44	54 %
Peas	0.425	60 %	0.45	56 %	0.18	56 %
Field vegetables	0.400	50 %	0.40	40 %	0.20	40 %
Berries and fruits	0.300	20 %	0.30	30 %	0.08	30 %

Erosion rate of croplands is taken into account in the radionuclide transport model explicitly due to its potential significance. In the future versions, the erosion rates for all objects are calculated using the UNTAMO model for terrestrial erosion and sedimentation (section 3.1.5). For croplands around Olkiluoto, a nominal value of 0.000125 $m^3_{soil}/m^2/y$ can be used, as an average of the estimate of 1-2 t/ha/y for a test plot in Aura, southwestern Finland. For comparison, in (Tattari & Rekolainen 2006) values of 0.6-3.3 t/ha/y have been given for a field with a slope of 7-8 % and 0.03-0.67 t/ha/y for a slope of 2 %. Both values are for a plot of winter wheat in southwestern Finland. For a forested catchment with slope of 5 % in the same region, estimate of 0.082-0.646 is used in (Tattari & Rekolainen 2006).

Biological factors

Estimates for standing biomass, annual production and net primary production of different types of grops are given in Table 5-24 as based on judgement by experts of the regional cultivation conditions. Also edible fractions of the biomass and production are given for the dose assessment use. Edible fraction of total production is lower than the edible fraction of standing biomass, because the production includes also the matter allocated to the roots and lost as litter. Berries and fruits are an exception as they are perennial crops where annual production can be lower than actual standing biomass.

As an expert judgement based on the agricultural machinery and instructions for agricultural soil management, the thickness of the mixing layer in the croplands can be said to be on average 0.25 m, or 0.2-0.3 m. Ploughing depth is commonly 0.20-0.27 m, but in other soil management methods the range is different, e.g. in stubble cultivation 0.10-0.18 m or in direct seed drilling 0-0.5 m.

Rooting depths and height of vegetation are given in Table 5-25 as typical values in Finland, partly based on crop experiments. The rooting depth refers to the depth where some roots can still participate in water and nutrient uptake. The biomass of roots is higher in the top soil (0-30 cm) than in the deeper layers.

Table 5-25. *Rooting depth and height of vegetation of various crop types as average height at the maximum growth or the maximum rooting depth on average, respectively, partly based on crop experiments. The ranges give the variation between crop species and growing seasons.*

	Height (m) *	Rooting depth (m)
Cereals	0.85 (0.5-1.0)	0.6 (0.4-1)
Grassland	0.5 (0.4-0.6)	0.5 (0.4-1)
Sugar beet	0.5 (0.4-0.6)	0.7 (0.5-1)
Potato	0.5 (0.4-0.6)	0.4 (0.4-0.6)
Peas	0.5 (0.4-0.6)	0.6 (0.4-0.7)
Field vegetables	0.4 (0.2-0.6)	0.5 (0.3-1)
Berries and fruits	0.5 (0.3-3)	0.5 (0.3-1)

* At the maximum growth, for averages over the growing season, these numbers should be divided with 2.

In an event of irrigation, the water applied is partly stored on the vegetation due to interception. For the water storage capacity (or interception capacity of irrigation water) a value of 0.2 mm/m^2 has been used in some regionally relevant studies.

For bioturbation of the soil (defined here as annual average mixing rate between the surface and subsoil), no Finnish data were found. The value of 2 $kg_{dw}/m^2/y$ used in earlier assessments (e.g. Kalsson & Bergström 2000) seems reasonable for the surface soil, whereas deeper the value is expected to be significantly smaller since the soil fauna inhabits mainly the plough layer. Furthermore, the recent Swedish study summarised in section 5.3.1 (Table 5-18, Fig. 5-6) gave a rate of 1.6 $kg_{dw}/m^2/y$ for an abandoned field, whereas for sheep-grazed pastures the value was much higher, 7.9 $kg_{dw}/m^2/y$ on average (Persson et al. 2006).

5.3.3 Mires

Most of the parameter values are same as for the forests, so they are not repeated here. Instead, see sections 5.3.1 and 5.3.7. However, e.g. for concentration ratios a more rigorous data analysis of the site-specific data from the forest sampling network might reveal differences, but the time available has not permitted that.

Bulk density of peat should have the same value as is used in the terrain and ecosystems development model (Table 3-12) to keep the models and results consistent.

5.3.4 Lakes

In this section, site and regional data for the remaining radionuclide transport modelling parameter values not discussed as key data in section 5.2.3 (net primary production, DIC concentration, sedimentation and resuspension rates) are addressed.

Biomass, production and loss rate of aquatic plants

Biomasses of aquatic plants in Lake Pyhäjärvi have been studied in the 1980's (Aulio 1981). The data are provided for half-metre water depth intervals (0-2.5 m) from five sampling points. From each point, ten sub-samples have been collected and the mean and range reported. This data have been processed to calculate mean biomass of aquatic plants in each depth interval (Table 5-26) by first calculating the depth-specific sums of biomasses of different plants at each sampling point, and then taking the mean over that. The plant species observed and included in the total numbers are listed in Table 5-27.

To derive an estimate for an overall aquatic plant biomass for the lake objects in the radionuclide transport modelling, this data should be used together with the depth distribution of each lake provided by the terrain and ecosystems development modelling (Chapter 3). However, this is not yet supported in the models, but a single number is required. Thus, we calculate a typical value based on the bathymetry of the predicted lakes (Ikonen et al. 2010) most relevant to the assessment, judged being those receiving direct releases from the repository (Hjerpe & Broed 2010, Hjerpe et al. 2010). These data are presented in Table 5-28, based on the assumption that on bottoms deeper than 2.5 m there are no bottom-attached aquatic plants.

Table 5-26. *Biomass of aquatic plants (g_{dw}/m^2) in Lake Pyhäjärvi (Aulio 1981).*

Water depth	Mean	Min.	Max.	Std
0-0.5 m	9.5	0	70	7.2
0.5-1 m	41	0	290	20
1-1.5 m	57	0	191	19
1.5-2 m	37	0	182	26
2-2.5 m	27	0	109	20

Table 5-27. *Aquatic plant species observed in Lake Pyhäjärvi (Aulio 1981) and included in the numbers presented in Table 5-26.*

Plant group	Scientific name	English name	Finnish name
Helophytes (emergent plants)	*Eleocharis acicularis* *Subularia aquatica* *Ranunculus repens*	Needle spikerush Water awlwort Creeping buttercup	Hapsiluikka Äimäruoho Rönsyleinikki
Nympheids (floating-leaved)	*Nuphar lutea* *Potamogeton berchtoldii* *Ranunculus peltatus* *Sparganium friesii (natans)*	Yellow water-lily Small pondweed Pond water-crowfoot Small bur-reed	Ulpukka Pikkuvita Järvisätkin Siimapalpakko
Elodeids (submerged-leaved)	*Isoëtes lacustris* *Lobelia dortmanna*	Lake quillwort Water lobelia	Tummalahnanruoho Nuottaruoho
Isoetids (benthic vascular plants)	*Elodea canadensis* *Myriophyllum alterniflorum* *Potamogeton perfoliatus*	Canadian waterweed Alternate water-milfoil Clasping-leaf pondweed	Vesirutto Ruskoärviä Ahvenvita
Aquatic mosses	(Not identified at species level)		

Table 5-28. *Bathymetrical data on predicted future lakes at Olkiluoto (Ikonen et al. 2010), and depth-weighted mean biomass of aquatic vegetation for the whole lake based on data in Table 5-26.*

Future lake	Area (ha)						Mean biomass
	0-0.5 m	0.5-1 m	1-1.5 m	1.5-2 m	2-2.5 m	total	(g_{dw}/m^2)
Mäntykarinjärvi	29.0	5.6	3.1	0	0	37.6	18
Tankarienjärvi	43.0	37.2	20.8	11.6	5.9	122.9	30
Susijärvi	55.8	34.0	25.6	24.8	33.4	203.3	26
Liiklanjärvi	15.8	2.8	2.8	1.4	1.1	28.0	18

Based on the results in Table 5-28, typical values for aquatic plant biomass in the BSA-2009 can be chosen to be 0.023 kg_{dw}/m^2 (mean of the estimates for the future lakes). The total maximum using the maximum biomasses for each depth interval would become 0.17 kg_{dw}/m^2.

For the respective annual production of aquatic plants there are no local data, so to keep consistent with the biomass values, they are scaled from the biomass values derived above with a production/biomass ratio of 1.23 taken from a Swedish data (Nordén et al. 2008) for macrophytes in a mesotrophic lake in the Laxemar-Simpevarp area. Using the scaling ratio, the annual production becomes on average 0.028 $kg_{dw}/m^2/y$ and at maximum 0.21 $kg_{dw}/m^2/y$.

In the Finnish conditions, practically all plant biomass above the bottom of the lakes is renewed due to the winter conditions. Numerically this implies a value of 1 y^{-1} for the biomass loss rate to the top sediment.

Concentration of suspended matter in lake water

Values for suspended matter concentrations were taken from the measurement data on lakes in the catchment of Eurajoki River (Environmental information and spatial data service - OIVA portal, May 4, 2009), yielding a mean of 0.004 kg_{dw}/m^3 in 1990-2009 for the surface water (0-2 m). The corresponding range is from practically 0 to 0.044 kg_{dw}/m^3 (standard deviation 0.0045 kg_{dw}/m^3).

Sediment properties

For bulk density of the sediment, there seems to be a general lack of directly suitable data, but some are available from Finnish lakes (Ilus et al. 1993), which is presented in Table 5-29 together with respective data on soil carbon concentrations needed for the C-14 modelling (section 5.3.7), and the calculated statistics of the bulk densities is presented in Table 5-30. For the active top sediment, values for gyttja and sludge should always be applied due to the high water content.

Table 5-29. *Available literature data on bulk densities (g_{dw}/cm^3) and carbon concentrations ($\%_{dw}$) in Finnish lake sediments (Ilus et al. 1993).*

Description	Depth	Lake	Density	Carbon
Clay				
clay (brown grey clay)	15-20 cm	Näsijärvi, Näsiselkä	0.23	10.9
clay (brown grey clay)	20-25 cm	Näsijärvi, Näsiselkä	0.22	12.5
clay (brown grey clay)	25-30 cm	Näsijärvi, Näsiselkä	0.17	15.8
clay (brown grey clay)	30-35 cm	Näsijärvi, Näsiselkä	0.19	15.2
clay (brown clay)	15-20 cm	Näsijärvi, Näsiselkä (1990)	0.20	10.9
clay (brown clay)	20-25 cm	Näsijärvi, Näsiselkä (1990)	0.20	12.3
clay (brown clay)	25-30 cm	Näsijärvi, Näsiselkä (1990)	0.16	15.7
clay (brown grey clay)	15-20 cm	Näsijärvi, Siilinkari	0.22	10.2
clay (brown grey clay)	20-25 cm	Näsijärvi, Siilinkari	0.17	14.0
clay (brown grey clay)	25-30 cm	Näsijärvi, Siilinkari	0.17	13.9
clay (grey clay)	10-15 cm	Pielinen, Suurselkä	0.30	8.5
clay (grey clay)	15-20 cm	Pielinen, Suurselkä	0.28	9.5
clay (grey clay)	20-25 cm	Pielinen, Suurselkä	0.28	9.5
clay (grey clay)	25-30 cm	Pielinen, Suurselkä	0.31	8.2
clay (brown clay)	30-35 cm	Pielinen, Suurselkä	0.32	7.9

Table 5-29 (cont'd). Available literature data on bulk densities (g_{dw}/cm^3) and carbon concentrations ($\%_{dw}$) in Finnish lake sediments (Ilus et al. 1993).

Description	Depth	Lake	Density	Carbon
Clay (cont'd)				
clay (dark clay)	5-10 cm	Pielinen, Suurselkä	0.29	7.4
clay (sulphidic clay)	10-14 cm	Pyhäjärvi, Lehtisaari	0.53	9.8
clay (sulphidic clay)	5-10 cm	Pyhäjärvi, Lehtisaari (1990)	0.27	14.7
clay (clay)	10-15 cm	Päijänne, Asikkalanselkä (1990)	0.24	19.4
clay (clay)	15-20 cm	Päijänne, Asikkalanselkä (1990)	0.19	11.6
clay (grey clay)	10-15 cm	Päijänne, Ristiselkä	0.42	4.3
clay (grey clay)	15-20 cm	Päijänne, Ristiselkä	0.65	2.9
clay (grey clay)	20-25 cm	Päijänne, Ristiselkä	0.50	4.1
clay (tough grey clay)	25-30 cm	Päijänne, Ristiselkä	0.35	6.4
clay (tough grey clay)	30-35 cm	Päijänne, Ristiselkä	0.31	7.9
clay (soft clay)	10-15 cm	Päijänne, Tehinselkä	0.16	13.5
clay (soft clay)	15-20 cm	Päijänne, Tehinselkä	0.17	13.6
clay (soft clay)	20-25 cm	Päijänne, Tehinselkä	0.18	13.1
clay (soft clay)	25-30 cm	Päijänne, Tehinselkä	0.19	11.9
clay (tough clay)	30-35 cm	Päijänne, Tehinselkä	0.21	11.1
clay (soft clay)	5-10 cm	Päijänne, Tehinselkä	0.19	10.7
Gyttja / sludgy top sediment				
gyttja (watery grey mud)	10-15 cm	Kallavesi, Muuraissaaret	0.18	10.2
gyttja (watery grey mud)	15-20 cm	Kallavesi, Muuraissaaret	0.16	11.8
gyttja (watery grey mud)	20-25 cm	Kallavesi, Muuraissaaret	0.15	12.5
gyttja (watery grey mud)	25-30 cm	Kallavesi, Muuraissaaret	0.14	15.6
gyttja (watery grey mud)	30-35 cm	Kallavesi, Muuraissaaret	0.14	16.2
gyttja (black watery mud)	0-2 cm	Keurusselkä, Vuolleselkä	0.063	22.5
gyttja (brown mud)	10-15 cm	Keurusselkä, Vuolleselkä	0.18	14.8
gyttja (brown mud)	15-20 cm	Keurusselkä, Vuolleselkä	0.17	15.5
gyttja (reddish brown mud)	20-25 cm	Keurusselkä, Vuolleselkä	0.12	22.7
gyttja (black mud)	2-5 cm	Keurusselkä, Vuolleselkä	0.099	20.5
gyttja (reddish brown mud)	25-30 cm	Keurusselkä, Vuolleselkä	0.12	23.4
gyttja (brown mud)	5-10 cm	Keurusselkä, Vuolleselkä	0.16	15.5
gyttja (mud)	0-2 cm	Keurusselkä, Vuolleselkä (1990)	0.041	22.3
gyttja (mud)	10-15 cm	Keurusselkä, Vuolleselkä (1990)	0.17	15.0
gyttja (mud)	15-20 cm	Keurusselkä, Vuolleselkä (1990)	0.19	14.4
gyttja (mud)	20-25 cm	Keurusselkä, Vuolleselkä (1990)	0.18	14.7
gyttja (mud)	2-5 cm	Keurusselkä, Vuolleselkä (1990)	0.068	23.5
gyttja (mud)	25-30 cm	Keurusselkä, Vuolleselkä (1990)	0.11	25.2
gyttja (mud)	5-10 cm	Keurusselkä, Vuolleselkä (1990)	0.10	20.0
gyttja (watery mud)	0-2 cm	Konnevesi, Konneselkä	0.072	21.7
gyttja (watery mud)	10-15 cm	Konnevesi, Konneselkä	0.077	24.2
gyttja (watery mud)	15-20 cm	Konnevesi, Konneselkä	0.071	25.4
gyttja (watery mud)	20-25 cm	Konnevesi, Konneselkä	0.075	25.6
gyttja (watery mud)	2-5 cm	Konnevesi, Konneselkä	0.087	21.7
gyttja (watery mud)	25-30 cm	Konnevesi, Konneselkä	0.074	25.9
gyttja (watery mud)	30-35 cm	Konnevesi, Konneselkä	0.08	24.5
gyttja (watery mud)	5-10 cm	Konnevesi, Konneselkä	0.076	23.0
gyttja (dark mud)	0-2 cm	Konnevesi, Konneselkä (1990)	0.036	27.0
gyttja (dark mud)	10-15 cm	Konnevesi, Konneselkä (1990)	0.085	24.0
gyttja (dark mud)	15-20 cm	Konnevesi, Konneselkä (1990)	0.091	24.7
gyttja (dark mud)	20-25 cm	Konnevesi, Konneselkä (1990)	0.091	26.6
gyttja (dark mud)	2-5 cm	Konnevesi, Konneselkä (1990)	0.054	24.5
gyttja (dark mud)	25-30 cm	Konnevesi, Konneselkä (1990)	0.091	27.6
gyttja (dark mud)	5-10 cm	Konnevesi, Konneselkä (1990)	0.066	23.0
gyttja (watery sulphidic mud)	0-2 cm	Näsijärvi, Näsiselkä	0.087	23.3
gyttja (sulphidic gyttja)	10-15 cm	Näsijärvi, Näsiselkä	0.25	10.2
gyttja (sulphidic mud)	2-5 cm	Näsijärvi, Näsiselkä	0.12	24.8
gyttja (sulphidic gyttja)	5-10 cm	Näsijärvi, Näsiselkä	0.13	23.3

Table 5-29 (cont'd). Available literature data on bulk densities (g_{dw}/cm^3) and carbon concentrations ($\%_{dw}$) in Finnish lake sediments (Ilus et al. 1993).

Description	Depth	Lake	Density	Carbon
Gyttja / sludgy top sediment (cont'd)				
gyttja (brown mud)	0-2 cm	Näsijärvi, Näsiselkä (1990)	0.057	22.8
gyttja (brown gyttja)	10-15 cm	Näsijärvi, Näsiselkä (1990)	0.21	10.6
gyttja (sulphidic gyttja)	2-5 cm	Näsijärvi, Näsiselkä (1990)	0.13	23.6
gyttja (sulphidic gyttja)	5-10 cm	Näsijärvi, Näsiselkä (1990)	0.12	24.2
gyttja (reddish brown mud)	0-2 cm	Näsijärvi, Siilinkari	0.10	17.7
gyttja (sulphidic gyttja)	10-15 cm	Näsijärvi, Siilinkari	0.23	10.1
gyttja (sulphidic mud)	2-5 cm	Näsijärvi, Siilinkari	0.19	18.7
gyttja (sulphidic gyttja)	5-10 cm	Näsijärvi, Siilinkari	0.23	12.6
gyttja (dark brown mud)	0-2 cm	Ontojärvi, Merjanselkä	0.11	18.2
gyttja (dark brown mud)	10-15 cm	Ontojärvi, Merjanselkä	0.16	16.6
gyttja (dark brown mud)	15-20 cm	Ontojärvi, Merjanselkä	0.14	19.4
gyttja (dark brown mud)	20-25 cm	Ontojärvi, Merjanselkä	0.14	20.1
gyttja (dark brown mud)	2-5 cm	Ontojärvi, Merjanselkä	0.21	12.9
gyttja (dark brown mud)	25-30 cm	Ontojärvi, Merjanselkä	0.15	19.2
gyttja (dark brown mud)	5-10 cm	Ontojärvi, Merjanselkä	0.18	13.7
gyttja (dark mud)	0-2 cm	Ontojärvi, Merjanselkä I (1990)	0.082	19.4
gyttja (dark mud)	10-15 cm	Ontojärvi, Merjanselkä I (1990)	0.17	17.7
gyttja (dark mud)	15-20 cm	Ontojärvi, Merjanselkä I (1990)	0.16	19.9
gyttja (dark mud)	2-5 cm	Ontojärvi, Merjanselkä I (1990)	0.13	18.2
gyttja (dark mud)	5-10 cm	Ontojärvi, Merjanselkä I (1990)	0.21	14.1
gyttja (watery mud)	0-2 cm	Ontojärvi, Merjanselkä II (1990)	0.096	18.9
gyttja (watery mud)	10-15 cm	Ontojärvi, Merjanselkä II (1990)	0.16	17.9
gyttja (dense mud)	15-20 cm	Ontojärvi, Merjanselkä II (1990)	0.14	20.4
gyttja (dense mud)	20-25 cm	Ontojärvi, Merjanselkä II (1990)	0.16	20.4
gyttja (watery mud)	2-5 cm	Ontojärvi, Merjanselkä II (1990)	0.18	15.9
gyttja (dense mud)	25-30 cm	Ontojärvi, Merjanselkä II (1990)	0.37	10.1
gyttja (watery mud)	5-10 cm	Ontojärvi, Merjanselkä II (1990)	0.23	14.5
gyttja (dark grey mud)	0-2 cm	Ontojärvi, Mulkkusaaret	0.077	22.1
gyttja (dark grey mud)	10-15 cm	Ontojärvi, Mulkkusaaret	0.089	26.3
gyttja (dark grey mud)	15-20 cm	Ontojärvi, Mulkkusaaret	0.09	28.3
gyttja (dark grey mud)	20-25 cm	Ontojärvi, Mulkkusaaret	0.091	30.1
gyttja (dark grey mud)	2-5 cm	Ontojärvi, Mulkkusaaret	0.087	22.8
gyttja (dark grey mud)	25-30 cm	Ontojärvi, Mulkkusaaret	0.095	30.7
gyttja (dark grey mud)	5-10 cm	Ontojärvi, Mulkkusaaret	0.093	24.6
gyttja (dark mud)	0-2 cm	Ontojärvi, Mulkkusaaret (1990)	0.037	25.6
gyttja (dark mud)	10-15 cm	Ontojärvi, Mulkkusaaret (1990)	0.11	23.7
gyttja (dark mud)	15-20 cm	Ontojärvi, Mulkkusaaret (1990)	0.11	25.7
gyttja (dark mud)	20-25 cm	Ontojärvi, Mulkkusaaret (1990)	0.10	27.9
gyttja (dark mud)	2-5 cm	Ontojärvi, Mulkkusaaret (1990)	0.063	25.2
gyttja (dark mud)	25-30 cm	Ontojärvi, Mulkkusaaret (1990)	0.10	29.4
gyttja (dark mud)	5-10 cm	Ontojärvi, Mulkkusaaret (1990)	0.084	23.9
gyttja (sulphidic sludge gyttja)	2-5 cm	Pyhäjärvi, Lehtisaari	0.23	14.1
gyttja (sulphidic gyttja)	5-10 cm	Pyhäjärvi, Lehtisaari	0.26	14.4
gyttja (sulphidic gyttja)	2-5 cm	Pyhäjärvi, Lehtisaari (1990)	0.21	15.0
gyttja (soft gyttja clay)	10-15 cm	Päijänne, Asikkalanselkä	0.28	7.3
gyttja (soft gyttja clay)	15-20 cm	Päijänne, Asikkalanselkä	0.21	10.2
gyttja (soft gyttja clay)	20-25 cm	Päijänne, Asikkalanselkä	0.18	12.3
gyttja (soft gyttja)	2-5 cm	Päijänne, Asikkalanselkä	0.19	8.2
gyttja (soft gyttja clay)	25-30 cm	Päijänne, Asikkalanselkä	0.17	12.8
gyttja (soft gyttja clay)	30-35 cm	Päijänne, Asikkalanselkä	0.17	11.8
gyttja (soft gyttja clay)	5-10 cm	Päijänne, Asikkalanselkä	0.32	5.6
gyttja (dark mud)	0-2 cm	Päijänne, Asikkalanselkä (1990)	0.079	14.1
gyttja (dark mud)	2-5 cm	Päijänne, Asikkalanselkä (1990)	0.15	10.0
gyttja (gyttja)	5-10 cm	Päijänne, Asikkalanselkä (1990)	0.31	5.8

Table 5-29 (cont'd). Available literature data on bulk densities (g_{dw}/cm^3) and carbon concentrations ($\%_{dw}$) in Finnish lake sediments (Ilus et al. 1993).

Description	Depth	Lake	Density	Carbon
Gyttja / sludgy top sediment (cont'd)				
gyttja (dusty mud)	0-2 cm	Päijänne, Ristiselkä	0.10	12.8
gyttja (mottled mud)	2-5 cm	Päijänne, Ristiselkä	0.14	13.9
gyttja (muddly clay)	5-10 cm	Päijänne, Ristiselkä	0.22	8.2
gyttja (grey gyttja clay)	10-15 cm	Päijänne, Souselkä	0.36	6.1
gyttja (grey gyttja clay)	15-20 cm	Päijänne, Souselkä	0.23	8.8
gyttja (grey gyttja clay)	20-25 cm	Päijänne, Souselkä	0.21	10.3
gyttja (grey gyttja clay)	25-30 cm	Päijänne, Souselkä	0.20	10.4
gyttja (grey gyttja clay)	30-35 cm	Päijänne, Souselkä	0.21	10.2
gyttja (grey gyttja clay)	35-40 cm	Päijänne, Souselkä	0.20	10.0
gyttja (grey gyttja clay)	5-10 cm	Päijänne, Souselkä	0.35	5.1
gyttja (soft gyttja)	2-5 cm	Päijänne, Tehinselkä	0.17	20.1
top sediment (black sludge)	0-2 cm	Kallavesi, Muuraissaaret	0.093	20.4
top sediment (black sludge)	2-5 cm	Kallavesi, Muuraissaaret	0.13	17.4
top sediment (black sludge)	5-10 cm	Kallavesi, Muuraissaaret	0.18	10.2
top sedim. (reddish brown sludge)	0-2 cm	Pielinen, Suurselkä	0.14	10.9
top sediment (watery sludge)	2-5 cm	Pielinen, Suurselkä	0.23	9.4
top sediment (light brown sludge)	0-2 cm	Pyhäjärvi, Lehtisaari	0.13	14.5
top sediment (brown sludge)	0-2 cm	Pyhäjärvi, Lehtisaari (1990)	0.11	15.5
top sediment (watery sludge)	0-2 cm	Päijänne, Asikkalanselkä	0.11	10.6
top sediment (watery sludge)	0-2 cm	Päijänne, Souselkä	0.15	13.4
top sedim. (watery black sludge)	2-5 cm	Päijänne, Souselkä	0.21	9.1
top sediment (watery sludge)	0-2 cm	Päijänne, Tehinselkä	0.082	14.8

Table 5-30. *Statistics of bulk density (g/cm^3) of lake sediments presented in Table 5-29.*

Soil type	Mean	Min.	Max.	Std	N
Gyttja/sludge	0.15	0.036	0.37	0.069	114
Clay (lake bottom)	0.27	0.16	0.65	0.12	31

Distribution coefficient (Kd) to sediment

Ilus et al. (1993) report data for Sb-125 in water and sediments of Finnish lakes, but this data for a Priority IV nuclide Sb-126 were not utilised due to lack of time since care is needed in interpreting the data because of the difference in half lives of the nuclides. They give data also for Cs-134 and Cs-137 (Cs-135 on Priority II) but these were considered to be adequately represented by the other literature data (Helin et al. 2010) at this stage of the programme, especially as the same cautiousness with the half-life differences needed to be taken.

5.3.5 Rivers

As rivers tend to play a relatively minor role in the radionuclide transport model due to their relatively small production of edibles to humans and the quick water exchange, all site and regional data for parameters specific to river ecosystems are discussed in this section except for those specific to C-14 modelling (section 5.3.7).

Biomass and production of aquatic plants, and loss from plants to sediment

Conceptually, and due to lack of data, the river ecosystems are treated as a special case of a lake, similarly as in the Swedish case (Nordén et al. 2008): the same habitats can be found in streams and rivers than in lakes, and the same functional groups are relevant. The differences are mainly the water flow, which is much more rapid in streams than in lakes. Also shading from the shoreline vegetation is more pronounced in streams and rivers than in larger lakes. Thus we conclude that while quantified site studies on the biomass and production of aquatic plants are lacking, the values presented above for lakes can be used in the assessment, as well as those for the loss rate from the aquatic plants to the sediment.

Concentration of suspended solids in river water

Suspended particulate matter in river water has been measured for long from the Eurajoki River discharging close to the Olkiluoto site (see also section 3.2.7). For the BSA-2009, the values are derived as mean and extreme concentrations in 2000-2009 at monitoring point specified in Table 3-3 above. The mean value becomes 0.022 kg_{dw}/m^3 with a respective range of 0.0005-0.13 and standard deviation of 0.021 (Environmental information and spatial data service - OIVA portal, May 4, 2009).

Sedimentation and resuspension rates

As assumed by a radionuclide transport model for streams (Jonsson & Elert 2005), the concentration of suspended material is constant in stream water, which implies that the sedimentation and resuspension rates of particulate matter equal. In this case, sedimentation and resuspension flux can be expressed as

$$S = R = c_p V_s A_s \quad \text{(Eq. 5-5)}$$

where S is the sedimentation and R the resuspension flux (kg/y), c_p the concentration of suspended particulate matter in the stream water (kg/m^3), V_s sedimentation velocity of the particulate matter (m/y), and A_s is the area of the sediment/stream water interface (m^2).

For a unit area, the sedimentation and resuspension rates can then be calculated from the data above as a product of the suspended sediment concentration (0.022 kg_{dw}/m^3) and the sedimentation velocity (400 m/y; Jonsson & Elert 2006), yielding 8.8 $kg_{dw}/m^2/y$, or correspondingly for the range 0.15-65 $kg_{dw}/m^2/y$ (sedimentation velocities 300-500 m/y; Jonsson & Elert 2006).

Sediment properties

As there are for the moment little directly applicable data on the river bottom sediment bulk densities, and carbon concentrations, the values derived for lake sediments (Table 5-30) and, if necessary in case of deep sediments, soils (Table 3-12) can be used as a surrogate. However, for the active top sediment, values for gyttja and sludge should always be applied due to the high water content.

5.3.6 Sea areas

Since for the sea areas the water volume is very large compared to what is collected for food by humans, none of the coastal area parameters has been identified as key data, and all site and regional data for them are discussed in this section, with the exception of the C-14 specific data (section 5.3.7).

Biomass and production of aquatic plants, and their loss rate to sediment

For the macrophyte vegetation in the sea area off Olkiluoto there are no quantitative analyses yet available, data from the Forsmark area, Sweden, is applied as an analogue. Table 6-1 of (Wijnbladh et al. 2008) provides data on the element storages in the whole Forsmark model area: the carbon pool in macrophytes is on average 8 g_C/m^2. By utilising the data in table 4-6 of (Wijnbladh et al. 2008), a conversion factor of 0.3 g_C/g_{dw} was used. This produces an estimate of 27 g_{dw}/m^2 for the average macrophyte vegetation. For the overall variation, appendix 8a of (Wijnbladh et al. 2008) presents corresponding values for the bathymetric basins of the area, varying from 0.33 to 93 g_C/m^2 with a median of 7.1 g_C/m^2. Using the same conversion factor, these values become 1.1, 310 and 24 g_C/m^2, respectively.

To estimate the production, same production/biomass ratio is used as for the lakes (section 5.3.4): the biomasses from above translate into productions of on average 33 $g_{dw}/m^2/y$, as median value 30 $g_{dw}/m^2/y$ and ranging 1.4-380 $g_{dw}/m^2/y$.

As for the lakes, practically all plant biomass above the bottom is renewed due to the winter conditions in Finland. Numerically this implies a value of 1 y^{-1} for the biomass loss rate to the top sediment.

Concentration of suspended matter

Suspended matter content of surface seawater (0-2 m) has been monitored from offshore Olkiluoto. For the use of BSA-2009, concentrations of the suspended matter (>0.4 µm) has been calculated as average and extreme values from all samples in 2006-2009[13]. The average yields 0.003 kg_{dw}/m^3, and the variation is from 0.0005 to 0.016 kg_{dw}/m^3 with a standard deviation of 0.0025 kg_{dw}/m^3 (Environmental information and spatial data service - OIVA portal, May 4, 2009).

Sedimentation and resuspension rates

Older reports on radioactivity in the environment (STL 1980a,b, 1982a,b, 1983) present also sedimentation data for offshore Olkiluoto (Table 5-31; Fig. 5-7). For the single sampling site OL-SEA12, data are available also from shallower depths, but not used here for consistency. The sedimentation rates are based on collection of the sedimenting material 1 m above the bottom with sediment traps (STL 1980a, STL 1979) described in few more detail in (STL 1982a). The data are from areas of likely present sedimentation, but there are large areas with much less or no sedimentation (Fig. 5-7).

[13] In other water quality data, the time period of 2000-2009 is generally used, but there were no measurements of the suspended matter concentration from the sea area in 2000-2005.

However, since the size of the sea basins are decreasing with the land uplift, especially those relevant to the radionuclide transport modelling, using these data will not bias the parameter values too much.

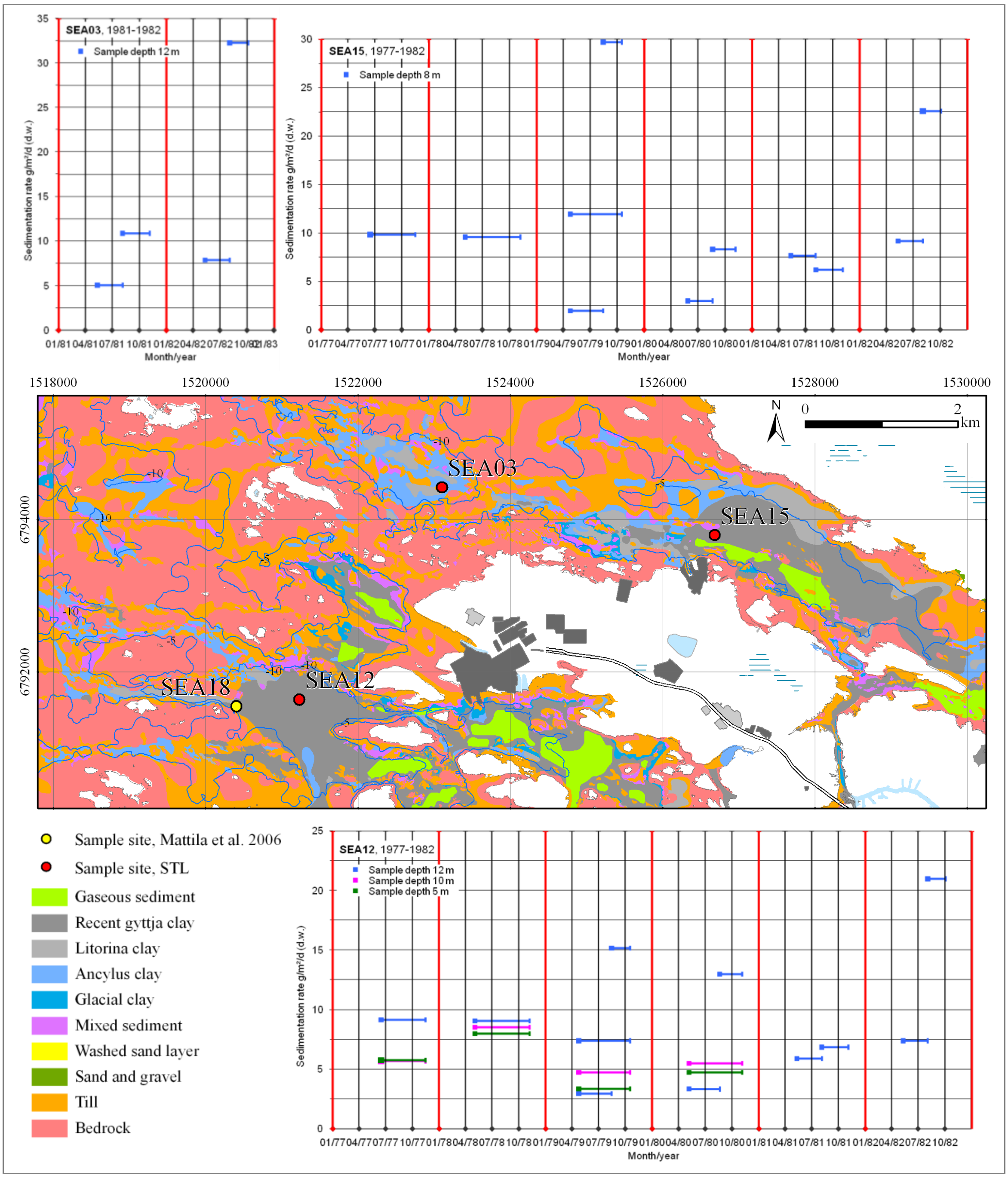

__Figure 5-7.__ Map of sedimentation rate measurement sites of (STL 1980a,b, 1982a,b, 1983). The map shows the present sea bottom sediments (Rantataro 2001, Rantataro & Kaskela 2010) and main depth contours (Pohjola et al. 2009). Also the measurement site of (Mattila et al. 2006) is shown as SEA18. Map layout Jani Helin/Posiva Oy.

