THE USE OF OPEN SPATIAL DATA IN THE CHARACTERISATION OF THE SURFACE ENVIRONMENT

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ABSTRACT

As the availability of open spatial data is increased, its use in various fields in working life has become more common. Posiva uses GIS in the biosphere assessment to produce projections of the development of the surface environment and ecosystems of Olkiluoto. Biosphere assessment is part of the safety case programme for assessing long-term safety and its purpose is to characterise the development of the surface environment and its conditions in the past, present and in the future at the Olkiluoto site and assess the radiological impacts in the surface environment during the assessment time frame. In former studies, Posiva has used open spatial data in the biosphere assessment as supplements in creating maps modelling the development of the Olkiluoto surface environment.

This study examined the new approaches to utilising open spatial data in surface environment characterisation, from a perspective of long-term safety case. The objective was to discover the features that are possible to represent with open spatial data. The work was conducted with the commercial ArcGIS programme application ArcMap 10.6 using only open spatial data.

The model characterisations were created from the Olkiluoto, Hanhikivi and Kivetty sites on their soil types, biotope types and land use, catchment areas, water quality and watersheds. The topics were selected according to the previous surface environment studies conducted by Posiva and the results of this study were compared to the results of previous characterisations conducted at the Olkiluoto site and its surrounding areas.

The results indicated that open spatial data can be utilised in characterising the surface environment and it is possible to partially replace other survey methods. The quality of open spatial data varied from very detailed to very coarse. The most informative characterisations were terrain maps, soil type and sea sediment maps, and biotope and land use maps as the data was the most detailed. When observed together these maps provided even more information.

As open spatial data can be produced by anyone, it is advisable to be aware of the producers when using the data. The data owned and produced by public administration are more reliable than the data produced and provided by an individual user of GIS.

Key words: Open spatial data, characterisation of the surface environment, GIS, ArcMap, final disposal, safety case programme

FOREWORD

This thesis was funded by Posiva Oy and it was done between June 2019 and August 2020. The purpose of this thesis was to examine the new approaches for using the open spatial data in surface environment characterisation, from a perspective of long-term safety case. Also, the objective was to discover the features that are possible to represent with open spatial data.

The work was conducted by using only open spatial data with the commercial ArcGIS programme application ArcMap 10.6. This thesis was supervised by research coordinator Lauri Parviainen from Posiva Oy and postdoctoral researcher Harri Antikainen from the University of Oulu.

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LIST OF ABBREVIATIONS

API	Application Programming Interface
AVI	Regional State Administrative Agencies
ELY	Centre Centres for Economic Development, Transport and the Environment
GIS	Geographical Information Systems
GTK	Geological Survey of Finland
INSPIRE	Infrastructure for Spatial Information in Europe
LiDAR	Light Detection and Ranging
Luke	Natural Resources Institute Finland
LWIR	Long Wavelength Infrared
NLS	National Land Survey of Finland
SAR	Synthetic Aperture Radar
SKB	Swedish Nuclear Fuel and Waste Management Co.
SYKE	Finnish Environment Institute
TESM	Terrain and ecosystems development modelling
VIS	Visible wavelength

1. Introduction

The use of GIS has been increased in various organisations and in various fields, for example, in governments, cities and companies in diverse ways: from urban planning to forest management, as well as in social and health services (Korte 2014; USC University of Southern California 2019). Posiva uses GIS in such applications as the biosphere assessment to produce projections of the development of the surface environment and ecosystems of Olkiluoto (Broed et al. 2008: 22). Biosphere assessment is part of the safety case programme for assessing long-term safety, which is part of the licence applications, for example, construction and operation licence applications and assesses the safety of the geological disposal facility for radioactive waste over a long period of time. The purpose of the biosphere assessment is to characterise the development of the surface environment and its conditions in the past, present and in the future at the Olkiluoto site (Ikonen et al. 2013: 17-18), and assess the radiological impacts in the surface environment during the assessment time frame (IAEA 2006: 35; IAEA 2012: 1). The assessment also includes models for the migration of radionuclides in the surface environment in scenarios where radionuclides are released from the repository. In addition, it estimates the doses from potential releases on the exposed human population and other biota. According to Ikonen et al. (2013: 18), one of the primary topics of the biosphere assessment is to develop a complete dynamic characterisation model of the Olkiluoto surface environment. The modelling of the future development covers the years from 2020 to 12020 (Hjerpe et al. 2010: 87). Previously, this approach has been developed, by such authors as Haapanen et al. (2007 & 2009) in the Olkiluoto Biosphere Description 2006 and Olkiluoto Biosphere Description 2009, and Hjerpe et al. (2010) in the Biosphere Assessment Report 2009. The biosphere descriptions have been produced to widen the general knowledge of the biosphere at the Olkiluoto site, and to benefit the representation of terrain and ecosystems development (Haapanen et al. 2007: 9). The present spatial data from the surface environment of Olkiluoto has been obtained by monitoring programmes (for example Posiva Oy 2003b, Posiva Oy 2013 & Sojakka et al. 2018) and characterisation methods that are closely related to monitoring programmes (Posiva Oy 2013: 26). The obtained information has been stored in the Posiva's GIS database and can be represented as maps or location data with suitable attributes and applied mostly as input data in terrain and ecosystems development modelling (Hjerpe 2006: 8, 28).

For a long time, ArcGIS, a commercial GIS programme, has been the most used software for managing spatial data. Nowadays, the free, alternative open source programmes have increased in popularity, QGIS being one of the most advanced and used (Korte 2014; Posiva Oy 2014: 338; Jokela 2017: 26). Also, the availability of open spatial data has been increased, since GIS has transformed from a tool to a platform that joins together various kinds of fields, and therefore the need for sharing and distributing spatial information among different fields and organisations has become more common (Bank 2004).

This study examines the new approaches to utilising open spatial data in surface environment characterisation, from a perspective of long-term safety case. Also, the objective is to discover the features that are possible to represent with open spatial data. The products of the site characterisation can be represented as spatial data, for example, as maps and location information of various kinds of features. The results bring new information on the usability of open spatial data in site characterisation, for example, how accurately the surface environment can be displayed with the open spatial data. In addition, if the open spatial data is detailed enough it can even be a substitute for some of the research or mapping methods, such as remote sensing and observation plots, and thus its use saves time in gathering the data. In addition, since open spatial data is free, its use saves costs as well. The study is topical, as obtaining open spatial data nowadays is effortless: it is available on the internet, in various kinds of open spatial data services, and can be produced by any user of GIS software. The data can be downloaded to the user's computer from the sites of download services and open spatial data services. In former studies, open spatial data has been utilised in the Posiva's biosphere assessment as supplements in creating maps modelling the development of the Olkiluoto surface environment. The results of this study could help in characterising and monitoring a site for disposal of spent nuclear fuel.

In this study, the work has been conducted by using only open spatial data with the commercial ArcGIS programme application ArcMap 10.6. The model characterisations have been created from three sites: the Olkiluoto, Hanhikivi and Kivetty sites. The unifying factor of these sites is their relation to the nuclear power plant sites and final disposal of the spent nuclear fuel: Olkiluoto Island has been chosen as the location for the repository (Ikonen et al. 2013: 7), the Hanhikivi site is the future location of a new nuclear power plant (Fennovoima: Tietoa… 2019), and the Kivetty site has been under research as it has been an option for the location of the disposal site in the past (Rautio 1996; Äikäs et al. 1999). The model characterisations are made on the sites' soil types, biotope types and land use, catchment areas, water quality and watersheds, and they are compared to the results of previous characterisations conducted at the Olkiluoto site and its surrounding areas. On account of the model characterisations, the usability and accuracy of open spatial data in the surface environment's characterisation is discussed as well as the potential of replacing some of the research methods currently used in the characterisation.

2. Background

Founded in 1995, Posiva Oy, has put into practice Finland's disposal programme for spent nuclear fuel and carried out the related studies and planning and concept development (Ikonen et al. 2013: 7, 18). The objective is to manage the final disposal of used nuclear fuel safely, economically and in a timely manner, and to work according to the requirements of the company's owners and other stakeholders (Posiva: Posiva-About… 2019; Posiva Solutions: Posiva 2019). The used nuclear fuel is going to be placed in a repository at a depth of approximately 420 m, in the bedrock of the Olkiluoto site (Ikonen et al. 2013: 7). The repository is located on the central-eastern part of the island, and the related underground rock characterisation facility, ONKALO, which will be part of the repository (Hjerpe et al. 2010: 7; Posiva: ONKALO 2019). The final disposal of spent nuclear fuel is estimated to start during the 2020s and will continue for the next hundred years (Posiva: Final… 2019).

The characterisation of the ecosystems of Olkiluoto Island and its surrounding sea areas began in the early 2000s. It is a systematic process that aims to gain in-depth knowledge of the site, so that the relevance of different models and the literature data to the site can be estimated and offer to the proper extent and quality support to the development of the safety case. Because of the assessment's cyclical nature, there already exist models that are in use, but developing the modelling has increased the need for new data (Posiva Oy 2013: 25). According to Posiva Oy (2003a: 15), the study focuses mainly on the Olkiluoto Island, except for the area where the nuclear power plant is located. In addition, the offshore study area reaches from 1 to 2 km to the north and west since the geological formations need to be projected further. As regards studying the biosphere, specific areas have been researched on a regional scale because all ecosystems required in the long-term are not available at the present Olkiluoto site. The majority of ecosystem characterisation has been done together with the monitoring programme of Olkiluoto. The basic spatial data has been brought together by gathering it from wide areas and using low-cost survey methods, and thus create the basis for allocating of more specific studies. More specific study has been conducted, for example, by intensive monitoring of ecosystems in a few parcels of land (Posiva Oy 2013: 26).

Similar site characterisation studies to those carried out at the Olkiluoto site have been conducted by SKB (Swedish Nuclear Fuel and Waste Management Co.) at the Forsmark (Lindborg 2008) and the Laxemark-Simpevarp sites in Sweden (Söderbäck & Lindborg 2013). The two sites resemble the Olkiluoto site (Haapanen et al. 2009: 19), particularly with respect to their biospheres (Posiva Oy 2003: 57). Both Posiva's and SKB's projects for final disposal of radioactive waste are based on the same concept. Due to the similarities, the companies have cooperated since 2001. In 2014 they began extended cooperation with an aim to optimise the facilities' operation in the future (Posiva: Posiva-SKB… 2019). To characterise the biospheres of the Forsmark and Laxemark-Simpevarp sites, SKB has analysed both the site-specific and other characteristic data of the sites, and developed and documented ecological, geological, hydrological and near-surface hydrogeological models. SKB has also produced the description of the site that combines all the fields of the surface system and, in addition, represented the transportation of the substances between the bedrock and surface system and described the relevant site-specific processes and features that support the understanding of the site (Lindborg 2008: 14; Söderbäck et al. 2009: 14). SKB has developed a site descriptive model (SDM) that combines all the gathered data from the site, including the surface systems of the site (Lindborg 2008: 13; Söderbäck et al. 2009: 13). The surface environment data from the site has been stored in GIS, for example, which supports over-layering techniques for combining the data, making the precise estimates of the spatial data from the surface environment possible (Lindborg 2008: 31; Söderbäck et al. 2009: 30).

3. Characterising the surface environment of a disposal site

3.1 Description of Olkiluoto surface environment

In this section the surface environment of the Olkiluoto site is described. The description is based on the results of the previous studies conducted by Posiva, the latest description being found from the Olkiluoto Biosphere Description 2012 (Ikonen et al. 2013). Olkiluoto is an island with a surface area of approximately 12 km^2, which is located off the south-west coast of Finland in the Baltic Sea, near to the mainland (Ikonen et al. 2010: 9). The features of Olkiluoto Island's environment are very similar to the areas in south-west Finland on the mainland (Hjerpe et al. 2010: 40). A large part of the island is covered by forest, whereas a wide area on the western side of the island is in industrial use, the most important being the nuclear power plant units and related facilities. Other human activity on the island is relatively light: on the south-eastern side of the island there are a small number of croplands (Posiva Oy 2003a: 45).

According to Tamminen et al. (2007: 59), the soils of Olkiluoto Island are much younger than the soils on the mainland the characteristics being rocky, a nutrient-rich composition and thin layers. As a result of sampling, it has been discovered that the most common soil types on Olkiluoto Island are poorly developed, coarse or medium-grained sandy soils, undeveloped and fine-grained sandy soils, thin layers of rocky soils, and fine-grained anoxic soils that are often saturated with ground water (Tamminen et al. 2007: 33; Tamminen 2009: 75; World Soil Resources Reports 2006: 72-92). Mineral soils that occur on Olkiluoto Island are rather rocky and contain boulders and exposures of bedrock. The coarse-grained texture of mineral soils is characteristic of Finnish forests. The most common coarse-grained soil type in the forests of Olkiluoto Island is fine sand. Peatlands are characteristic of young soil in the coastal areas of western Finland, including Olkiluoto Island. Due to the young age of soils they are not well developed, which appears, for example, in the absence of podzol. As regards, vegetation, for example, alders thrive in thicker peatlands, whereas pines thrive in thin peatlands (Tamminen et al. 2007: 21, 32).

As a result of the forest vegetation mapping, Miettinen et al. (2002: 33) state that the largest part of Olkiluoto Island is covered by spruce-dominated forests the proportion being 34%. Mixed deciduous forests and coniferous forests cover 31% of all forests. It was observed that the majority of the forests have been under heavy forestry and therefore the field layer is mainly in the first or second successional phase. In the middle of the island there are open areas and pine plantations. Mires are rather rare on the island and many of them have been drained. Thus, some of them have turned into peatland forests and some of them are in various transitional phases. In the coastal areas there are narrow belts of meadows around the island. Near coastal areas alders are common. Posiva Oy (2013: 12) states that the vegetation in general is characteristic of the vegetation on the southwest coast. In addition, a conservation area of old forest is located on the southern side of the island. It is part of the Natura 2000 programme of the European Union for the conservation of landscape, habitats and species in a location that is significant to the community (Posiva Oy 2003b: 75).

It has been observed that the sea sediments near Olkiluoto Island consist of gravel, fine sand, clay, sandy gravel and sandy till (Kallio et al. 2017: 11-12, 20). More specific results of sea sediment sampling have been introduced by Lahdenperä & Keskinen (2011), who state that the sea sediments near Olkiluoto contain till, mixed sediment, sand, gravel, clays from different phases of Baltic Sea, recent gyttja clay and gaseous sediments. In addition, there is areas with bedrock exposures. As regards sea depth, it has been observed that the adjacent sea areas of Olkiluoto Island are rather shallow. Mostly, the sea depth is 0-10 m but in a few area, it is even 15 m (Lahdenperä et al. 2011: 7-9). Posiva Oy (2014: 158-159) adds that the composition and consistency of sea sediments and sea depth are also influencing on the aquatic flora. It has been observed that aquatic vegetation thrives on photic soft bottoms and algae on photic hard bottom. There does not occur primary production in aphotic bottoms. In such areas it is concentrated in the euphotic zone.

The catchment areas of the major water systems near Olkiluoto Island have been studied, for example, by Ojala et al. (2006). There are two major rivers near Olkiluoto Island: the Eurajoki River and the Lapinjoki River. The catchment area of the Eurajoki River reaches Pyhäjärvi Lake, the largest lake in south-west Finland (Ojala et al.

2006: 7, 10). The area of the Eurajoki River's catchment area is approximately 1336 km^2 and Lapinjoki River's approximately 462 km^2 (Ekholm 1993: 57-58). The two rivers are located in an area characterised by plainness, a small number of lakes and clayey soils. The proportion of croplands is rather large. The Eurajoki River flows to the Eurajoensalmi Strait and Lapinjoki River to the narrow strait between the Olkiluoto Island and the mainland (Kirkkala & Oravainen 2005a: 10; Kirkkala & Turkki 2005b: 48).

According to Koivunen (2017: 30-31) the quality of water in the Eurajoki River during the year 2016 varied from poor to good depending on the sampling location and season. The Eurajoensalmi Strait's water quality varied from good to excellent. Regarding the quality of sea water, Kirkkala et al. (2005b: 56) state that the most significant factors influencing it are the general condition of the coastal areas of the Bothnian Sea, the amount of matter transported by the Eurajoki and Lapinjoki Rivers, and the cooling water originating from the nuclear power plant site as well as the load of waste water at its discharge area.

The watershed delineations have been discussed, for example, by Ojala et al. (2006). The delineations have been modelled with ArcMap's Spatial Analyst Tool's Hydrology tool. As a base, it has been used a digital elevation model (DEM) of the present surface environment of the Eurajoki River's catchment area. The result of watershed delineation is an artificial subdivision of a catchment area. A watershed is considered as an area where the water flows to outlet as concentrated drainage. An outlet is the lowest point in the borderline of the watershed (Ojala et al. 2006: 17-18, 28).