Table 5-31. *Sedimentation rate data collected with traps for sedimenting material 1 m above the bottom during the open-water seasons (usually from May to November) at Olkiluoto (STL 1980a,b, 1982a,b, 1983).*

Open-water season	Cumulative amount, g_{dw}/m^2	Duration of sampling period, days	Sedimentation rate, $kg_{dw}/m^2/y$
Site OL-SEA03			
1981	1430	177	2.95
1982	2660	146	6.65
Site OL-SEA12			
1978	1700	188	3.30
1979	1300	176	2.70
1980	1350	182	2.71
1981	1130	177	2.33
1982	1920	146	4.80
Site OL-SEA15			
1978	1800	188	3.49
1979	2120	176	4.40
1980	890	161	2.02
1981	1220	177	2.52
1982	2170	146	5.43

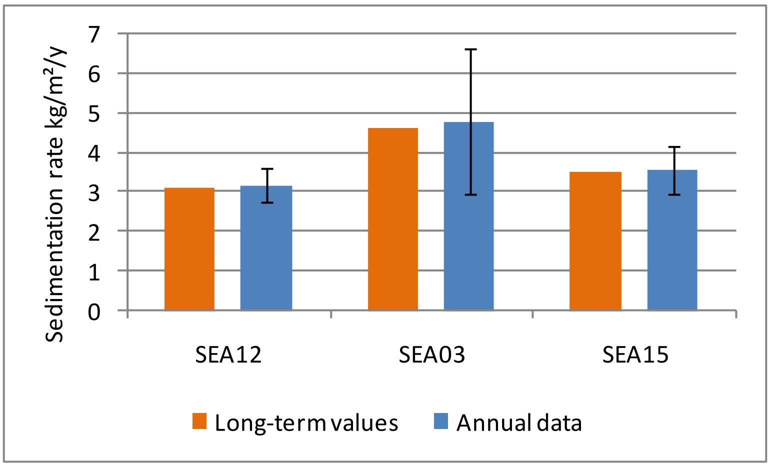

Figure 5-8. *Comparison of average sedimentation rates of long-term and open-water periods (annual data) offshore Olkiluoto from data of (STL 1980a,b, 1982a,b, 1983), arithmetic mean with standard error as error bars.*

From the data, average sedimentation rates for open-water seasons and for the long-term (as long as there are data available for each point) were calculated (Fig. 5-8). The difference between the sites is not significant. There was no significant difference between the full open-water-season averages and values from shorter collection periods either, but the variation is larger the shorter the time frame is.

The mean average value for the open-water season is 3.1 $kg_{dw}/m^2/y$ with a range of 1.2-6.7 and stardard deviation of 1.4 (N = 18). The individual data from the shorter collection periods range 0.7-12 $kg_{dw}/m^2/y$. As the sampler is located 1 m above the bottom, these are likely corresponding to the cross sedimentation rates.

Mattila et al. (2006) studied the average bulk sediment accumulation rate (SAR) at 69 stations and in 99 cores from the Baltic Sea during 1995-2003 with a method based on accumulation of anthropogenic Cs and Pu. SAR values varied widely, being between 0.6 and 6 kg/m²/y. The highest values were observed in the northern part of the Bothnian Sea, river estuaries and in the eastern part of the Gulf of Finland. In the Bothnian Sea, the median SAR values were two, three and seven times higher than at the stations in the Bothnian Bay, Gulf of Finland and Baltic Proper, respectively. Near Olkiluoto, a value of 1.81 kg_{dw}/m²/y ±0.22 % was estimated (Mattila et al. 2006). Since long-term accumulation is measured, these are most likely net sedimentation rates.

Assuming that Mattila et al. (2006) give a representative rate of net sedimentation and the other data above are for gross sedimentation, and that the closest point of the latter data (OL-SEA12) gives adequately respective value (3.17 kg_{dw}/m²/y) than Mattila et al. (2006), an estimate of resuspension rate of 1.36 kg_{dw}/m²/y is obtained. This neglects the effect of winter period to the OL-SEA12 value. Also, the data represent different periods of time, so here it is assumed also that both correspond to a constant long-term average.

To generalise this to the whole area of earlier observations, the relative value of 1.36/3.17 = 42.9 % of gross sedimentation can be used for the resuspension rate. This yields a resuspension rate of 1.3 kg_{dw}/m²/y for the whole area.

Sediment properties

As there are for the moment little directly applicable data on the sea bottom sediment bulk densities, and carbon concentrations, the values derived for lake sediments (Table 5-30) and, if necessary in case of deep sediments, soils (Table 3-12) can be used as a surrogate. However, for the active top sediment, values for gyttja and sludge should always be applied due to the high water content.

Some initial site specific data are expected when recent and forthcoming sediment sampling data from offshore Olkiluoto (summarised on p. 188 of Haapanen et al. 2009a) become available.

Nuclide-specific parameters

Some potential data for deriving distribution coefficients and concentration ratios are available from the monitoring programme of environmental radioactivity in sea areas off Olkiluoto. Possibilities of their utilisation are discussed below, based on a review of all available data (summarised in STL 1977, 1979, STL 1980a,b, 1982a,b, 1983, Ikonen 2003, Roivainen 2005, Haapanen 2005, 2006, 2007, 2008, 2009). In any use of those data as analoguous to the long-lived nuclides released from the deep repository, caution needs to be taken due to the differences in half lives and the effect to the behaviour of stocks and flows in the different media. Anyway, the data need also to be complemented with literature reviews (such as Helin et al. 2010).

Monitoring data from Olkiluoto, and from the Loviisa nuclear power plant reported in the same reports, include data on Nb-95 (half life 35 d) for seawater and suspended matter but the latter are reported for period of May-November whereas the former observation are only in April (STL 1980a); the sample-specific data not reported would be required for Kd estimates. Similarly, there are data on Nb-95 in seawater and algae (STL 1979, 1980a), but since the sampling date of the alga samples is not reported, no reliable concentration ratio estimates can be calculated for this Priority II element.

Monitoring data from the Loviisa nuclear power plant area, encountered when Olkiluoto-specific data was searched, include few observations of Sb-124 (half life 60 d) and Sb-125 (2.77 y) with a potential to provide Kd to suspended matter and concentration ratio to algae (STL 1980a, 1984), but these data for the Priority IV element were not utilised due to lack of time and needed care in the analysis.

The nuclear power plant monitoring data include also some individual occurrences of I-131, Nb-95, Y-88, Sb-124, Sb-125 and Cr-51 (possible analogue to Mo but half life only 27.7 d) (STL 1982b, 1983, 1984), but the respective concentration in seawater, suspended matter, sediment or biota has been below the detection limit or has not been reported.

The data in (Ikonen 2003) include potential concentration ratio data for Cr-51 (chemical analogue to Mo, see above) to alga in a single occasion and potential Kd data to suspended matter for Sb-125, both requiring care in interpreting the results. There is also some, although less, potential for concentration ratios of Sb-125 to alga and bottom fauna. Even though the concentrations in suspended matter are usually below the detection limit, it might be possible to estimate some Kd values to suspended matter for Nb-95. For concentration ratios of Nb-95 it might be possible to bridge the individual concentration pairs: if a relationship between the seawater and suspended matter can be established, then concentration ratios from water to alga and bladder wrack could be calculated indirectly using the suspended matter-biota concentration ratios. This is however, a rather speculative process compared to just arranging targeted measurement campaigns.

The most use from the environmental radioactivity data in the sea ecosystem might be to use it for model testing. However, then the source term and overall conditions needed to be characterised in detail. Also some indirect indications of the function of the ecosystem could be extracted, e.g. figure 11 in (Ikonen 2003) shows that at least for Cs-137 the concentrations in the seawater at the sampling points rather far away are practically the same before, during and even long after the Chernobyl fallout. Such supporting analyses become much more feasible when the data have been included into Posiva's research database likely within some years.

5.3.7 C-14 modelling

In this section, site and regional data are provided for those radionuclide transport parameters that are specific to the C-14 modelling and were not identified as the key data addressed in section 5.2.3.

Carbon concentrations in soil and sediment

For croplands, the carbon concentration of 0.03 (0.01-0.3) $\%_{dw}$ in the top soil is based on 6 % organic matter content, that can be considered a median value in Satakunta region (Kähäri et al. 1987), and assumption of 50 % of organic matter being carbon. Peat soils in agricultural use can contain 50 % organic matter. In the deeper layers carbon concentration decreases, and as the carbon concentrations of the other soils (Table 5-33 below) correspond to those met in deeper layers of croplands, e.g. from a 15-plot study in Yläne (Table 5-32; source: Agrifood Finland), the more generic data should be used for the deeper layers of croplands as well.

For other soil and sediment types, the carbon concentrations based on soil samples from Olkiluoto (Lahdenperä 2009) and from Espoo, southern Finland (Ojala 2007), and on lake bottom sediments from Finland (Ilus et al. 1993). The original data are presented in Tables 3-13 and 5-29 are the summary of the data in Table 5-33. It is noteworthy that such directly applicable data seem to be lacking from sea (and river) bottom sediments.

However, some site specific data are expected when recent and forthcoming sediment sampling data from offshore Olkiluoto (summarised on p. 188 of Haapanen et al. 2009a) become available.

Carbon content in the acrotelm of peat bogs has been estimated based on the forest sample plot data from Olkiluoto (Tamminen et al. 2007; site class 5): average concentration in peat layer of 0-20 cm is 0.46 kg_C/kg_{dw}, and the respective range is 0.31-0.53 and standard deviation of 0.05 kg_C/kg_{dw}. This is consistent with the more generic values discussed above for the deeper layers. The carbon content in catotelm is based on literature on Finnish peat deposits (Table 3-13 in section 3.3.5), and yields in a mean value of 0.51 kg_C/kg_{dw} and range of 0.50-0.54 kg_C/kg_{dw}.

Table 5-32. *Carbon concentrations ($\%_{dw}$) in 15 agricultural plots in Yläne, southwestern Finland (data of Agrifood Finland).*

Depth	Concentration
0-30 cm	2.66
30-60 cm	0.42
60-80 cm	0.30

Table 5-33. *Statistics of carbon concentrations ($\%_{dw}$) in soil and sediment types based on data collected into Tables 3-13 and 5-29.*

Type	Mean	Min.	Max.	Std	N
Gyttja and sludge	18	5.1	31	6.4	114
Clay, aquatic	11	2.9	19	3.7	31
Clay, terrestrial *	0.18	0.14	0.23	0.04	4
Fine sand	0.18				1
Sand	0.48	0.13	1.5	0.47	7
Fine-grained till	0.20	0.07	0.41	0.12	9
Washed till	0.14				1

* For plough layer of croplands another values should be used, see the text above.

Vegetation height in croplands and forests

Height of cropland vegetation was already given in Table 5-25 (section 5.3.2) with other crop data as typical values in Finland, partly based on crop experiments.

Vegetation height for forests has been calculated from the tree measurements at the monitoring plot network (Saramäki & Korhonen 2005), from which the results derived are presented in Table 5-34. This excludes the understorey and shorter trees than the breast height (1.3 m), thus no minimum value is meaningful to give here. It needs to be noted also that the results represent the status of the forest in Olkiluoto in 2004, and no attempt to correct for the whole rotation time has been made.

As the vegetation height determines the ratio of the volume of CO_2 emitted from the soil to the volume of CO_2 captured for the photosynthesis[14] (Avila & Pröhl 2007), especially for forests it would be useful in the future, when available resources allow, to provide the vegetation height, net primary production and mixing height estimates together for different forest classes, preferably separated to the trees and the understorey and with correlations between the parameters.

Table 5-34. *Heights of trees by UNTAMO site classes (section 3.2.3) as derived from the measurement data of (Saramäki & Korhonen 2005).*

UNTAMO site class	Mean height (m)	Max. height (m)	Std (m)	N *
1 Rocky forest	7.9	15.3	3.1	28
2 Heath forest	9.3	25.0	4.8	1793
3 Herb-rich heath f.	10.9	27.0	5.4	502
4 Herb-rich forest	10.7	19.6	4.9	46
5 Peatland forest	9.0	23.7	4.3	522

* Number of trees measured.

Net primary production

Estimates for net primary production in forests and lakes have been discussed as key data in section 5.2.3 above, and the estimates for croplands, mires and sea remain to be addressed here. For the rivers, the data for lakes can be used as surrogate to better data, as discussed above.

For the sea areas, net primary production is estimated for the biosphere assessment from the measurements at points OL-SEA06 and OL-SEA08 (see e.g. figure 7-26 in Haapanen et al. 2009a) in 1990-2008. The average yields 55 $g_C/m^2/y$ and the range 37-83 $g_C/m^2/y$ (standard deviation 12 $g_C/m^2/y$) (Environmental information and spatial data service - OIVA portal, May 4, 2009).

Net primary production of crops has already been described along with other crop parameters in section 5.3.2 with the data in Table 5-25.

In the landscape model, the peat bogs are based on the simulations with the UNTAMO peat growth model (section 3.1), which is based on the model of (Clymo 1984). In the

[14] See also "Wind speed and mixing height" in section 5.2.3.

original article on the model, there are equations relating the annual productivity on the acrotelm to the matter passing to the catotelm (data given in section 3.2.5), but it would require information on the decay rate in the acrotelm as well. However, Clymo et al. (1998) give a value of 28 $g_C/m^2/y$ (range 23-31) for the "addition of plant dry mass at the surface" in the concentric bog region in Finland. In respect of NPP, these lack the contribution from the below-ground production.

Overall, few studies have quantified NPP in peatlands for all vegetation layers at a single site[15], and furthermore, the growth has been measured in quantities that are not useful in estimating the NPP (e.g. growth in length of mosses) (Wieder 2006). Based on a recent compendium (Wieder 2006), the range of NPP is likely in the order of 37.1-642 $g_{dw}/m^2/y$ for peatlands in Finland.

Concentration of dissolved inorganic carbon

For river water, no direct measurements of concentration of dissolved inorganic carbon (DIC) are available. However, total organic carbon (TOC) is part of the routine monitoring. It is known, that of the global carbon fluxes to the oceans from the continents, about 18 % moves in riverine transport as particulate organic matter (POC), 37 % in dissolved organic form (DOC), and 45 % as DIC Wetzel (2001). As the total organic carbon equals the other two forms (TOC = POC + DOC), the DIC concentrations are thus 0.818 times the TOC. This, of course, assumes that all inorganic carbon is in the dissolved form. Using this conversion factor, the mean TOC concentration in measured from Eurajoki River in 2000-2009 results in a DIC concentration of 8.7 mg/L, and the range becomes 2.5-27 mg/L with a standard deviation of 12 mg/L (Environmental information and spatial data service - OIVA portal, May 4, 2009).

For seawater, DIC is estimated from the TOC concentrations measured at Olkiluoto in 2007-2008 (all available data). The conversion ratio is established based on data reported in (Wijnbladh et al. 2008) for the Forsmark site in Sweden. From the monthly mean values of their samples in 2002-2006, presented in their Figure 3-2, a ratio of 2.6 ±0.2 is obtained for DIC/TOC (mean ± standard error). The TOC data from monitoring sites OL-SEA03 and OL-SEA05...10 at Olkiluoto (Haapanen et al. 2009a) as coverted using the mean ratio gives an estimate of 13 mg/L for the mean DIC concentration (range 1.8-25, standard deviation 2.8, number of samples 106). This is consistent with the Swedish data (Wijnbladh et al. 2008) giving a mean of 11 mg/L and standard deviation of 5 mg/L.

[15] Composition and production of species and nutrient and climatic factors produce a great variability.

6 MODELLING OF DOSES TO HUMANS

As described above, the radionuclide transport modelling provides the input for dose assessment, spatially distributed time-dependent radioactivity concentrations. The models and concepts presented below are used to estimate consequences to humans and other biota potentially arising due to these activity concentrations. The focus is on the main quantities to be used in the compliance assessment. The models to derive other quantities that will likely be used in the biosphere assessment, such as collective doses or ecosystem-specific dose conversion factors, are not included.

6.1 Model description

The dose assessment aims to determine compliance with the regulatory dose constraints. According to ICRP (2007), dose assessment is a multistage process that is summarised as it is applied in the Posiva biosphere assessment in Fig. 6-1.

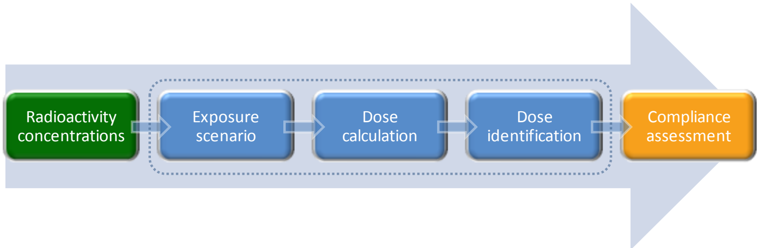

Figure 6-1. *General process for converting calculated environmental media radioactivity into suitable quantities to be used in the compliance assessment.*

The key conceptual assumptions and models used in assessing the doses to humans are:

- Radioactivity concentrations in the foodstuffs produced in the biosphere model area are calculated using moderately pessimistic site and complementary literature values for key parameters such as transfers to the foodstuffs and their productivity.
- The exposure scenario is a reasonable one, in line with the ICRP representative person concept (IAEA 2007), with ingestion of food, water, inhalation and external exposure as the pathways, cautious assumptions for occupancy and use of the local resources and average intake rates. The number of exposed people, or the size of the "other persons" (STUK 2009), is restricted by the capacity to produce food and drinking water, and by population density based on the current demography.
- Dose calculation and identification are based on a deterministic approach, where annual effective doses from the use of the landscape are derived from one dominant pathway and typical values for other pathways for each exposed person in each generation, with typical doses being pathway-specific population-weighted average doses.
- The most exposed group is identified as all persons receiving a dose over the 95^{th} percentile in the annual landscape dose distribution, and the dose for the representative person of this group is the average dose within the group. The

dose for the representative person for other members of the public is the average dose in the entire annual landscape dose distribution.

- In the compliance assessment, the doses defined above are compared with the regulatory dose constraints to the most exposed members and other members of the public (Section 1.2.3).

6.2 Key input data

The dose from given radionuclide concentrations in an ecosystem is, in most cases, dominated by the dose from ingestion of food or water[16]. In our dose concept, the food intake is presented in terms of the annual demand for carbon, which is harvested from a pessimistic location representing average conditions for production of foodstuffs and radionuclide transport to them. The former is presented by total productivity of edibles in an ecosystem, and the latter as aggregated (productivity-weighted average) concentration ratios[17] to the edibles. In this section, the site-specific productivity estimates are given, and, in addition, the site data available for concentration ratios to the foodstuff are presented for complementing and derivation of the aggregated concentration ratios in (Helin et al. 2010).

For the forests, productivity can be presented by site class, although site class 4 (herb-rich forest) is not considered here since these sites fall under agricultural land in the biosphere base case. For the other ecosystems, only best-estimate values and ranges are given, and, for mires, only likely pessimistic best estimates. On croplands, the various crops are not cultivated at the same time. Thus, a characteristic value has been chosen to be used in the assessment.

6.2.1 Normalisation to carbon content

The productivity of the edibles is calculated by summation over all plant parts and animal products normally consumed by man. The original data are in terms of fresh weight, or, in some cases, dry weight, and, for the purposes of our model, it needs to be converted to carbon-kilograms. In the edibles, the carbon content has been calculated based on the nutrient contents reported in the FINELI database of the National Institute for Health and Welfare (www.fineli.fi) by conversion as in Altman & Ditmer (1964), Dyson (1978), Rouwenhorst et al. (1991) and Bergström et al. (2008):

$$CC = 0.53P + 0.44CH + 0.66L \qquad \text{(Eq. 6-1)}$$

where CC is the carbon content in the food product (kg_C/kg_{FW}), and P, CH and L are the protein, carbohydrate and lipid (fat) contents of the food (kg/kg_{FW}) as taken from the database. The carbon content derived from this method using the nutrient content database is thus applied to the edible part, not the whole body or plant.

[16] For some of the significant nuclides presented in Table 2-1 the doses are dominated by accumulation in overburden and subsequent external exposure (Nb-94, Sn-126). Similarly, if alpha emitters (such as Pu-239) were released within the biosphere assessment time window, the dose from them would be dominated by the inhalation pathway

[17] The aggregated concentration ratio (CR_{agg}) is identical with the quantity *aggregated transfer factor* (TF_{agg}) used in (Haapanen et al. 2009), which has been used earlier for example in (Broed et al. 2007) and (Bergström et al. 2008).

6.2.2 Productivity of edibles in forests

The edibles produced in forests comprise of berries, mushrooms and game. Their productivity has been estimated first separately and then combined into a sum value. Berries, and mushrooms, are an important pathway to human foodchain in forested environment, and the premilinary values presented here are planned to be complemented by both more comprehensive literature review and site studies for the next assessment round.

Berries

The productivity of berries firstly based on the data in (Turtiainen et al. 2005, 2007) and (Salo 2008), taken the site type into account when possible. Secondly, those berries not growing on a specific site type were given a value of 0 by expert judgment. This was then expanded to cover the data gaps by a three-level abundance classification. Finally, productivity values for assessment use were assigned to them based on subjective scaling of the scarce data. In the following, the data presented in Table 11-1 of the Biosphere description 2009 (Haapanen et al. 2009a) is derived in detail.

For upland forests, Turtiainen et al. (2005) have presented estimates for average-year average crops for different site types by administrational areas. Their data are based on models that were calibrated to the regions with empirical data. The data for area including the Forest Centre of Southwestern Finland are presented in Table 6-1. From these, sub-xeric heath forest is paralleled here to the forest class 2 (heath forest; Table 3-4) and herb-rich heath forest to class 3 (herb-rich heath forest).

Table 6-1. *Estimated average-year average crops (g_{fw}/m^2) for a region including the Forest Centre of Southwestern Finland (Turtiainen et al. 2005).*

Site type	Bilberry	Lingonberry
Xeric heath forest	0.43	1.87
Sub-xeric heath forest	0.95	2.59
Mesic heath forest	1.40	1.48
Herb-rich heath forest	0.20	0.10

Table 6-2. *Average bilberry and lingonberry yields (g_{fw}/m^2) from pristine and drained spruce and pine mires, by the nutrient status levels of the peatland (Turtiainen et al. 2007).*

Undrained mire type	Undrained sites				Drained sites		Drained mire type
	Bilberry		Lingonberry		Bilberry	Lingon-berry	
	Spruce	Pine	Spruce	Pine			
Eutrophic	0	-	-	-	0.54	0.36	Spruce, recent [e]
Herb	0.010	-	0.08	-	0.11	0.14	Pine, recent [e]
Tall-sedge [a]	0.081	0.03	0.28	0.14	0.21	0.21	Transformed
Small-sedge [b]	0.020	1.11	0.31	1.00	0	0	Spruce shrub [f]
Cottongrass [c]	-	0.48	-	0.57	0.02	0.04	Pine shrub [f]
Sphagnum [d]	-	0.10	-	0.25			

a *Vaccinium myrtillus*
b *Vaccinium vitis-idaea*
c Cottongrass-dwarf shrub
d *Sphagnum fuscum*
e Recently drained
f Shrub and waste land

Table 6-3. *National average-year total berry yields from (Salo 2008) divided by the respective land areas from (Tomppo et al. 2001, cited by Turtiainen et al. 2007).*

	Forested land, g_{fw}/m^2	Drained and pristine mires, g_{fw}/m^2
Lingonberry	1.21	0.15
Bilberry	0.84	0.17
Cloudberry	-	0.34
Cranberry	-	0.22
Crowberry	-	0.42
Red whortleberry	-	0.30
Raspberry	-	0.0056

Berry yields in mires have been studied by Turtiainen et al. (2007) and Salo (2008). The former used similar methods as the study on upland forest summarised above, and the latter gives average-year total berry yields in Finland, which have been divided by the respective total areas taken from (Tomppo et al. 2001) as cited by Turtiainen et al. (2007). The data from both studies are presented in Tables 7-2 and 7-3.

From the alternative values of Tables 6-1, 6-2 and 6-3, the selection for Classes 2 and 3 is to use the data of (Turtiainen et al. 2005) since they are most detailed. For lingonberry and bilberry in Class 5, the maximum of the alternative values is taken for cautiousness. For the other berries in Class 5, the data of (Salo 2008) are used as the only available source.

However, some gaps remain: whole Class 1 and the other berries than lingonberry and bilberry in Classes 2 and 3. To fill these, relative abundance estimates are done by expert judgement (Table 6-4). Those berries not met on a Class are marked with 0, those encountered in minor abundance with + and those that are abundant in the Class with +++. Logically, ++ indicates a medium level. To convert these into scaling factors, a subjective decision is taken that 0 = 0, + = 1, ++ = 3 and +++ = 6. Furthermore, in filling the gaps by the given numerical ratios, the scaling is done from the closest abundance value, e.g. to fill a +, the productivity value of a ++ is used instead of a +++.

After the gaps have been filled using this procedure, conversion from the fresh-weight units to carbon weights are needed for the final results. The concentration values and related assumptions are presented in Table 6-5.

Table 6-4. *Relative abundance estimates of berries in different forest classes based on expert judgement (for the scale, see the text).*

Edible	UNTAMO site class			
	1 Rocky	2 Heath	3 Herb-rich	5 Peatland
Lingonberry	+	+++	+	++
Bilberry	+	+++	+++	++
Cloudberry	0	0	0	+++
Cranberry	0	0	0	+++
Crowberry	+++	++	+	+++
Red whortleberry	0	+	+	+++
Raspberry	+	++	+++	+

Table 6-5. *Carbon concentrations in berries based on the FINELI database (www.fineli.fi) and equation 7-1.*

Edible	Carbohydrates $g/100\ g_{fw}$	Fats $g/100\ g_{fw}$	Proteins $g/100\ g_{fw}$	Carbon content kg_C/kg_{fw}
Lingonberry	6.8	0.5	0.4	0.03534
Bilberry	6.4	0.6	0.5	0.03477
Cloudberry	7.8	0.5	1.4	0.04504
Cranberry	3.5	0.7	0.4	0.02214
Crowberry	7.2 *	0.5 *	0.7 *	0.03869
Red whortleberry	7.2 *	0.5 *	0.7 *	0.03869
Raspberry	4.1	0.8	1.0	0.02862

* Mean value for berries in general (no specific data available)

Table 6-6. *Productivity of berries and edible fungi in forest and mire ecosystems ($kg_C/m^2/y$). Values without a reference are based on scaling based on the abundance rating (expert judgement).*

Edible	UNTAMO site class				Maximum
	1 Rocky	2 Heath	3 Herb-r. heath	5 Peatland	
Lingonberry	3.5e-6 (+)	7.00e-5 * (+++)	3.53e-6 * (+)	3.53e-5 ** (++)	7.00e-5
Bilberry	5.4e-5 (+)	3.22e-5 * (+++)	6.95e-6 * (+++)	3.82e-5 ** (++)	3.82e-5
Cloudberry	0	0	0	1.52e-5 *** (+++)	1.52e-5
Cranberry	0	0	0	4.98e-6 *** (+++)	4.98e-6
Crowberry	1.6e-5 (+++)	8.1e-6 (++)	2.7e-6 (+)	1.61e-5 *** (+++)	1.61e-5
Red whortleb.	0	2.0e-6 (+)	2.0e-6 (+)	1.17e-5 *** (+++)	1.17e-5
Raspberry	1.6e-7 (+)	4.8e-7 (++)	9.7e-7 (+++)	1.61e-7 *** (+)	9.66e-7
Berries, total	2.5e-7	1.13e-4	1.61e-5	1.22e-4	1.22e-4
Edible fungi	5.12e-4 ****	5.12e-4 ****	5.12e-4 ****	2.56e-5 ****	5.12e-4

* Turtiainen et al. (2005)
** Maximum value from Turtiainen et al. (2007) across different mire types
*** Salo (2008) for forest land or drained and undrained mires
**** Ohenoja (1978)
\+ May be found occasionally; reliable data for productivity were not found
++ Common but reliable data for productivity were not found
+++ Typical growing site, but reliable data for productivity were not found

Table 6-6 presents the final estimates, with the values derived from the literature marked separately and the rest being based on expert judgement as described above. For lingonberry and bilberry, there is also a model available (Ihalainen et al. 2003; summarised by Löfgren 2008), but this was not used since the model was derived from conditions of Northern Karelia. Furthermore, in any case, the heterogeneity of the landscape, among other factors, greatly influences the large spatial variation of berry crops; using a model for some of the berries would not produce much better results in the context of far future predictions needed in the biosphere assessment. In Olkiluoto and surroundings, sea buckthorn (*Hippophaë rhamnoides*) is abundant in places in the shoreline, and the berries are picked from the easiest reachable locations. The species is found also in some places inland. However, as the overall contribution to the berry yield in forested land is rather small (although there are no quantified data), the buckthorn berries are omitted from the calculations.

Mushrooms

Productivity of edible fungi was estimated based on Ohenoja (1978): mushroom yield in Lapland (Northern Finland) varies yearly between 10 and 200 kg_{fw}/ha with about a half being edible, and the yield is on the average nearly as great as that in Southern and Central Finland. Thus the minimum and maximum values are used as such as indicated in Table 6-6. Compared with recent values used by SKB (Löfgren 2008), the upper estimate of productivity for edible fungi seems rather high, i.e., pessimistic with respect to dose assessment.

Game

The productivity of game at the Olkiluoto site (Table 6-7) has been evaluated on the basis of the average game bag in 2002–2007 (Ikonen et al. 2003, Oja & Oja 2006, Haapanen 2007, 2008) divided with the respective forest area (evenly distributed game). Waterfowl is considered within aquatic systems. Of the live weight of a moose, 0.51 kg_{fw}/kg_{fw} is assumed to be edible, based on the average weight of an individual and weight of the edible part from Lokki et al. (1997), and for hare and grouse estimated as from figures of annual total catch (individuals) and total game meat catch (RKTL 2008), 0.51 and 0.60, respectively. The value for moose has been applied to deer, and the value for grouse to other fowl.

For the edible live weight fraction, some more information was found after the Biosphere description 2009 (Haapanen et al. 2009a) from which the data above are taken as such. Rantavaara et al. (1987) have used a correction factor to estimate of the weight of edible meat as presented in Table 6-8.

Table 6-7. *Productivity of edibles in forest ecosystem ($kg_C/m^2/y$).*

Edible	Best estimate	Min.	Max.
Moose	2.83×10^{-5}	2.02×10^{-5}	4.04×10^{-5}
White-tailed deer	1.24×10^{-5}	5.78×10^{-6}	1.62×10^{-5}
Roe deer	6.64×10^{-7}	0	3.47×10^{-6}
Hare	7.73×10^{-8}	0	2.35×10^{-7}
Partridge/hazelhen	7.09×10^{-9}	0	2.84×10^{-8}
Grouse	7.09×10^{-9}	0	1.42×10^{-8}
Berries, max. [a]	1.13×10^{-4}	1.61×10^{-5}	1.22×10^{-4}
Edible fungi, max.	5.12×10^{-4}	2.56×10^{-5}	5.12×10^{-4}
Forest, max. [a]	6.66×10^{-4}	6.77×10^{-5}	6.94×10^{-4}

a In the best estimate only forest classes 1-3 have been included, but in the minimum and maximum values also Class 5 (peatlands) is included for cautiousness; in the radionuclide transport modelling and the dose assessment the peatlands are treated separately.

Table 6-8. *Correction factors for edible meat used in (Rantavaara et al. 1987). The factor gives the proportion of "bone weight" over the carcass weight, kg_{fw}/kg_{fw}, carcass being the whole animal except head, legs below knees, entrails and skin.*

Game species	Bone weight: carcass (kg_{fw}/kg_{fw})
Moose, adult	0.80
Moose, calf	0.78
Other cervids	0.78
Hare	0.90
Birds	0.90

6.2.3 Productivity of edibles in croplands

The productivity of crops is calculated according to the average yields in Satakunta in 2007 and 2008 (www.matilda.fi). The flour supply from grain was estimated to be 60 % and sugar supply from sugar beet carbohydrates 78 %. The carbon content of yield dry matter was calculated as 40 %. Since the various crops are not cultivated at the same time, a characteristically cautious value, with respect to the dose assessment, has been chosen for use in the assessment (Table 6-9).

6.2.4 Productivity of edibles in coastal areas

Productivity of other edibles than fish and waterfowl from the coastal areas is minor; for example, crustaceans or algae are not utilised in the Olkiluoto area. Table 6-10 represents the total productivity of edibles in the coastal areas, and the values are derived in the rest of this section.

Fish

The productivity of fish in the sea areas is based on the draught statistics of 2007 and 2008 for the Bothnian Sea by the Finnish Game and Fisheries Research Institute (www.rktl.fi). The calculated draughts per unit area were converted to carbon units with data from the FINELI database (www.fineli.fi) and the Equation (6-1) above. For sprat, smelt and ide the database had no specific values, so the data for Baltic herring, bream and vendace were used, respectively, by the similarities between the species.

Losses from the ordinary cleaning of some fish were taken from Sääksjärvi & Reinivuo (2004) for burbot, pike, whitefish and vendace. For trout and rainbow trout, loss values for salmon from the FINELI database were applied. For other fish, the losses were assumed to be 30 %, except for sprat 35 % as for Baltic herring (Sääksjärvi & Reinivuo 2004). The loss factors are presented in Table 6-11.

Table 6-9. *Productivity of edibles in croplands ($kg_C/m^2/y$).*

Edible	Best estimate	Min.	Max.
Grain (flour)	0.074	0.018	0.103
Potato	0.200	0.080	0.320
Pea	0.020	0.010	0.025
Sugar beet (15% sugar)	0.180	0.118	0.234
Field vegetables	0.148	0.024	0.480
Berries and fruit	0.020	0.004	0.064
In assessment	0.200	0.004	0.480

Table 6-10. *Productivity of edibles in coastal areas ($kg_C/m^2/y$). Maximum data are given only for the waterfowl due to lack of specific data on fish; for all waterfowl, the minimum can be regarded as nil. For details, see text and tables below.*

Edible	Best estimate	Max.
Fish, sum	8.47e-5	no data
Waterfowl, sum	0.014e-5	0.14e-5
Coastal area, total	8.49e-5	-

Given the lack of more specific quantified data, recreational fishing was taken into account by scaling with the following value: catch in commercial fishing/total catch (national average separately for each species; www.rktl.fi). Due to lack of more local statistics, only best estimate values are given in Table 6-12. Assignment of proper range to cover the overall uncertainties will be then made and justified in the subsequent biosphere assessment reports.

Additional information, found after the completion of the Biosphere description 2009 (Haapanen et al. 2009a), on weights and processing losses for pike, Baltic herring, whitefish, roach and perch was found from the results of the Olkiluoto nuclear power plant's monitoring programme of environmental radioactivity (Roivainen 2005): for the samples of 1977-1981 the sample weight, weight after processing and number of individuals have been reported (Table 6-13). The processing varies by species to result in only the edible part being analysed for the radionuclides (Roivainen 2005):

- pikes are scaled and filleted,
- perch and roach are scaled and head and entrails are removed,
- Baltic herring is not scaled but head and guts are removed.

Table 6-11. *Processing losses of Baltic fish, i.e. weight fraction of the non-edible part, kg_{fw}/kg_{fw}. Where only ranges were available, minimum was taken for cautiousness.*

Fish	Loss	Removed part	Reference
Baltic herring	0.35	head and entrails	Sääksjärvi & Reinivuo 2004
Bream	0.3		assumption
Burbot	0.3	skin and entrails	Sääksjärvi & Reinivuo 2004
Perch	0.3		assumption
Pike	0.5	scales entrails and backbones	Sääksjärvi & Reinivuo 2004
Pikeperch	0.3		assumption
Roach	0.3		assumption
Smelt	0.3		assumption
Sprat	0.35	head and entrails	same as for Baltic herring
Trout and rainbow trout	0.35		same value as for salmon in FINELI
Whitefish	0.3	made into fillets	Sääksjärvi & Reinivuo 2004
Vendace	0.2	cleaned (term used in the reference)	Sääksjärvi & Reinivuo 2004

Table 6-12. *Productivity of coastal fish ($kg_C/m^2/y$).*

Edible	Best estimate
Baltic herring	7.33e-5
Sprat	6.16e-6
Perch	2.14e-6
Pike	8.57e-7
Whitefish	6.16e-7
Roach	5.33e-7
Bream	3.67e-7
Ide	1.89e-7
Pikeperch	1.65e-7
Trout	1.30e-7
Salmon	8.03e-8
Smelt	7.45e-8
Rainbow trout	5.27e-8
Burbot	4.60e-8
Flounder	3.10e-9
Fish, total in coastal areas	8.47e-5

Table 6-13. *Mean weights of individual and processing losses of fish from Olkiluoto in 1977-1981, calculated from data in (Roivainen 2005). Mean, minimum and maximum, standard deviation and number of data are given.*

Fish	Weight of individual, kg_{fw}	Processing loss, kg_{fw}/kg_{fw}
Pike	1.02 (0.71-1.44; 0.26; 7)	0.42 (0.38-0.46; 0.03; 8)
Whitefish	0.44 (0.34-0.73; 0.11; 17)	0.26 (0.07-0.40; 0.07; 21)
Perch	0.26 (0.19-0.29; 0.04; 4)	0.36 (0.30-0.47; 0.08; 4)
Roach	0.22 (0.16-0.26; 0.06; 11)	0.38 (0.38-0.39; 0.005; 4)
Baltic herring	0.034 (0.025-0.064; 0.01; 23)	0.32 (0.18-0.45; 0.07; 29)

Waterfowl

The best estimate for waterfowl game at coastal areas (Table 6-14) was derived from the 2002–2007 game bag and with assumptions as described for terrestrial game above. Maximum values are based on bird countings at the site (Yrjölä 1997, 2009). The minimum can be regarded as nil.

The edible fraction for grouse was estimated as from figures of annual total catch (individuals) and total game meat catch (RKTL 2008), 0.60. The value has been applied to all other fowl. For carbon content, data for "game fowl" in the FINELI database (www.fineli.fi) were used to calculate a generic value for all waterfowl using Equation (6-1); this value became 0.137 kg_C/kg_{fw}.

The density was calculated by using the total area of waterfowl counting sectors (Yrjölä 1997, 2009). These data apply to the shore area, but not necessarily to the open sea. However, using these data is believed to overestimate the doses in the further modelling. In any case, the coastal areas to be modelled decrease with the land uplift to better correspond the conditions of the site data.

Table 6-14. *Productivity of edibles in coastal areas; waterfowl ($kg_C/m^2/y$). For all waterfowl, the minimum can be regarded as nil.*

Edible	Best estimate	Max.
Greylag goose	0	3.22e-7
Canadian goose	0	6.77e-7
Shelduck	0	2.63e-8
Mallard	1.32e-7	1.01e-6
Northern shoveler	0	4.54e-8
Eurasian teal	4.96e-9	1.84e-8
Goldeneye	0	1.08e-6
Tufted duck	0	8.38e-7
Greater scaup	0	3.31e-8
Common eider	0	7.98e-6
Red-breasted merganser	0	7.86e-7
Goosander	0	1.07e-6
Common coot	0	7.97e-8
Waterfowl, total in coast	0.014e-5	1.40e-5

6.2.5 Productivity of edibles in lakes and rivers

Fish are the only commonly used edibles in Finnish lakes, in addition to waterfowl. Crayfish is also captured from some lakes, but the overall amount is very small especially near the Olkiluoto site. For rivers, data collected for lakes are to be used at the moment, due to lack of specific information on rivers Eurajoki and Lapinjoki, selected to represent the future river systems. Table 6-15 presents the total productivity of edibles, and the details of their derivation are discussed in the rest of this section.

Fish

The productivity of fish is based on a study of water quality, fishing efforts and fish yields in lakes (Table 2 in Ranta et al. 1992). Edible parts account for 65-95 % of the live weight in the case of burbot, pike, whitefish and vendace (Sääksjärvi & Reinivuo 2004; see also Table 6-11). For other fish species, the portion was assumed to be 70 %. Median of the productivity value given in (Ranta et al. 1992) for each species was used as the best estimate (Table 6-16).

Waterfowl

There are few applicable data on hunting of birds from lakes or rivers. On the other hand, it is known that the catch almost solely consists of Anseriformes (e.g. ducks). Given the lack of data, the values derived for the coastal area of Olkiluoto (Table 6-14) for those species were used to represent lakes as well. For clarity, these are repeated for the limnic water bodies in Table 6-17.

Table 6-15. *Productivity of edibles in lakes and rivers ($kg_C/m^2/y$).*

Edible	Best estimate	Min.	Max.
Fish, sum	5.33e-5	0.678e-5	55.3e-5
Waterfowl, sum	0.137e-5	0	1.29e-5
Lake/river, total	5.34e-5	0.678e-5	56.6e-5

Table 6-16. *Productivity of fish in lakes and rivers ($kg_C/m^2/y$).*

Edible	Best estimate	Min.	Max.
Vendace	1.68e-5	9.89e-7	3.15e-4
Perch	9.98e-6	7.13e-7	3.85e-5
Pike	6.78e-6	5.21e-7	3.34e-5
Roach	6.21e-6	8.87e-7	3.01e-5
Bream	4.13e-6	8.27e-7	3.72e-5
Whitefish	3.98e-6	7.95e-7	5.80e-5
Burbot	2.42e-6	6.06e-7	8.48e-6
Trout	2.02e-6	8.07e-7	6.46e-6
Pikeperch	9.50e-7	6.33e-7	2.60e-5
Lake/river, fish total	5.33e-5	0.678e-5	55.3e-5

6.2.6 Productivity of edibles in mires

The productivity of edibles in the mires (wetland objects) is presented in Table 6-18. The data for berries are from Table 6-6, site class 5, which represents mires. Productivity of game is based on the habitat descriptions in (Haapanen et al. 2009a, sections 4.1.6 and 4.2.3), and scaling of the data presented in Tables 6-7 and 6-17 by expert judgment. It should be noted that the game bag for the mires is based on data on the Olkiluoto site with very limited mire areas, and is likely an over-estimate.

Table 6-17. *Productivity of waterfowl in lakes and rivers ($kg_C/m^2/y$). For all waterfowl, the minimum can be regarded as nil.*

Edible	Scientific name	Best estimate	Max.
Mallard		1.32e-7	1.01e-6
Eurasian teal		4.96e-9	1.83e-8
Common eider		0	7.98e-6
Goldeneye		0	1.08e-6
Goosander		0	1.07e-6
Tufted duck		0	8.38e-7
Red-breasted merganser		0	7.86e-7
Northern shoveler		0	4.54e-8
Greater scaup		0	3.31e-8
Lake/river, waterfowl total		1.37e-7	127e-7

Table 6-18. *Productivity of edibles in mires (wetland objects; $kg_C/m^2/y$). The best estimate is likely pessimistic with respect to the dose contribution from mires, and possible minimum value would be negligibly small.*

Edible	Best estimate	Rationale
Moose	2.02e-5	Minimum for the respective data to forests; seldom hunted from wetlands
White-tailed deer	5.78e-6	Minimum for the respective data to forests; seldom met on wetlands
Roe deer	0	Not a typical habitat
Hare	0	Not a typical habitat
Partridge/hazelhen	0	Not a typical habitat
Grouse	7.09e-9	Same as for the forests; the difference in the game bag would not be significant for the total productivity
Mallard	1.32e-7	Considered the only waterfowl, taken as for Olkiluoto coastal area (contribution by teal and other possible species would be negligible)
Lingonberry	3.53e-5	Turtiainen et al. (2007) for undrained pine mire (higher value than from Salo (2008) for mires)
Bilberry	3.82e-5	Salo (2008) for mires
Cloudberry	1.52e-5	Salo (2008) for mires
Cranberry	4.98e-6	Salo (2008) for mires
Crowberry	1.61e-5	Salo (2008) for mires
Red whortleberry	1.17e-5	Salo (2008) for mires
Raspberry	1.61e-7	Salo (2008) for mires
Edible fungi	2.56e-5	At Olkiluoto, also in future, mineral soil sites will be preferred for picking mushrooms; also lower productivity per averaged area in general wetland conditions
Mire (wetland), total	1.73e-4	

Table 6-19. *Site-specific concentration ratios (CR) to berries for iodine (kg_{dw}/kg_{dw}) from humus layer, rooted mineral soil (0–30 cm), and as effective concentration ratio corresponding to averaged concentration in soil; geometric mean (number of samples; geometric standard deviation) are given.*

Edible	Humus	Min. soil	Effective
Bilberry	0.077 (6; 1.6)	0.001 (1; --)	0.103 (2; 1.0)
Raspberry	0.064 (4; 1.2)	0.101 (2; 1.2)	--
All berries	0.071 (10; 1.5)	0.024 (3; 11.7)	0.103 (2; 1.0)

6.2.7 Concentration ratios to edibles for iodine

Out of the Priority I radionuclides (section 2.1), C-14 is treated otherwise with the specific activity model and for Cl-36, or chlorine, there are no site data available at the moment. For stable iodine (applicable to I-129), only few site data (Haapanen 2009) are at hand and, due to sampling conditions, those are not directly to the berries but to leaves and stems (see Table 5-7). The methodology to calculate the concentration ratios from the humus layer and from the rooted mineral soil, as well as the effective concentration ratios to the leaves of the plants bearing edibles, as well as the applied depth distribution of root biomass are presented above in sections 5.1.3 and 5.2.1. Table 6-19 presents the calculated concentration ratios for berries, assuming concentrations in the berries to be similar to those in leaves (this is to be exemplified with few available data by Helin et al. 2010). Since samples are few at the moment, the given data encompass all forest types (Scots pine, Norway spruce and black alder stand). Data for the elements of lower priority are given in sections 5.3.1 and 6.3.1.

It should be noted that while the scope of the present report is to document the site and regional data applied in the biosphere assessment, these data need to be complemented with literature values to ensure adequate data basis. This is done in (Helin et al. 2010).

The literature data of Sheppard et al. (2006) give a CR to plants for human foods (including also agricultural products) of 0.005 kg_{soil}/kg_{fw} for iodine. For plants for native browse and forage of animals the corresponding value is 0.03. By assuming a dry weight content of 11.8 % in berries (Laine et al. 1993), we obtain approximate dry-weight numbers of 0.042 and 0.25, respectively. In the light of the modest extent of data, our results are comparable, but should be complemented with broader literature data before use in assessments.

6.3 Other site and regional input data

As the other than the key data in section 6.2, this section discusses the available site and regional data for the dose assessment of humans. As for the concentration ratios for iodine above, also for the few other elements only the site data are given here and complementing them and deriving the aggregated concentration ratios are left for (Helin et al. 2010). Other possible site data are those related to duration or extent of exposure and the intake rates.

Table 6-20. *Effective concentration ratios from soil to leaves (surrogate to berries) of berry-bearing plants in forests of Olkiluoto (kg_{dw}/kg_{dw}), regrouped from section 5.3.1. Values given as geometric mean (geometric standard deviation; number of samples).*

Species	Ni	Se	Cr
Bilberry	0.071 (1.5; 60)	0.06 (1.4; 2)	0.059 (2.0; 60)
Lingonberry	0.077 (-; 1)	0.03 (-; 1)	0.019 (-; 1)
Raspberry	0.088 (-; 1)	0.06 (-; 1)	0.028 (-; 1)

6.3.1 Concentration ratios to edibles for other nuclides

Similarly to the concentration ratios of iodine to edibles, also for the other elements the leaves of the respective plants are needed to be used as surrogates of berries in the forest environment. For the other ecosystems, no applicable site data are available, as discussed already above for the similar parameters of the radionuclide transport modelling.

Although there is generally lack of data on site or regional concentration ratios, variability between different species caught at about the same time from the same area (e.g. for waterfowl in Rantavaara et al. 1987, p. 52-53, and for fish in Saxén & Rantavaara 1987) or between different nuclides in the same sample (e.g. for moose Rantavaara et al. 1987, p. 55) could be used as complementary data. These have not been used, though, since either the division between species is not meaningful or the nuclides available are not those of interest, both reasons to be taken in the perspective of the present assessment.

For the forests, some site-specific concentration ratios can be given for leaves (as surrogates of berries) of bilberry, lingonberry and raspberry for Ni, Se and Cr (chemical analogue of Mo). The data and their derivation have been presented in section 5.3.1 (esp. Tables 5-21, 5-22 and 5-23), and only the effective concentration ratios are repeated here in Table 6-20 since due the need of combine the site data with literature (to be done by Helin et al. 2010) the ratios specific to soil layers cannot be used directly.

6.3.2 Exposure parameters

In this section, some site, regional or national data are provided for further definition of exposure parameters in the dose assessment for humans.

Intake rates

For the intake by livestock, (Haapanen et al. 2009a) present detailed data on the water consumption (their table 8-3) and feed intake by origin (their table 8-2). The data are reproduced here in Tables 6-21 and 6-22, respectively. To compare, the feed intake of cattle in general has been 50 kg/d of pasturage both in (Rämä 2006) and (Vieno & Suolanen 1991), and the water-drinking rate 100 L/d and 50 L/d, respectively. In addition to the plain pasturage, Rämä (2006) has assumed 0.04 $kg_{soil}/kg_{pasturage}$ to be ingested, whereas Vieno & Suolanen (1991) have used a value of 2 kg_{soil}/d.

Table 6-21. *Water consumption of cattle and pigs (Greenhalg et al. 2002).*

Animal group		Water consumption (L/d)
Dairy cow yielding	10 kg/d	92
	20 kg/d	104
	30 kg/d	116
	40 kg/d	128
Non-lactating cattle		8 L/kg$_{dw}$ intake
Growing pigs	15 kg live-weight	2
	90 kg live-weight	6
Non-lactating sows		5–8
Lactating sows		15–20

Table 6-22. *Production and feed intake in Satakunta area around the Olkiluoto site (compiled from statistics by Marketta Rinne and Jouni Nousiainen, Agrifood Finland).*

Species	Animal group	Used to produce	Production per animal	Feed intake (kg$_{dw}$/d) Forage	Concentrate produced on farm	Concentr. purchased
Cattle	Dairy cows	Milk	25 kg/d	9.39	3.01	4.20
	Suckler cows	Calves		9.55	0.70	0.0
	Steers	Meat	1 kg/d	5.49	2.02	0.61
	Heifers	Repl./meat*		4.79	0.77	0.50
	Calves, heifer			2.20	0.73	0.69
	Calves, bull			3.35	1.44	0.77
Sheep	Ewes	Lambs		1.35	0.12	0.03
	Other sheep	Meat	0.2 kg/d	0.82	0.19	0.05
Pigs	Boars			none	1.86	0.62
	Sows	Piglets		none	2.08	0.90
	Fattening pigs (>50 kg)	Meat	1 kg/d	none	1.66	0.36
	Piglets (<50 kg)			none	0.42	0.32
Chicken	Laying hens	Eggs	17.7 kg/y	none	0.04	0.053
	Broilers	Meat	1.64 kg/ind.	none	0.0111	0.0817
Turkeys			8.6 kg/ind.	none	0.0578	0.1733
Horses	Horse, adult	Recreation		7.10	2.66	0.09
	Pony, adult	Recreation		4.28	1.60	0.06

* Replacement and eventually meat

7 MODELLING OF DOSES TO OTHER BIOTA

The radionuclide transport modelling provides the input for dose assessment, spatially distributed time-dependent radioactivity concentrations. The models and concepts presented below are used to estimate consequences to humans and other biota potentially arising due to these activity concentrations. The focus is on the main quantities to be used in the compliance assessment. The models to derive other quantities that will likely be used in the biosphere assessment, such as collective doses or ecosystem-specific dose conversion factors, are not included.

7.1 Model description

The assessment of consequences to other biota is not as mature as for humans, both in the Posiva safety case and internationally. In the following, first a European ERICA approach is briefly presented and thereafter Posiva's approach which is based on ERICA's Tier 3.

7.1.1 ERICA approach

The ERICA project (Beresford et al. 2007) was conducted under the EC 6th framework program. It aimed to provide an integrated approach to scientific, managerial and societal issues concerning the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. Exposure of biota to radiation and transfer of radionuclides in the environment, are intimately linked. Exposure of biota to ionising radiation occurs when radionuclides, present naturally in the environment or released through man’s activities, decay releasing radiation of various types and energies. For utilisation within the impact assessment process, each (ERICA) reference organism has been assigned default attributes relating to radioecology and dosimetry in order to derive dose conversion factors; these are equilibrium concentration ratios, occupancy factors, and ellipsoidal geometries. The ERICA Tool, which is a piece of software, has a structure based upon the ERICA tiered approach to assess the radiological risk to other biota. The tiers can be summarised as (modified from Brown et al 2008):

- Tier 1 assessments are based on environmental media concentration, and use pre-determined environmental media concentration limits (EMCL) to estimate risk quotients (RQ).
- Tier 2 calculates absorbed dose rates, but allows examination and editing of most of the parameters used, including concentration ratios, distribution coefficients, percentage dry weight soil or sediment, dose conversion coefficients, radiation weighting factors and occupancy factors.
- Tier 3 offers the same flexibility as Tier 2, but allows the option of running the assessment probabilistically if the underlying parameter probability distribution functions are defined.

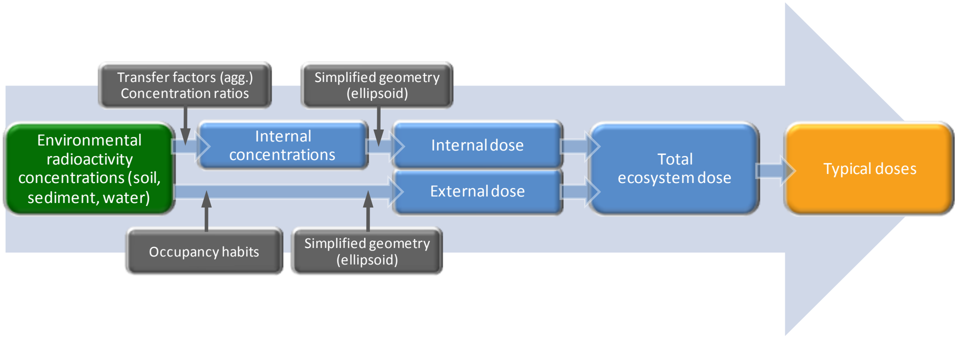

Figure 7-1. *General process for converting calculated environmental media radio-activity into suitable quantities to be used in assessing the doses to the other biota.*

7.1.2 Posiva's approach

To assess these consequences, typical doses to flora and fauna of the types currently present at the site will be calculated. The approach is based on Tier 3 of the ERICA project (Beresford et al. 2007) conducted under the EC 6th framework programme. The ERICA approach has been summarised in the previous section. Our general approach is presented in Figure 7-1.

One major difference regarding the other biota, compared with assessing doses to humans, is the wide variety of taxa. Consequently, the first task to carry out is to identify a group of *assessment species* (reference organisms; reference animals and plants, or RAPs). Then, as for humans, the assessment is a multistage process, and can be summarised as follows:

- Obtain information about the environment, specifically the simulated concentrations of radionuclides in environmental media, but also site-specific geometrical data for the identified reference organisms.
- Derive the internal concentrations in the biota to be assessed, by application of concentration ratios. Ingestion and inhalation are described through the use of aggregated concentration ratios.
- Calculate internal and external doses. Following the methodology recently adopted internationally, a simplified (ellipsoidal, see Fig. 7-2) geometry representative of the dimensions of the main body of the organism is assumed in the derivation of dose conversion coefficients. Species-specific occupancy habits are also considered.
- Sum the contributions from external and internal exposure as appropriate.
- Lastly, identify typical doses for reference organisms to be used in the compliance assessment.

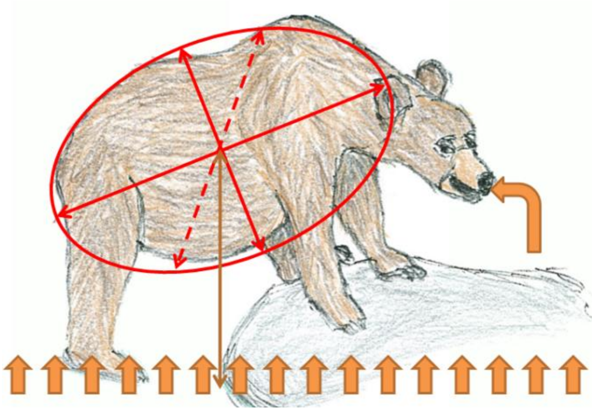

Figure 7-2. *Illustration of the applied simplified geometry and the exposure pathways considered (external radiation; combined ingestion and inhalation). Background drawing: Ari Ikonen/Posiva Oy.*

7.2 Key input data

When calculating typical doses to the other biota, the transfer factors to (Brown 2009) and the sizes of the selected biota species or their surrogates form the essential data. As the assessment methodology is still somewhat immature despite of some testing (Smith & Robinson 2006, Broed et al. 2007), only the assessment species have been selected and their geometry (and weights of some individuals) is defined based on the site and regional data. The dose conversion factors from the external and internal exposure to the whole-body dose and the concentration ratios are left for future work - meanwhile the ERICA default data seem appropriate to use.

Outside of Posiva's future programme, some other data specific to Olkiluoto might also come available: STUK has taken samples for the GAPRAD project from lakes, Baltic Sea and from the environments of the two nuclear power plants in 2007 (Brown 2009). From the environments of the nuclear power plant in Olkiluoto samples representing reptiles (a snake) and amphibians (a frog) were taken for the analyses. To get the concentration ratios for the terrestrial organisms, also samples of surface soil (0-10 cm) were taken.

In the following the selected assessment species are presented with their geometry and weights. They are based on expert judgement, and partially on available data, and cover the significant trophy levels (roles) in the food webs of the ecosystems prevailing and expected at the site. The names of the respective reference organisms in the ERICA approach are given in the tables for comparison.

The body diameters and weights for the assessment species are collected from site data and literature, and interpreted as major axis lengths of an ellipsoid used as a surrogate to the organism body in the calculations of dose conversion factors (absorbed dose from in-taken radioactivity assumed to be homogeneously distributed in the body (ellipsoid)).

7.2.1 Assessment species for terrestrial ecosystems

The tree biomasses are calculated from data by Saramäki & Korhonen (2005), as are the dimensions, too; they represent an average tree in Olkiluoto in 2004, based on the measurements of 22 801 individual trees (i.e., taller than breast height, 1.3 m), irrespective of species or size. Crown dimensions and part of the stem to be included in the crown ellipsoid are based on expert judgment. Biomass equations (Marklund 1988) were used, and it was assumed that all parts have the same dry-fresh weight ratio (Hakkila 1989). For weights of the tree ellipsoids, see discussion on average biomass in section 5.2.1. It is acknowledged that these, as well as those for the other forest plants, are rather tentative data, possibly requiring additional measurements. Also some other notes on the application of the ellipsoid geometry to forest and mire plants are in place: the dimensions for bilberry are for a shoot but the plant is a clone community often extending over several square metres, and similarly wavy hair-grass includes the main tussock but not the flowering stems, which grow higher but have very little biomass.

7.2.2 Assessment species for freshwater environment

Dimensions of the phytoplankton species are well-documented in the phytoplankton register maintained by Finnish Environment Institute. Other dimensions of freshwater species have been collected from the literature, where usually only length was available.

7.2.3 Assessment species for brackish sea environment

Dimensions of the phytoplankton species are well-documented in the phytoplankton register maintained by Finnish Environment Institute. Other dimensions of species in the sea environment have been collected from the literature, where usually only length was available.

After completion of the Biosphere description 2009 (Haapanen et al. 2009a), some weight data were found for a benthic isopod (crustacean), *Saturia endomon*: within the nuclear power plant monitoring programme of environmental radioactivity, sample weights and numbers of individuals were reported. The average weight of an individual was 1.4 g_{fw} (0.9-2.0, std 0.6, 3 samples) as calculated from the data in (Roivainen 2005).

Table 7-1. *Site-relevant data for terrestrial assessment species for Olkiluoto site [respective ERICA reference organisms (Beresford et al. 2007) in brackets] and their size and body weights. Sizes are based on the assumption of ellipsoidal shape unless mentioned otherwise.*

Assessment species [ERICA reference organism]	Ellipsoid size, length x height x width (cm)	Average body weight (kg_{FW})	Reference to size and weight
Herbivorous invertebrate, Ringlet [flying insect]	1.5 x 0.2 x 0.2	6.63 x 10^{-5}	Weight and dimension data: Ahmad et al. (2006), Bjärvall & Ullström (2003), Bommarco (1997), Karlsson & Wiklund (2005), Kivirikko (1940), Lokki et al. (1997, 1998a,b), Mullarney et al. (1999), Oja & Oja (2006), Olsen et al. (1997), Schrader et al. (2008), Wright et al. (2000). Ellipsoid sizes partly an expert judgment.
Herbivorous bird, Hazel grouse [bird]	19 x 12 x 12	0.4	
Herbivorous rodent, Bank vole [mammal (rat)]	7 x 3.5 x 3.5	0.0196	
Herbivorous mammal, Mountain hare [mammal (rat)]	35 x 15 x 15	3.5	
Large herbivorous mammal, Moose [mammal (deer)]	165 x 75 x 50	350	
Omnivorous invertebrate, Ant [-]	0.8 x 0.2 x 0.2	1 x 10^{-5}	
Omnivorous reptile/amphibian, Common frog [amphibian]	4.5 x 3 x 2.5	0.04	
Insectivorous/omnivorous bird, Hooded crow [bird]	18 x 7 x 7	0.525	
Omnivorous mammal, Red fox [mammal (rat)]	45 x 13 x 13	6	
Large omnivorous mammal, Brown bear [mammal (deer)] [a]	250 x 80 x 60 (male) 160 x 50 x 40 (female)	200 (male), 130 (female)	
Carnivorous invertebrate, Carabid beetle	1 x 4 x 5	0.0077	
Carnivorous reptile/amphibian, Viper (without tail) [reptile]	58 x 2.5 x 2.5	0.1	
Carnivorous bird, Tawny owl [bird]	18 x 8 x 9	0.52	
Carnivorous mammal, American mink [mammal (rat)]	20 x 6 x 6	1	
Decomposer, Earthworm [soil invertebrate]	1 x 0.4 x 0.4	0.004	
Red-stemmed feather-moss, *Pleurozium schreberi* [bryophyte]	3.5 x 2 x 2	not available	Expert judgement based on Hämet-Ahti et al. (1986) and Mossberg & Stenberg (2005)
Reindeer lichen, *Cladonia rangiferina* [lichen]	2 x 4 x 2	not available	
May lily, *Maianthemum bifolium* [herb]	10 x 10 x 10	not available	
Bracken, *Pteridium aquilinum* [herb]	50 x 60 x 50	not available	
Wavy hair-grass, *Deschampsia flexuosa* [grass]	50 x 40 x 50	not available	
Bilberry, *Vaccinium myrtillus* [shrub]	15 x 20 x 15	not available	
Stem of tree below crown [tree]	10 x 475 x 10	46 (DW 23)	Saramäki & Korhonen (2005), distribution of weight between stem below crown and included in crown an expert judgment; see the text above
Crown of tree [tree]	100 x 475 x 100	62 (DW 31)	Dimensions expert judgment, weight based on (Saramäki & Korhonen 2005) and for included part of stem on an expert judgment; see the text above

[a] Specific case due to the hibernation; spends a large part of the year *in* the soil. Not currently present at Olkiluoto, but the site is peripheral to the present area of distribution.

Table 7-2. *Site-relevant data for freswater assessment species for Olkiluoto site [respective ERICA reference organisms (Beresford et al. 2007) in brackets] and their size and body weights. Sizes are based on the assumption of ellipsoidal shape unless mentioned otherwise.*

Assessment species [ERICA reference organism]	**Ellipsoid size, length x height x width (cm)**	**Average body weight (kg_{FW})**	**Reference to size and weight**
Phytoplankton, *Anabaena flos-aquae*, a spiral-shaped filament [phytoplankton]	(L 26–36 x W 4–9) x 10^{-4}	not available	Phytoplankton register maintained by Finnish Environment Institute (www.ymparisto.fi)
Phytoplankton, *Anabaena lemmermannii*, a spiral-shaped filament [phytoplankton]	(L 5–20 x W 3–8) x 10^{-4}	not available	
Phytoplankton, *Tabellaria fenestrata* [phytoplankton]	(59–85 x 3 x 6) x 10^{-4}	not available	
Phytoplankton, *Gonyostomum semen* [phytoplankton]	3.6 x 10^{-3} (diam.) x 5.5 x 10^{-3} (H)	not available	
Vascular plant, Common reed (*Phragmites australis)* [vascular plant]	100–300 (H, above bottom [a])	not available	Huhta (2008)
Zooplankton, *Cladocera* [zooplankton]	0.02 - 0.3 (L)	not available	Wetzel (2001)
Insect larvae, *Chironomus plumosus* [insect larvae]	0.2–3 (L)	not available	www.first-nature.com/ insects/diptera/ chironomus_plumosus.htm
Bivalve mollusc, *Anodonta* sp. [bivalve mollusc]	<20 (L)	not available	Expert judgment
Gastropod, a snail, *Lymnaea peregra* [gastropod]	1.5–2.0 (H)	not available	Hutri & Mattila (1991)
Gastropod, a snail, *Planorbis planorbis* [gastropod]	0.02–0.03 (H), 0.12–0.18 (W)	not available	Hutri & Mattila (1991)
Crustacean, Crayfish *(Astacus astacus)* [crustacean]	10 (L)	not available	Kilpinen (2001)
Benthic fish, Ruffe (*Gymnocephalus cernuus*) [(benthic) fish]	8–15 (L)	0.013	Koli (1994), Tarvainen et al. (2008)
Pelagic fish, Vendace (*Coregonus albula*) [(pelagic) fish]	10–20 (L)	0.020–0.080	Koli (1994)
Amphibian, Common frog (*Rana temporaria*) [amphibian]	7.9 (L; female) 7.2 (L; male)	0.038–0.046	Alho (2004)
Reptile, Grass snake (*Natrix natrix*) [reptile]	70–80 (L)	0.04–0.2	Size www.wikipedia.org and expert judgment, weight Nieminen & Saarikivi (2009)
Bird, Mallard (*Anas platyrhynchos*) [bird]	50–65 (L) x 80–100 (wingspan)	1.1	Size www.wikipedia.org, weight Yrjölä (2009)
Mammal, Otter (*Lutra lutra*) [mammal]	50–100 (L) plus a tail of 30-50	3-15	www.wikipedia.org and expert judgment

[a] Roots may have 75-80% of the total biomass (Huhta 2008)

Table 7-3. *Site-relevant data for brackish-water assessment species for Olkiluoto site [respective ERICA reference organisms (Beresford et al. 2007) in brackets] and their size and body weights. Sizes are based on the assumption of ellipsoidal shape unless mentioned otherwise.*

Assessment species [ERICA reference organism]	**Ellipsoid size, length x height x width (cm)**	**Average body weight (kg_{FW})**	**Reference to size and weight**
Phytoplankton, *Chaetoceros wighamii* [phytoplankton]	(5–9 x 5.1–11 x 6–17) x 10^{-4}	not available	Phytoplankton register by Finnish Environment Institute (www.ymparisto.fi)
Phytoplankton, *Aphanizomenon* sp. [phytoplankton]	(100 x 3.4–6) x 10^{-4}	not available	
Macroalgae, *Cladophora glomerata* [macroalgae]	23 (H)	not available	On average, data from Ilmarinen et al. (2008)
Vascular plant, Common reed (*Phragmites australis)* [vascular plant]	100–300 (H, above bottom [a])	not available	Huhta (2008)
Zooplankton (*Cladocera*) [zooplankton]	0.05–3 (L)	not available	Eloranta (1996)
Benthic mollusc, Blue mussel (*Mytilus edulis*) [benthic mollusc]	2–3 (L)	not available	Expert judgment
Benthic mollusc, Baltic macoma (*Macoma baltica*) [benthic mollusc]	2 (L) x 2 (W)	not available	Koli (1986)
Crustacean, Baltic prawn *(Palaemon adspersus)* [crustacean]	5 (L)	not available	Koli (1986)
Benthic fish, Flounder (*Platichthys flesus*) [(benthic) fish]	20–35 (L)	0.3-0.6	Koli (1994)
Pelagic fish, Baltic herring (*Clupea harengus membras*) [(pelagic) fish]	15–20 (L)	0.02	Koli (1994), www.rktl.fi/kala/ tietoa_kalalajeista/silakka/#tunto
Polychaete worm, a ragworm (*Nereis diversicolor*) [polychaete worm]	3–6 (L)	not available	Koli (1986)
Bird, Oystercatcher (*Haematopus ostralegus*) [(wading) bird]	40–49 (L) x 80 (wingspan)	0.48	Size www.wikipedia.org and expert judgment, weight Yrjölä (2009)
Mammal, Gray seal (*Halichoerus gryphus*) [mammal]	250–330 (L male) 160-200 (L female)	300 (male) 100–150 (female)	www.wikipedia.org and expert judgment

[a] Roots may have 75-80% of the total biomass (Huhta 2008)

8 DATA QUALITY EVALUATION

In this chapter, the results of data quality evaluation process concerning the site and regional data delivered to the biosphere assessment are presented. The process is a lighter version of the Knowledge quality assessment (KQA), which spans over the different stages in the biosphere assessment process and in the broader safety case. The aim of both the streamlined data quality evaluation and the full KQA is to foster communication of assumptions and uncertainties throughout the assessment chain in a systematic and comprehensive manner. The different aspects covered by the KQA, developed on the basis of Ikonen (2006), Hjerpe (2006), Broed (2007b), Broed et al. (2007) are as organised in this chapter:

- Main assumptions: assumptions, their impact, potential for alternative interpretations.
- Main uncertainties: uncertainties in the input data and those produced during the interpretation or modelling process, their cause, whether the uncertainty has been assessed, means to resolve and whether it would help the further assessment.
- Sensitivity and data quality: how sensitive the models are to the input data, confidence to adequately high quality of the data and underlying process understanding.