Features of landscape and land use have been monitored with maps and remote sensing data. The data of Olkiluoto topography is available at the National Land Survey of Finland's Open data file service (Sojakka et al. 2018: 37). The topography of the Olkiluoto Island has been affected by the relief and composition of the bedrock and the activities of the glacier. As regards land use on the island, there are areas under severe industrial activities, residential environments and crop production. There are also areas with no habitation and only or no utilisation of resources (Ikonen et al. 2013: 39, 133).

3.2 Characterisation methods used in the Olkiluoto site

3.2.1 The use of characterisation data

The spatial data produced of the surface environment is utilised as a basis when creating models for the final disposal site. For example, such model is the terrain and ecosystems development modelling (TESM), which was developed to produce projections of the changes in the landscape due to land uplift, so that in the long-term safety assessment scenarios may receive radionuclides from the repository over several thousands of years, and even up to 10 000 years. TESM is a separate project where the forecasts are based on the geological elements that are least vulnerable to changes before the next glaciation. TESM contains sub-models of the evolution of shorelines, surface water bodies, or lakes and rivers, sediment accumulation, evolution of coastline vegetation in the lakes and sea bays. Models have been produced with different methods, for example, by calculating mathematical functions, applying models to similar reference areas and using standard GIS tools (Broed et al. 2008: 22, 26). A company named Arbonaut Ltd Oy has produced a GIS toolbox called UNTAMO for Posiva for TESM (Hjerpe et al. 2010: 5; Ikonen et al. 2010: 27). The toolbox contains extensive data on topographical and geological conditions, land uplift and sea area delineation, bodies of surface water, runoff formation and emission, delineation of the reed beds, the level of groundwater, accretion of peat and gyttja, sedimentation in water bodies and arable land (Posiva Oy 2013: 63). In addition, Karvonen (2012: 39) has mentioned that the toolbox contains the data from terrestrial and aquatic vegetation, fauna habitation, erosion in terrestrial and aquatic circumstances and human habitation. The toolbox runs on commercial spatial data software, ArcGIS (Ormsby et al. 2001: 11; Posiva Oy 2014: 338).

3.2.2 Monitoring the Olkiluoto surface environment

The monitoring programme was initiated in 2004 to observe the changes that construction of ONKALO and, in the future, the repository will cause to the surface and underground environment of Olkiluoto Island. The changes will occur in the bedrock and groundwater flow system. It also causes chemical changes to the surface environment as well as in the deep bedrock (Posiva Oy 2003b 57; Posiva Oy 2012a). Monitoring of the surface environment has been carried out by Posiva. The programme is rather like SKB's (e.g. Löfgren & Lindborg 2003) due to the similarities of the sites' environments, particularly with respect to the surface environment (Posiva Oy 2003b: 57-58). It is based on the study of long-term safety requirements and modelling and the results have provided information on the accumulation and drift features of the radionuclides. The results have also provided information on the interaction between the deep groundwater and the surface environment, and how it affects the operating capability of the repository. At the same time, the usual environmental impacts of the disposal project, as well as changes in land use and weather conditions have been monitored. The data obtained from monitoring is utilised, for example, in the characterisation and modelling the surface environment but also for site characterisation underground (Posiva Oy 2003b; Posiva Oy 2012a: 40, 87).

For example, the forest vegetation has been surveyed by monitoring system that includes various overlapping levels. At the first level, it is observed alterations in land use by aerial image interpretation. The second level contains vegetation type mapping and survey of forest resources that help categorising vegetation and its distribution, and thus the data can be used as a basis in the monitoring of primary plant succession and human impacts. The third level consists of systematically locating plots that together form a grid. The plots are utilised in characterising biomass distribution of forests and monitoring increment and other alteration in tree stand. Some of the plots have been chosen for more specific surveys where soil characteristics, needles, vegetation structure and nutrient concentrations of vegetation are studied. The fourth and the fifth level include the plots where observations are conducted every day or even every hour. The stone dust, which originates from construction works and rock crushing on Olkiluoto Island, may have a negative impact on forests. Thus, the impacts have been monitored by surveying a bulk deposition, stand throughfall, precipitation and interception of the tree canopies. The data is gathered also with rainwater and snow collectors (Aro et al. 2010: 5-6). In addition, according to Haapanen (2005: 12), the hydrogeochemistry of the artificial lake, Korvensuo reservoir, is monitored every week. Instead, the Eurajoki River is monitored mainly by industrial concerns locating on its upper reach as well as the Köyliönjoki River flowing into the Eurajoki River. Posiva has only one monitoring plot along the Eurajoki River, which observes the plot's chemical features (Sojakka et al. 2018: 31).

3.2.3 Observation plots

Most of the island of Olkiluoto has been divided into a grid of observation plots, which forms the coordinate basis for sampling and research. This method is widely utilised in different programmes in Europe, and it has been improved to meet the exact needs of Posiva. In Olkiluoto, the location of each observation plot is defined precisely enabling repetitive sampling and research. The plot has a pole indicating its centre, which, in turn, has been defined using GPS. Most of the plots also have nested rings surrounding the common pole for measuring at various intensities. The samples, measurement points and areas vary in amount and type in every plot. To secure the systematic sampling, some observation plots have different sampling and measurement locations (Posiva 2003b: 62-63). While forming the grid, the characteristic features of each observation plot are described. The described characteristics include the habitat type of plant or animal, the occurrence of rocks, drainage and alteration in it, forest management and land use, and the features of the vegetation. The description is updated regularly in most of the observation plots, in every four to six years, in context with other large-scale operations (Posiva 2003b: 63).

On observation plots, there has been surveyed, for example, soil types. The samplings are made repeatedly from every horizon in the soil. The horizons are photographed, described and documented in detail (Posiva 2003b: 65). Tamminen et al. (2007: 15, 59) add that the samples are taken from the surface to the depth of 60 cm. The surface layers are sampled more often since they are easily affected by changes in environment. Posiva Oy (2003b: 65) add, that vegetation has been surveyed by observation plots as well. Vegetation polygons have been digitalised by ArcMap by using ortho-rectified images as base map. The borders of polygons in the field have been controlled with mirror stereoscope and transmitted to GIS software. In the finished maps, every vegetation type attribute has been attached to each polygon separately by hand (Miettinen et al. 2002: 17-18).

3.2.4 Deep excavator pits

According to Lahdenperä (2009: 3), the deep excavator pit method has been used in Posiva's studies in defining the soil's geochemical and geophysical features as well as providing additional information on the stratigraphy of the soil and geochemical features in the interface of geosphere-biosphere. The results are utilised in the modelling of soil. The research method allows the detailed study of soils. The samplings are made from several soil layers including the humus layer and 2-5 layers of mineral soil. The deepest sample is aimed to reach the bedrock, if possible. Due to the young age, and thus poor development of the soil layers, the layers from which the samples are taken, are selected by their visual appearance. The visual factors affecting the sampling include the stratigraphy of soil, soil type, the amount of stones and colour. After sampling, the pH, moisture, and proportions of dry and organic matter are determined, as well as element concentrations. In addition, the total organic carbon is determined form humus layers (Lahdenperä 2009: 57). According to Lahdenperä (2016: 5) the analysis of soil samples forms the basis for the classification of biotopes since the characteristics of soils have a significant impact on the vegetation type and growth, and thus even on the fauna in the long term.

3.2.5 Remote sensed data

Remote sensing is a method suitable for monitoring the features of the landscape, such as topography. Before the database of aerial photographs was updated every 5 to 10 years, and if any alteration occurred, the changes were digitised manually. The National Land Survey of Finland has attached the topographic database into Posiva's GIS database. Nowadays, it is available for free at the open data file download service (Sojakka et al. 2018: 37). Remote sensing is suitable for producing base maps, where various kinds of data can be combined. Also, the alterations in the surface environment are easily observed, for example, by aerial photography it is possible to observe changes in land use, vegetation or biomass (Posiva 2003b: 61; Sojakka et al. 2018: 19).

According to Posiva Oy (2003b: 61) the Olkiluoto nuclear power plant's closeness to the monitoring area prevents taking detailed aerial images from the monitoring area, and they can be used only as background maps at low resolution. Aerial images are updated regularly to make sure that the temporal resolution is good enough. The monitoring area is photographed in the spring as soon as the leaves are fully grown on trees. The changes in environment are updated to Posiva's GIS database (Posiva Oy 2012a: 120). Satellite imagery has a lower resolution, which makes it a viable and supplementary option to aerial imagery. Compared to aerial imagery, satellite imagery covers a larger area. Like aerial photography, satellite imagery is also conducted in the spring when the leaves are fully grown, and it should consist of multichannel images with adequate resolution. The new satellite images are taken every ten years the resolution being 1 to 5 m (Posiva Oy 2003b: 61-62).