The aspects of listing applied and not applied data and analysing their consequences and of the consistency comparison with earlier versions and external data have been left out through priorisation. It is acknowledged though, that also these aspects are important to be covered in the future assessments, and plans have been made to incorporate them more closely to the assessment process from the beginning.

The quality evaluation here focuses on the main assumptions and uncertainties underlying the given data, and on the appropriateness of the data in the assessment context. As it is not always possible to measure directly the needed parameter data, proxies or surrogate data are needed, in addition to temporal and spatial averaging of the measurements. These are assessed in the following sections, and the assessment will be improved by iteration as the overall biosphere assessment matures.

The parts concerning the key data have been reproduced and shortened from the Biosphere description 2009 (Haapanen et al. 2009a) for comprehensiveness, and those parts evaluating the data for the other parameters have been added. It should be noted that the evaluation does not address the model assumptions and uncertainties themselves but concentrates on the input data alone; KQA of the models are to be presented in the actual modelling reports.

8.1 Main assumptions

In Tables 8-2 to 8-6, the main assumptions underlying the data recommended to the assessment use are listed and classified by their nature.

The classification of assumptions is presented in Table 8-1, which is a modified version of the approach of Swiss National Cooperative for the Disposal of Radioactive Waste

(Nagra 2002). Following from the scope of the present report, the model assumptions are excluded and left for the actual modelling reports to discuss on.

Table 8-1. *Classification system of assumptions, modified from (Nagra 2002).*

Categorisation of assumptions for broad characteristics and evolutionary path followed by the system and conceptualisation of phenomena	
LE	Conceptual assumption corresponds to the likely/expected characteristics and evolution of the system
PCA	Pessimistic conceptual assumption within the reasonably expected range of possibilities
WRP	Within the range of possibilities but likelihood not currently possible to evaluate — other (and sometimes more pessimistic) assumptions may not be unreasonable
ST	Stylised conceptualisation of system characteristics and evolution
Categorisation of simplifications made for modelling purposes	
MS	Modelling simplification — not significantly affecting numerical results
CS	Modelling simplification — intrinsically conservative
CP	Modelling simplification — conservative given the assumed model parameters

Table 8-2. *Main assumptions in data for terrain and ecosystems development modelling. The assumptions related to the identified key data are on bold.*

Assumption	Class	Comment
Land uplift model		
Individual shoreline dating points are aggragated into shore level displacement curves representing larger sites and then interpolated	WRP	Relatively scarce data in respect of the area to be covered (see Fig. 3-8). A project has been initiated in 2009 to study different methods to derive the land uplift model input data rasters.
Water bodies, runoff formation and flow rates		
Share of total precipitation reaching river water flow is estimated from the precipitation on the river catchment area and the measured flow rate	ST	A reasonable proxy for the present rivers and their catchment areas at annual levels, and likely for their future extensions provided that the land use and soil types remain similar. More uncertain for other future catchments. A more detailed model version based on simplification of the surface hydrology model is planned.
It is assumed that the runoff formation remains the same as at present in the main river catchments, i.e. the existing catchment areas, their future extentions and the future new catchment areas have the same proportional land use, vegetation,soil type and structure of the water course as those used to derive the parameter values.	WRP	See also the assumption just above. Quantification of the impact of this assumption require rather detailed process-level modelling of the entire catchment using a scenario approach, with calculation cases limited to conceivable combinations of land use patterns etc. This is also dependent on the dose assessment scenario (defining e.g. the land use changes) applied.
The precipitation measured at Olkiluoto has been used for the whole large catchment area (1775 km²) of the main rivers.	MS	Precipitation at Olkiluoto is taken as a realistic proxy of the precipitation in the whole area. This is also consistent to the fact that in the climate scenarios the precipitation at Olkiluoto (and not necessarily more detailed in the affecting catchment areas) is defined.
Cross-section of rivers is based on generic data and theoretical evaluations	LE	The shape of the cross section as such is not affecting to the outcome of the radionuclide transport modelling where the results are propagated. The area of the flow cross section is more relevant quantity.

Table 8-2 (cont'd). Main assumptions in data for terrain and ecosystems development modelling. The assumptions related to the identified key data are on bold.

Assumption	Class	Comment
Terrestrial vegetation		
Classification of future forest types based on predicted soil type	LE	There is large variation in properties within the forest site classes (created for the needs of practical forestry). Same site type may exist on several soil types, for example the OMT type on fine grained tills, clay or silt soils or even sorted sand soils.
Aquatic vegetation		
Calibration of reed colonisation model with data from Olkiluoto alone	WRP	Independent datasets are available for testing the applicability of the calibration (Alahuhta 2008), but testing is forthcoming. Overall conservativeness is difficult to estimate at the moment.
Terrestrial erosion and sedimentation		
Transport of eroded material from land to suspended matter in rivers is calibrated by adjusting terrestrial erosion model values to fit to average suspended matter load in river water	ST	A similar situation as for water described just above. Development of an improved model is somewhat more difficult.
Peat growth parameters have been derived from national-level data	WRP	Describes the broad characteristics of peat bog formation, identified as an issue for further study and testing
Peat growth parameters assume linear relationships	LE	Coupled to the peat growth model, implications have been discussed in Clymo (1984, 1992) and Clymo et al. (1998)
Existing peat formations are not given as input data to the peat accumulation model	ST	Existing peat areas are few in the modelling area and none of them has been identified to locate in the area receiving possible releases from the repository (Karvonen 2009c, Hjerpe & Broed 2010).
Aquatic erosion and sedimentation		
Critical shear stress values are based on data for a single large lake	WRP	Sediment type to which the data are applicable corresponds to observed surface sediment type offshore Olkiluoto
For aquatic erosion and sedimentation model, wind data from present-day Olkiluoto is used	WRP	Most local weather station with reasonably long time series. Major change in wind conditions in the site scale is unlikely. For the impact of coastline retreat rather sophisticated models would be needed.
Accumulation rate of gyttja is based solely on data from Olkiluodonjärvi mire, and an average rate is derived	ST	At the present no other data sets are available, and the present data are not detailed enough for more elaborate model.
Sedimentation in lakes is dependent only on the volume of the water body (in the simpler model version)	WRP	Validity of the assumption is related to the conditions from which the accumulation rate vs. water volume function has been derived. The version given in this report is likely representative to the conditions similar than those at present in the bottom of the Baltic bay.
Delineation of croplands		
Suitability of soils to agricultural use depends on their nutrient and water availability, and only best areas are taken into cultivation.	WRP	Given the present land use, expected future soil type distribution and need for agricultural products remaining similar, this is a realistic assumption (Ikonen 2007b).

Table 8-2 (cont'd). Main assumptions in data for terrain and ecosystems development modelling. The assumptions related to the identified key data are on bold.

Assumption	Class	Comment
Other land use		
Housing pattern in the future will follow the present-day distributions	WRP	This is the base case assumption, alternatives are to be considered in other dose assessment scenarios. This assumption is also supported to an extent by the regulatory guideline (STUK 2009).

Table 8-3. *Main assumptions in data for surface and near-surface hydrological model. The assumptions related to the identified key data are on bold.*

Assumption	Class	Comment
Saturated hydraulic conductivities of the future soil types are similar to those at present	LE	A reasonable assumption given that future soil types corresponding to the present sea bottom sediments are known and accumulation/erosion processes are modelled adequately
Sap flow measurements are used as a proxy to actual transpiration	LE	Sap flow is a widely accepted proxy for actual transpiration

Table 8-4. *Main assumptions in data for radionuclide transport modelling. The assumptions related to the identified key data are on bold. (MAI, mean annual increment, see section 5.2.1).*

Assumption	Class	Comment
Data for forests and mires		
Same carbon concentration (50 $\%_{dw}$) is assumed for all terrestrial plant material and for litter, and 30 $\%_{dw}$.	MS	The error caused by using the constant value for convenience is marginal in comparison to overall uncertainties of the parameter values.
Basing MAI approach on the future forest type classes	LE	Success of implementation depends on the forest type prediction (above).
Derivation of MAI values for wood	ST	Using MAI values from the literature instead of site data smoothes the 'noise' in Olkiluoto data caused by forest management fashions some 40 years ago (Scots pine is growing on sites suitable for Norway spruce). However, data from average values of Southern Finland are not best possible for coastal conditions; source data are scarce and old.
MAI values are derived for a rotation period of 100 years	ST	Using the MAI concept and applying the rotation time are tied to the dose assessment scenario: here a typical value has been chosen (expected ages of tree species are discussed in more detail in section 5.3.1).
Derivation of biomass values	WRP	Swedish models are used; they should be replaced by the recent Finnish ones in the future as they have been published just recently.
Stands older than 100 years were excluded from derivation of the biomass values	ST	Consistent with the MAI concept (see assumptions above).
UNTAMO site class 4 (herb-rich forest) has been assumed to be always turned into cropland and practically no data are provided for the class	LE	Given the present land use, expected future soil type distribution and need for agricultural products remaining similar, this is a realistic assumption (Ikonen 2007b).
Element transport from soil to wood, foliage, understorey and berries is proportional to the fine root biomass and concentration in the soil compartments	LE	A conventional transfer factor approach elaborated to accommodate several soil layers; the parameters are defined so that effectively the data result in the conventional approach (see sections 5.1.3, 5.2.1 and 5.3.1).

Table 8-4 (cont'd). Main assumptions in data for radionuclide transport modelling. The assumptions related to the identified key data are on bold. (MAI, mean annual increment, see section 5.2.1).

Assumption	Class	Comment
Data for forests and mires (cont'd)		
Literature values for soil bulk density have been used in calculation of the effective concentration ratio (average concentration in soil)	MS	Lack of site data from the same places, expected variation rather small compared with those of the other variables. Class is MS especially if the same soil bulk density values are applied when the concentration ratio values are used - on the other hand, only the relative differences matter for the effective concentration ratios which are the only ones applied in BSA-2009 since the site data need to be complemented with literature data (not specific to soil layer).
Soil type on forest sampling plots, from which the concentration ratio data are derived, is determined by grain size data	MS	The soil types are anyway properly identified (defined) by their median grain size.
Site measurements of concentrations of stable elements are representative in regards of the uptake process of released radionuclides in the future as concentration ratios.	WRP	A commonly used assumption; the issue will be discussed in more detail in the future assessments when more site data becomes available.
Distribution of fine root biomass used in deriving the concentration ratios is based on three plots in Olkiluoto	WRP	Distributions are consistent with Finnish average data (Helmisaari et al. 2007, 2009a).
Fine root distribution of young birch stand is applied to all deciduous stands	WRP	At the moment, there are no alternative datasets available
Fine root distribution in other than studied sampling plots have been derived as averages weighted by the biomasses of main and side tree species	WRP	In lack of data a reasonable assumption (validity should be tested in the future programme).
Turnover rates of foliage, branches and understorey are taken from the literature and weighted by the site data of average biomass of tree species in each site class	WRP	No direct adequately long-term site-specific data available (litterfall monitoring data from the site should be utilised better in the next assessment round).
Decay of litter and dead wood is assumed to happen on a constant rate	MS	Over the rotation period of the forest, the results coincide with the literature data. In shorter time periods exponential or multi-rate decomposition might be a better model (Mäkinen et al. 2006, Palosuo 2008).
No foliage or thinner branches are harvested	WRP	Corresponds roughly to most of the present management practises. The assumption is tied to the assessment context and scenario (present type of forest management).
Vegetation height in forest is based on one-layer concept, representing height of trees in Olkiluoto at the present	ST	Depends on the implementation of the C-14 model; should be at least two-layered with understorey and tree crown to represent the CO_2 intake processes in a typical forest.
Data for croplands		
Crop irrigation data are based on existing recommendations in Finland	LE	No site-specific data available.
Leaf area indices for crops are based on Finnish experiments	LE	No site-specific data available.
Carbon content of 50 $\%_{dw}$ is assumed for all plant material	MS	The error caused by using the constant value for convenience is marginal in comparison to overall uncertainties of the parameter values.
Generic soil data should be used for deeper parts of cropland (specific data are provided only for plough layer)	LE	Few specific data available. Literature values suggest the assumption to be valid (sections 5.3.2 and 5.3.7).

Table 8-4 (cont'd). Main assumptions in data for radionuclide transport modelling. The assumptions related to the identified key data are on bold. (MAI, mean annual increment, see section 5.2.1).

Assumption	Class	Comment
Data for lakes		
Sedimentation rate in lakes is based on two separate studies combined for best estimate gross sedimentation and resuspension rates	WRP	Lack of data from more relevant conditions.
Resuspension rate in lakes is derived by scaling the net sedimentation rate from a lake in the Reference area by literature data	WRP	Likely captures the order of magnitude, measurements from the chosen lakes analoguous to those expected to form at the site (Haapanen et al. 2009a, b) should be performed.
Bathymetry of future lakes expected to form at the site (and most relevant to the assessment) is used to calculate a nominal value for aquatic plant biomass by scaling data for water depth intervals from a lake less analoguous to those expected to form in the future	WRP	No better data available. The model should be developed so that the biomasses for each lake are calculated based on the depth distribution, and the biomass values are given for depth intervals, not the same value for all the lakes.
No bottom-attached aquatic plants are present in lake areas deeper than 2.5 m.	WRP	No explicit data available. The assumption is based on a rough estimate of lighting conditions at the bottom resulting from expected water turbidity.
Annual production of aquatic plants is estimated using a production/biomass ratio derived from Swedish data.	WRP	No better data available.
All above-bottom plant biomass is assumed to be renewed due to winter conditions.	WRP	No better data available.
For the active layer of sediment (top sediment) values for sludge or fluffy gyttja/mud are to be used.	LE	Expected result from the high water content and diffuse interface between water column and sediment.
For the deep sediments, data for respective soil types can be used as a surrogate data.	WRP	Lack of data.
Data for rivers		
All other than suspended solid load and suspended sediment, same data and assumptions are applied for rivers as for lakes.	WRP	No better data available.
Sedimentation rate is estimated by assumed settling velocity (particle size) and measured load of suspended matter in the water.	LE	A physical theory alternative to specific measurements. No detailed data available and difficult to obtain due to the flow domain.
Resuspension rate is estimated to equal the gross sedimentation rate (no net sedimentation).	ST	In larger scale the assumption is valid; otherwise river channels would be filled and surroundings easily flooded, which is not occurring in the region. In the model, the river segments should be long enough to average over possible local erosion/deposition spots (that are likely to be in constant motion, anyway).
Data for coastal areas		
Annual production of aquatic plants is estimated from biomass data using the same production/biomass ratio as for the aquatic plants in lakes.	WRP	No better data available.

Table 8-4 (cont'd). Main assumptions in data for radionuclide transport modelling. The assumptions related to the identified key data are on bold. (MAI, mean annual increment, see section 5.2.1).

Assumption	Class	Comment
Data for coastal areas (cont'd)		
All above-bottom plant biomass is assumed to be renewed due to winter conditions.	WRP	No better data available.
Net sedimentation and resuspension rates have been estimated from two independent datasets from some distance from each other, both assumed to represent the long-term rates on the same locations.	ST	No better data available, but a monitoring study of resuspension conditions is on-going.
Sedimentation during winter conditions is assumed negligible (i.e. cumulative open-water data would adequately represent the annual sedimentation).	ST	No better data available and difficult to obtain by direct sampling (only net sedimentation data can be easily obtained integrating continuously over several years, leading to lack of estimates of resuspension; determination of net sedimentation in the monitoring sites of resuspension conditions should be carried out).
For the sediments, data for lake sediments are used as surrogate.	WRP	Lack of data. Some sediments samples from the site have been taken but results have not been yet available.
For the active layer of sediment (top sediment) values for sludge or fluffy gyttja/mud are to be used.	LE	Expected result from the high water content and diffuse interface between water column and sediment.
For the deep sediments, data for respective soil types can be used as a surrogate data.	WRP	Lack of data, but taking longer sediment core samples from the site has been planned.
Data specific to C-14 transport modelling		
Mixing height for forest is based on literature data concerning well developed canopy and its CO_2 demand	WRP	Literature data on CO_2 demand of different vegetation types and development stages shall be reviewed and compared with vegetation growth data. Affects only the C-14 transport model.
Net primary production in lakes is based on generic data for a shallow and mesotrophic lake	LE	As there are presently no lakes at the site, the lake type is based on geometrical and hydrological data from biosphere forecasts. Affects only C-14 transport model.
Dissolved inorganic carbon content in lake water is based on a value for Lake Pääjärvi	WRP	Measurement data from relevant conditions are scarce. Affects only C-14 transport model.
Dissolved inorganic carbon contents in river water and seawater are scaled from measured total organic carbon data using a ratio from literature	LE	No better data available. Considering possible processes transforming a carbon species to another, no large differences are expected across study locations.
For decomposition rate of exposed sediment a literature value is used	WRP	No better data available. Affects only C-14 transport model.

Table 8-5. *Main assumptions in data for dose assessment for humans. The assumptions related to the identified key data are on bold.*

Assumption	Class	Comment
General approaches		
Carbon content of edible products follows from the main nutrient contents taken from the national FINELI database	LE	Well established data, small variability across data sources. In some cases the nutrient contents have been assigned based on the similarity of the edibles.
Edible portion of grouse and moose are assumed to be valid to all wildfowl and deer, respectively	WRP	Lack of data, a reasonable assumption based on anatomy.

Table 8-5 (cont'd). Main assumptions in data for dose assessment for humans. The assumptions related to the identified key data are on bold.

Assumption	Class	Comment
General approaches (cont'd)		
Carbon content and edible portion of some fish are estimated by using values for an analoguous fish species	WRP	Lack of data, no large variations anyway.
Productivity of edibles in forests and mires		
Production of a berry species is independent from other species	CS	
Productivity values for some berries and site types have been scaled from the others	WRP	Lack of data.
Data gaps in berry productivity are filled by scaling by abundance (expert judgement) and their subjectively chosen relative magnitudes of productivity	WRP	Lack of data.
Productivity of mushrooms is based on literature value, an estimate for Nouthern Finland said to be valid also to the rest of the country	WRP	Lack of data.
Production of game is based on game bag of 2002–2007	WRP	Comparably long site-specific time series in comparison to other data applied, the data basis will enlarge with time
Game production at the entire site is evenly distributed to derive an area-based number	PCA	Likely over-estimates the production in potentially contaminated areas and involves less assumptions than attempting a classification based on, for example, vegetation type
Productivity of edibles in sea		
Productivity of edible fish in coastal areas is based on generic statistics	WRP	Lack of site data
Productivity of hunted waterfowl is based on bird counting from shoreline	PCA	Overestimation in open sea areas; the value assumes as high bird density overall as in the coastal areas of Olkiluoto
Productivity of edibles in lakes		
Productivity of edible fish in lakes is based on a number of separate literature values	WRP	Lack of comprehensive site-relevant data
Contribution by crustaceans to the productivity of edibles in lakes is judged insignificant	WRP	Lack of quantified data
Productivity of hunted birds on lakes is assumed the same as in coastal areas at Olkiluoto for the selected species known to comprise the game bag almost entirely	WRP	Lack of quantified data
Productivity of edibles in rivers		
Productivity of edibles in rivers is taken as the same as in lakes	WRP	Lack of specific data
Concentration ratios from soil (or water) to edibles		
Concentration ratios to berries are assumed the same as to leaves of the respective plants (on dry-weight basis)	WRP	More site data need to be acquired. The site-specific data will be complemented by literature values for the final assessment use.
Site measurements of concentrations of stable elements are representative in regards of the uptake process of released radionuclides in the future	WRP	A commonly used assumption; the issue will be discussed in more detail in the future assessments when more site data becomes available.

Table 8-6. *Main assumptions in data for dose assessment for other biota. The assumptions related to the identified key data are on bold.*

Assumption	Class	Comment
The other biota is adequately represented by selecting one species from a trophic compartment	LE	Availability of data (and practicality in modelling) limits the range of species to be considered. The assessment species should be taken indicative and representative of feeding and other habits (exposure modes and transfer to body). Within the trophic compartments the variation, for example, in body size is less significant to the exposure than between them.
Assessment species are taken as ellipsoids for which shape the dimensions are adjusted	ST	The internationally developed ERICA methodology is adopted.
A tree has been divided into two ellipsoids (trunk and crown) to represent the true entity more realistically	ST	More realistic than the standard approach.
Sizes of assessment species are mainly based on average size and weight	WRP	Data are scarce. Sensitivity of actual model parameters to the size should be explored in further modelling.

8.2 Pedigree evaluation

The sensitivity of the assessment models to the changes in the value of an input parameter are explored by sensitivity analysis (e.g., Ekström & Broed 2006). This is done in Posiva's biosphere assessment in the modelling processes following the biosphere description. However, to give a better overall picture of the data basis of the assessment, it is useful to compare the sensitivity information with an index to the data quality to capture both the qualitative and the quantitative dimensions of the total uncertainty. For such an evaluation, a method usually called pedigree analysis has been developed (see Ikonen 2006, Hjerpe 2006 and references therein). Due to the needed effort in comprehensive pedigree analysis, here a simpler version, further developed from that of Broed (2007b), Broed et al. (2007) has been utilised and called Data Quality Index to make the difference from the conceptually more comprehensive measure of strength of the data quality in the pedigree analysis (e.g., Ellis et al. 2002a, Jeroen et al. 2002).

A five-criterion matrix for evaluating the data quality is presented in Table B-1 of App. B, and the criteria can be summarised as:

- Empirical, statistical and methodological quality; from educated guesses to controlled experiments, direct measurement by best available practise and good statistical basis;
- Proxy (parameterisation); whether the actual measurements used to derive the parameter value adequately describe the process or aggregate of processes in the model;
- Spatial variability in the scale of the Olkiluoto site, in the assessment context; from virtually certain changes to situation that it is unlikely that the parameter value would significantly differ in the other parts of the site for which the underlying data are valid;
- Robustness against time scales and external conditions, in the assessment context; virtually certain to unlikely that parameter value will be significantly altered over time or due to changes in the external conditions;

- Appropriateness to the Olkiluoto site; whether the data are from the site itself or a variably good analogous site.

The scoring was carried out by individual persons in the biosphere description team, thus reflecting only the view of individual experts, and the results are compiled into the tables in App. B. In the future assessment rounds, the scoring should be done more comprehensively and involve a consensus over a larger group of experts of the area and other members of the biosphere description team.

Figures 8-1 to 8-5 summarise the data quality indices (average scores) of all parameters considered for each modelling phase. The plots are organised by the DQI value and do not express any relationship to the significance of the parameter to the overall assessment (unlike in Fig. 8-1), except that the identified key parameters have been presented on capital letters for illustrativeness.

To illustrate the applicability of the data quality scoring in the overall assessment, Figure 8-6 presents a plot of the data quality indices (average of aspect-specific scores; 0-3) against the respective sensitivity measure in the case of the C-14 transport model (Avila & Pröhl 2007). For each of the parameters, the corresponding Spearman rank correlation coefficient (SRCC) was taken from (Avila & Pröhl 2007). In case of a parameter having several such values, only the maximum within the cases of a forest, a lake and a drained lake was taken to simplify the plot. In the lower right corner of the figure, the data quality has been evaluated low and at the same time the model is relatively very sensitive to small changes in the parameter value; parameters situated here would require immediate improvement. The further the individual parameters locate to the upper left corner on the plot, the higher the confidence to the model output is, by the view of this evaluation. However, also other aspects need to be considered, e.g., the needed effort or possible means to improve the data basis. On the other hand, with the model development, the overall picture might change as the model sensitivity changes (this would imply a fundamental improvement in the system understanding).

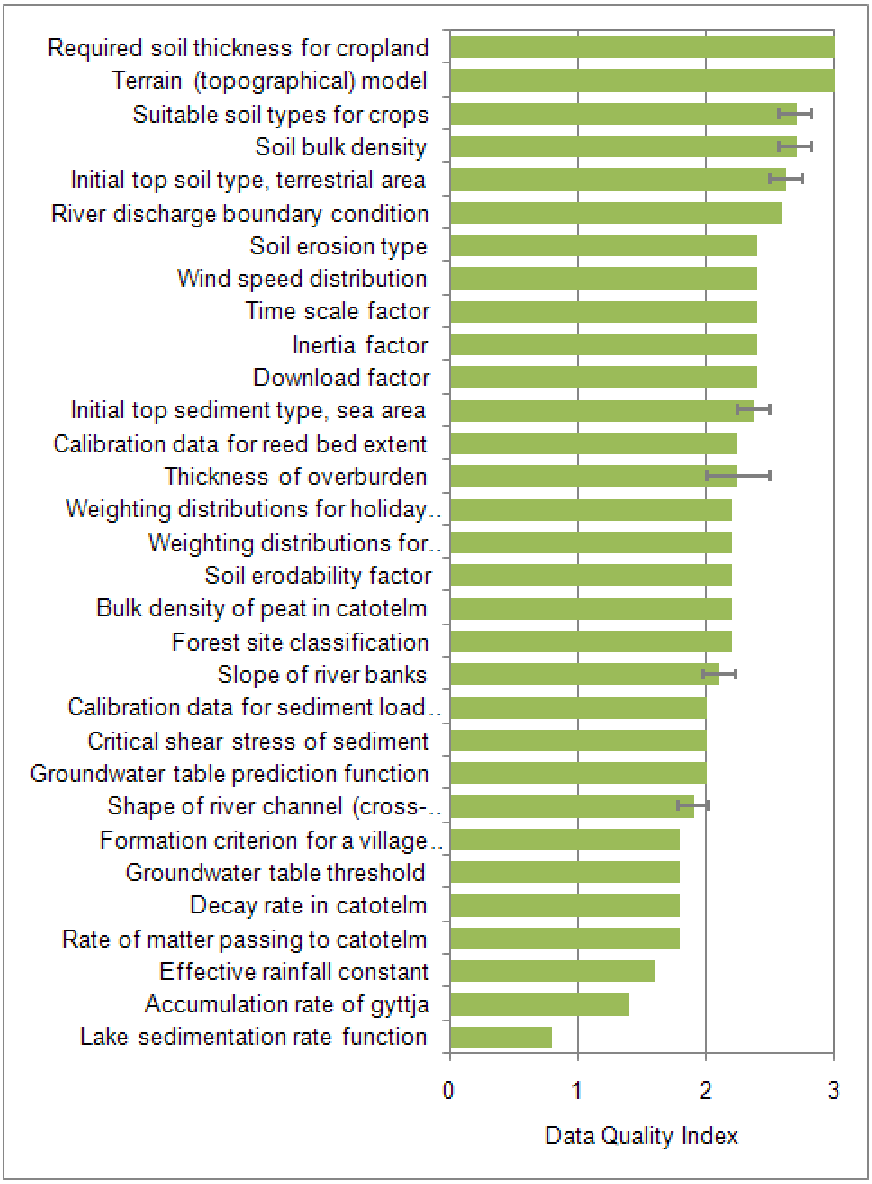

Figure 8-1. *Data Quality Index for all site and regional data for terrain and ecosystems development modelling in the order of DQI score.*

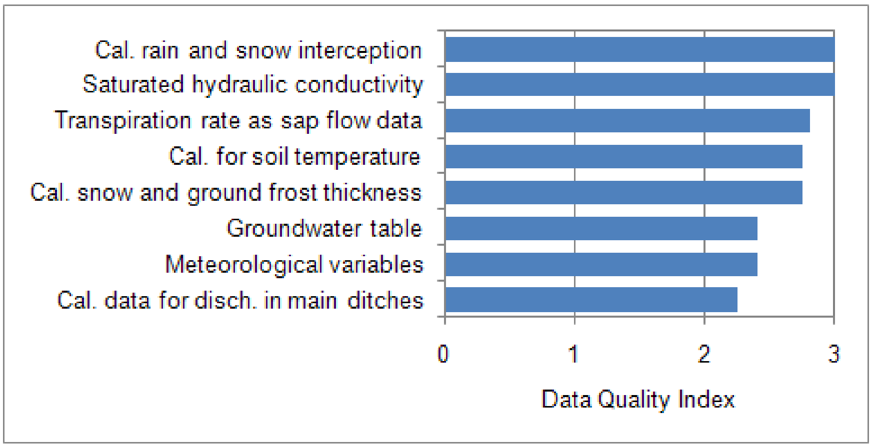

Figure 8-2. *Data Quality Index for all site and regional data for surface and near-surface modelling in the order of DQI score. Cal.: calibration data.*

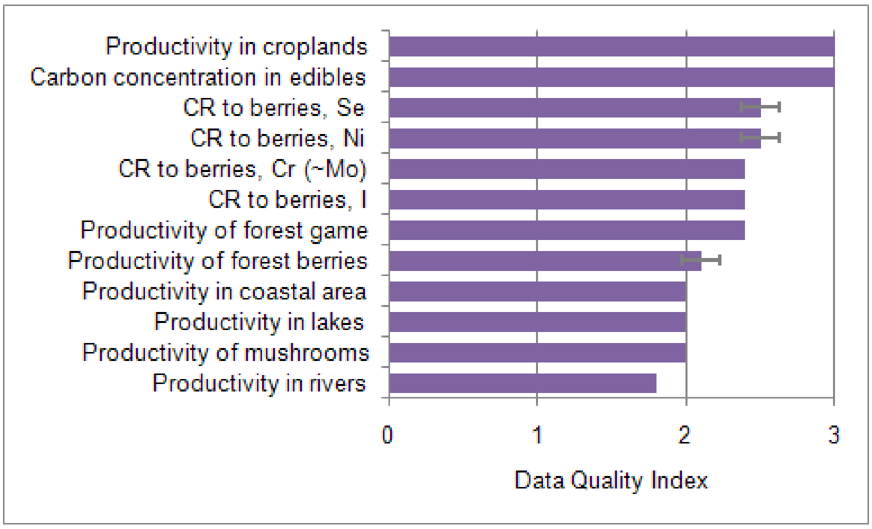

Figure 8-3. *Data Quality Index for all site and regional data for dose assessment for humans in the order of DQI score.*

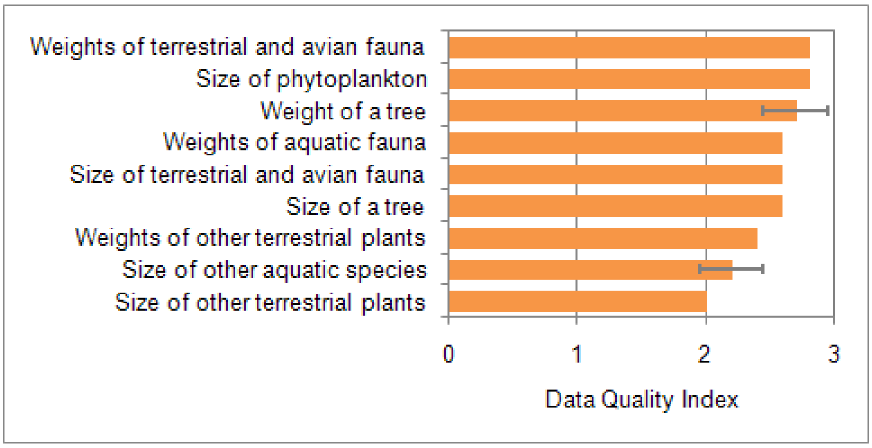

Figure 8-4. *Data Quality Index for all site and regional data for terrain dose assessment for other biota in the order of DQI score.*

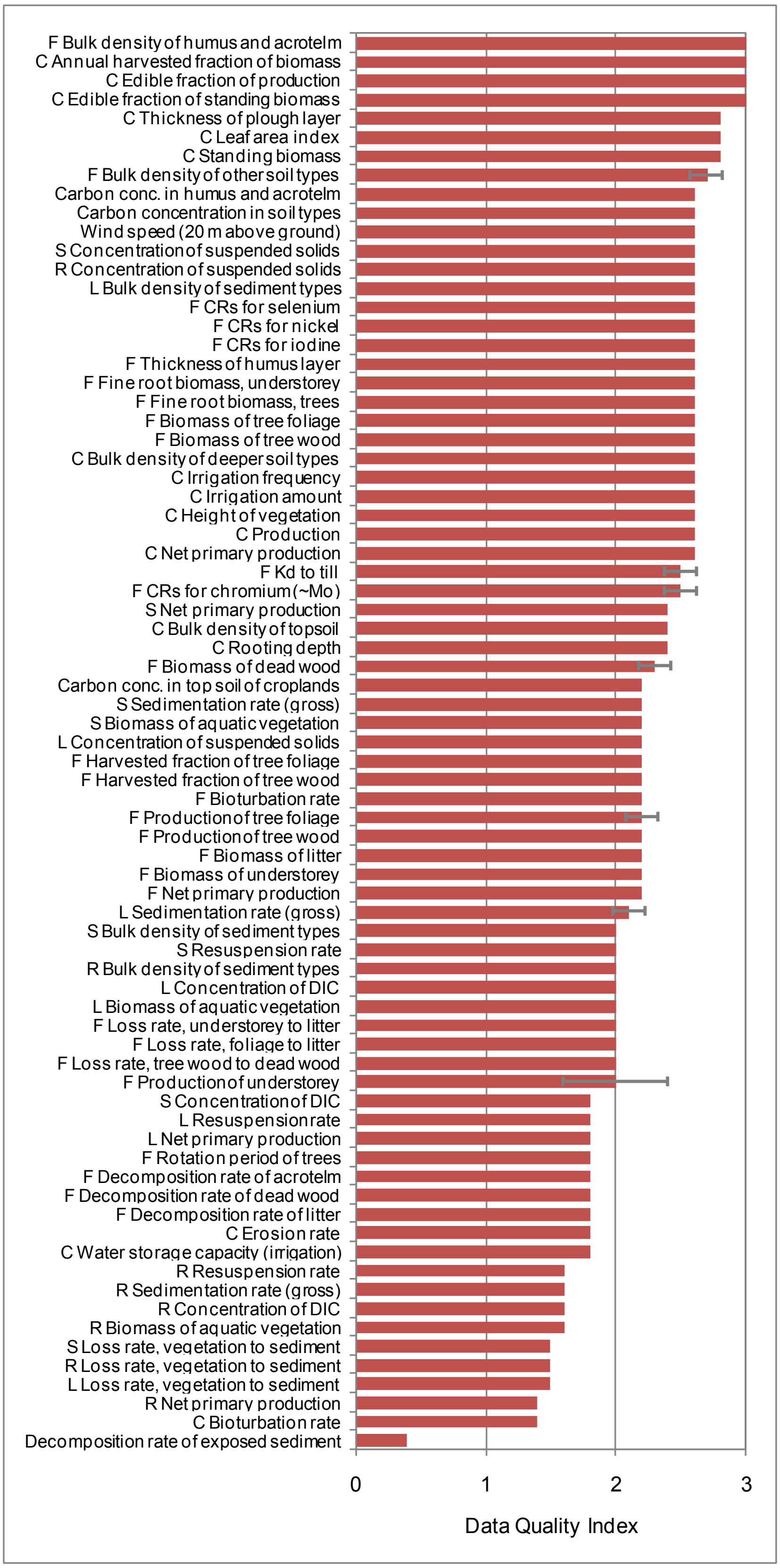

Figure 8-5. *Data Quality Index for all site and regional data for radionuclide transport modelling in the order of DQI score. F: forest, S: sea, L: lake, R: river, C: cropland.*

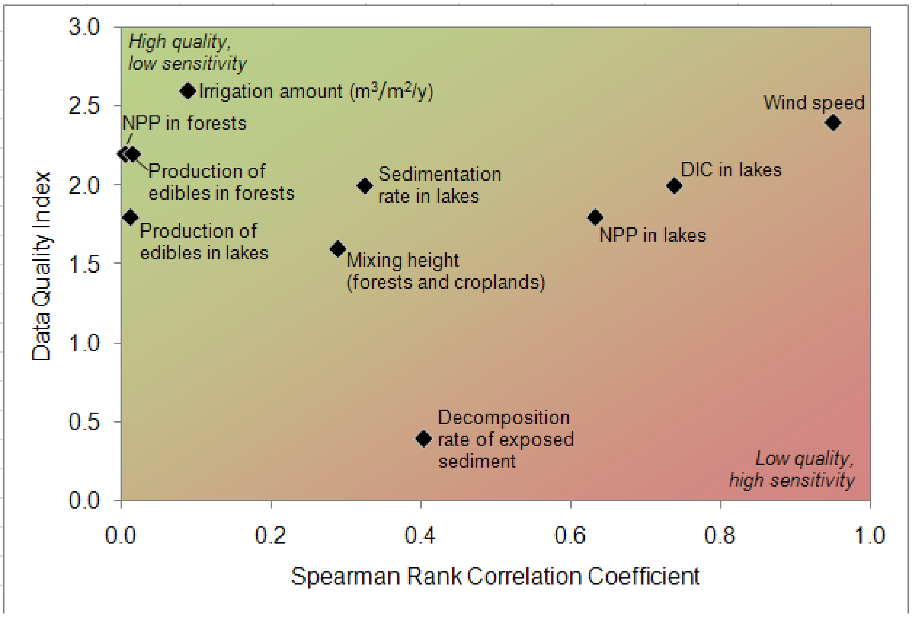

Figure 8-6. *Data Quality Index for the key data related to the C-14 transport model (from App. B) against the sensitivity of the transport model to the parameter expressed by the Spearman Rank Correlation Coefficient (maximum of those given for cases of forest, lake and drained lake in (Avila & Pröhl 2007)).*

8.3 Main uncertainties

In this section the main uncertainties in the data are discussed: uncertainties related to the models and assessment scenarios are left for the respective other reports. Also the focus here is in the data itself, and its appropriateness to the Olkiluoto site has been evaluated by means of the data quality index (section 8.2).

Only main uncertainties are included; for example, the uncertainty of the proportion of bark in trees, affecting to the transfer rate from trees to dead wood and rather easy to improve in quality from the forthcoming data from the sample trees taken from Olkiluoto, has been omitted since the contribution of bark is only about 1% of the overall flux to the dead wood compartment (most is the fall of twigs and branches). On the other hand, in many cases, no such clear quantification of the meaning of the uncertainty is yet possible. Thus, in the future assessment rounds, the impact of the uncertainties in the input data and of the assumptions used in the assessment data derivation are planned to be quantified using methods of sensitivity and uncertainty analysis.

Table 8-7. *Main uncertainties in the data for terrain and ecosystems development modelling. The uncertainties of the identified key data are on bold.*

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Initial terrain and overburden			
Uncertainties in the elevation values in possibly contaminated areas	Information density; magnitude assessed by confidence intervals (see section 3.2.1, fig. 3-7)	Uncertainty primarily in the geometry of the biosphere objects (and their type in some extent)	Site studies, especially water depth soundings from most important areas

Table 8-7 (cont'd). Main uncertainties in the data for terrain and ecosystems development modelling. The uncertainties of the identified key data are on bold.

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Initial terrain and overburden (cont'd)			
Top soil and sediment type	Information density; possibilities to characterise sea bottom sediments in large scale; combination of different classifications	Uncertainty in soil and sediment types, especially in respect of the fertility of future soils (cf. to uncertainties related to terrestrial vegetation)	Site studies, study of possible modelling approaches (correlation of more detailed soil type distribution and e.g. degree of physical exposure)
Thickness of overburden	Information density, methods of unavoidable interpolation	Uncertainty mainly in possible paths of releases from the repository	Site studies, especially in the areas of and near the flow paths of the releases (Karvonen 2009c)
Land uplift model parameters			
Data points are scattered rather sparsely and heterogeneously in different directions	Information density; general concentration of shorelevel dating points to specific regions	Uncertainty mainly in the crustal tilting in larger area around Olkiluoto	Site studies, especially in the most weakly represented directions
Terrestrial vegetation			
Heterogeneity within the forest site classes	Process understanding and inherent variability (many alternatives to make the classification)	Uncertainty in biosphere forecasts (and further in radionuclide transport modelling as other parameter data are derived following the classification)	Alternative models, however the fertility of forest sites is judged to be the main driver (this is related to how well the future soil types can be identified)
Aquatic vegetation			
Representativity of the calibration data for the reed bed model to the larger modelling area	A prioritisation issue; testing of model out of scope of the present report	Expected to be minor	Use of available datasets (e.g. Alahuhta 2008)
Representativity of the calibration data for the reed bed model to lakes and rivers	Lack of data	Uncertainty in the extent of the reed beds in lakes and rivers; does not affect to the radionuclide transport or dose assessment (but in the future reed beds should be separated from the water bodies since they form the main habitat for waterfowl which is hunted)	Reed bed characterisation in the analogue lakes and rivers (Figs. 1-6 and 1-7)
Terrestrial erosion and sedimentation			
Peat growth model parameters	Information density; lack of consistent peat profile data from site-relevant mires	Uncertainty in size of peat bogs (and further in the size of the respective biosphere object)	Site studies in the selected mire analogues, model testing with known peat thicknesses at present
Groundwater table threshold to sustain peat-producing vegetation	Lack of data	Uncertainty in the location of peat bog foci (whether a bog forms or not in a given location)	Comparison of groundwater table data/predictions and vegetation mapping data

Table 8-7 (cont'd). Main uncertainties in the data for terrain and ecosystems development modelling. The uncertainties of the identified key data are on bold.

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Terrestrial erosion and sedimentation (cont'd)			
Erodability factor and erosion type	Information density; very few data from Finnish conditions	Terrestrial erosion model not applied in BSA-2009, but would be useful in the next assessments	Literature review and careful comparison of experimental conditions; if this does not produce more reliable data, experimental studies needed
Erosivity factor	Information density; no data from Finnish conditions	As above	Calculation from meteorological data (see section 3.3.5)
Cover and management factor	Information density	As above	These are likely site-independent data; literature review
Soil bulk density	Information density; few directly applicable data	As above for TESM (on the other hand, needed also in other models)	Establishment of site-specific database (a measurement campaign)
Aquatic erosion and sedimentation			
Critical shear stresses	Lack of data; only a single site-relevant value available	Uncertainty in thickness and type of future overburden (see also *Thickness of overburden*)	Monitoring of sedimentation conditions has been planned, needs support from modelling
Varying filter sizes in monitoring data of suspended solids load	Development of monitoring methods	Expected to be minor (see section 3.2.7)	Comparison study either based on recorded data or on a sampling campaign
Accumulation of gyttja in reed bed areas	Lack of data	Uncertainty in thickness and type of future overburden (see also *Thickness of overburden*)	Field studies connected to characterisation of reed beds in reference lakes (and rivers); further analysis of sea bottom sediment and other data (source and fate of suspended matter/sediments)
Sedimentation equation for the simplistic model	Information density; a stylised approach not covering all relevant aspects (see section 3.3.6)	Uncertainty in thickness and type of future overburden (see also Thickness of overburden)	Taking the more advanced fetch-based model into production use
Croplands			
Suitability of soils for cultivation of different crops	Mainly a scenario-related uncertainty	Uncertainty in the amount of land area in cultivation; rather minor effect in the case of the present situation is assumed to prevail also in the future (Ikonen 2007b)	Propagating the issue into the formulation of dose assessment scenarios

Table 8-8. *Main uncertainties in the data for surface and near-surface hydrological model.*

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Spatial coverage of meteorological and transpiration data	Information density	Uncertainty in the calibration of the model	Need for supplementary measurements to be studied in the modelling
Hydraulic properties of soil and sediment types	Information density	Uncertainty in the flow domain and rates	Further accumulation of site data base

Table 8-9. *Main uncertainties in the data for radionuclide transport modelling. The uncertainties of the identified key data are on bold.*

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Issues common for all ecosystems			
Concentration ratios from soil to plants	Lack of data; only few site data are available	Biosphere assessment needs to be based on literature data (Helin et al. 2010)	Systematic sampling and chemical analysis of concentrations of the key elements in various media
Distribution coefficient (Kd)	Lack of data; only few site data are available	As above	Laboratory experiments (ongoing) and further site characterisation of the media
Bulk density of soils and sediments	Information density; few directly applicable data	Uncertainty in the values of the assessment data; uncertainty in the effective concentration ratios (soil to plant) in regards of the relative densities of soil layers	Establishment of site-specific database (a measurement campaign)
Data for forests			
Mean annual increment (of stem wood biomass)	Dependency of the MAI on the stand age (Fig. 5-4)	Uncertainty in annual production of tree wood (and foliage); range judged to represent overall variability (section 5.2.1)	More detailed analysis of the data and improved consistency between MAI and forest rotation scenarios
Mean annual increment of foliage is taken to be a fixed multiple of MAI	Lack of detailed measurement data	Uncertainty in annual production of foliage	Application of dynamic process models of tree growth to MAI
Conversion of MAI of stem wood from m³ to kg_{dw}	Information density; based on rather generic data	Uncertainty in annual production of tree wood (variability judged to be rather small, though)	Measurement campaign at the site
Annual production of understorey	Information density; few monitoring plots	Uncertainty in the data value	Measurement campaign in different site classes, better quantification of plant biomasses (see below)
Biomass of trees	Biomass calculations are based mainly on (Marklund 1988), for Swedish conditions	Effect is likely minor due to similarity of conditions	Sample tree collection campaign at Olkiluoto, and new biomass estimations using recently published Finnish models

Table 8-9 (cont'd). Main uncertainties in the data for radionuclide transport modelling. The uncertainties of the identified key data are on bold.

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Data for forests (cont'd)			
Division of tree biomass to wood and foliage	Average value over tree species and sizes is used, as derived from site data and biomass equations	Uncertainty in wood and foliage biomass values	More detailed derivation in consistency with forest site classification and management assumptions
Biomass of shrub layer	Lack of data	Generally the biomass is estimated small (e.g. Mälkönen 1974)	Measurement campaign (see also *Annual production*)
Biomass of other understorey	Estimates have been modelled from the tree biomass estimates	Uncertainty in the biomass of understorey plants	Measurement campaign (see also *Annual production*)
Root biomass distribution	Information density; data are lacking from some forest site classes	If soil layer-specific concentration ratios were used, uncertainty in their values (that mostly would be cancelled by use of the same data both in derivation of concentration ratios and in the radionuclide transport model)	Supplementary measurements in most central forest stand types
Transfer rates from trees to litter and dead wood	Information density; based on scaling literature with tree wood or foliage biomass	Uncertainty in the biological turnover rates/accumulation	Analysis of litterfall data from the Olkiluoto site
Biomass of dead wood	Information density; no detailed site data, and only literature data for the bulk density	Uncertainty in the biomass and element storages	Sampling campaign on the different forest site classes at Olkiluoto
Decomposition rate of litter	Lack of data; based on modelled estimates	Uncertainty in the biological turnover rate	Application of mass balance modelling to the site data
Decomposition rate of dead wood	Information density; few literature data, uncertainty of the time a snag remains upright	Uncertainty in the biological turnover rate	A long-term, well-controlled site experiment
Decay rate in acrotelm of peat bogs	Information density; only single numerical value for a Finnish bog found	Uncertainty in the biological turnover rate	Modelling of well-characterised peat bogs (with density profiles) using the TESM model
Life span of trees and harvested biomass	A forest management scenario uncertainty	Uncertainty in the time span of radionuclide accumulation to trees	Propagating the issue into the formulation of dose assessment scenarios and setting consistent datasets
Bioturbation rate	Information density; Swedish data are applied	Uncertainty in rate of mixing between topmost soil layers	Analysis and application of forthcoming data on soil fauna in Olkiluoto
Element concentrations in rooted mineral soil	Information density; only few samples from Olkiluoto analysed	Uncertainty in concentration ratios from soil to forest plants (needed to be complemented by literature data anyway)	Chemical analyses of archive samples and/or supplementary samples

Table 8-9 (cont'd). Main uncertainties in the data for radionuclide transport modelling. The uncertainties of the identified key data are on bold.

Uncertainty	**Cause and assessment of uncertainty**	**Effect on the product**	**Means to reduce the uncertainty**
Data for croplands			
Irrigation statistics	Based on recommendations and a regional survey	Uncertainties in the degree of indirect contamination of crops	More localised interview study, and assessment of feasibility vs. benefit
Data for lakes			
Sedimentation rate in lakes	Information density; combination of single surveys on more applicable estimates of net sedimentation and resuspension rates	Uncertainty in radionuclide transport models (removal of radioactivity from water column to sediment)	Sediment studies in the selected analogue lakes (Figs. 1-6 and 1-7)
Biomass of aquatic plants	Information density; data from Pyhäjärvi Lake scaled to depth distribution of expected future lakes	Uncertainty in biomass and element storages in lakes	Biomass measurements by depth intervals in the selected analogue lakes (Figs. 1-6 and 1-7)
Annual production of aquatic plants	Information density; Swedish data used to scale estimated biomass to production	Uncertainty in biological turnover rates	More comprehensive literature review; measurements in the selected analogue lakes
Data for rivers			
Biomass and production of aquatic plants	Lack of data; same values as for lakes assumed	Uncertainty in biological storages and turnover rates	Measurements of biomass (and production if possible) from rivers
Sedimentation and resuspension rates	Lack of data; at present generic model estimates	Uncertainty in removal of radioactivity from water column to sediment	Further characterisation of suspended solids in river water, sampling of bottom sediments, and more detailed modelling with specific river sediment models
Data for coastal areas			
Biomass and production of aquatic plants	Information density; Swedish data applied	Uncertainty in biological storages and turnover rates	Measurements of biomass (and production if possible) from the site
Concentration of suspended solids	Information density; rather short time series	Uncertainty in radio-nuclide transport and removal to sediment	Continuation of monitoring
Sedimentation and resuspension rates	Information density; combination of single surveys on more applicable estimates of net sedimentation and resuspension rates	Uncertainty in removal of radioactivity from water column to sediment	Establishing co-operation to get mass of radioactivity samples reported; continuation of resuspension monitoring campaign at the site; improved analysis and modelling (source and fate of suspended matter/sediments)
Data specific for C-14 transport modelling			
Mixing height	Literature value of unknown basis	Uncertainty in C-14 transport model (terrestrial systems)	Improved carbon cycle estimates for forests and croplands
Net primary production in lakes	Literature value for a shallow, mesotrophic lake	Uncertainty in C-14 transport model (lakes)	Improved mass balance and flux estimates for lakes
Dissolved inorganic carbon concentration in lakes	Literature value for a humic, mesotrophic lake	Uncertainty in C-14 transport model (lakes)	Sampling from the selected analogue lakes, a monitoring programme to be developed

Table 8-9 (cont'd). Main uncertainties in the data for radionuclide transport modelling. The uncertainties of the identified key data are on bold.

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Data specific for C-14 transport modelling (cont'd)			
Decomposition rate of exposed sediment	Literature value of unknown basis	Uncertainty in C-14 transport model (alluvious land, draining of a lake)	Overburden studies on alluvious land; a simplistic decomposition experiment has been planned
Carbon concentrations in soils and sediments	Information density; generally little directly applicable data available	Uncertainty in C-14 transport model (all cases)	Establishment of site-specific database covering central overburden types
Vegetation height in forest ecosystems	Information density (trees are well covered but data lacking on understorey); conceptual uncertainty (one- or multi-layered mixing/CO_2 uptake model)	Uncertainty in C-14 transport model (all cases), related also to *Mixing height*	Conceptual improvement of the model, and measurements of understorey plant communities (related to geometry issues in dose assessment of other biota)
Net primary production in coastal areas	Information density; only two monitoring points	Uncertainty in C-14 transport model (coastal areas)	Evaluation of spatial representativeness and possibilities to rectify the potential bias; additional sampling locations for some years
Net primary production in peatlands	Information density, practically lack of comprehensive datasets (see section 5.3.7)	Uncertainty in C-14 transport model (wetlands)	Measurement campaign (a challenging task)
Concentration of dissolved inorganic carbon in coastal areas and rivers	Information density; scaling by literature data used to convert TOC measurements	Uncertainty in C-14 transport model (coastal areas and rivers)	Measurement campaigns to establish well-based conversion, continuation of TOC concentration monitoring

Table 8-10. *Main uncertainties in the data for dose assessment for humans.*

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Productivity of berries	Information density; inherent heterogeneity of the landscape	Uncertainty in doses and number of exposed persons (forests and wetlands)	Sampling campaigns at the site
Productivity of mushrooms	Information density; inherent heterogeneity of the landscape	Uncertainty in doses and number of exposed persons (forests)	Literature review on required conditions for various mushroom species; sampling campaigns
Productivity of game from forests and wetlands	Information density; inherent heterogeneity of the landscape	Uncertainty in doses and number of exposed persons (forests and wetlands), smaller contribution than from berries and mushrooms	More specific spatial characterisation of game habitats and catches
Productivity of crops	Information density; inherent heterogeneity due to variability of conditions	Uncertainty in doses and number of exposed persons (croplands)	Improvement of data basis: better categorisation and acceptance/exclusion of specific data

Table 8-10 (cont'd). Main uncertainties in the data for dose assessment for humans.

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Productivity of fish in coastal areas	Information density; coverage and comparability of reporting areas, contribution from recreational fishing	Uncertainty in doses and number of exposed persons (coastal areas)	More specific spatial characterisation of fish stocks and catches
Productivity of game (waterfowl) in coastal areas	Generalisation of game bag and bird counting data to area-based data	Uncertainty in doses and number of exposed persons (coastal areas), minor compared to fish	Improvement of concepts/models: waterfowl should be calculated based on the habitat area, not by the whole coastal extent
Productivity of fish in lakes	Information density; no direct data from analoguous lakes to those expected at the site in future	Uncertainty in doses and number of exposed persons (lakes)	Test fishing in the analoguous lakes
Productivity of fish in rivers	Information density	Uncertainty in doses and number of exposed persons (rivers)	More comprehensive literature review; test fishing
Productivity of game (waterfowl) from lakes, rivers and wetlands	Information density	Uncertainty in doses and number of exposed persons (lakes, rivers, wetlands), likely small	Literature review, survey or interview study of local catches (potential)
Contribution by crayfish to the productivity of edibles	Information density	Uncertainty in doses and number of exposed persons (lakes and rivers), likely small	Literature review, survey or interview study of local catches (potential)
Concentration ratios from soil/water to edibles	Lack of site-specific data, few literature data especially to boreal forests and mires and brackish sea areas	Uncertainty in the doses (all ecosystems)	Samping and chemical analyses of respective media and edibles, analyses of already collected fauna samples

Table 8-11. *Main uncertainties in the data for dose assessment of other biota.*

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Representativeness of assessment species	The endpoint is not totally clear (e.g. whether typical or most sensitive species should be identified)	Representativeness of selected assessment species, and uncertainty in compliance with regulatory criteria	Clarification of conceptual models and the overall methodology
Dimensions and weight of a tree	Conceptual uncertainty (interpretation of the ellipsoid concept), few directly applicable data	Uncertainty in the uptake by and dose to a specific assessment species (forest and wetland)	Clarification of the conceptual model; utilisation of forthcoming data on sample trees
Dimensions and weights of forest/wetland plants	Information density; few directly applicable data	Uncertainty in the uptake by and dose to assessment species (forest and wetland)	Measurement campaign
Dimensions and weights of terrestrial fauna	Information density; few reliable data available	Uncertainty in the intake by and dose to assessment species (forest and wetland)	Measurement campaign, in connection of acquiring sample material for improving the concentration ratio database

Table 8-11 (cont'd). Main uncertainties in the data for dose assessment of other biota.

Uncertainty	Cause and assessment of uncertainty	Effect on the product	Means to reduce the uncertainty
Dimensions and weights of aquatic assessment species	Information density; few reliable data available (except for phyto-plankton)	Uncertainty in the uptake/intake by and dose to assessment species (aquatic ecosystems)	Sampling and measurement campaign in connection of other studies (see e.g. *Biomass* in uncertainties in radionuclide transport modelling data)
Concentration ratios from living environment to assessment species	Information density; general lack of data for most organisms; conceptual and data uncertainty on the representative concentration in media/food for animals with large home range	Uncertainty in the uptake/intake by and dose to assessment species (all ecosystems)	Samping and measurement campaigns; literature review and development of conceptual basis to take into account the home range; direct sampling of non-digested food from gastro-intestinal tract of larger animals

8.4 Feedback to characterisation and research programme

The ongoing monitoring and research programmes are adjusted according to experiences, analysis results and outcomes of data use and integration efforts such as this Biosphere description process. The database created so far is extensive, but there are still gaps in information. Some objects have not been studied; some elements have not been analysed. As well, spatial coverage is sparse or time series are short. While some of these gaps may be filled using generic values from the literature, a statistically solid database from the site is necessary to evaluate the suitability of these generic data. Furthermore, there are ecological data, which are not directly needed in biosphere description, but instead are used as input for work in other disciplines. In this chapter, we present the data needs identified during the biosphere description process. Since this report serves several purposes, the following aspects have been considered in Tables 8-12 to 8-15:

- Site characterisation activities
- Other research activities (e.g. sorption studies carried out in a laboratory)
- Modelling activities
- Quality management

Table 8-12. *Feedback to site characterisation. Those topics identified already in (Haapanen et al. 2009a) have been presented on bold.*

Topic	Feasibility	Importance
Include the key nuclides (elements; Table 2-1) to all relevant chemical analysis programmes, and lower the quantification limits.	High	High
Acquire spatially more detailed water depth data from the sea area of relevance to the further assessment modelling.	High	High
Monitoring of dry deposition.	High	High
More soil characterisation and sampling locations: pits dug by excavator, shallow soil pits, investigation trenches, transparent groundwater tubes etc.	High	High
Establishment and improvement of site-specific database on bulk densities of soils and sediments	High	High
Spatially extensive soil type and thickness study on shoreline and known or expected thin soil areas. Consider also the relation between vegetation and soil thickness.	High	High

Table 8-12 (cont'd). Feedback to site characterisation. Those topics identified already in (Haapanen et al. 2009a) have been presented on bold.

Topic	Feasibility	Importance
More forest sampling plots to deciduous forests (esp. alder stands).	High	High
Continuation of tree samples collection for biomass determinations and chemical analyses.	High	High
Extension of sap flow measurement network (more trees per monitoring plot).	High	High
Systematic sampling of berries and mushrooms (yield and chemical analyses for transfer factors).	High	High
Chemical analyses of animal samples for transfer factors (and complementary soil samples, if necessary).	High	High
Monitoring of sea level at Olkiluoto.	High	High
Monitoring of seawater turbidity and modelling of illumination conditions (dark and illuminated bottom habitats)	High	High
More sampling sites and more frequent sampling for zooplankton.	High	High
Chemical analyses of the collected bottom fauna samples.	High	High
Systematic littoral habitat survey on coastline.	High	High
Mapping of sediments and channel cross-sections of rivers Eurajoki and Lapinjoki, and the strait between Olkiluoto and the mainland.	Medium to high	High
Chemical analyses of plant and animal samples from sea for transfer factors (at the same time also sediment and water sampling)	Medium to high	High
Determintion of root biomass distribution in plots representing different forest classes and testing of the assumption that effective values can be derived as averages weighted by the biomasses of main and side tree species	Medium to high	High
Site measurements of aquatic plant biomasses by depth intervals and physical exposure types	Medium to high	High
Deposition collectors to shoreline (alder forest, open area, a nearby island).	Medium	High
Long terrestrial transects from Olkiluoto to mainland to study primary succession.	Medium	High
Better definition of values for mass balances and fluxes in mineral soils; estimates, modelling and direct measurements.	Medium	High
Extension of laboratory premises and acquisition of more equipment for sampling, pre-treatment and simplest analyses.	Medium	High
Gather more data on understorey biomass and productivity for a 100-year rotation period in different site types.	Medium	High
Vegetation inventory of the riparian zones and aquatic plants of rivers Eurajoki and Lapinjoki.	Medium	High
Chemical analyses of freshwater plant and animal samples for transfer factors (at the same time also sediment and water sampling).	Medium	High
Study of structure and amount of fish for ecosystem modelling and determination of transfer factors.	Medium	High
Monitoring campaign on sedimentation and erosion conditions in sea bottom, supported by modelling	Medium	High
Sediment sampling and determination of long-term net sedimentation rates from locations of the monitoroing points of the campaign above	Medium to high	High
Measurements of C-14 concentrations in different environmental media and biota	Medium	High (for C-14)
Measurement of dissolved/particulate and organic/inorganic carbon species in surface waters	Medium	High (for C-14)
Establishment of site-specific database on partition coefficients (Kd) (continuation of the work of Lusa et al. (2009)).	Medium (high for few selected radionuclide)	Medium to high
Complementary sampling of the seawater and biota to better cover the spatial and temporal (incl. growing season) variability.	Medium	Medium to high
Gather data on dimensions and weights of terrestrial assessment species of terrestrial flora and fauna.	High	Medium
Continuation of monitoring of springs near Olkiluoto.	High	Medium
Collect monitoring data on ice conditions and seawater temperature.	High	Medium
Continuation of the seawater quality mappings in different times of year and in different flow conditions	Medium to high	Medium
Monitoring of water quality (suspended solids, nutrients) of runoff to the sea outside the major river catchments.	Medium to high	Medium
Better temporal coverage of snow cover measurements (automatic measurement).	Medium *	Medium
More datings from different shore phases, especially in nearby areas of Olkiluoto (<50 m a.s.l) and in different directions. History of ancient pool and dam height to be taken into account.	Medium	Medium
Updated vegetation polygons data on forest status.	Medium	Medium

* Evaluated as high in (Haapanen et al. 2009a), since then it has been found out that the technical development of such equipment is not on the level originally expected.

Table 8-12 (cont'd). Feedback to site characterisation. Those topics identified already in (Haapanen et al. 2009a) have been presented on bold.

Topic	Feasibility	Importance
More data (temporal variation) on water quality of River Lapinjoki; continuous monitoring at least for some years.	Medium	Medium
Mapping of small water bodies on and around Olkiluoto Island, and characterisation of the most relevant ones.	Medium	Medium
Gather data on dimensions and weights of assessment species of flora and fauna of the sea environment	Medium	Medium
Survey of irrigation practises and amounts near Olkiluoto	Medium	Medium
Sampling of farm products and soils for transfer factors	Medium	Medium (crops) or low (animal products)
Studies on crustal thickness, especially near Olkiluoto and in different directions. Check usability of HIRE investigation in 2008.	Medium (existing data) or low (new field work)	Medium
Characterisation of alluvious lands for determination of gyttja accumulation rate and the decomposition rate of terrestrialised former sea/lake bottom sediment, and an experiment on the same topic.	Low to medium	Medium
Bottom fauna and fish studies of River Lapinjoki.	Low	Medium
Estimation of berry yields of sea buckthorn and its relevance in the berry catch	Medium to high	Low to medium

Table 8-13. *Feedback to characterisation of analogue lakes and mires. Those topics identified already in (Haapanen et al. 2009a) have been presented on bold. Not all topics possibly relevant also here have been repeated from Table 8-12.*

Topic	Feasibility	Importance
Include the key nuclides (elements; Table 2-1) to all relevant chemical analysis programmes, and lower the quantification limits.	High	High
Estimation of mass balances and fluxes on peatlands (both treeless mires and forested peatlands).	High	High
Outline a characterisation plan for filling data gaps on the analogue lakes and rivers Eurajoki and Lapinjoki.	High	High
Site measurements of aquatic plant biomasses by depth intervals and physical exposure types	Medium to high	High
Sampling of the selected analogue lakes for dissolved inorganic carbon (and other carbon species) covering spatial and temporal variation at least for some years.	Medium (logistics)	High
Study most important carbon storages and fluxes in the selected analogue lakes.	Medium	High
Data on hunted birds in the analogue lakes and rivers Eurajoki and Lapinjoki.	Medium	High
Study on gyttja accumulation rates and sedimentation rates in the selected analogue lakes	Medium	High
Measurements of C-14 concentrations in different environmental media and biota	Medium	High (for C-14)
Measurement of dissolved/particulate and organic/inorganic carbon species in surface waters	Medium	High (for C-14)
Radiocarbon dating and chemical analyses of peat profiles from relevant mires selected as analogues to the future Olkiluoto site. The survey should be connected with testing of the UNTAMO peat growth model.	Medium	Medium
Comprehensive vegetation inventories on the selected analogue mires.	Medium	Medium
Gather data on dimensions and weights of assessment species of freshwater flora and fauna.	Medium	Medium

Table 8-14. *Feedback to biosphere description work (analysis and synthesis). Those topics identified already in (Haapanen et al. 2009a) have been presented on bold.*

Topic	Feasibility	Importance
Literature review of transfer factors by experts knowing the site.	High	High (see also Table 2-1)
Enhancement of interdisciplinary integration throughout the Biosphere description process.	High	High
Continue the overburden 3D modelling and its utilisation in the biosphere description.	High	High
Analysis of litterfall monitoring data from Olkiluoto for the loss rate fluxes from the different forest compartments	High	High
Systematic littoral habitat survey on coastline.	High	High
Improved classification of sea bottom habitats and description of their mass balances and flows.	High	High
Further development of use of the hydrodynamic 3D models (Lauri 2008) in modelling of mass balances and fluxes in the sea environment	High	High
Addressing derivation of data for appropriate spatial and temporal scale for the subsequent modelling (averaging, down-/up-scaling) in more detail.	Medium to high	High
Application of new information on C-14 cycling from a public nuclear waste research programme (KYT) project to biomass and other data from Olkiluoto	Medium to high	High
Quantification of the impact of the uncertainties in the input data and of the assumptions used in the assessment data derivation by methods of sensitivity and uncertainty analysis	Medium to high	High
Better definition of values for mass balances and fluxes in mineral soils; estimates, modelling and direct measurements.	Medium	High
Derivation of consistent and correlated data for vegetation height of trees and understorey, and net primary production of forest classes	Low to medium	High (for C-14)
Sensitivity of the *effective rainfall constant* to different land use combinations	Low to medium (requires process-level modelling)	High
Quantitative surveys of biomass densities of fauna for ecosystem mass balance estimations (nearly all biomass in each trophic compartment).	Low	Medium to high
Analysis of measurement data of Eurajoki River cross sections	High	Medium
Map and aerial photo analysis of river width vs. discharge	High	Medium
Comparison of groundwater table (measured and/or modelled) and occurrence of peat-forming vegetation to estimate the groundwater table threshold	High	Medium
Gather data on river processes and adapt to conditions near Olkiluoto.	Medium	Medium
Visual interpretation of photographs on riverbanks to estimate bank slopes and role of vegetation	Medium	Medium
Calculation of erosivity factor from meteorological data	High	Low to medium
Estimation of wave area buffer prohibiting peat formation (wave and ice conditions)	High	Low to medium

Table 8-15. *Feedback to further assessment modelling. Those topics identified already in (Haapanen et al. 2009a) have been presented on bold.*

Topic	Feasibility	Importance
Testing of the TESM/UNTAMO models (especially peat growth model and themes in section 3.4)	High	High
Relevance of springs and other small water bodies (section 6.8 in Haapanen et al. 2009a) should be assessed for radionuclide transport modelling and especially for dose assessment of other biota	Medium to high	High
Developing radionuclide transport models to calculate object-specific aquatic plant biomass values from depth distribution and given biomass values specific to depth intervals	High	Medium to high

9 CONCLUDING REMARKS

The present report provides the site-specific and regional data basis of the biosphere assessment BSA-2009 (Hjerpe et al. 2010) and is a supplement to the Olkiluoto biosphere description report (Haapanen et al. 2009a), which describes in more detail the site understanding and studies utilised here. Generally, the data basis to be on a reasonably good level, although many possibilities for improvement have been identified (section 8.4) – this can be stated to be characteristic to the iterative development in the assessment which will be ongoing also in the future. The most prominent gaps in the data are related to

- concentration ratios to terrestrial and aquatic plants – these are complemented by literature data in (Helin et al. 2010) and a significant amount of new site data is expected to become available by the 2012 biosphere assessment;
- distribution coefficients in soils and sediments – an expental programme is ongoing to provide more site-specific data in the near future, and also these data are complemented by literature data in (Helin et al. 2010);
- aquatic systems in general – the monitoring programmes of the nuclear power plant and the environmental authorities are producing useful information, but not on all the needed parameters, and thus measurement campaigns have been planned above;
- parameters specific to the C-14 specific activity model – these usually require complicated measurements, possible improvements to the site characterisation have been listed in section 8.4.

9.1 Thematic considerations

In this section, some themes that arose from the previous biosphere description (Haapanen et al. 2007) and an earlier overall plan of biosphere assessment (Ikonen 2006) in the dialogue with the authorities are discussed. As well, some themes that appeared during the expert review of this work and during the compilation of the three-year research plan (Posiva 2009b) have been included for clarification.

Site vs. generic data

In this report, parameter data from the Olkiluoto site or the region around it have been provided for further modelling in the biosphere assessment, based on a rather elaborate summary of their origin. However, it is clear that they will not be sufficient for all models and input data, but that also more generic data are needed. There is also a justified question: Are the site data automatically preferred, and are they automatically better than generic information?

The various parameters and conditions in the different models of the biosphere assessment can be divided into groups, for example, as:

- Climate conditions: by the scenario formulation in Posiva's safety case (Posiva 2008), these are given to the biosphere assessment from the upper level
- Geometrical properties: by their nature, these need to be based on the site properties as interpreted in the forecast modelling

- Properties of overburden, waterbodies and biota: in order to meet the context of a site-specific assessment, these need to be derived from the site and its expected evolution[18], although for the use of sensitivity assessment a broader view is preferred for the range and probability density function
- Radionuclide transport parameters: for some there exists site data, but as a rule they are not used exclusively unless they have been shown to be significantly different from the generic data
- Dose factors for ingestion, inhalation and external exposure: by definition, these are generic handbook values
- Other dose assessment parameters: following from the approach these are by default site or regional data where available

If we consider, for example, the transport parameters, like Sheppard (2005), it is indeed nearly impossible to know whether there is an unexpected bias when there are only few data (from the site or the literature), and also to exemplify whether a species in a group is different from another, for example, is an ass bioconcentrating more effectively than a horse? In any case, the more data available, the more we can know about the underlying processes and relevant differences in conditions. Since the literature data on these parameters are notoriously scarce (with compendium values usually lacking description of the range of conditions the data are derived from), the contribution of even a few site data would be useful. Still, a few site data alone could be insufficient since the inherent variability of the transport parameters is so large that site data would be significantly different only for "fairly exceptional on-site properties" (Sheppard 2005). To address these questions, a software called Babar is being developed for Posiva, NRPA and IRSN to facilitate statistical analysis and correct sample-size weighted updates of generic distributions with site data. The methodology is to be used in the biosphere assessment of 2009, and the results reported in the subsequent publications.