Kumpumäki et al. (2018: 10, 13, 21) state that there are two types of remote sensing: passive and active. Passive sensors function at wavelengths from the visible (VIS) to the Long Wave InfraRed (LWIR) zone, from which reflected solar wave radiation and heat radiation originating from the Earth's surface can be gauged. One passive gauging method is hyperspectral remote sensing. The method is based on the measurement of radiance of optical radiation that is reflected from an object. However, in the surveys conducted by Posiva, it has been observed that the method is not practical in vegetation mapping or observing the alterations of the surface environment. This is due to the method's sensitivity to weather conditions, the data's low resolution, and requirement for reference data in order to make atmospheric corrections. According to Kumpumäki et al. (2018: 21), aerial photography is a better method for vegetation mapping and observing alterations in the environment. In turn, the active radar surveying systems function at microwave frequencies. At these frequencies, atmospheric transmittance is high whereas background radiation and solar wave radiation are low. For example, there is an active sensor type, bathymetric LiDAR, where a LiDAR pulse is emitted from an airborne platform and the returning echo wave shape is gauged. Bathymetric LiDAR is suitable for mapping shallow sea areas and lakes as the LiDAR beam is chosen from the green visible light range so that it penetrates as deep as possible into the water layers. Bathymetric LiDAR has been mainly utilised in Posiva's surveys in mapping the depth of the seabed. The method also provides information on seawater conditions, such as turbidity, and vegetation in the sea bottom as well as features of sea sediment (Kumpumäki et al. 2018: 10, 23). Another active radar survey system is synthetic aperture radar (SAR). The method is based on narrow radio wave beams that are sent in a slant range and gauging the returned response as a high frequency signal. SAR can be used to obtain information on the structure of the gauged objects using different wavelength regions. For example, long wavelengths can provide information on tree trunks whereas shorter wavelengths provide information on the tree canopies (Kumpumäki et al. 2018: 29).

Aerial photography has been used in characterising the soil (Posiva Oy 2003b: 65) and mapping the vegetation. According to Miettinen et al. (2002: 15-16, 33), vegetation is first photographed by false-colour aerial photographs at a scale of 1:10 000. By this method it has been gathered information on field layer, forests and mires. For more specific surveys, such as mapping a single tree, it has been used scales from 1:3000 to 1:6000. As a result of photography, analogical photographs and digital ortophotos mosaics are produced, after which they are digitalised. Analog aerial photographs are visually interpreted. Preparatory polygons for vegetation are represented on maps at a scale of 1:5000. As a result, it is obtained information on stage of development of forests, dominant tree species and a few vegetation colonies in coastal areas. Miettinen et al. (2002: 16-17) continue that after the preparatory polygons are made, vegetation is characterised in the field inventory. The inventory is done by walking through every polygon and observing alteration in vegetation. For example, the proportion of tree species and canopy layers are observed. If little variation is occurring in a polygon, it is simplified by including small spots of minority vegetation types in the dominant vegetation type.

Acoustic seismic sounding is used as a research method in the basic mapping of sea sediments and the study was conducted in collaboration with GTK. In addition to sounding, samples are taken with vibration drilling to enhance interpretation. The sounding transects have been turned into a sea sediment map with the help of side scan sonar. The sea sediment map is represented at a scale of 1:20 000. The sounding lines have also been considered as geological cross sections, and according to them, a map has been produced that represents the sea depth at a scale of 1:20 000 (Rantataro 2001: 2-3).

3.2.6 Survey transects from land to sea

Haapanen & Lahdenperä (2011) have reported of the research method of survey transects: there are six survey transects that reach from land to sea at the Olkiluoto site. The survey transects survey the properties of soil and vegetation in land and sea, and in their transitional zone. The length of transects vary from 360 m to 970 m and the survey has been conducted at 25 m intervals. The size of the survey plots is 4 m × 4 m except the tree stand, where the study is done within a radius of 20 m. The survey plots and their surroundings are photographed in four directions and in the middle of the plot. In addition, the vegetation has been photographed in every plot. On the survey plots on land, the soil properties and soil type are studied with drills. The soil type is identified visually and photographed, and the soil thickness has been measured. Also, other soil properties, such as stoniness has been observed. The vegetation survey has been conducted by assessing visually the phase of development of the tree stand, dominating tree species, forest type, species in shrub and ground layer and the distance to the boundary of the polygon (Haapanen et al. 2011: 11-12).

Sea sediments have been surveyed by diving and taking the samples with a tube sampler with a diameter of 8 cm. The sampling interval is 50 m and the samples are sliced into 0-5 cm, 5-20 cm and 20-50 cm layers. In cases where the sea bottom has been hard, only one sample from the surface has been taken. The samples are photographed, described verbally and taken away for the further study. The sea depth has been surveyed by echo sounding in the sea area with a maximum depth of 2 m. The survey interval is 50 m. The areas with a depth of less than 0,7 m is measured manually since the echo sounder cannot record such shallow areas. The results of echo sounding are merged with the depth data of GTK and created a depth model of the study area (Ilmarinen et al. 2009: 8, 10). Open sea ecosystem studies are studied over a long period of time. The area of research contains the sea area adjacent to the Olkiluoto Island and reaches to the 5-6 km from the island. There are 10 monitoring plots in the study area. Various kinds of samplings are done, such as phytoplankton analysis and bottom fauna sampling. In addition, it is monitored water quality with the parameters of cloudiness, visibility depth, suspended solids, electrical conductivity, pH and A-chlorophyll (Haapanen 2005: 12, Sojakka et al. 2018:

32, app. E). The purpose of the research is to study the environmental impacts of cooling water discharge site of the nuclear power plant (Turkki 2015: 56).

4. Sources and use of open spatial on characterisation of the surface environment

4.1 INSPIRE directive and open spatial data

According to European Environment Agency (EEA) (INSPIRE 2011), the objective of the EU INSPIRE (Infrastructure for Spatial Information in Europe) directive is to promote European public authorities by providing relevant, unified and high-quality geographic information supporting policies and activities that have impact on the environment. The requirement of the directive is that members of EU share spatial data themes through service network. NLS (Mikä… 2020) states that INSPIRE directive enables interoperability of spatial data across organisations and state borders since many environmental impacts are transboundary, such as air and water quality. Each member of EU forms and maintains national spatial data infrastructure. It has been jointly agreed that accessible spatial data and spatial data services, their descriptions and technical implementation, and the principles and processes for accessing and using the data, are produced with uniform methods. The INSPIRE directive has come into effect on 15.5.2007 and its implementation will progress in stages until 2021. The object is that spatial data sets and services are interoperable, the data is in joint use and uniformly described and open for all users. Interoperability enables combining spatial data as new data, joint use and unified descriptions facilitate discovering and utilising other organisations' data. Open spatial data enables to discover and access the data everyone. Open spatial data is accessible through open application programming interface (API). API is technical user interface that connects to server that provides for open spatial data and enables user to access the data. The use of API requires an application supporting interface solution, which can be GIS software or browser application. Open API provides open spatial data for public use (SYKE:

SYKEn avoimet… 2019). API enables users to obtain spatial data that is up-to-date directly from producers (City of Jämsä: Kartasto… 2020).

The use and availability of open spatial data has increased globally, especially in the public sector. In Finland, many public administrative organisations have opened their own map and spatial data services for public use as well (Rainio 2012: 12-13; Ahola-Rainio et al. 2014: 1). Poikola et al. (2010: 11-12, 22) add that the data owned and managed by public administration is extensive and valuable both financially and societally. Due to the development of the technological and communal aspects of the internet, there are plenty of new possibilities and practices for accessing open spatial data. The use of open spatial data has benefited, for example, business and the competitiveness of companies: it increases public accountability, internal efficiency, and creates new markets and innovations. In addition, open spatial data can be utilised in many other fields, such as research, education, applications and process automation.

4.2 The spatial data services used in the study

In this section the spatial data services that have been used in the model characterisations are introduced in tables. The sources have been selected for the model characterisation according to diversity of the open spatial data they supply and the reliability of the producers. The National Land Survey of Finland (NLS) (Table 1.) provides open spatial data in its Open data file service. The Open data file service provides versatile spatial data products in different scales.

Table 1. Information on the open data file service of the National Land Survey of Finland (NLS: File… 2019).

Spatial data service	NLS
Web/download service	Open data file service
Spatial data products	Background maps, basic raster maps, cadastral index maps, control points, elevation models and zones, general maps, hillshades, laser scanning data, map sheet grid, municipal divisions, orthophotos, place names, topographic databases and maps
License	Creative Commons Attribution 4.0 International Licence
Link to the download service	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=fi

Finnish Environment Institute (SYKE) and the Centre for Economic Development, Transport and the Environment (ELY Centre) provide open spatial data files on SYKE's websites. SYKE has multiple download services that provide material (Table 2.) (SYKE: Avoin… 2019; SYKE: Ladattavat… 2019).