Furthermore, the issue of validity of conditions from which the key data have been derived with respect to the assessment context is addressed also in the data quality evalutation (Chapter 8) and especially in its pedigree analysis part. In this work, aspects of spatial and temporal variability, robustness against external factors and appropriateness for the Olkiluoto site are evaluated in the data quality index (App. B). This information is propagated throughout the subsequent parts of the biosphere assessment for overall evaluation of the strength of the knowledge underlying the assessment results. In the future assessments, the methodology can of course be further developed to better encompass the variety of conditions affecting different types of parameters as the level of knowledge increases with iteration.

To conclude on this theme, generally site data are useful but only in the perspective provided by the literature, since it needs to be confirmed that there is no significant bias, and that for the sensitivity analyses the ranges and shape of the distribution are sufficient in the assessment context. This is a major task, and the need for individual data should be viewed based on the potential impact to the assessment endpoints. Following from the assessment context, some of the data need to be from the site anyway.

[18] Otherwise, it could not be known whether a generic data is valid or whether the conditions are for an exceptional situation with a significantly better estimate from the site data than from the literature.

Propagation of uncertainties in biosphere assessment

The biosphere assessment is organised into an overall process of subsequent tasks dealing with the different aspects, time windows and levels of pessimism within the assessment. The uncertainties, or more broadly, the quality of the knowledge base, are assessed systematically in all of the tasks propagating also the results from the inputting tasks so that the main uncertainties are handled at appropriate levels of the assessment. In some cases, handling may be adequate already at the first level of the knowledge quality assessment; it can be justified that uncertainty does not have any significant implications in the further assessment, or can be handled with a reasonably pessimistic assumption or parameter value. The most significant uncertainties – and major qualitative assumptions, too – in their part are propagated throughout the assessment and tied to the formulation of calculation cases in the biosphere forecasts and the radionuclide transport and dose calculations. The calculation cases are formulated in a systematic way, bound by the higher-level safety case scenarios, and the methodology will be described in the forthcoming biosphere assessment reports.

Maturity and future programme of ecosystem characterisation

The aim of the ecosystem characterisation, summarised by the biosphere description, is to eventually provide data of sufficient scope and quality to fully underpin the safety case development. Due to the iterative nature of the assessments throughout the repository programme, not all needs can be known beforehand but they depend also on the changes in the relative impact of the uncertainties both in data and in the understanding of the system under analysis. Furthermore, they also depend on the possible changes in site-independent data and the assessment context, including regulatory and other societal requirements. The sufficiency of the data provided on a stage of the programme can be evaluated for example from the perspective of the level of pessimism: the assessment is required to overestimate the potential harm, but not unnecessarily. However, how much pessimism can be allowed depends on the source term (release from the bedrock following the postulated defects in repository), on the desired margin to the regulatory compliance, and on the required level of confidence on the quality and the comprehensiveness of the knowledge base of the assessment. In the Finnish programme, this evaluation comes out of the dialogue between Posiva and the regulator, both with their external advisors.

So far the focus in ecosystem characterisation has been on gaining an understanding on the ecosystems and their function in general in order to have a firm basis for more detailed – and usually much more expensive and demanding – studies on specific topics. However, at the same time, much general-level knowledge is gained also on radionuclide migration and accumulation both from the site studies on analogous stable elements and modelling efforts internally (parallel to the Swedish programme) and through international co-operation (e.g., BIOPROTA and IUR). On this basis, the 2009 biosphere assessment starting from this report aims to meet the needs for an outline and further production plans for the material supporting the construction licence application in 2012.

In the future programme of ecosystem characterisation, the environmental monitoring programme is continued, and some more basic characterisation in domains still needing complementation (identified in section 8.4) will be done, but the focus has turned to first improving the quantification of the most important mass fluxes (chapter 10 in Haapanen et al. 2009a) for the key elements (radionuclides; Table 2-1), and second to improving the data basis for the input data required by the biosphere assessment models (Chapters 3-7 in this report), following the principles outlined above. Efforts will be made to further improve the surface and near-surface hydrological modelling (Karvonen 2008, 2009a-c), which is, in practice, the link between the biosphere and the repository host rock.

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APPENDIX A: SUMMARY OF SITE AND REGIONAL DATA TO RADIONUCLIDE TRANSPORT MODELLING

In this appendix, a summary of the site and regional data to radionuclide transport modelling are presented for convenience. For the rationale of the selected data, see the respective sections of Chaper 5. The site-specific data on concentration ratios to forest plants or distribution coefficients in till, described in sections 5.2.1 and 5.3.1, have not been included in the tables below since they are to be complemented with literature data in (Helin et al. 2010) before the use in the assessment.

The data here is presented in tables arranged in an order of:

- A-1: Data specific to crop type;
- A-2: Other data for croplands;
- A-3: Data generic to all forest and wetland objects;
- A-4: Data specific to C-14 modelling;
- A-5: Data specific to forest type (UNTAMO class);
- A-6: Properties of soils and sediments;
- A-7: Data for lakes;
- A-8: Data for rivers;
- A-9: Data for coastal areas.

Table A-1. *Site and region data on crops for radionuclide transport modelling, given as best estimates (and range).*

Parameter	Unit	Crop type							Rationale
		Cereals	**Grassland**	**Sugar beet**	**Potato**	**Peas**	**Field vegetables**	**Berries and fruits**	
Net primary production	$kg_C/m^2/y$	0.18	0.40	0.52	0.44	0.18	0.20	0.080	Regional/national data, section 5.3.2.
Standing biomass	kg_{dw}/m^2	0.425	0.5	1.20	1.0	0.425	0.40	0.30	
of which edible	kg_{dw}/kg_{dw}	0.60	0.80	0.15	0.60	0.60	0.50	0.20	
Production	$kg_{dw}/m^2/y$	0.45	1.0	1.3	1.1	0.45	0.50	0.20	
of which edible	kg_{dw}/kg_{dw}	0.57	0.80	0.14	0.55	0.56	0.40	0.30	
Annual harvested fraction of biomass	kg_{dw}/kg_{dw}	0.57	0.80	0.14	0.54	0.56	0.40	0.30	
Height of vegetation [a]	m	0.85 (0.5-1.0)	0.5 (0.4-0.6)	0.5 (0.4-0.6)	0.5 (0.4-0.6)	0.5 (0.4-0.6)	0.4 (0.2-0.6)	0.5 (0.3-3)	National data, section 5.3.2.
Rooting depth [b]	m	0.6 (0.4-1)	0.5 (0.4-1)	0.7 (0.5-1)	0.4 (0.4-0.6)	0.6 (0.4-0.7)	0.5 (0.3-1)	0.5 (0.3-1)	
Irrigation amount	m^3/m^2/event	0.030	0.030	0.030	0.020	0.025	0.025	0.015	Regional data, section 5.2.2.
Irrigation frequency	event/y	1	1	1	2	1	3	3	
Leaf area index	m^2_{leaves}/m^2_{soil}	1.5	1	2	2	2.5	2	2	National data, section 5.2.2.

a Nominal value is the average height at maximum growth, the range gives the variation between crop species and growing seasons. For averages over the growing season, these should be divided by 2.
b Nominal value is the maximum rooting depth on average, the range gives the variation between crop species and growing seasons.

Table A-2. *Site and region data on top soil in croplands for radionuclide transport modelling.*

Parameter	Unit	Nominal	Min	Max	Rationale
Thickness of plough layer	m	0.25	0.2	0.3	Expert judgement, see discussion in section 5.3.2.
Water storage capacity [a]	m^3/m^2_{leaves}	0.0002			Experimental/modelled national data, section 5.3.2.
Soil bulk density	kg_{dw}/m^3	1200	1000	1500	Typical regional/national values, section 5.3.2.
Concentration of carbon in soil	kg_C/kg_{dw}	0.03	0.01	0.3	Typical national values, see section 5.3.2.
Erosion rate	$m^3_{soil}/m^2/y$	1.25×10^{-4}	2.5×10^{-6}	2.75×10^{-4}	Modelling studies for Finnish conditions, see section 5.3.2.
Bioturbation rate	$kg_{dw}/m^2/y$	2			Site-relevant literature data, see section 5.3.2 (and further section 5.3.1).

a Interception capacity of irrigation water

Table A-3. *Site and region data generic to forest and wetland objects in radionuclide transport modelling.*

Parameter	Unit	Nominal	Min	Max	Std	Rationale
Biomass of dead wood (forest and wetland)	kg_{dw}/m^2	0.158				Average value for Olkiluoto, scaled by national density data (section 5.3.1).
Decomposition rate of litter (forest)	1/y	0.030	0.02	0.1		Modelled for Finnish conditions, section 5.3.1
...of acrotelm (wetland)	1/y	0.015			0.015	For Kunnonniemensuo, southern Finland (Clymo 1984)
...of dead wood (forest and wetland)	1/y	0.054	0.016 [a]	0.12 [a]		Derived from a Finnish field experiment; section 5.3.1.
Rotation period of trees	y	100	(0)	600		Nominal value related to average growth and biomass models applied, section 5.3.1.
Harvested fraction of tree wood biomass	1/event	0.89	0.66 [b]	1		Literature data on Finnish conditions, section 5.3.1.
...of tree foliage biomass	1/event	0	0	1		See discussion in section 5.3.1.

a The given range may be too narrow due to rather weak data basis.
b Whole share of the trunk of the wood biomass (trunk and branches). This is partly scenario-dependent value, could be also near 0.

Table A-4. *Data specific to C-14 in all ecosystem types in the radionuclide transport modelling.*

Parameter	Unit	Nominal	Min	Max	Std	N	Rationale
Wind speed 20 m above ground [a]	m/s	4.1 [b]	3.6 [b]	4.5 [b]	0.19 [b]	16	Site data, Table 3-7.
Decomposition rate of exposed sediment	1/y	0.03			0.01		Literature data, section 5.2.3.

a Note that the wind speed may need scaling to another altitude, depending on the model assumptions. Best fitting distribution to the data is the one of Weibull (Avila & Pröhl 2007).
b Arithmetic mean and variation of annual average wind speeds in 1993-2008. Minimum hourly average is 0 m/s and corresponding maximum 16.8 m/s. Variation of monthly averages has been 2.7-6.2 m/s.

Table A-5. *Forest and mire vegetation data for radionuclide transport modelling, given as best estimate (minimum-maximum; standard deviation; number of data). The best estimate is the the arithmetic mean of the data unless otherwise indicated.*

Parameter	Unit	Forest class				Rationale
		1 Rocky	2 Heath	3 Herb-rich heath	5 Peat land	
Net primary production	$kg_C/m^2/y$	0.140 (0.114-0.223)	0.249 (0.090-0.422)	0.349 (0.245-0.427)	- (0.019-0.321[g])	Site data in Table 5-9, except for class 5 literature data (section 5.2.3).
Height of vegetation (trees)	m	7.9 (- -15.3; 3.1; 28)	9.3 (- -25.0; 4.8; 1793)	10.9 (- -27.0; 5.4; 502)	9.0 (- -23.7; 4.3; 522)	Site data representing state of forests in Olkiluto in 2004 (section 5.3.7)
Tree wood parameters						
Biomass (above-ground)	kg_{dw}/m^2	1.7 (0.76[a]-2.5; 0.7; 7)	4.6 (0.02-18; 3.1; 369)	6.4 (0.07-29; 4.5; 141)	4.4 (0.02-15; 3.2; 85)	Site data summarised in Tables 5-1 and 5-4; 65% being wood and other conversions as in section 5.2.1.
Production	$kg_{dw}/m^2/y$	0.079 (0.017-0.12; 0.046; 3)	0.20 (0.033-0.35; 0.07; 40)	0.25 (0.0042-0.47; 0.08; 36)	0.17 (0.0085-0.48; 0.09; 9)	
Loss rate to dead wood [b]	1/y	0.0013	0.0028	0.0031	0.0012	Literature data, weighted with site data (tree species biomass), see section 5.3.1.
Tree foliage parameters						
Biomass	kg_{dw}/m^2	0.90 (0.41-1.4; 0.4; 7)	2.5 (0.01-9.7; 1.7; 369)	3.4 (0.04-15; 2.4; 141)	2.4 (0.01-8.1; 1.7; 85)	Site data summarised in Tables 5-1 and 5-4; 35% being foliage and other conversions as in section 5.2.1.
Production	$kg_{dw}/m^2/y$	0.064 (0.014-0.098; 0.04 3)	0.17 (0.027-0.29; 0.06; 40)	0.21 (0.0035-0.39; 0.07; 36)	0.17 (0.0070-0.39; 0.08; 9)	
Loss rate to litter	1/y	0.21 (0.1-1)	0.32 (0.1-1)	0.34 (0.1-1)	0.40 (0.1-1)	Literature data, weighted with site data (tree species biomass), range estimated by extreme plant composition; section 5.3.1.
Understorey parameters						
Biomass	kg_{dw}/m^2	0.25 (-[c])	0.11 (0.07-0.25; 0.06; 110)	0.12 (0.07-0.25; 0.08; 22)	0.16 (0.14-0.30; 0.05; 10)	Site data, from data summarised in Table 5-4.
Production	$kg_{dw}/m^2/y$	not available (-[c])	0.096 (0.080-0.122)	0.063 (0.042-0.075)	0.19[d] (0.028-0.346)	Site data summarised in Table 5-3, but literature for class 5.
Loss rate to litter	1/y	0.31 (0.1-1)	0.40 (0.33-1)	0.38 (0.33-1)	0.43 (0.33-1)	Literature data, weighted with site data (tree species biomass), range estimated by extreme plant composition; section 5.3.1.

Table A-5 (cont'd). Forest and mire vegetation data for radionuclide transport modelling, given as best estimate (minimum-maximum; standard deviation; number of data). The best estimate is the the arithmetic mean of the data unless otherwise indicated.

Parameter	Unit	Forest class				Rationale
		1 Rocky	2 Heath	3 Herb-rich heath	5 Peat land	
Fine root biomass fractions						
Trees, in humus	kg_{dw}/kg_{dw}	0.43	0.55	0.58	0.4[e]	Site data (classes 1-3), Table 5-5. Species composition as for MAI and for understorey as below-ground biomasses.
Trees, in mineral soil	kg_{dw}/kg_{dw}	0.57	0.45	0.42	0.6[e]	
Understorey, in humus	kg_{dw}/kg_{dw}	0.88	0.88	0.89	0.9[e]	
Understorey, in min. soil	kg_{dw}/kg_{dw}	0.12	0.12	0.11	0.1[e]	
Biomass of litter layer						
Litter	kg_{dw}/m^2	not available	0.5	not available	–	Literature data, section 5.3.1.
Humus/acrotelm properties						
Thickness	m	0.041 (0.026-0.066; 0.013; 9)	0.055 (0.025-0.096; 0.018; 40)	0.065 (0.023-0.21; 0.033; 36)	–	Site data[f], see section 5.3.1.
Density	kg_{dw}/m^3	140	160	170	91	Site data, see section 5.3.1, except class 5 same as for TESM model, section 3.2.5.
Carbon concentration	kg_C/kg_{dw}	0.43 (0.36-0.49; 0.041; 9)	0.39 (0.20-0.48; 0.064; 40)	0.37 (0.26-0.48; 0.060; 36)	0.46 (0.31-0.53; 0.05; 15)	Site data, see section 5.3.7.
Bioturbation						
Bioturbation rate	$kg_{dw}/m^2/y$	0.5 (0.3-0.6; 0.3, 2)	6.5 (0.1-21; 9, 5)	4.3 (0.1-9.8; 5, 3)	6.1 (0.01-14; 6, 6)	Swedish data, section 5.3.1.

This minimum value is from the inventoried plots in Olkiluoto - there might be also areas where the tree wood and foliage biomass is 0.
b Excluding harvesting of the stems, see Table A3-3 for harvested fractions; the remainder is left to the forest, as dead wood (from the "tree wood") and litter (from the foliage).
c Only few measurement plots available; not considered to adequately cover the natural variability.
d Nominal value given as the arithmetic mean of the minimum and maximum values. Due to a communication error in the data compilation phase, erroneous values of 0.75 (0.136-1.370) $kg_{dw}/m^2/y$ were propagated to the futher assessment.
e A coarse estimate in the lack of data; here "humus" refers to the acrotelm and "mineral soil" to the catotelm.
f Except for Class 5 this is a result of the TESM modelling (UNTAMO peat growth model, see section 3.1).
g The range is likely an overestimate, see section 5.2.3.

Table A3-6. *Soil and sediment properties for radionuclide transport modelling. The properties of the top soil in croplands are given in Table A-2 and those of humus and acrotelm in Table A-5 above. For details of the data, see sections 3.3.5 and 4.3.7.*

Soil / sediment type	Bulk density (kg_{dw}/m^3)			Carbon concentration (kg_C/kg_{dw})			Rationale
	Value (mean)	Std	N	Value (mean)	Std	N	
Peat	91[a] (64-148)	16	26	0.51 (0.50-0.54)	0.02	5	Literature on Finnish peat deposits.
Gyttja (recent mud/clay/detritus/gyttja)	150 (36-370)	69	114	0.18 (0.051-0.31)	0.064	114	Finnish lakes (Ilus et al. 1993).
Clay, terrestrialised	1600 (-)	-	1	0.0018 (0.0014-0.0023)	0.0004	4	Density from Forsmark, carbon conc. site data.
in water bodies	270 (160-650)	120	31	0.11 (0.029-0.19)	0.037	31	Finnish lakes (Ilus et al. 1993).
Very fine sand (silt)	(1700-2000)						Density from generic literature on Finnish soils,
Fine sand	(1700-2000)			0.0018 (-)	-	1	carbon concentration from site data.
Sand	1600 (1400-2000)	250	5	0.0048 (0.0013-0.015)	0.0047	7	Various data sources, see sections 3.1 and 3.2.4.
Fine-grained till	1800 (1200-2300)	350	39	0.0020 (0.0007-0.0041)	0.0012	9	Density from Forsmark, carbon conc. site data.
Washed till (coarse-/medium-grained)	1600 (400-2300)	430	105	0.0014 (-)	-	1	Density from Forsmark, carbon conc. site data.

a This is a nominal value for consistency with the peat volume simulated by the UNTAMO tool (sections 3.1 and 3.2.4) - the arithmetic mean of the data is 82.

Table A-7. *Site and regional data for lake objects in radionuclide transport modelling.*

Parameter	Unit	Nominal	Min	Max	Std	Rationale
Net primary production	$kg_C/m^2/y$	0.064[a]	0.037	0.091		Mesotrophic lakes in Finland [b], section 5.2.3.
Biomass of vegetation	kg_{dw}/m^2	0.023	0	0.17		Data from Lake Pyhäjärvi, Finland, scaled to predicted future lakes (section 5.3.4).
Production of vegetation	$kg_{dw}/m^2/y$	0.028	0	0.21		Biomass data scaled by a factor from a lake in the Laxemar-Simpevarp area, Sweden (section 5.3.4).
Concentration of suspended solids	kg_{dw}/m^3	0.004	0.0000	0.044	0.0045	Catchment of Eurajoki River, monitoring data (section 5.3.4).
Concentration of dissolved inorganic carbon	kg/m^3	0.003	c	c		For a lake in southern Finland, section 5.2.3.
Sedimentation rate (gross)	$kg_{dw}/m^2/y$	1.1	0.37	11		Derived from data from Finnish lakes, section 5.2.3.
Resuspension rate	% [d]	73	15	110		Data on few Finnish lakes in section 5.2.3.
Loss rate from vegetation to active sediment	1/y	1	0	1		In the Finnish conditions practically all parts above the bottom are renewed because of the winter; section 5.3.4.

a No direct best estimate or average data available; the nominal value has been taken as the arithmetic mean of the minimum and maximum values.
b Future lakes at Olkiluoto are expected to be mesotrophic. The range of net primary production for all lake types is 0.018-0.37 $kg_C/m^2/y$ (section 5.2.3).
c No data are available on the variation of the DIC concentration, but the concentration of total organic carbon in the same lake has been 0.0075-0.010 kg/m^3 (section 5.2.3).
d % of the gross sedimentation rate.

Table A3-8. *Site and regional data for river objects in radionuclide transport modelling.*

Parameter	Unit	Nominal	Min	Max	Std	Rationale
Net primary production	$kg_C/m^2/y$	0.064	0.037	0.091		Same as for lakes, as in the Swedish assessment as well; see section 5.3.5.
Biomass of vegetation	kg_{dw}/m^2	0.023	0	0.17		
Production of vegetation	$kg_{dw}/m^2/y$	0.029	0	0.21		
Concentration of suspended solids	kg_{dw}/m^3	0.022	0.0005	0.130	0.021	Measured from Eurajoki River (section 5.3.5).
Concentration of dissolved inorganic carbon	kg/m^3	0.0087	0.0025	0.027	0.0028	TOC measurements from Eurajoki River converted to DIC by generic data (section 5.3.7).
Sedimentation rate (gross)	$kg_{dw}/m^2/y$	8.8	0.15	0.65		Estimated from concentration of suspended solids and a settling velocity used in a Swedish radionuclide transport model, see section 5.3.5.
Resuspension rate	$kg_{dw}/m^2/y$	8.8	0.15	0.65		Assumed the same as the gross sedimentation rate, section 5.3.5.
Loss rate from vegetation to active sediment	1/y	1	0	1		Same as for lakes, as in the Swedish assessment as well; see section 5.3.5.

***Table A3-9.** Site and regional data for coastal objects in radionuclide transport modelling.*

Parameter	Unit	Nominal	Min	Max	Std	Rationale
Net primary production	$kg_C/m^2/y$	0.055	0.037	0.083	0.012	Measured from offshore Olkiluoto (section 5.3.7).
Biomass of vegetation	kg_{dw}/m^2	0.027	0.0011 [a]	0.31 [a]		Data for Forsmark area, Sweden (section 5.3.6)
Production of vegetation	$kg_{dw}/m^2/y$	0.180 [b]	0.004 [a]	0.77 [a]		Data for Forsmark area, Sweden (section 5.3.6).
Concentration of suspended solids	kg_{dw}/m^3	0.003	0.0005	0.016	0.0025	Measured from offshore Olkiluoto (section 5.3.6).
Concentration of dissolved inorganic carbon	kg/m^3	0.013	0.0018	0.025	0.0028	Olkiluoto monitoring data scaled with DIC/TOC ratio from Forsmark area, Sweden (section 5.3.6).
Sedimentation rate (gross)	$kg_{dw}/m^2/y$	3.1	1.2[c]	6.7[c]	1.4	Measured from offshore Olkiluoto (section 5.3.6).
Resuspension rate	$kg_{dw}/m^2/y$	1.3				Derived from site data, see section 5.3.6.
Loss rate from vegetation to active sediment	1/y	1	0	1		In the Finnish conditions practically all parts above the bottom are renewed because of the winter; section 5.3.6.

a The range is the variation of best estimates for 28 different basins at Forsmark (and for biomass the nominal value is average over the entire study area).

b Nominal value is the median of the best estimates for 28 basins at Forsmark.

c Range of averages over open-water periods. Shorter collection periods give a larger variation, 0.7-12 $kg_{dw}/m^2/y$ (section 5.3.6).

APPENDIX B: DATA QUALITY SCORING TABLES

In this appendix, the detailed information on the data quality scoring summarised in section 8.2 are provided, together with the scoring table (Table B-1). For the descriptions of the parameters and the data to which these scores are related, see the respective sections of this report.

The tables in this appendix are in the order of:

Table B-1. *Scoring table for Data Quality Indices (applied from Ikonen 2006 and Hjerpe 2006).*

Score	Empirical, statistical and methodological quality [a]	Proxy (parameterisation) [b]	Spatial variability in the scale of the Olkiluoto site	Robustness against time scales and external conditions	Appropriateness for the Olkiluoto site
3	Controlled experiments, direct measurements, historical or field data. Good or better fit to a reliable statistical model by most fitting tests. Best available practise, or reliable method common within established discipline.	An exact or good description / measure of the process	It is *unlikely* that the parameter value is significantly different in the other parts of the site. The variability has been included in the data. Note: the aspect is under-stood by the assessment context	*Unlikely* that the parameter value will be significantly altered over time or due to changes in the external conditions. Note: changes of external conditions are understood by the assessment context	Site-specific, regional or at least likely site-independent data; *very likely* that the data are appropriate.
2	Modelled data, indirect estimates. Acceptable method but with limited consensus on its reliability.	Fairly good but simplified representation of the process, or an aggregate measure with adequate information on conditions	There is a *medium likelihood* that ... The variability has been included in the data but the spatial extent is inconclusive.	*Medium likelihood* that the parameter value will be significantly altered over time or due to changes in the external conditions.	Data from similar sites; *likely* that the data are appropriate.
1	Handbook estimates, indirect approximations. Preliminary methods with assessed reliability.	Very simplified representation / measure of the process, considering only basic properties.	It is *likely* that the parameter value differs. Variability not included in the data.	It is *likely* that the parameter value will be significantly altered ...	Data from other similar sites; *medium likelihood* that the data are appropriate.
0	Educated guesses, rules of thumb, very indirect approximations. Preliminary methods with unknown reliability.	Poor representation of the process, or measurement likely not totally appropriate or likely not bound with relevant conditions.	It is *virtually certain* that the parameter value is significantly different in the areas not covered by site characterisation.	It is *virtually certain* that the parameter value will be significantly altered ...	Data from other sites or data from similar sites; *unlikely* that the data are totally appropriate.

a Applied from (Ellis et al. 2002a, b) and (Jeroen et al. 2002)
b Applied from (Jeroen et al. 2002)

Table B-2. *Data quality evaluation of parameters for terrain and ecosystems development modelling. ESM empirical, statistical and methodological quality; P proxy quality; S spatial variability; R robustness against time and external conditions; A appropriateness to Olkiluoto site; DQI data quality index (mean of scores). Parameters on bold have been identified as key data and were evaluated in (Haapanen et al. 2009a).*

Parameter	ESM	P	S	R	A	DQI	Comment
Initial data							e
Terrain (topographical) model	3	3	3	-	3	3.0	d
Initial top soil type, terrestrial area	2...3	3	2	-	3	2.5...2.8	
Initial top sediment type, sea area	2	2...3	2	-	3	2.3...2.5	
Thickness of overburden	2...3	2...3	1	-	3	2.0...2.5	
Land uplift							
Download factor	2	2	2	3	3	2.4	
Inertia factor	2	2	2	3	3	2.4	
Time scale factor	1	2	3	3	3	2.4	
Runoff formation and river channels							
Effective rainfall constant	1	2	1	1	3	1.6	f
River discharge boundary condition	3	3	3	1	3	2.6	
Shape of river channel (cross-section)	1	2	2...3	2	2	1.8...2.0	
Slope of river banks	1	3	2...3	2	2	2.0...2.2	
Vegetation							
Forest site classification	2	2	2	2	3	2.2	f
Calibration data for reed bed extent	-	2	2	2	3	2.2	(f), g
Peat growth							
Rate of matter passing to catotelm	2	2	2	2	1	1.8	
Decay rate in catotelm	2	2	2	2	1	1.8	
Bulk density of peat in catotelm	3	3	2	2	1	2.2	
Groundwater table prediction function	2	1	2	2	3	2.0	
Groundwater table threshold	0	2	3	2	2	1.8	
Erosion and sedimentation							
Accumulation rate of gyttja	0	1	1	2	3	1.4	
Wind speed distribution	3	3	2	1	3	2.4	a
Critical shear stress of sediment	1	2	3	3	1	2.0	a
Calibration data for sediment load from terrestrial areas	-	2	2	1	3	2.0	a, b, f, g
Soil erodability factor	2	2	3	3	1	2.2	b
Soil erosion type	2	2	3	3	2	2.4	b
Soil bulk density	3	3	2	3	2...3	2.6...2.8	b
Lake sedimentation rate function	1	0	0	2	1	0.8	c
Cropland delineation							
Suitable soil types	3	2	3	2...3	3	2.7	
Required soil thickness	3	3	3	3	3	3.0	
Illustrative housing prediction							
Weighting distributions for permanently inhabited houses	2	1	3	2	3	2.2	
Weighting distributions for holiday houses	2	1	3	2	3	2.2	
Formation criterion for a village centre	2	0	2	2	3	1.8	

a Used in the fetch-based aquatic erosion/sedimentation model, not utilised in the BSA-2009 simulations.
b Used in the terrestrial erosion/sedimentation model, not utilised in the BSA-2009 simulations.
c Used in the simplistic lake sedimentation model, utilised in a specific case in BSA-2009.
d The primary data are direct observations, but the interpolation is made using a best available method (Pohjola et al. 2009).
e For initial data, the robustness against time scales and external conditions is not evaluated due to the nature and use of the data set.
f Re-evaluated from those scores presented in (Haapanen et al. 2009a).
g For calibration data no scoring for *ESM* criteria has been made due to the nature and use of the data.

Table B-3. *Data quality evaluation of parameters for surface and near-surface hydrological modelling. ESM empirical, statistical and methodological quality; P proxy quality; S spatial variability; R robustness against time and external conditions; A appropriateness to Olkiluoto site; DQI data quality index (mean of scores). Parameters on bold have been identified as key data and were evaluated in (Haapanen et al. 2009a).*

Parameter	ESM	P	S	R	A	DQI	Comment
Meteorological variables	**3**	**3**	**2**	**1**	**3**	**2.4**	**a**
Groundwater table	**3**	**3**	**2**	**1**	**3**	**2.4**	
Saturated hydraulic conductivity	**3**	**3**	**3**	**3**	**3**	**3.0**	
Transpiration rate as sap flow data	**3**	**3**	**2**	**3**	**3**	**2.8**	
Calibration data for rain and snow interception	-	**3**	**3**	**3**	**3**	3.0	b
Calibration data for snow and ground frost thickness	-	3	2	3	3	2.8	b
Calibration data for soil temperature	-	3	2	3	3	2.8	b
Calibration data for discharge in main ditches	-	3	0	3	3	2.8	b

a These include precipitation, air temperature, radiation, relative humidity, wind speed.
b For calibration data no scoring for *ESM* criteria has been made due to the nature and use of the data.

Table B-4. *Data quality evaluation of radionuclide transport modelling parameters. ESM empirical, statistical and methodological quality; P proxy quality; S spatial variability; R robustness against time and external conditions; A appropriateness to Olkiluoto site; DQI data quality index (mean of scores). Parameters on bold have been identified as key data and were evaluated in (Haapanen et al. 2009a).*

Parameter	ESM	P	S	R	A	DQI	Comment
Croplands							
Net primary production	3	2	3	2	3	2.6	
Standing biomass	3	3	3	2	3	2.8	
Edible fraction of standing biomass	3	3	3	3	3	3.0	
Production	3	2	3	2	3	2.6	
Edible fraction of production	3	3	3	3	3	3.0	
Annual harvested fraction of biomass	3	3	3	3	3	3.0	
Height of vegetation	3	3	3	2	2	2.6	
Rooting depth	3	3	2	2	2	2.4	
Irrigation amount	**3**	**3**	**3**	**2**	**2**	**2.6**	
Irrigation frequency	**3**	**3**	**3**	**2**	**2**	**2.6**	
Leaf area index	**3**	**3**	**3**	**3**	**2**	**2.8**	
Water storage capacity (irrigation)	2	2	2	2	1	1.8	
Thickness of plough layer	2	3	3	3	3	2.8	
Bulk density of topsoil	2	3	2	3	2	2.4	
Bulk density of deeper soil types	3	3	2	3	2	2.6	
Erosion rate	1	2	2	2	2	1.8	
Bioturbation rate	1	2	1	2	1	1.4	
Forests and wetlands							
Net primary production	**3**	**2**	**2**	**2**	**3**	**2.2**	
Biomass of tree wood	**3**	**3**	**2**	**2**	**3**	**2.6**	
...of tree foliage	**3**	**3**	**2**	**2**	**3**	**2.6**	
...of understorey	**2**	**2**	**2**	**2**	**3**	**2.2**	
...of dead wood	2...3	2	2	2	3	2.2...2.4	
...of litter	3	3	1	2	2	2.2	
Production of tree wood	**2**	**2**	**2**	**2**	**3**	**2.2**	
...of tree foliage	2...3	2	2	2	3	2.1...2.3	
...of understorey	**0...3**	**2**	**2**	**2**	**2...3**	**1.6...2.4**	**a**
Loss rate, tree wood to dead wood	2	2	2	2	2	2.0	
... tree foliage to litter	2	2	2	2	2	2.0	
... understorey to litter	2	2	2	2	2	2.0	

Table B-4 (cont'd). Data quality evaluation of radionuclide transport modelling parameters.

Parameter	ESM	P	S	R	A	DQI	Comment
Fine root biomass fraction, trees	**3**	**3**	**2**	**2**	**3**	**2.6**	
... understorey	**3**	**3**	**2**	**2**	**3**	**2.6**	
Decomposition rate of litter	2	2	2	2	1	1.8	
...of dead wood	2	2	2	2	1	1.8	
...of acrotelm	2	2	2	2	1	1.8	
Thickness of humus layer	3	3	2	2	3	2.6	
Bulk density of humus layer and acrotelm	3	3	3	3	3	3.0	
...of other soil types	3	3	2	3	2...3	2.6...2.8	
Bioturbation rate	3	2	2	2	2	2.2	
Rotation period of trees (harvesting)	2	1	2	2	2	1.8	
Harvested fraction of tree wood	2	3	2	2	2	2.2	
...of tree foliage biomass	2	3	2	2	2	2.2	
Concentration ratios to wood, foliage and understorey (only in regards of site data)							
...for iodine	**3**	**2**	**2**	**3**	**3**	**2.6**	
...for nickel	3	2	2	3	3	2.6	
...for selenium	3	2	2	3	3	2.6	
...for chromium (as analogue of Mo)	3	1...2	2	3	3	2.4...2.6	
Distribution coefficient (Kd) to till	3	2	2	3	2...3	2.4...2.6	
Lakes							
Net primary production	**2**	**2**	**1**	**2**	**2**	**1.8**	
Biomass of aquatic vegetation	2	3	1	2	2	2.0	
Loss rate, vegetation to sediment	0	2	2	2	-	1.5	d
Concentration of suspended solids	3	3	1	2	2	2.2	
Concentration of DIC	**3**	**3**	**1**	**2**	**1**	**2.0**	
Sedimentation rate (gross)	2	3	1...2	2	2	2.0...2.2	**b**
Resuspension rate	2	2	2	2	1	1.8	**b**
Bulk density of sediment types	3	3	2	3	2	2.6	
Rivers							
Net primary production	1	2	1	2	1	1.4	
Biomass of aquatic vegetation	1	3	1	2	1	1.6	
Loss rate, vegetation to sediment	0	2	2	2	-	1.5	d
Concentration of suspended solids	3	3	2	2	3	2.6	
Concentration of DIC	1	2	2	2	1	1.6	e
Sedimentation rate (gross)	2	1	2	2	1	1.6	
Resuspension rate	2	1	2	2	1	1.6	
Bulk density of sediment types	1	3	2	3	1	2.0	
Coastal areas (sea)							
Net primary production	3	2	2	2	3	2.4	
Biomass of aquatic vegetation	2	3	2	2	2	2.2	
Loss rate, vegetation to sediment	0	2	2	2	-	1.5	d
Concentration of suspended solids	3	3	2	2	3	2.6	
Concentration of DIC	1	2	2	2	2	1.8	e
Sedimentation rate (gross)	2	3	1	2	3	2.2	
Resuspension rate	2	2	1	2	3	2.0	
Bulk density of sediment types	1	3	2	3	1	2.0	
C-14 specific parameters							
Wind speed (20 m above ground)	3	3	2	2	3	2.6	
Decomposition rate of exposed sediment	**1**	**1**	**0**	**0**	**0**	**0.4**	
Carbon concentration in soil types	3	3	2	2	3	2.6	c
...in top soil of croplands	2	3	2	2	2	2.2	
...in humus layer and acrotelm	3	3	2	2	3	2.6	

a Varies: some data are very site-specific, some other from similar sites or even estimated values.
b The net sedimentation rate was identified as key parameter and was evaluated in (Haapanen et al. 2009a) to have a DQI of 2.0. Here the evaluation has been done separately for the gross sedimentation and resuspension rates, see section 5.
c Soil types in general, excluding those listed separately.
d Appropriateness to Olkiluoto not logical to be evaluated as the data are very low in *ESM* quality.
e Appropriateness to Olkiluoto results from the estimation method.

Table B-5. *Data quality evaluation of parameters for modelling of doses to humans. ESM empirical, statistical and methodological quality; P proxy quality; S spatial variability; R robustness against time and external conditions; A appropriateness to Olkiluoto site; DQI data quality index (mean of scores). Parameters on bold have been identified as key data and were evaluated in (Haapanen et al. 2009a). Exposure parameters have been omitted since they are closely tied to the dose assessment scenario applied in each case.*

Parameter	ESM	P	S	R	A	DQI	Comment
Carbon concentration in edibles	3	3	3	3	3	3.0	a
Productivity of edibles							
forest berries	**1...2**	**3**	**2**	**3**	**1**	**2.0...2.2**	**b**
forest mushrooms	**1**	**3**	**2**	**3**	**1**	**2.0**	
forest game	**2**	**2**	**2**	**3**	**3**	**2.4**	
croplands	**3**	**3**	**3**	**3**	**3**	**3.0**	
lakes	**2**	**3**	**2**	**2**	**1**	**2.0**	
rivers	**1**	**3**	**2**	**2**	**1**	**1.8**	
coastal area	**2**	**3**	**2**	**2**	**1**	**2.0**	
Concentration ratios to edibles (in regards of the site data only)							
berries, for iodine	**2**	**2**	**2**	**3**	**3**	**2.4**	
...for nickel	3	1...2	2	3	3	2.4...2.6	
...for selenium	3	1...2	2	3	3	2.4...2.6	
...for chromium (as analogue of Mo)	3	1	2	3	3	2.4	

a Concentration of nutritionally available carbon as calculated by Eq. 6-1.
b Varies: some data are very site-specific, some other from similar sites or even estimated values.

Table B-6. *Data quality evaluation of parameters for modelling of doses to other biota. ESM empirical, statistical and methodological quality; P proxy quality; S spatial variability; R robustness against time and external conditions; A appropriateness to Olkiluoto site; DQI data quality index (mean of scores). Parameters on bold have been identified as key data and were evaluated in (Haapanen et al. 2009a).*

Parameter	ESM	P	S	R	A	DQI	Comment
Geometry							
Size of a tree	3	2	3	2	3	2.6	b
Size of other terrestrial plants	3	1	2	2	2	2.0	b
Size of terrestrial and avian fauna	**3**	2	**3**	**3**	**2**	**2.8**	c
Size of phytoplankton	3	3	3	2	3	2.8	b
Size of other aquatic species	3	1...2	2	2...3	2	2.0...2.5	b
Weights							
Weight of a tree	2...3	3	3	2	3	2.5...3.0	b
Weights of other terrestrial plants	3	3	2	2	2	2.4	b
Weights of terrestrial and avian fauna	**3**	**3**	**3**	**3**	**2**	**2.8**	
Weights of aquatic fauna	3	3	2	3	2	2.6	a

a Only those data that are available (Tables 7-2 and 7-3).
b Parameters have been regrouped and re-evaluated from those presented in (Haapanen et al. 2009a).
c Re-evaluated from (Haapanen et al. 2009a) considering the shape of the conceptualised animal (proxy score).

APPENDIX C: LIFE HISTORIES OF TERRESTRIAL AND AVIAN FAUNA

In this appendix, life histories of selected species of terrestrial and avian fauna are described to support the development of ecological and terrain and ecosystems development modelling and dose assessement for flora and fauna. At present, aquatic biota have not been included The terrestrial and avian example species were selected using a food web analysis (see see section 4.1.6 and pages 258-264 of Haapanen et al. 2010a). Their life histories are presented below in the order of:

- carnivorous mammal: American mink
- carnivorous bird: Tawny owl
- insectivorous bird: Willow warbler
- carnivorous reptile: Adder
- carnivorous invertebrate: Carabid beetle
- (large) herbivorous mammal: Moose
- (medium-sized) herbivorous mammal: Mountain hare
- (small) herbivorous mammal: Bank vole
- herbivorous bird: Hazel grouse
- herbivorous invertebrate: Ringlet
- omnivorous mammal: Raccoon dog
- omnivorous mammal: Red fox
- omnivorous bird: Hooded crow
- omnivorous amphibian: Common frog
- omnivorous invertebrate: Ant
- detrivore: Ant

Carnivorous mammal: American mink

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Mammalia*
Order	*Carnivora*
Family	*Mustelidae*
Genus	*Mustela*
Species	*M. vison*

General habits, habitat and home range

American mink is a semi-aquatic predator. It lives in the vicinity of rivers, streams, lakes and other water elements with thick herbaceous vegetation along the banks. Also found by the seaside and in the archipelago. It digs burrows in the banks of rivers and other water bodies or may utilise old dens of other mammals, such as Muskrats. A skilled swimmer and climber, it can swim up to 30 m underwater and dive to depths of 5 m. In Olkiluoto the most suitable habitat is in the middle parts of the island. Some acceptable habitats are also in the western and northern parts of the island. American mink is mostly active at night, especially near dawn and dusk.

Home range is ca. 1.5-6 km of shoreline or on average 8-20 ha for females and up to 800 ha for males. If the population density is high, male natal dispersal may be tens of kilometres in a few days or a week. American mink is primarily a solitary animal, males being particularly intolerant of one another.

Dietary habits and main prey species

American mink is a true predator, which uses only prey it has caught by itself and very little carrion or plant matter. The diet varies a lot according to the season and the environment – in winter mainly fish, in summer mammals (almost all small rodents except shrews and European moles), birds (mainly ducks and seagulls; bird chicks in spring), crayfish and frogs, and also some insects - depending on what is available. Males seem to hunt on dry land more than females. American mink kills often more than it can eat, and stores the food. It finds a lot of food from the seashore, which in Olkiluoto is mainly open also in the winter as the nuclear power plant heats up the sea water.

Life cycle and reproduction

Mating happens during February-April, after which the development of the embryo is delayed for approximately 13-50 days. After a 28-30 day gestation, the young (on average 4-6) are born in April-May. The young stay together until the end of the summer, after which they disperse. A population of American mink has a relatively fast turnover time: it has been estimated that all individuals of a population are replaced every 3 years.

Sources of information

Faunatica Oy 2008a; Bjärvall & Ullström 2003; Haapanen 2007; Hammershoj et al. 2004; Jussila & Nieminen 2008; Lokki et al. 1997; Oja & Oja 2006.

Carnivorous bird: Tawny owl

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Aves*
Order	*Strigiformes*
Family	*Strigidae*
Genus	*Strix*
Species	*S. aluco*

General habits, habitat and home range

Tawny owl is a sedentary and nocturnal predatory bird. It nests in forests, forest patches surrounded by farmland and large parks which have old deciduous trees, especially oaks which have holes for nesting, also in forests on lakeshores. It is often found near housing. Tawny owl spends daytime in thick spruces. Young individuals can disperse large distances, but once they start nesting, they stay in the same area.

Dietary habits and main prey species

Tawny owl's diet is very broad resulting from the sedentary lifestyle. Diet consists of small rodents (voles, mice and rats, also shrews), birds (mostly chicks), earthworms, frogs, common lizards and insects such as beetles. Sometimes also catches frogs, common lizards, insects and earthworms. Daily food intake is 44-75 g, with the higher value being counted for winter.

Table C-1. *Tawny owl's diet composition in Norway (Overskaug et al 1995).*

	Male	Female
Small mammals	897 g (22.93%)	1710 g (43.73%)
Birds	502 g (12.83%)	683 g (17.45%)
Amphibians	10 g (0.26%)	0 g (0%)
Invertebrates	12 g (0.31%)	98 g (2.49%)

Table C-2: *Tawny owl's diet composition in Poland (urban and suburban areas), biomass-%; invertebrates: numbers of individuals; not included in biomass calculations (Zalewski 1994).*

	Urban	Suburban
Anura (frogs)	2.4%	36.1%
Aves (birds)	68.2%	12.9%
Mammals	29.4%	51.0%
Invertebrates	37 ind.	21 ind.

Life cycle and reproduction

The nest is in a treehole or a nest-box. The female lays 2-6 eggs in the end of March or in April. Incubation is 28-30 days, and it starts after the first egg is laid, so chicks from the earlier eggs are ahead of the chicks from later eggs in their ontogenetic stage. The chicks fledge at the age of 25-30 days, before they are able to fly. The parents take care of the chicks up to the age of three months. May reproduce already at the age of one year, however usually starts reproduction at a later age.

Sources of information

Lokki & Palmgren 1990; Mullarney 1999; Overskaug et al. 1995; Yrjölä 2008; Zalewski 1994

Insectivorous bird: Willow warbler

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Aves*
Order	*Passeriformes*
Family	*Phylloscopidae*
Genus	*Phylloscopus*
Species	*P. trochilus*

General habits, habitat and home range

Willow warbler is the most common bird species in Finland. It is found in many types of habitats - it can be seen or heard nearly everywhere: all kinds of forest, lush parklands and gardens, birch and willow thickets on fields. It nests mostly deciduous and mixed forests, but also in nearly pure coniferous forests and open bush areas, even in juniper stands. The home range is usually ca. 0.2-0.5 ha but varies e.g. in Northern Europe from ca. 0.09 to 1.5 ha, with the larger home range sizes reported from harsh environments. Willow warbler is migratory in Finland, present from May to mid-September.

Dietary habits and main prey species

The main diet of Willow warbler consists of insects (mainly dipterans) and spiders. In the autumn it may also eat berries. According to a study done in Poland (Krupa 2004), nestlings were fed with *Arthropoda* (94.6%) and *Mollusca* (5.4%) - within the main groups the dominant food items were *Diptera* (29.8%), *Homoptera* (28.7%), *Ephemeroptera* (10.5%), *Araneida* (7.6%) and *Trichoptera* (6.5%).

Life cycle and reproduction

Willow warbler builds its nest on the ground, often in the shelter of thick vegetation. The nest is bowl-shaped with a roof and an entrance hole on the side. It is built with dry grass and moss, and lined with feathers. Eggs (usually 6-7) are laid in the end of May or early June. The female incubates for 11-15 days. Both parents feed the nestlings. The chicks fledge at the age of 12-15 days. In Southern Finland, Willow warblers have two broods per year.

Sources of information

Krupa 2004; Lokki & Palmgren 1990; Mullarney 1999; Yrjölä 2008.

Carnivorous reptile/amphibian: Adder

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Reptilia*
Order	*Squamata*
Family	*Viperidae*
Genus	*Vipera*
Species	*V. berus*

General habits, habitat and home range

As an ectothermic species, Adder requires sunlight to maintain its body temperature. Suitable habitats for Adder must thus include a mosaic of open patches where the sun reaches the ground. The culture landscape with a combination of grazed and cultivated areas, ditches, stone walls, bushes and base rocks offers these optimal conditions. Adder is often found on rocky hillsides, meadows, forest edges and clearings, bushy slopes, coastal dunes and stone quarries. It may also inhabit damp areas like swamps and may be encountered on the banks of streams, lakes and ponds. It hides under rocks, under tree roots, in mouse or shrew burrows etc. Adder hibernates a large part of the year – in Northern Finland ca. 9 months; in Southern Finland it comes out from hibernation in March – mid-April. There are historic notes of Adders gathering in large numbers into wintering nests; in recent years, there have been no records of large wintering nests.

Dietary habits and main prey species

The main diet of Adder consists of small mammals and reptiles. Newborn juveniles also eat insects (e.g. grasshoppers), but turn into vertebrate diet as they mature. Young individuals eat especially Common lizards (*Zootoca vivipara*). As they grow, they start using larger prey items, such as small rodents, bird chicks, frogs and also Smooth newts (*Triturus vulgaris*). Farming normally increases the density of rodents, which is the main food for the Adder. After a farm has closed down, there is a period during early succession when meadows produce high numbers of rodents, which also may result in extreme densities of adders (up to 4 per hectare). When bushes and trees start to cover the ground, the adder population again decreases as a result of lower prey density. Average daily food intake is 0.9 mg_{dw}/d, or 330 g_{dw}/y.

Life cycle and reproduction

Mating takes place in spring after the Adders have awakened from hibernation. The female gives birth to ca. 10 or fewer young in August or September. In warm summers the young are born earlier and have thus more time to gather reserve nutrition for the winter. In Finland the females reproduce only every other year.

Sources of information

Andrén 2004; Kivirikko 1940; Lindborg 2005; Lokki et al. 1998a; Nieminen & Saarikivi 2008.

Carnivorous invertebrate: Carabid beetles

Kingdom	*Animalia*
Phylum	*Arthropoda*
Class	*Insecta*
Order	*Coleoptera*
Family	*Carabidae*
Several genera and species	

General habits, habitat and home range

Globally Carabid beetles form one of the most species-rich beetle groups. Some 40 000 species have been described; of these, about 300 are found in Finland. In studies done in Olkiluoto, a total of 32-33 species of Carabid beetles have been identified, the most numerous of these being *Pterostichus cupreus, Patrobus atrorufus, Carabus hortensis, Calathus micropterus* and *Pterostichus niger*. Carabid beetles are mostly dark, long-legged predatory beetles. Their length varies from 2 mm to 3 cm, and the weight of a midsized (1 cm) species, *Pterostichus cupreus* is ca. 77 mg. Among Carabid beetles there are both species that are able to fly and those that are not; generally speaking the largest ones are less likely to be able to fly. Some species hunt during the day, but most are nocturnal. Carabid beetles are found in nearly all types of habitats, and are most numerous in open areas such as meadows, farmlands, and lush forests. Unproductive coniferous forests are less suitable habitats for Carabid beetles. Population densities can reach tens of individuals per m^2.

Dietary habits and main prey species

Carabid beetles are mainly predatory; they hunt small animals in the field layer. Their diet consists of other insects, maggots, worms and snails. Some species also eat plant material. In a laboratory study done on *Pterostichus cupreus*, the species was fed daily 1-4 mg maggots, with 2 mg being the “medium” diet. In another laboratory experiment, a feeding regime of 9 mg fresh maggots a day (10-15 % of body mass) was seen to guarantee ad libitum feeding for *P. cupreus*. Daily food intake in the field for the species could thus be estimated to be below this level.

Life cycle and reproduction

Carabid beetles overwinter as either adults or larvae depending on the species; for several species both adults and larvae overwinter. *Pterostichus cupreus* overwinters as adults. Reproductive period in central and northern parts of Sweden is from May to July. Oviposition rates of ca. 0.45 eggs/d were recorded in a study in Sweden. The larvae develop in the field during the summer and new adults (tenerals) emerge in late August, enter diapause in late September and hibernate until the next spring. Consequently, the species has two activity periods as an adult: one in the fall as a newly hatched adult and a longer period in the next spring and summer. The life span of an individual is usually 2-3 years.

Sources of information

Bommarco 1997, 1998; Kurtto 1987; Lokki et al 1998b; Mundy et al. 2000; Santaharju et al. 2009.

Herbivorous mammal (large): Moose

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Mammalia*
Order	*Artiodactyla*
Family	*Cervidae*
Genus	*Alces*
Species	*A. alces*

General habits, habitat and home range

The original habitat of Moose is northern coniferous forest, but the species adapts to almost any type of forest habitat. It is found in boreal coniferous and mixed deciduous forests, and prefers continuously forested areas and relatively young forests. Moose forages in open areas such as fields, and is often found in spring and summer in open habitats such as mires, or areas with young deciduous trees around woodland glades and clearings. In autumn it is found in mature forests and in early winter along forest streams and rivers. It prefers pine seedlings and young birch in winter but also mature forests with lighter snow cover. In Olkiluoto most suitable habitat is in the northern parts of the island, several acceptable habitats also exist in other parts of the island.

Moose are solitary animals, although two individuals sometimes can be found feeding in the same area. The strongest social bond is between the mother and the calf. In Finland Moose sometimes gather in the winter in groups consisting of 20-40 individuals. In a Swedish study, home ranges were slightly over 1000 ha in winter, in summer they were notably larger. Average home range is 5 to 10 km^2; in Olkiluoto the home ranges are much smaller and overlap widely.

Moose mainly stay in the same general area, though young males move quite a lot, from distances of a few to hundreds of kilometres. Some populations also migrate between sites favourable at different times of the year. These migrations can exceed 300 km in European populations. In patchy landscapes Moose are more sedentary. In Finland some Moose populations migrate from coastal area to inland. Moose of the Rauma archipelago use Olkiluoto as a passage to wintering areas on the mainland. Sedentary individuals have overlapping summer and winter home ranges; the summer and winter home ranges of dispersing individuals do not overlap. In Satakunta the mean density after the hunt in 2007 was 2.6-3.0 individuals/1000 ha and in Southwestern Satakunta Province 5.9 individuals/1000 ha.

Dietary habits and main prey species

The summer diet of Moose is wide, and it uses almost any available plant material: leaves, needles, twigs and buds of trees (pine, birch, aspen, willow, rowan) and shrubs (blueberry, lingonberry, heather), sprouts of cereals, grains and some aquatic and terrestrial herbaceous plants (e.g. water lilies, grasses, fireweed). In winter it feeds on twigs and buds of trees and shrubs, bark and buds of pine and aspen, pine needles, juniper and lichens. Spruce and alder are consumed only when little else is available. Even though Moose has a wide diet, it is choosy with food and chooses individual plants with specific chemical composition (toxins, nutrients, energy content).

Adult Moose can eat daily up to 50 kg in summertime due to the high water content of the food. Daily food intake in winter is 10-20 kg. Only 30-40 % (dry weight) of winter food is digested.

Table C-3. *Moose diet composition at Grimsö in Sweden, summary of monthly statistics over a year (Cederlund et al. 1980).*

	Percent dry weight		
	minimum	maximum	mean
Trees and shrubs	37.5	87	58.8
Dwarf-shrubs	2	41.1	17.6
Forbs	0	17.4	5.8
Grasses, sedges, rushes	0	5.3	1.9
Mosses and lichens	0	0.1	0.0
Ferns, lycopods, horsetails	0	5.2	1.2
Undetermined remainder	4.7	22.7	14.4
Other	0	2.4	1.0
Fungi	0	0.6	0.1

Table C-4. *Values of model parameters related to fauna characteristics (Avila 2006).*

Parameter	Unit	Nominal	Min	Max	Comments
Fraction of tree wood in the diet of moose (αLi)	%	1.6	0.7	2.4	(1) (3)
Fraction of tree wood in the diet of roe deer (αLi)	%	0.9	0.3	1	(2) (3)
Fraction of tree leaves in the diet of moose (αL)	%	54	38	55	(1) (3)
Fraction of tree leaves in the diet of roe deer (αL)	%	8.4	3.2	17.6	(2) (3)
Fraction of understorey plants in the diet of moose (αU)	%	43.5	28	47	(1) (3)
Fraction of understorey plants in the diet of roe deer (αU)	%	77	45	94	(2) (3)
Fraction of mushrooms in the diet of moose (αM)	%	0.9	0.25	1.1	(3) (4)
Fraction of mushrooms in the diet of roe deer (αM)	%	13.7	4.5	20	(3) (4)
Body weight of a moose (WH)	kg_{fw}	279	260	296	(5)
Body weight of a roe deer (WH)	kg_{fw}	21.3	18.6	24	(6)

(1) Based on values reported in (Cerderlund et al. 1980) for August, September and October.
(2) Based on values reported in (Cerderlund et al. 1980) for July, August and October.
(3) Nominal values were obtained by normalising the average values in the corresponding period by the sum of the contribution from all diet components.
(4) Based in values reported in (Avila 1998) and (Avila et al. 1999).
(5) Based in values reported for the Forsmark area in (Lindborg & Kautsky 2004).
(6) Based in values reported in (Lindborg & Kautsky 2004). The maximum relates to adults and the minimum to calves.

Table C-5. *Proportion of diets in moose in Scandinavia (Mysterud 2000 cited by Truvé & Cederlund 2005).*

	Winter	Summer
Gramonoids	0.8	5.0
Herbs	0.1	25.8
Low shrubs	6.5	12.9
Ferns/lycopods/horsetails	0.0	1.6
Deciduous browse	49.7	42.6
Coniferous trees	36.6	4.4
Lichens	0.5	0.0
Mosses	0.0	0.0
Other	5.9	7.7

Life cycle and reproduction

Moose's oestrus is in September-October. Fawns (usually two) are born in the spring after a gestation period of approximately 235 days. A young cow usually gives birth to only one fawn, and triplets are very rare, quadruplets extremely rare. A cow can give birth up to the age of ca. 20 years. A newborn fawn weighs about 10 kg, and doubles its weight in a month. After this it can gain over 1 kg/d, and by the turn of August-September it weighs 85-90 kg. The fawns follow the mother a year and are weaned 10-15 days before the next fawns are born. The average life span of Moose is approximately 20 years.

Sources of information

Avila 2006; Bjärvall & Ullström 2003; Brown et al 2003b; Cederlund et al. 1980; Haapanen 2007; Jussila & Nieminen 2008; Kivirikko 1940; Lokki et al 1997; Mysterud 2000; Oja & Oja 2006; Ranta et al. 2005; Truvé & Cederlund 2005;

Herbivorous mammal (medium-sized): Mountain hare

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Mammalia*
Order	*Lagomorpha*
Family	*Leporidae*
Genus	*Lepus*
Species	*L. timidus*

General habits, habitat and home range

Mountain hare is found in different habitats but it prefers forests and woodland glades, clearing, copses and field thickets. Young commercial forests and thickets provide a good food source. In Olkiluoto the most suitable habitat is in the northern parts of the island. A lot of acceptable habitats are also in other parts of the island. Mountain hare is active mainly in the evening and at night, but during the breeding season it becomes more active during the day. It tends to rest during the day in forms, scrapes or burrows in the snow or soil. At night it can move in forest areas ca. 4 km per night. It is also a strong swimmer.

The average home range is reported to be from 2 to over 10 ha. However, in a study in Finland, mean yearly home range size in boreal forests was 206 ha, being largest in late winter-spring (mean 202 ha) and smallest in autumn (mean 71 ha). According to the study, home ranges were rather stationary, and only minor shifts in home range locations occurred between seasons. The hares used, however, partly different core areas in different seasons. Although Mountain hare is typically a solitary species, occasionally small groups of up to 10 individuals may gather to feed.

Food

Mountain hare eats a variety of plant material. In summer the diet consists mainly of young heather, grasses, clovers, vetches, sprouts of oat, leaves of willow and aspen, shrubs (blackberry), thin (<7mm) branches and bark of deciduous trees (Goat willow *Salix caprea* and other willow species, aspen, rowan and birch). Especially important are protein-rich buds of birch. Also reed, sedge, twigs (bilberry *Vaccinium myrtillus*, bog bilberry *Vaccinium uliginosum*) and year-old pine buds are eaten. In winter the diet consists mainly of shoots and bark of young trees (birch, aspen, willow, rowan, juniper), but twigs are preferred when available. In winter because of the high content of woody material in the diet Mountain hare eats its own faeces in order to use all available nutrients in the diet: coarse material from diet moves quickly through the intestine to the elongated appendix, where it is broken down to a more digestable form and then defecated as pellets. The hare eats these pellets, which allows the nutrients to be digested as the food travels a second time through the intestine. Daily food intake in wintertime is about 0.5 kg, and defecation rate is ca. 400 pellets a day.

Life cycle and reproduction

Mountain hare's oestrus begins in March. Gestation is ca. 50 days, and the young (normally 2-5 per female, in some cases even 8) are born with fur and with their eyes open. The female mates again in a few days, even only a few hours after giving birth. The female can have two, sometimes even three litters per year. The young nurse only once a day and for just a few minutes a time. They start eating plant matter at the age of a few days and can forage independently in about a week.

Sources of information

Bjärvall & Ullström 2003; Hulbert & Andersen 2001; Haapanen 2007; Jussila & Nieminen 2008; Kauhala et al. 2005; Kivirikko 1940; Kurtto et al. 1987; Lokki et al 1997; Oja & Oja 2006; Pulliainen & Tunkkari 1987; Truvé & Cederlund 2005.

Herbivorous mammal (small): Bank vole

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Mammalia*
Order	*Rodentia*
Family	*Muridae*
Genus	*Clethrionomys*
Species	*C. glareolus*

General habits, habitat and home range

Bank vole lives mostly in different types of forests (both deciduous and coniferous) and bush-dominated areas including semi-open pastures, field edges and parks. It prefers dense undergrowth and therefore often younger forests. In thick bushes it can also be found far from forests. Highest abundances among coniferous forests are found in 6-30 year old stands. Home range varies 300-7000 m^2 depending on e.g. population density and habitat type. Population density is usually 10-80 individuals/ha in habitats suitable for breeding.

Dietary habits and main prey species

Bank vole is almost purely herbivorous: it eats herbs, grasses, seeds, fruits, berries, nuts, moss, roots, mushrooms, and leaves and bark of trees, but occasionally also insects and other small invertebrates. In spring and summer up to 60 % of diet may consist of green plant parts. As a skilled climber Bank vole, seems to prefer tree leaves over grasses. It also likes nuts: when nuts are abundant, it stores them underground, in tree holes or in nest boxes. In a feeding experiment, food intake of wild-caught Bank voles was 1,8 g per night (10-12 h) in laboratory conditions, and the food choice was as follows: spruce seeds 57 %, barley 12 %, animal-based food (fish pellets + insect larvae) 15 %. In two other laboratory experiments average daily (24h) food intake rates were 3.5 g and 2.82 g for wild-caught individuals.

Life cycle and reproduction

The reproductive period is usually from April to September-October, but when food is readily available, it can extend even over the turn of the year. The female becomes sexually mature at the age of one month, the male not before the age of 2 months. If population density becomes too high, reproduction may be suppressed. Gestation is usually ca. 3 weeks, and the number of young varies from 1 to 10. Gestation can however be as short as 17 days if food is abundant or as long as 24 days if the female mates directly after the previous litter is born and is therefore pregnant during lactation. The nest is lined with mosses, leaves and feathers and is usually underground, sometimes also in tussocks or in thick bushes. The life span of voles is between 1-3 years, generally less than 2 years.

Sources of information

Bjärvall & Ullström 2003; Brown et al. 2003a; Eccard & Ylönen 2006; Nieminen & Saarikivi 2008; Peacock & Speakman 2001; Shore et al. 1995.

Herbivorous bird: Hazel grouse

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Aves*
Order	*Galliformes*
Family	*Tetraonidae*
Genus	*Tetrastes*
Species	*T. bonasia* (aka. *Bonasa bonasia*)

General habits, habitat and home range

Hazel grouse nests in thick coniferous and mixed forests, but is rarely found in deciduous forests. It prefers dense, damp, mixed coniferous forests with spruce and some deciduous trees and dense undergrowth, and also forests along deciduous swamps, bogs and streams. It prefers glens of streams and shore areas of lakes and the sea where alder is abundant. In winter it spends nights in thick spruces. It spends a lot of time on the ground, but also runs on tree branches and sits high in trees. In Southern Finland the density is on average 2 nesting pairs per km^2 in spruce forests and 4 pairs/km^2 in mixed forests.

Dietary habits and main prey species

Hazel grouse is herbivorous, but chicks eat also insects. It feeds mostly on the ground. The diet of an adult consists of catkins, seeds and buds, and leaves and shoots of herbaceous plants and shrubs, berries etc. In winter the diet consists of buds and catkins, mainly from alder and birch. Daily food intake is 27-58 g, depending on the time of year.

Life cycle and reproduction

The nest is a shallow dent on the ground, surrounded by grass, twigs and leaves and always well hidden under trees or bushes. The female lays 7-11 eggs and incubates them for 25 days. Within 2 days of hatching the young leave the nest and the female takes care of them on her own. The chicks are able to fly short distances at the age of only a few days, and are fully able to fly in a little over a month. The brood stays together until the autumn, when the young disperse and the old male reclaims its territory. The yearly mortality of adults is ca. 65 %.

Sources of information

Jussila & Nieminen 2008; Lokki & Palmgren 1990; Mullarney 1999; Oja & Oja 2006; www.jagareforbundet.se

Herbivorous invertebrate: Ringlet

Kingdom	*Animalia*
Phylum	*Arthropoda*
Class	*Insecta*
Order	*Lepidoptera*
Family	*Nymphalidae*
Genus	*Aphantopus*
Species	*A. hyperatus*

General habits, habitat and home range

Ringlet is the most common butterfly of Finland. It is found on meadows, forest clearings and clear-cut areas grown over with grass. It is diurnal, and flies also during cloudy days more often than other diurnal butterflies, and can be startled to flight also at night. Adults are active from late June to early August. Ringlet overwinters as larvae.

Dietary habits and main prey species

Adults feed mainly on nectar from flowers, especially *Rubus* spp. and thistles *Cirsium* spp. Maggots eat grasses such as *Poa* spp., *Milium* spp., *Calamagrostis* spp., *Dactylis* spp., *Elytrigia* spp., *Holcus* spp., *Anthoxantum* spp., and also *Carex* spp.

Life cycle and reproduction

Larvae form pupae in mid-June; these develop into adults in early July. Adults are active and reproduce from late June to early August. The second instar larvae (ca. 25 mm) overwinter and resume growth in spring.

Sources of information

Laine 2000; Kurtto 1987; Ukkola 2007; www.rusinsects.com/satyrid/s-ap-hyp.htm; www.habitats.org.uk/moths/; www.butterfly-conservation.org; www.toyen.uio.no/norlep/nymphalidae/hyperantus.html

Omnivorous mammal: Raccoon dog

Kingdom	Animalia
Phylum	*Chordata*
Class	*Mammalia*
Order	*Carnivora*
Family	*Canidae*
Genus	*Nyctereutes*
Species	*N. procyonoides*

General habits, habitat and home range

Raccoon dog is found in broadleaved and mixed woodlands intersected by streams and other water elements, scrubby and cultivated areas. It prefers to forage in woodland with an abundant understorey, especially of ferns. Raccoon dog is often found near water and shores, and if threatened, it escapes to water. In Olkiluoto the most suitable habitat is in the western parts of the island. Some acceptable habitats also occur in other parts of the island.

Raccoon dog hibernates (though for a relatively short period, from November to February-March in Southern Finland) in a fox- or badger-made burrow or in burrow it has dug itself. It can sometimes move about in winter.

Raccon dog is mostly nocturnal. Individuals spend most of the night searching for food; they begin to forage within two hours of sunset, break about midnight, and are active again until sunrise.

Male and female share a home range with a core area of 3-4 km^2; total home range can be up to 10 km^2. Especially during the reproductive period, home ranges of different individuals do not overlap, but may do so during autumn especially when food availability is high. Especially juveniles disperse heavily during autumn. In a case study in Virolahti, eastern Finland, home range was 2.6 km^2 on average and density 0.77 individuals/ km^2. In Satakunta the mean density was 0.60-0.69 ind./km^2 in spring 2007. The dispersal distances of young females were 14 km and of young males 19 km.

Food

Raccoon dog has a wide diet (Table C-6, and the composition of the diet varies with varying seasonal availability of food types. The diet includes small mammals (also shrews), but also insects (e.g. beetles), larvae, and earthworms. Berries, fruits and grains are prominent in the diet in autumn. Birds and bird eggs are eaten when available, also aquatic (marine) organisms including fish, and reptiles and amphibians, carrion and waste of foodstuff. Raccoon dogs can also scavenge food from bins and gardens. Gallinaceous birds and ducks are rarely eaten.

Table C-6. *Diet composition of raccoon dog (Lokki et al 1997).*

	%
Voles, mice, shrews	40
Plants	15
Invertebrates	10
Fish, carrion	8
Frogs, lizards	10
Birds, eggs	9
Hares	5
Water vole, muskrat	3

Life cycle and reproduction

Oestrus is in February-March. The young are born after a two-month gestation usually in late May, but can be born as early as in April or as late as in late June. The litter size varies somewhat according to vole densities: in years with low vole densities it can be 8 and in good years it can be 10, even litters of 16 cubs have been recorded in Finland. In Southern Finland the litter size is 9, on average. Both parents take part in rearing the young: one stays in the den while the other is foraging. The den is abandoned as the cubs are about 1.5 months old, and the family moves to a meadow, mire or field nearby; a thick undergrowth providing shelter for the cubs is important. The cubs disperse in August-September. If food is abundant in the summer and autumn, the cubs are able to survive the winter in good health and can reproduce the following winter. Sexual maturity is thus reached at the age of 10 months.

Sources of information

Bjärvall & Ullström 2003; Haapanen 2007; Jussila & Nieminen 2008; Lokki et al 1997; Oja & Oja 2006.

Omnivorous mammal: Red fox

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Mammalia*
Order	*Carnivora*
Family	*Canidae*
Genus	*Vulpes*
Species	*V. vulpes*

General habits, habitat and home range

Red fox is a habitat generalist, and is found mainly in forests, copses and field thickets, often in places with rock cavities and sandy ground. It can live in cultivated areas and near developments. In Olkiluoto the most suitable habitat is in the northern parts of the island. Several acceptable habitats also exist in other parts of the island.

Red fox is either nocturnal or crepuscular. It is mainly a solitary animal and does not form large packs. Ranges are occupied by an adult male and one or two adult females with their associated young. The size of the home range varies depending on the location (e.g. how easy it is to defend the area) and food availability. In good habitats the home range is 5-12 km², in poor ones 12-50 km². Population density varies greatly depending on the environment – in landscapes with patchy forests and meadows, it can be up to 1 pair/km², but in unproductive habitats the density may be $^{1}/_{40}$ of that. In a case study in Virolahti the home range was 5.7 km² on average and density 0.44 individuals/km². In Satakunta the mean density was 0.50-0.59 individuals/km² in spring

2007. During some parts of the year, adjacent ranges may overlap somewhat, but parts may be regularly defended, as Red fox is at least partly territorial. In Olkiluoto area home ranges probably overlap widely and foxes move freely to and from inland.