Table 2. Information on SYKE's open spatial data services (Hertta ©… 2019; SYKE: Avoin… 2019; Vesikartta: Vesien… 2019)

Spatial data service	SYKE	SYKE	SYKE
Web or download service	List of data file packages	Vesikartta service	VALUE tool
Spatial data products	Town planning, residential areas, CORINE land cover and land cover change, phenology, hydrological observation plots, flood areas, satellite images, nature conservation areas, groundwater basins	The quality of Finnish water systems (the sea, lakes and rivers)	Catchment area of a river or lake
License	Creative Commons Attribution 4.0 International License	Creative Commons Attribution 4.0 International Licence	Creative Commons Attribution 4.0 International Licence
Link to the download service	https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot	http://paikkatieto.ymparisto.fi/vesikarttaviewers/Html5Viewer_2_11_2/Index.html?configBase=http://paikkatieto.ymparisto.fi/Geocortex/Essentials/REST/sites/VesikarttaKansa/viewers/VesikarttaHTML525/virtualdirectory/Resources/Config/Default&locale=fi-FI	http://paikkatieto.ymparisto.fi/value/

Geological Survey of Finland (GTK) provides Finnish open spatial data files in its Hakku service that contains regarding Finland's geological features. (Table 3.) (Hakku: Tietoa palvelusta 2019).

Table 3. Information on the GTK's Hakku service (Hakku: Portti… 2019).

Spatial data service	GTK
Web or download service	Hakku
Spatial data products	Geochemical and geophysical features, aerial photographs, anomaly maps, bedrock maps, mineral deposits, acid sulphate soil maps, glacial landforms, mines and topsoil maps
License	GTK Open Licence
Link to the download service	https://hakku.gtk.fi/fi/locations/search

4.3 The relevance of surface environment in the planning of the repository

When planning the repository for the spent nuclear fuel, there are many subjects in the surface environment that can be represented by open spatial data. The proper description of surface environment is important in order to produce models for the future development of the surface environment and radionuclide transport (Ikonen et al. 2013: 63). Helin & Ikonen (2009) list that these subjects are, for example, soil types, topography, land use, biotopes, water systems, bedrock and climatic zones. This section discusses the subjects that are also represented in the model characterisation and their properties that influence surface environment, and thus are taken into account in safety case and in the site description (Posiva Oy 2011; Posiva Oy 2012b). The significance of the subjects in the environment is also discussed. Krebs (2014: 2, 4) states that the Earth forms one large ecosystem as the biosphere includes all ecosystems and their biotic communities and abiotic environments. Kaihovaara et al. (2016: 3) add that ecosystems are not only independent systems but also interactional and dependent on other ecosystems. They also adapt to changes in the environment.

4.3.1 Soil

According to Korhonen et al. (1974: 11), peat and gyttja are organic soil types that have formed from the remains of dead plants with variable degrees of decomposition. Turveteollisuusliitto (Mitä on… 2019) states that peat contains at least 75% organic matter, whereas the main matter of gyttja is mineral soil, but it also contains over 20% of organic matter remains (Korhonen et al. 1974: app. 1/6). Virkkala (1972: 14) mentions that usually gyttja occurs under peat layers as variable layers. Fine-grained soils, clay and silt, are very fine mineral soils. The grain size of clay is under 0,002 mm and silt under 0,06 mm (Ronkainen 2012: 11). According to Isotalo et al. (1982: 22), clay and silt occur in areas that have been covered by glacial meltwater. Depending on the conditions of stratification, clays and silts occur as layers or homogenous deposits. Thick clay soils are common in southwest Finland the thickest layers being 50-60 m. Clay soils occur in the coastal areas of southern Finland and Ostrobothnia as well (City of Helsinki 2007: 10). Isotalo et al. (1982: 22-23) state, that sand and gravel are considered as coarse-grained soils that have been formed during the retreat of the continental glacier. Coarse-grained soils often form geological formations that stand out from their surrounding environment, such as eskers and deltas. The grain size can differ even within the same formation due to the conditions during formation. Coarse-grained soils are unevenly distributed in Finland. Till is the most common soil type in Finland the proportion being 60% of the area of the country. Till has formed during the latest glaciation over 10 000 years ago. The movement of the glacier borrowed matter from bedrock and soil and mixed them together, and thus, all soil types occur in till. Often, one soil type is more abundant than others, in which case the till can be called, for example, silty till, sandy till or gravelly till. Sharp-edged rocks of various sizes covered by a fine fraction are characteristic of till. The most common till type is silty till (Isotalo et al. 1982: 15, 24). Till occurs in various formations, the most often as basal till that follows the topography of bedrock (Isotalo et al. 1982: 24).

According to Heikkinen (2000: 48), permeability of till-derived soils depends on the soil type. For example, silty till adsorbs water well, in which case the permeability is low. Gravelly till, in turn, has good permeability. Altogether, lateral and hummocky moraines contain coarse, washed superficial till that is permeable to water. However, organic soils have very poor bearing capacity (Ikävalko & Huitti 2008: 1). According to Turveinfo (Tiivisturvetta… 2019), peat has an excellent water retention capacity and low permeability, which makes it a good material for retaining harmful substances, for example, in the foundations and surface structures of landfill areas. Due to high cation exchange capacity, heavy metals bind well to peat. Clay and silt have poor bearing capacity, high frost susceptibility and contractibility, and thus demand piling and stabilisation of the base in construction work (Ikävalko et al. 2008: 1). Hämäläinen (2017: 10) mentions that sandy clay is the most suitable clay type for construction work. Sulphidic clay soils are the least suitable type since the soil encountering air, sulphide oxidises to sulphate forming sulphuric acid. Instead, clay and silt are suitable soil types for cultivation. Coarse silt is loose and porous, and therefore it both has high permeability and adsorbs water well. Fine silt is soft, and it adsorbs nutrients well. As for clay soils, sandy clay and heavy clay are best suited for cultivation (Hirvonen & Koski 2016: 8). Heikkinen (2000: 48) adds that clay minerals adsorb detrimental elements, for example heavy metals, effectively.

According to Turveteollisuusliitto (Mitä on… 2019) organic soils are formed of organogenic matter in the areas where climatic conditions are optimal for alternation of enough high and low temperature. Heikkinen (2000: 11) adds that organic soils have very low permeability due to the high amount of organic matter they contain. Warm temperature ensures the fast growth of plants and low temperature slow microbiological decomposition. As a result, mires are formed to this kind of areas (Turveteollisuusliitto: Mitä on… 2019). Mires, and thus peat and gyttja as well, cover a third of Finland's area. There are different types of mires depending on the prevailing vegetation, humidity conditions and topography (Isotalo et al. 1982: 19). Areas covered by fine-grained soils, clay and silt, are nowadays commonly used as croplands. Often, clays and silts occur under peatlands due to their low permeability. Thus, mire vegetation is common in these areas as well (ELY Centre: Pohjois-Pohjanmaan… 2014; Kaiva: Suomen… 2019). Also, according to the City of Helsinki (2007: 10) meadow vegetation and herb-rich forests are characteristic to clay and silt soils. Due to coarse-grained soils' high permeability the soil is dry. Thus, the vegetation occurring on it is characteristic to dry areas as well. Typical vegetation contains mostly of pine and heath (Isotalo et al. 1982: 23). Vegetation on till-derived soils depends on the nutrient content of the soils, moisture conditions, brightness, topography and the stage of tree succession. Usually, the vegetation is a mix of several vegetation types. For example, if the till-derived soil contains fine-grained mineral matter, it has low permeability and thus the dominant type of forest is moist heath forest or forest with rich grass-herb vegetation. In the areas of coarse till with no fine-grained mineral matter, the soil is dry and thus the dominant forest type is dry heath forest (Mäkinen et al. 2007: 18). Open spatial data of Finnish soil is provided in GTK's Hakku service, where data on soil and its features are available versatilely on multiple scales (Hakku: Portti… 2019).

4.3.2 Biotopes

Raunio et al. (2008: 10) divide Finland's biotopes into the following main groups: Baltic Sea and its coasts, inland waters and inland coastal areas, mires, forests, open stands and fells. In addition to these biotopes, Tuominen et al. (2001: 14) mention more biotopes: rocks and cobble deposits, wetlands, croplands and built-up environments. Each biotope has characteristic environmental features and biota, and with these features they can be distinguished from other biotopes. Environmental features are, for example, soil, climate and topography. The characteristics of biotas are the structure and composition of the biotic community. Biotopes may vary in size and internal variation, and different types can be classified according to the general features of vegetation and flora, and in some cases fauna as well. Also, abiotic factors have an effect. These factors are climate, acidity and nutrient content of soil and bedrock, topography and hydrology (Kontula et al. 2008: 11).

Ikonen et al. (2013: 68) define open sea as sea area, where the water exchange is high and coastal areas do not directly affect the area. The water depth is at least 10 m and, sea bottom is completely aphotic. According to Tuominen et al. (2001: 17), the Baltic Sea's brackish water areas along with its islets and reefs are characteristic of the sea biotopes. The sea shore biotopes, in turn, include open stands, rocks, beaches and dunes bordered by the sea. The water depth is commonly less than 10 m, and the salinity is lower than in the open sea (Tuominen et al. 2001: 20-21; Ikonen et al. 2013: 72). Due to the brackish water of the Baltic Sea, both freshwater and marine species can be found therein. The most diverse habitats and the most extensive primary production in the northern Baltic Sea are located from the archipelagos of Stockholm and Åland to the Finnish Archipelago Sea and southern coast of Finland. These areas include numerous of diverse islands, shallow and sheltered bays, reed beds and both rocky and sandy beaches. The composition of the sea bottom defines the species found there: the biota varies according to whether the bottom consists of soft mud, sand or rock. Other factors affecting the biota are the muddiness and brightness of the sea water. For example, vascular plants favour a soft and bright bottom whereas algae favour a hard bottom. Only animals live in the dark sea bottom. Mussels are the most common species in the dark and soft sea bottom (Lundberg et al. 2012: 8). Biotopes of inland waters include lakes, ponds, springs, streams and rivers. Their surrounding areas – inland coast biotopes – contain rocks, islets and reefs (Tuominen et al. 2001: 23). There are only a few lakes in the coastal areas of Finland, but these areas are rich in rivers flowing through them. In terms of landscape and biodiversity, these areas are significant (Luonnontila 2014). The flora and fauna living in inland waters are diverse: the biotope provides important habitats especially for fishes, *Odonata* and *Trichoptera*. In addition, many molluscs, birds, mosses and vascular plants thrive in inland waters, particularly in lakes and ponds. Inland waters are very vulnerable to environmental changes due to their small area and predominance of shallow water and coastal areas. Thus, changes in the surrounding environment and catchment area have major impacts on the aquatic ecosystem (Luonnontila 2014).

Forests are the most significant biotope type in terms of area and number of species (Luonnontila 2014). According to Tuominen et al. (2001: 30-31), forest biotopes can be roughly divided into three categories according to their prevailing tree species: coniferous forests, deciduous forests and mixed forest. Luke (Suomen… 2012) defines forests more detailed as areas where the tree canopy density is over 10%, and the area has to be over 0,5 hectares and the tree stand has to reach at height of at least 5 m. The most common type of forest is pine-dominated forests with the proportion 67% of all Finnish forests, whereas spruce-dominated forests cover 22%, birch-dominated woods 11% and other deciduous forests 1%. Many habitats contain forest stands with naturally only one tree species. Such forests account 52% of all forests. Slightly mixed forests account for 22% and true mixed forests 10% of all forests (Luke: Suomen… 2012). According to the City of Tampere (2019), pine-dominated forests occur in barren and dry sandy soils, whereas spruce-dominated forests occur on till-derived soils, since spruces thrive in nutrient-rich and moist soils. The roots of spruces occur near the surface and thus spruces are not common in sandy areas. Instead, till adsorbs water well and contains more nutrients than sand. Deciduous forests commonly contain birch, aspen and rowan, and they thrive in various conditions. Herb-rich forests thrive in nutrient and humus-rich soils, and may contain hardwoods, such as oaks, maples and lime trees. Forests are used for a variety of purposes, such as wood production, fuel, construction work, recreational use, nature conservation, tourism and landscape management. Commercial forest lands are also utilised as building lands and traffic routes. In addition, forests can function as carbon sinks if the annual growth rate is higher than its depletion. Carbon dioxide binds both to the soil and vegetation of forests (Luke: Suomen… 2012).

According to Luonnontila (2014), mires are the second most common biotope type, which are defined as environments where the ground is covered by a layer of peat or the proportion of peatland vegetation is at least 75% of all vegetation. By geological definition, the thickness of the peatland must be at least 30 cm. If the peat layer is thinner, the soil is considered as mineral soil (Vanhatalo et al. 2015: 10). Mires can be differentiated from forests according to the surface soil type and the proportion of mire vegetation of all ground cover. In mires, the surface soil is peat, whereas in forests it is mineral soil, and the proportion of mire vegetation must be over 75% of all vegetation (MetsäVerkko: Metsäekologia… 2019). According to Tuominen et al. (2001: 37-38), the tree canopy density in open mires is less than 10%. If the density is over 30%, the biotope is considered as forest biotope. Altogether, the boundary between the mire and forest biotope is gradual. Only few species of flora and fauna occur in mires; the most common species are mosses and vascular plants (Luonnontila 2014).

According to Tuominen et al. (2001: 31-33) open stands in rocky areas and cobble deposits are biotopes, where tree canopy density is over 10% but less than 30%. The thinness of tree stands can be permanent and depend on site factors, such as rocky areas. It can also be temporary due to, for example, forest fires, storms or forest management. Permanent open stands are rare in southern Finland; this biotope occurs naturally only in rocky areas. Temporary open stands are more common due to forest management. Rocks and cobble deposits are treeless areas or areas where tree canopy density is 1-10%. The sparse tree stand is usually permanent in these biotopes due to site factors. Also, forest felling causes the environment to be rocky and treeless since the regeneration of forests is very slow (Tuominen et al. 2001: 46). According to SYKE (Kalliot… 2019), rocks and cobble deposits occur most commonly in the southern coast of Finland. Characteristic to rocks and cobble deposits is a mosaic pattern of rocky areas alternating with areas of dense forest. In the hollows of rocks there may occur peat-covered areas and ponds. Cobble deposits are often related to ancient shores, coastal areas of water systems and weathering areas of fells (Tuominen et al. 2001: 46). This kind of biotope provide habitats for several species of flora and fauna since different species favour different types of rocks. Topography, lighting and moisture conditions have a significant impact on vegetation as well. Often, undergrowth is the most diverse, and sometimes the only, vegetation type on rocks and cobble deposits. For example, species of moss and lichen are more common in this biotope than in other biotopes (Kontula et al. 2018: 574; SYKE: Kalliot… 2019).

Wetlands are humid areas near water systems that are covered by water most of the year. Characteristic to this biotope are aquatic vegetation and hygrophytes. Wetlands can occur naturally, but they can also be set up artificially. With wetlands it is possible to preserve flood areas and equalise the flow rates of water system areas. Wetlands have also many environmental benefits: they clear runoff waters, adsorb nutrients and solid matter and in that way reduce the eutrophication of water systems. Wetlands also reduce erosion and damage caused by floods. From the perspective of biodiversity, wetlands provide habitats for various kinds of flora and fauna. For example, aquatic birds favour wetlands as nesting sites (Ymparisto: Monivaikutteiset… 2019).

Croplands are diverse biotopes where natural ecosystems have been put to agricultural use by humans. Most of the Finnish croplands are in Southwest Finland and South Ostrobothnia (Luonnontila 2014). Croplands occur commonly near water systems (Tattari et al. 2015: 9). Agriculture is a significant polluter, particularly in catchment areas with plenty of croplands. More than 50% of the nutrient load ending up in the water systems is estimated to originate from agriculture (ELY Centre: Maatalouden… 2013).

Built-up environments are defined as centres of population, and industrial and traffic areas as well as parks, courtyards and gardens (Luonnontila 2014). This biotope is common almost in the whole country, but the proportion is largest in southern Finland and often coastal areas of water systems (Luonnontila 2014). Built-up environments are diverse biotopes: for example, parks, courtyards and gardens provide habitats even for many demanding species, such as beetles, mushrooms, butterflies, hymenoptera and diptera. Population centres are common habitats for beetles, butterflies, mushrooms and lichens. Also, invasive species are common. The biodiversity is the result of disturbances caused by human activity, which maintain the early phases of succession (Luonnontila 2014). Open spatial data on biotopes is available, for example, in SYKE's CORINE Land Cover 2018, in the list of data file packages, GTK's Hakku service, and in NLS's Open data file service. (Hakku: Portti… 2019; NLS: File service… 2019; SYKE: Ladattavat… 2019).