Individuals and family groups have main earthen dens and often emergency burrows in the home range (often badger dens that have been taken over). Larger dens may be dug and used during the winter and rearing of the young. Pathways connect the main den with other dens, favorite hunting grounds and food storage areas. However, Red fox does not spend as much time in caves as e.g. Badger, and lives there mainly during the reproductive period – i.e. it spends underground in total ca. 10% of its time.

In the autumn following the birth, the pups of the litter will disperse to their own territories. Especially young males disperse away from their natal area; dispersal distances of up to 400 km have been recorded. The dispersal distances of young females have been recorded to be 21 km in a case study in Finland and of young males 29 km. Animals remain in the same home range for life.

Food

Red fox is mainly carnivorous, but berries and fruit are abundant in the diet in autumn. The main diet consists mostly of various vertebrates, especially rodents (Water vole and Muskrat especially, also other voles and mice; prefers voles over mice and Microtus voles especially) and hares, but also insects, mollusks, berries and fruits. Birds and eggs of ground-nesting birds are eaten when available. Red fox can also catch bigger animals, even roe deer fawn, especially when vole densities are low. Sometimes it feeds also on carrion (e.g. in harsh winters carrion of deer that have starved to death) and waste of foodstuff (e.g. surplus of butcheries and fisheries). Daily food intake is between 0.5-1 kg fresh weight.

Life cycle and reproduction

Mating takes place in January-February. After a gestation period of ca. 52 days the young are born during March-May. During cold and snowy winters and in the northern parts of the range reproduction happens later in the spring. If food is scarce, Red fox may not reproduce, and the amount of food available regulates the numbers of young. The average litter size is four, but it can vary 1-9. Newborn cubs weigh ca. 100 g. The young stay near the den until the end of the summer, and within their parents' home range for some months after that, dispersing in the late autumn. Mortality during the first year is high; in some areas even 80%. The average life expectancy is between 3 to 6 years.

Sources of information

Bjärvall & Ullström 2003; Brown et al. 2003a, 2003b; Haapanen 2007; Jussila & Nieminen 2008; Kauhala et al. 1998; Kivirikko 1940; Lokki et al. 1997; Oja & Oja 2006; Truvé & Cederlund 2005.

Table C-7. *Diet composition of Red fox (Lokki et al. 1997).*

	%
Voles, mice, shrews	15
Plants	4
Invertebrates	2
Fish, carrion	3
Frogs, lizards	2
Birds, eggs	10
Hares	25
Water vole, Muskrat	39

Table C-8. *Summer diet of Red fox in Finland presented as frequency of occurrence (FO; %) (Kauhala et al. 1998 as cited by Truvé & Cederlund 2005).*

	Min	Max
Voles	13	63
Water voles	19	83
Muskrat	0	21
Mice	0	11
Shrews	0	14
Hares	35	91
Birds	18	96
Eggs	0	6
Fish	0	15
Carrion	0	9
Insects	5	60
Berries	0	7
Other plants	7	13

Omnivorous bird: Hooded crow

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Aves*
Order	*Passeriformes*
Family	*Corvidae*
Genus	*Corvus*
Species	*C. corone*

General habits, habitat and home range

Hooded crow is a common bird species found in a variety of habitats such as open forests, small forest patches, trees along shoreline, open countryside, parks and gardens, and several urban environments. In Northern Finland it nests mainly near human settlements, but in Southern Finland also further away from urban areas. It is also found in the archipelago. Hooded crow is mainly sedentary, but individuals from Finland and Russia migrate for the winter in large numbers to Sweden and along the North Sea. In the summer it lives in family groups or larger murders of non-nesting individuals, which move in large areas. In winter it forms larger murders which live near dumping grounds or human settlements. There are on average 1.9 nesting pairs per km² in southwestern Finland.

Table C-9. *Diet composition of coastal-breeding Hooded crows in Ireland (Berrow et al. 1992).*

	% of total mass	
	from pellets	items from drop sites
Crustaceans	46.5	0.7
Gastropods	27.3	12
Bivalves	1.1	82.1
Echinoderms	2.4	5.1
Mammals	10.7	-
Birds	4.9	-
Others	0.1 *	-

*The percentages of total mass from pellets total only 93%; there is an error in the original table in the reference used.

Dietary habits and main prey species

Hooded crow is omnivorous, an opportunistic feeder and a regular scavenger. Its diet includes other birds' eggs and nestlings, garbage, carrion and wastes of foodstuff, insects, different kinds of small animals (rodents, earthworms, fish and molluscs), fruits, berries, seeds etc. It often scavenges in dumping grounds and middens in winter. According to a study in Norway, a fledgling's daily food intake is 140 g.

Life cycle and reproduction

The nest is built usually high in a coniferous or deciduous tree. It is made of dry twigs, soil and clay and lined with feathers, hairs, pieces of fabric etc. Hooded crow builds almost always a new nest every year; old nests are utilised by other bird species. The female lays 4-5 eggs and incubates them for 19-20 days. During the incubation the male guards the nest. Both parents feed the nestlings by regurgitating partly digested food to them. The chicks fledge at the age of 4 to 5 weeks.

Sources of information

Berrow et al. 1992; Jussila & Nieminen 2008; Lokki & Palmgren 1990; Mullarney 1999.

Omnivorous reptile/amphibian: Common frog

Kingdom	*Animalia*
Phylum	*Chordata*
Class	*Amphibia*
Order	*Anura*
Family	*Ranidae*
Genus	*Rana*
Species	*R. temporaria*

General habits, habitat and home range

Common frog inhabits a wide variety of habitats. Tadpoles are strictly aquatic, but adults live both on land and in water. Terrestrial habitat types used include coniferous, mixed and deciduous forests, forested tundra and steppe, bush and shrublands, glades, grasslands, dry and wet meadows, marches, fields, rural gardens, parks and urban areas. Aquatic habitats include both temporary and permanent ponds, lakes and rivers; spawning and larval development occur in these water bodies. Even shallow ditches where other frogs and toads do not spawn can be used by Common frog. Modified habitats in general such as rural gardens or cultivated farm land are readily used by Common frog. It is less well-adapted to low pH habitats as Sphagnum bogs and pine tree forests. It overwinters mostly in water: it buries itself in mud in ditches, trenches, lakes or seashore bays etc. – some individuals overwinter on dry land. Hibernation begins in September-October in Southern Finland.

Dietary habits and main prey species

Across its life cycle, the Common frog is omnivorous – the tadpoles are herbivorous and adults carnivorous. Tadpoles start their life as herbivores feeding on algae, detritus and some plant material, but turn to carnivores already at the tadpole stage feeding on aquatic invertebrates and even display cannibalistic behavior during periods of food shortages. Adults feed only on ground – the diet consists of insects (especially dipterans), slugs and snails, spiders and other small animals. The diet varies considerably depending on what is available: any invertebrate of suitable size can be included in the diet. Common frog is itself prey for pike, adder, grass snake, crane, several prey birds, raccoon dog, fox, mink and several other predatory or omnivorous vertebrates.

Life cycle and reproduction

In the spring frogs gather to freshwater bodies (ponds, ditches, puddles, water meadows etc.) to breed. Breeding begins in April in Southern Finland, and in June in northern Finland. The female lays ca. 400 eggs into the water and the male riding on the back of the female fertilises them immediately. After laying the eggs the females return to dry land but the males stay in the water for a few more days. The fertilised eggs first sink to the bottom but after the gelatinous envelope surrounding them swells, they rise to float on the surface of the water in thick groups. The eggs develop into about 1-cm long, limbless tadpoles in a few weeks. The tadpoles spend 2-3 months in the water eating mainly plant material. After metamorphosis the young frogs leave the ponds. Common frog reaches sexual maturity in three years. Its average life time is estimated to be about 10 years.

Sources of information

Andrén 2004; Brown et al 2003b; Kurtto et al 1987; Lokki et al 1998a; Nieminen & Saarikivi 2008.

Omnivorous invertebrate: Ants

Kingdom	*Animalia*
Phylom	*Arthropoda*
Class	*Insecta*
Order	*Hymenoptera*
Family	*Formicidae*
Several genera and species	

General habits, habitat and home range

Ants are social insects which live in colonies with one or several reproducing queens, infertile female workers and fertile males. There are ca. 60 species of ants found in Finland, of which three are only found in association with human. The most common ant species in Finland is *Myrmica ruginodis*. This species was also the most numerous in the ant study done in Olkiluoto in 2008.

The so called *Formica rufa* group, or wood ants, build nest mounds which can be active for more than 30 years. 12 of the ant species found in Finland build nest mounds. Other species like *Myrmica* spp. build small nests that are inhabited for only one or two months during summertime. Wood ants are considered to be key species in boreal forests due to their great abundance and multitude and magnitude of their roles in the ecosystem. They cycle and aggregate carbon and nutrients, mix soil and alter its structure, and affect invertebrate and vertebrate distributions and plant production. They also defend their territories against other ant species, and are a food source for other animals and support various myrmecophiles. One ant mound can contain one million worker ants, and the foraging area protected by a single-mound colony can be several hectares, and that of a colony of several mounds can reach tens of km^2. Mean ant mound density across Finland according to the 1950 National Forest Inventory was 2.5 mounds/ha, and that of the hemi-and south-boreal Finland 3.1 mounds/ha. The C, N and P pools in the above-ground mounds of 100-year-old Norwegian spruce stands in eastern Finland were 180, 4 and 0.3 kg/ha, respectively. The contribution of these pools to the total C, N, and P pools of the forest was thus under 1%. However, ant mounds increase the spatial heterogeneity in the distribution of C, N and P in the forest soil.

Dietary habits and main prey species

Ants in general are omnivorous, though there are species that are strictly herbivorous or those that are mainly carnivorous. Wood ants feed on the sugary secretions of aphids, plants, invertebrates and carrion of vertebrate animals. A large ant colony can eat 100 000 insects a day.

Life cycle and reproduction

One or several queens per colony lay eggs from which larvae are hatched. These develop into pupae, which develop into workers, queens or males. The life span of workers can be up to three years depending on species, and the queens can live up to 20 years. Development time from egg to adult varies among species and is also dependent on temperature. Forest ants have development times of 30-45 days, *Myrmica* spp. ca. 80 days and carpenter ants (*Camponotus* spp.) two years.

Sources of information

Kurtto et al. 1987; Lokki et al. 1998b; Persson et al. 2006; Santaharju et al. 2009.

Detritivores: Earthworm

Kingdom	*Animalia*
Phylum	*Annelida*
Class	*Oligochaeta*
Order	*Haplotaxida*
Family	*Lumbricidae*
Genus	*Lumbricus*
Species	*L. terrestris*

General habits, habitat and home range

There are 17 species of earthworms found in Finland, which range in size of 1.5 -20 cm (length) and 2-6 mm (width). Earthworms aerate the soil thus improving its production, and in addition their castings fertilise the soil. The mucus excreted by earthworms provides an excellent growth medium for many soil bacteria. In addition, soil loses its acidity when it travels through the digestive system of earthworms. Earthworms require adequate moisture for growth and survival and will live and breed at temperatures up to 38°C. They will die in freezing temperatures but protect themselves as much as is possible by moving to lower depths in soil, burrowing to a maximum depth of about 2.5 m. They do not hibernate and can be found in most soils with a pH range of about 4.2 - >8.0 with as many as 50-500 per m². The colonies cand spread about 3-5 m per year. Individual densities can reach 300 individuals/m² in lush forests, moist meadows or fields in southern Finland. Most earthworm species live in the soil, but some are found also in water.

Dietary habits and main prey species

Earthworm is a detritivor; its main food consists of decaying organisms. As earthworms eat, they also ingest soil, sand, and tiny pebbles, and can ingest and discard their own weight (about 6 g) in food and soil every day. In an average adult worm, digestion takes about twenty-four hours.

Life cycle and reproduction

Earthworms are hermaphrodite organisms, but are not usually self-mating. They mate on the surface of the soil at night. Mating happens only in warm conditions; the eggs develop within a cocoon and the youngs (usually two to twenty; most commonly four) will hatch from it after about three weeks. Each worm is capable of producing 38 cocoons per year. The young reach maturity in about one year and have a life expectancy of up to six years. Worms have an ability to maintain optimum population size according to the available food and space. While conditions are right, they will breed until the optimum food and space ratio is reached and will cease breeding until more food and/or space is provided. Their main predators are the mole (*Talpa europaea*) and many species of birds.

Sources of information

Brown et al. 2003b; Lokki et al. 1998b.

APPENDIX D: OLKILUOTO SAMPLING NETWORKS

In this appendix, the sampling networks at Olkiluoto site are depicted. For further details of the locations and the ecosystem characterisation programme, see (Haapanen et al. 2009a). In the following, the sampling networks are presented in the order of:

- Sea monitoring locations on Olkiluoto offshore. Background maps: topographic database by the National Land Survey of Finland, digital elevation model by Pohjola et al. (2009).
- Soil investigation locations on Olkiluoto Island. Background map: topographic database by the National Land Survey of Finland.
- Forest investigation locations on Olkiluoto Island. Background maps: topographic database by the National Land Survey of Finland.
- Schematic figure of a forest sampling plot design.

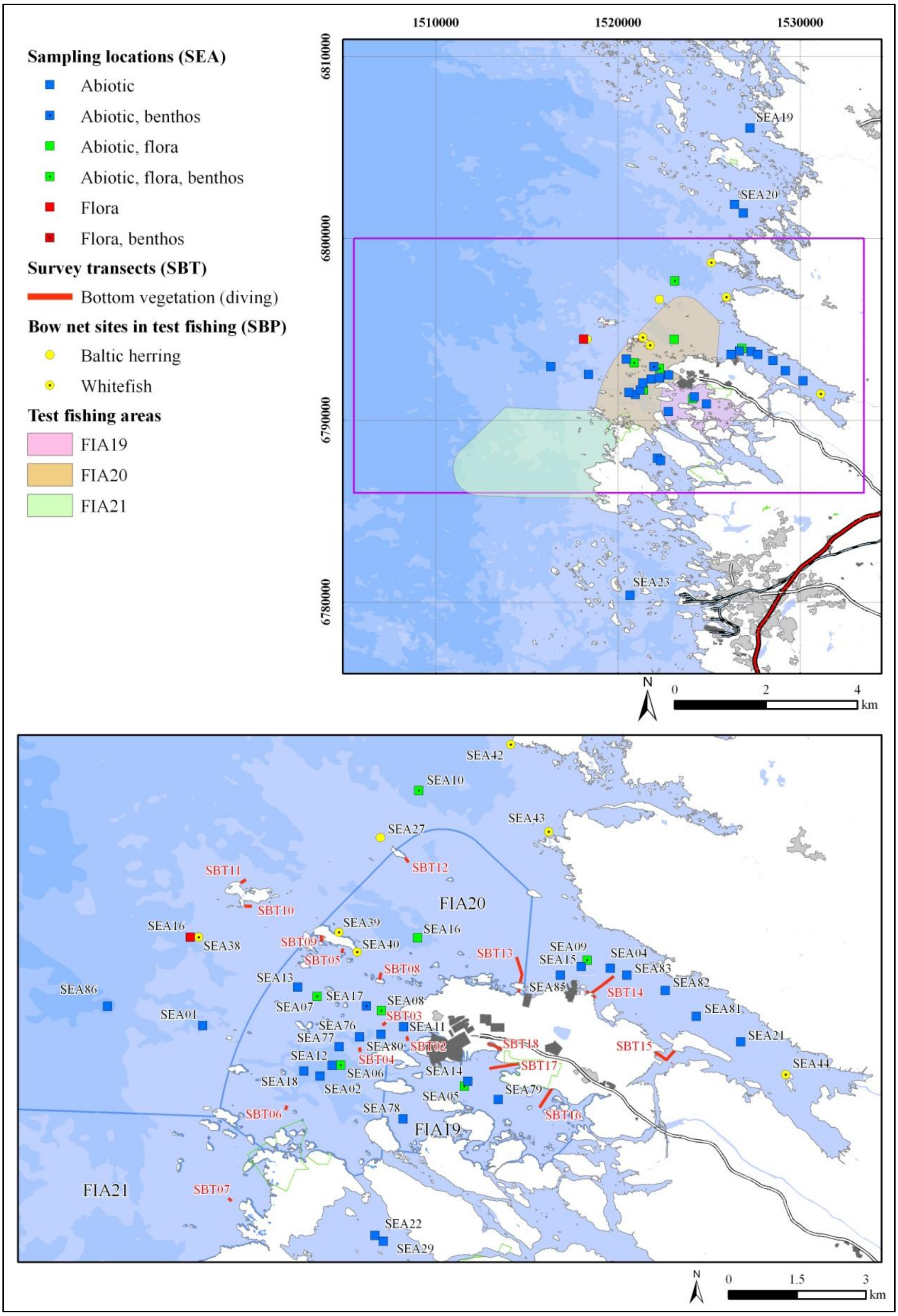

Figure D-1. *Sea monitoring locations on Olkiluoto offshore. Note that two locations (SEA87 and SEA88) are not shown; they are located approximately 20 km west from Olkiluoto, in open sea. Map layout by Jani Helin/Posiva Oy.*

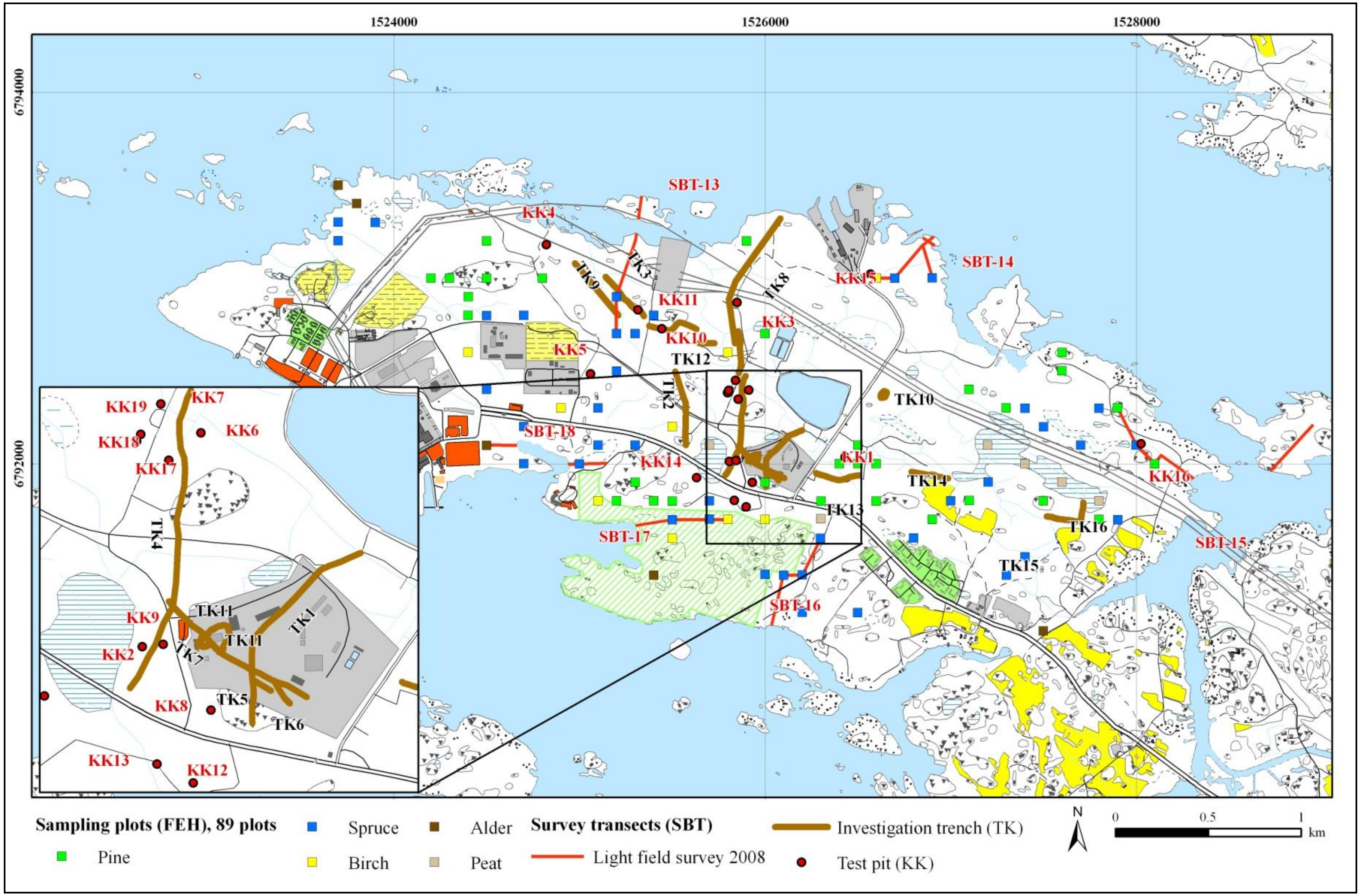

Figure D-2. *Soil investigation locations on Olkiluoto Island. Map layout by Jani Helin/Posiva Oy.*

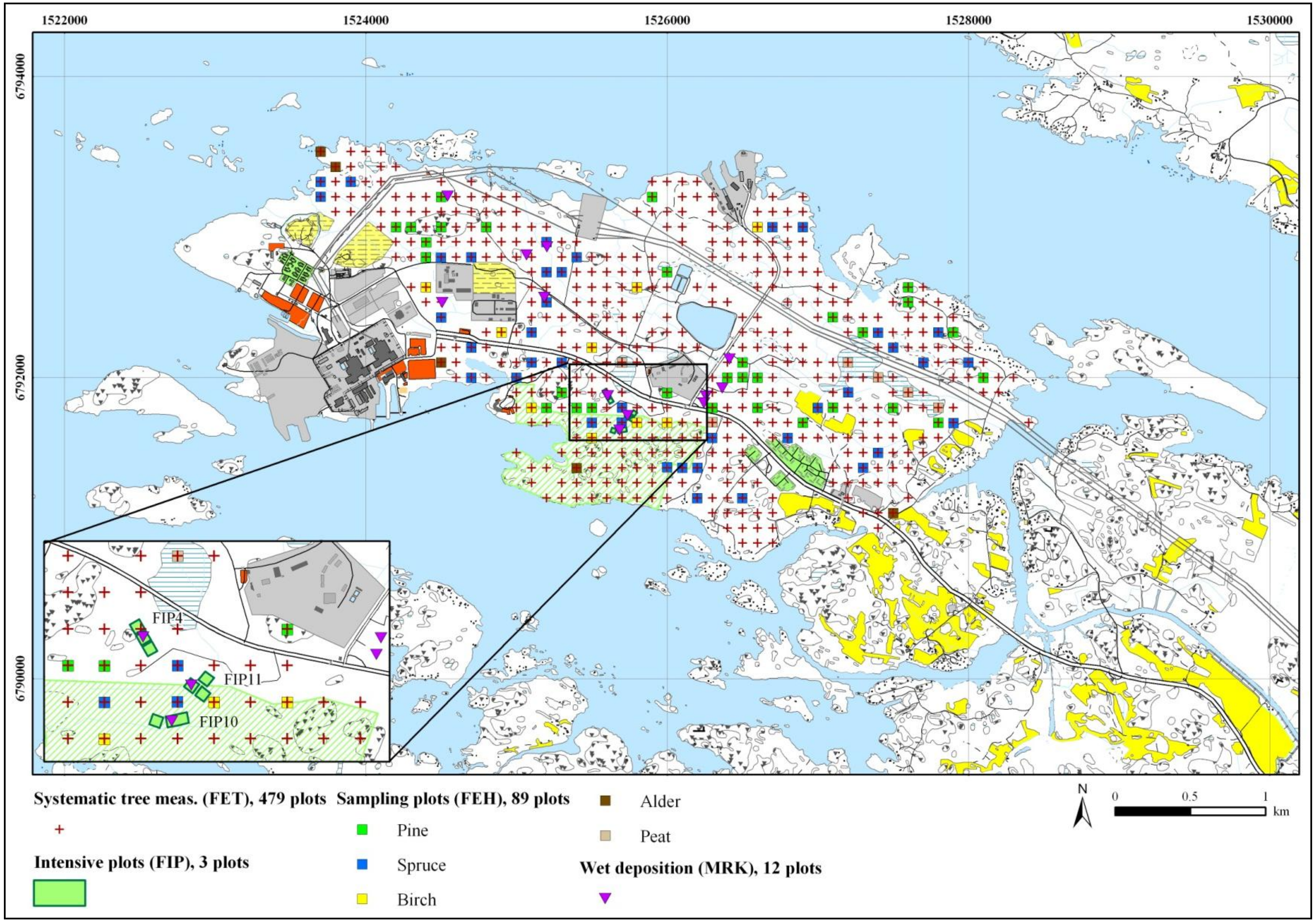

Figure D-3. *Forest investigation locations on Olkiluoto Island. Map layout by Jani Helin/Posiva Oy.*

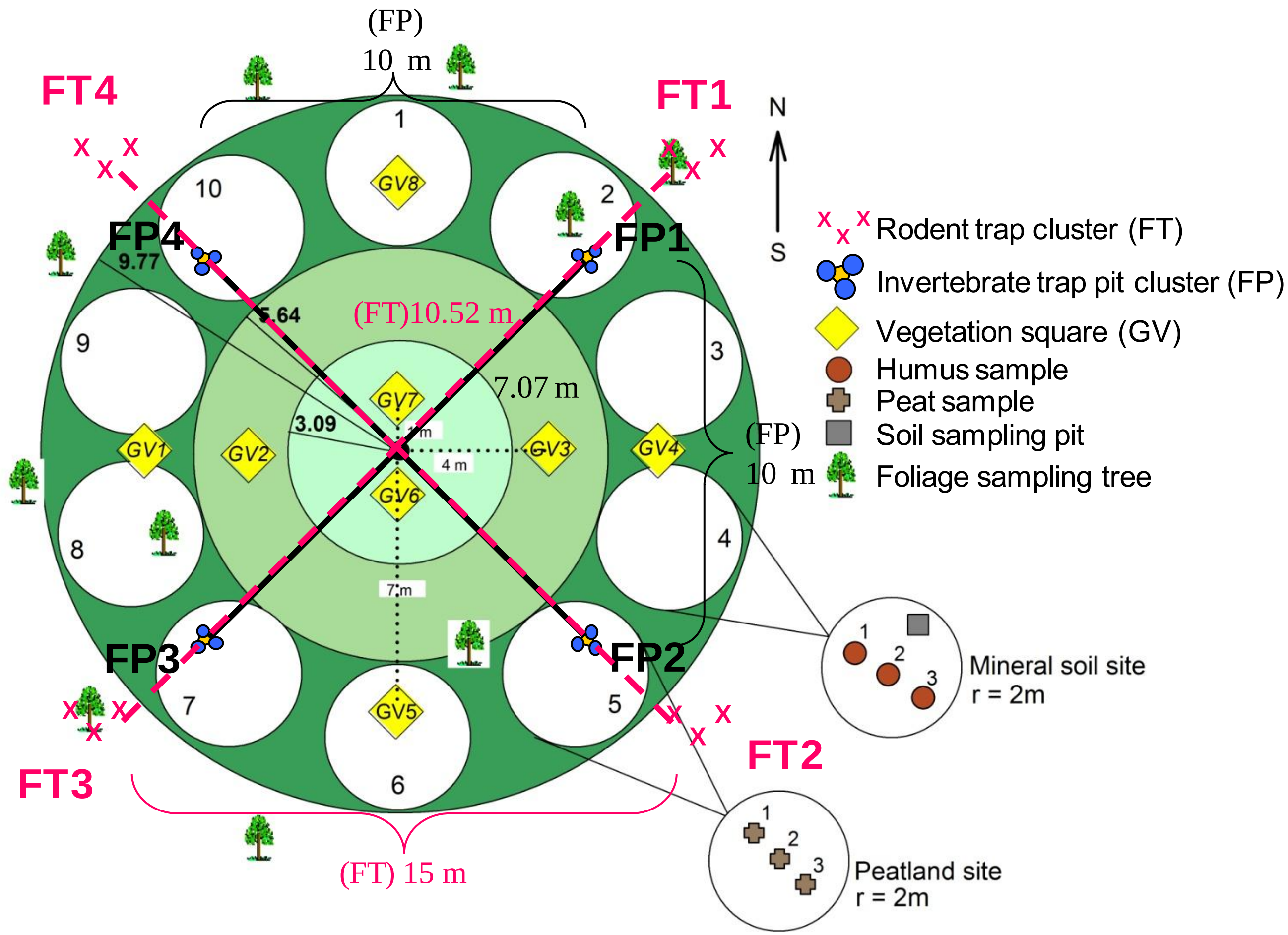

Figure D-4. *Layout of a forest sampling plot design with all systematic sampling types and measurements combined. Original layout by Lasse Aro / Finnish Forest Research Institute; further developed by Ari Ikonen / Posiva Oy.*

APPENDIX E: GROUNDWATER TABLE DATA

In this appendix, the data included in the analysis presented in section 3.4 is listed by monitoring hole/tube and time period included. In Fig. E-1 an example is given on the level of detail of the full dataset. The types of the holes and tubes have been presented in section 2.4 of (Posiva 2009a) and section 2.2.6 of (Posiva 2003).

Table E-1. *Monitoring data utilised in the groundwater table analysis of section 3.4.*

Monitoring target	Full years included
PVP1	2001-2008
PVP2	2001-2008
PVP3A	2001-2008
PVP3B	2001-2008
PVP4A	2001-2008
PVP4B	2001-2008
PVP5A	2001-2004
PVP5B	2001-2004
PVP6A	2001-2008
PVP6B	2001-2008
PVP7A	2001-2008
PVP8A	2001-2008
PVP8B	2001-2008
PVP9A	2001-2008
PVP9B	2001-2008
PVP9C	2001-2008
PVP10A	2001-2008
PVP10B	2001-2008
PVP11	2004-2008
PVP12	2004-2008
PVP13	2004-2008
PVP14	2004-2008
PVP17	2004-2008
PVP18A	2004-2008
PVP19	2004-2008
PVP20	2004-2008
PVP21	2008
PVP22	2008
PVP23	2008
PVP24	2008
PVP25	2008
PVP26	2008
PVP27	2008
PVP28	2008
PVP29	2008
PP1	2001-2008
PP2	2001-2008
PP3	2001-2008
PP5	2001-2008
PP6	2002-2008
PP7	2001-2008
PP8	2001-2008
PP9	2001-2008

Monitoring target	Full years included
PP10	2001-2008
PP31	2001-2008
PP32	2001-2004
PP34	2001-2004
PP35	2001-2004
PP36	2004-2008
PP37	2004-2008
PP38	2004-2005
PP39	2004-2008
PP51	2006-2008
PP52	2006-2008
PP53	2006-2008
PP54	2006-2008
PP55	2006-2008
PP56	2006-2008
PP66	2008
PP67	2008
PP68	2008
PP69	2008
PR1	2002-2008
PR2	2002-2008
PR3	2002, 2004
PR4	2002-2004
L1/1	2004-2008
L2/1	2002-2008
L3/1	2002-2008
L4/1	2001-2008
L8/1	2004-2008
L13/3	2004-2008
L14/3	2004-2008
L15/1	2004-2008
L16/2	2004-2008
L26/1	2004-2008
L27/1	2004-2008
PA1/2	2002-2008
PA2/3	2004-2008
PA3/2	2008
PA4/1	2004-2005
PA5/3	2004-2008
EP1 (level 4)	2001-2008
EP2 (level 4)	2001-2008
EP3 (level 4)	2003-2008
EP4 (level 4)	2001-2008

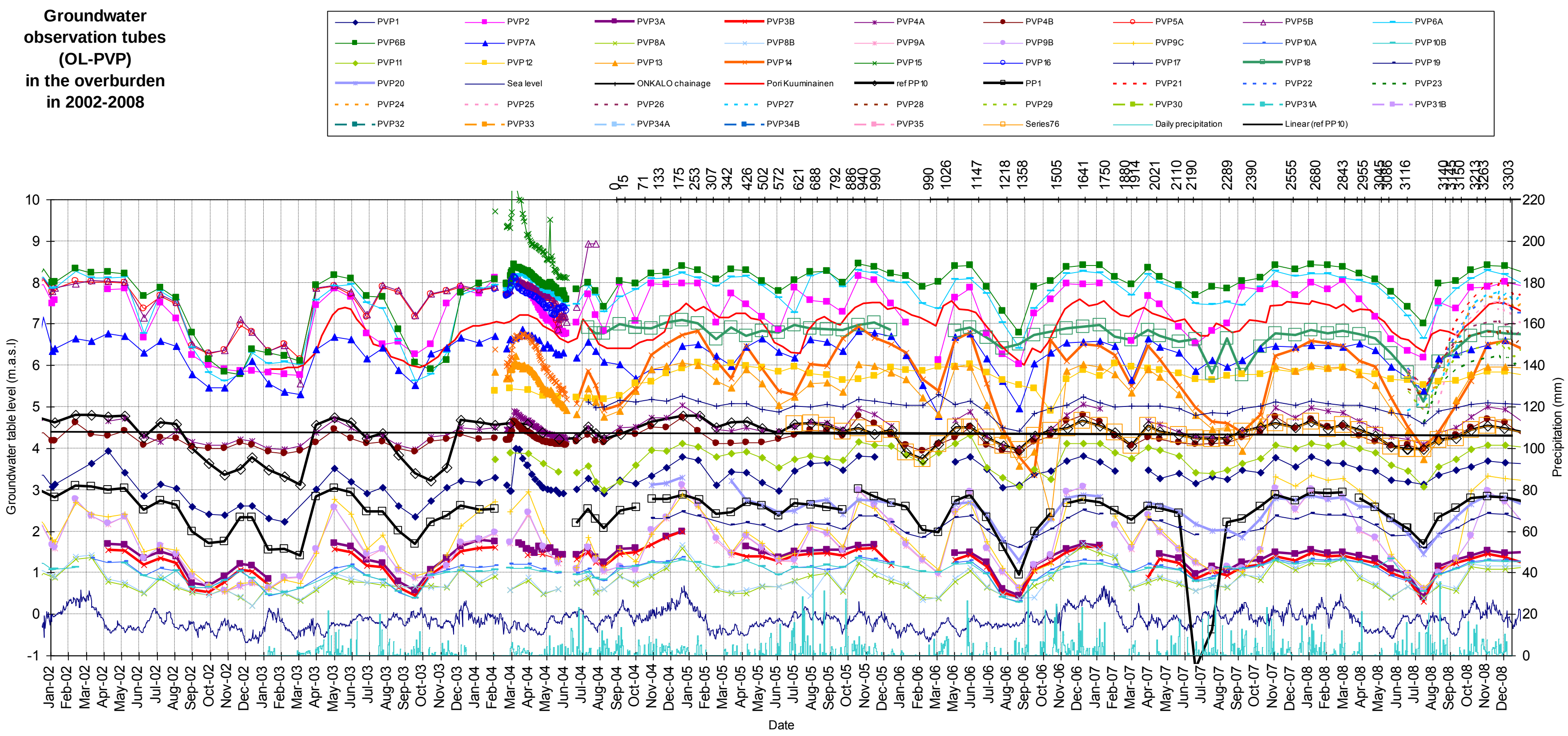

Figure E-1. *Groundwater table in groundwater observation tubes (PVP) in the overburden of Olkiluoto Island in 2002-2008.*