4.3.3 Aquatic environments

According to SYKE (Suomen vesien… 2019) the water quality in most of the Finnish water systems is good or excellent when observing the ecological condition. The ecological factors include, for example, the condition of algae, benthic fauna and fish stock. The ecological condition indicates the human impact in the water systems: the better the water quality, the less human impact (Ymparisto: Pintavesien… 2019). SYKE (Suomen vesien… 2019) adds, that the most significant factor influencing on the quality is eutrophication. The conditions of inland waters have not changed significantly since the year 2013, however, there has been observed a slight local improvement. The condition of the Finnish coastal areas is mostly sufficient, although the condition of the Gulf of Finland has improved due to the water-protective measures. According to Ymparisto (Pintavesien… 2019) the water quality can also be classified according to physical and chemical conditions, which include the concentration of harmful or dangerous substances. The water quality is categorised as good or worse. The quality factors are, inter alia, nutrient load, pH, visibility depth and oxygen concentration (Alahuhta 2008: 9). Alahuhta (2008: 23-24) states that aquatic flora and fauna indicate the water quality, and their composition depends on several quality factors. For example, the increased nutrient content in water may increase the biomass of phytoplankton, and thus leads to eutrophication. Also, the decrease of benthic fauna may indicate the decrease of oxygen concentration of water.

According to Posiva Oy (2014: 389) the water depth can be divided into aphotic and photic zones according to the amount of light. The Helsinki Term Bank for the Arts and Sciences (2019) defines aphotic zone as water layer where the amount of light is too low for photosynthesis. The photic zone is water layer where the amount of light is sufficient for photosynthesis, and it occurs on top of the aphotic zone. The euphotic zone is the top layer of photic zone where the amount of light is most abundant and sufficient for photosynthesis. Posiva Oy (2014: 389) states that the photic zone reaches approximately to a depth of 6 m in the marine coastal areas and to 2 m in lakes. The thickness of euphotic zone is approximately 3 m in marine coastal areas and 1 m in lakes. The diversity of aquatic flora and fauna depends on the amount of light: the diversity is higher in photic areas compared to the deep aphotic open sea environment. In aphotic zone the primary production is based on phytoplankton concentrated in the euphotic zone. Instead, photic bottom environments enable habitats also for aquatic vegetation and algae, and thus increases the diversity as aquatic fauna is dependent on the flora. The diversity increases from open sea to coastal environment (Posiva Oy 2014: 70, 80).

SYKE provides open spatial data on aquatic environments. Water quality of sea areas and inland waters are available at Vesikartta service. Open spatial data on water depth is available at VELMU service and the catchment areas of Finnish lakes and rivers are available at VALUE tool. (SYKE: Ladattavat… 2019; Vesikartta: Vesien… 2019; VALUE tool 2019). LAPIO download service provides open spatial data on Finnish ground water areas at (LAPIO: Ladattavat… 2019). Hertta © service provides information on the quality, flow rate and runoff of the inland water systems. It also contains quality data on groundwater. The data is provided in spreadsheets (Hertta ©: Hertta 2019).

4.3.4 Topography

The topography of Finland is rather low-lying and height differences are small. Due to these characteristics, the climate and vegetation zones are exceptional in various ways. For example, south boreal forest and mire vegetation occur widely in central Finland, and the mid-boreal zone extends far into Ostrobothnia. Also, the northern boreal zone occurring in southern Lapland and pine growing further in the north than spruce in central Lapland are exceptional. Due to land uplift, forests are young in coastal areas, whereas some forests in eastern Finland have produced over 100 generations of trees in the same spot (Ministry of the Environment 2007: 16-17). NLS provides multiple open spatial data on topography files in its Open data file service (NLS: File service of open data 2019).

5. Model characterisation

This section introduces the model characterisations made in the Olkiluoto, Hanhikivi and Kivetty areas using only open spatial data. The model characterisations represent the features of surface environment, such as terrain, soil types, vegetation, land use and properties of water systems. The topics have been selected according to the earlier surface environment surveys and characterisations conducted by Posiva. In order to obtain extensive information on the usability of open spatial data, the characterisation has been made on the three sites. Each site has its characteristic features, and thus every model characterisation provides unique information.

5.1 Terrain

Terrain maps created of the Olkiluoto (Figure 1.), Hanhikivi (Figure 2.) and Kivetty (Figure 3.) sites represent an overview of the sites. The details on the information on used data, sources of the materials and modifications of the maps are represented in Table 4.

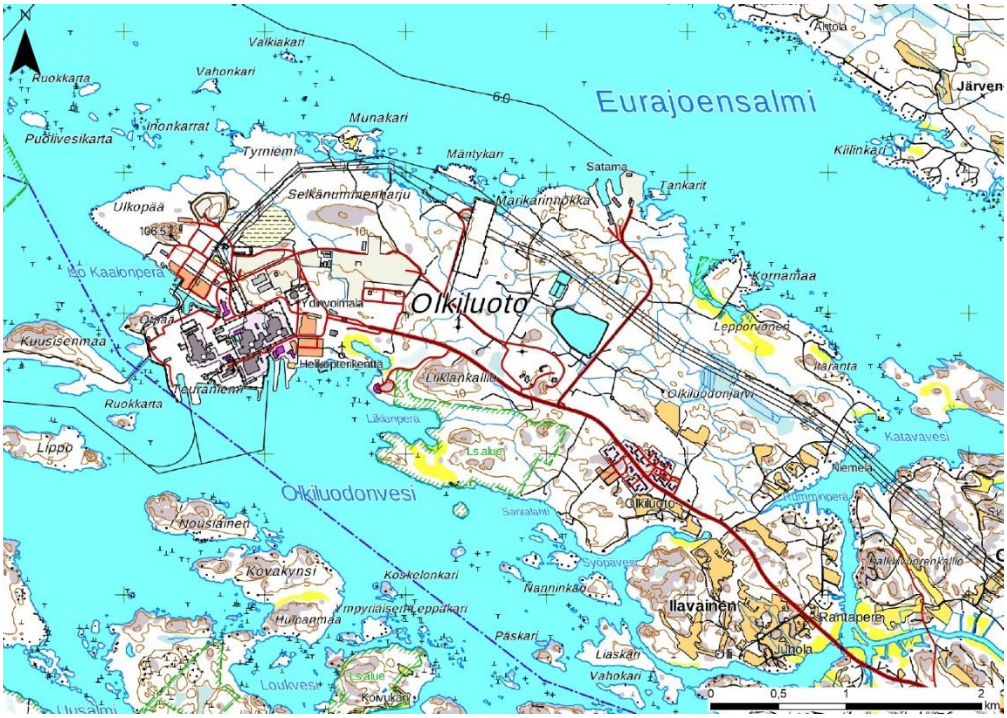

Figure 1. Terrain map of the Olkiluoto site.

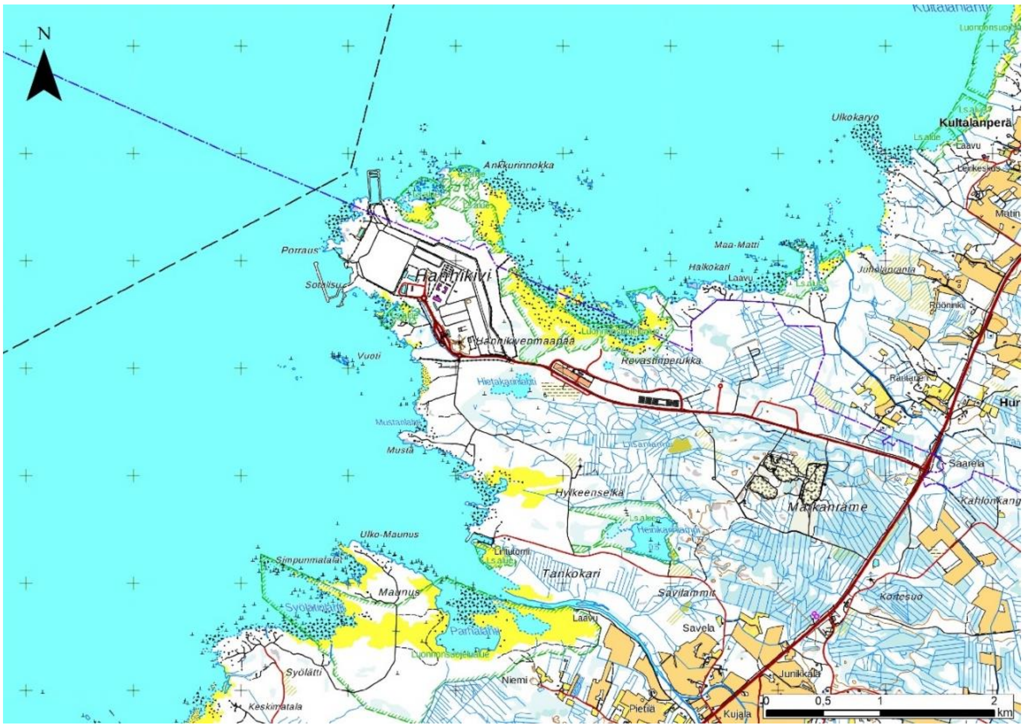

Figure 2. Terrain map of the Hanhikivi site.

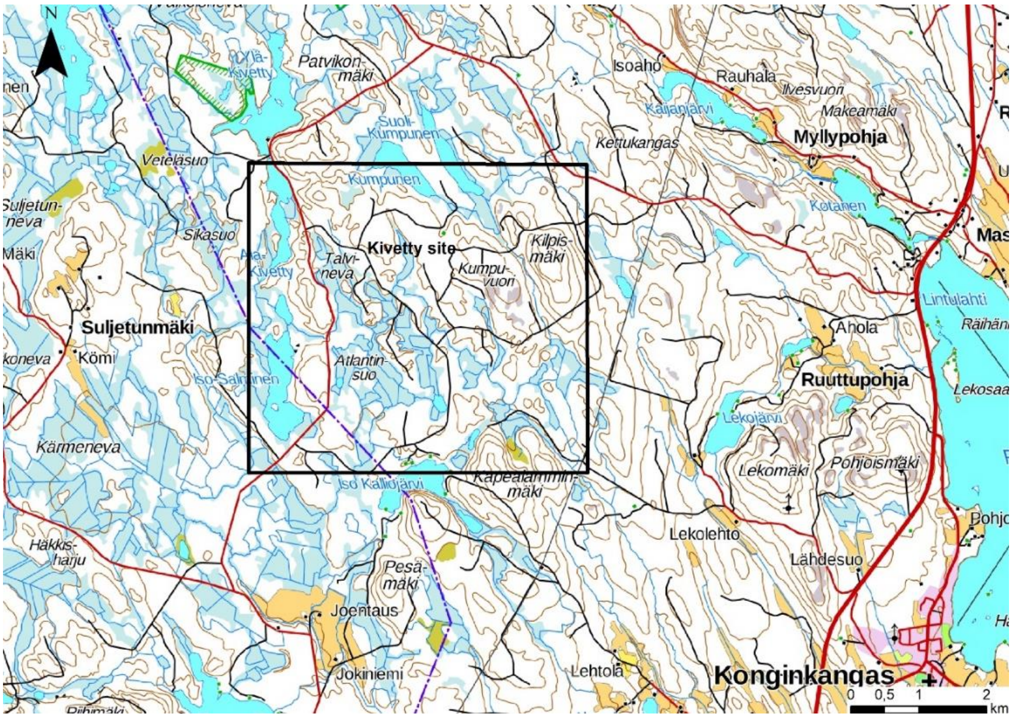

Figure 3. Terrain map of the Kivetty site.

Table 4. Information of the terrain maps of Olkiluoto, Hanhikivi and Kivetty sites.

	Olkiluoto site	**Hanhikivi site**	**Kivetty site**
Spatial data service	NLS		
Web or download service	File service of open spatial data		
Data	Topographic map raster 1:50 000		
Link to data	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en		

The terrain maps of the Olkiluoto (Figure 1.), Hanhikivi (Figure 2.) and Kivetty (Figure 3.) sites provide a general overview of the sites and their characteristics. The data is detailed and provides versatile information on the sites, as there are displayed the place names, roads, industrial areas, residential areas, croplands, water areas, wetlands, mires, rock exposures, altitude contours and nature conservation areas. In summary, the open spatial data used is suitable for representing the terrain of the Olkiluoto, Hanhikivi and Kivetty sites. With the landmarks displayed on the maps the user of the map can use them, for example, in navigation.

5.2 Soil types and sea sediments

The maps are representing superficial soil types occurring at the Olkiluoto (Figure 4.), Hanhikivi (Figure 5.) and Kivetty (Figure 6.) sites. To bring more information on the maps hillshade data has been added as well as polygons displaying power lines, roads and buildings on each map, and sea sediment data on maps representing the Olkiluoto and Hanhikivi sites. The inland location of the Kivetty site restricts the use of sea sediment data in the map. Also, the map representing soil thickness is not included into this study, since the only data available is very coarse and is not suitable for representing such small areas as the Olkiluoto, Hanhikivi and Kivetty sites. The data is more suitable for representing regional differences in soil thickness in large areas. The soil thickness can be roughly estimated by observing other features represented by open spatial data, such as topography, and draw conclusions from it. The details of the information of used data, sources of the materials and modifications of the maps are represented in Table 5. (Olkiluoto site), Table 6. (Hanhikivi site and Table 7. (Kivetty site).

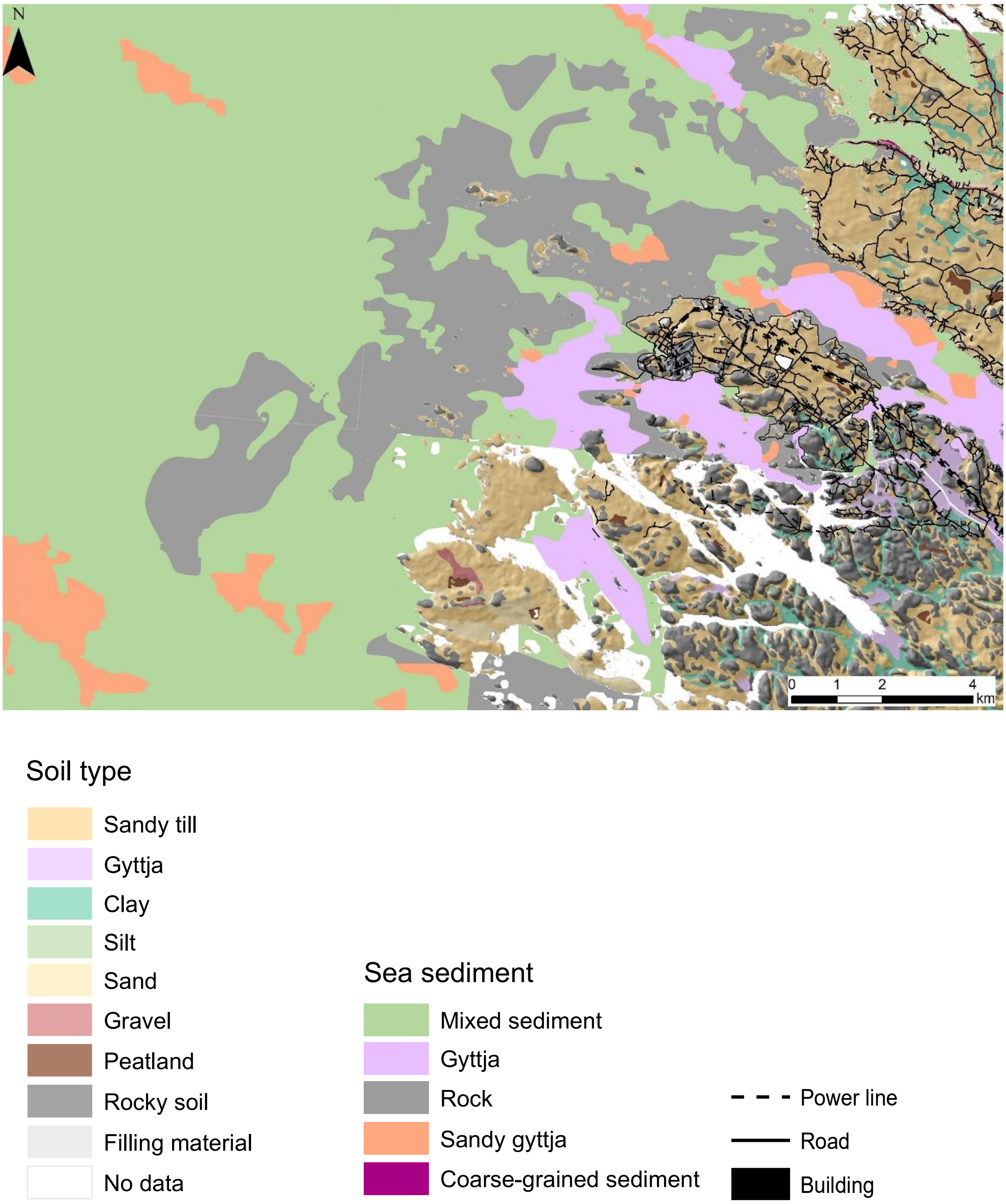

Figure 4. Soil type and sea sediment map of the Olkiluoto site.

Table 5. Information of the soil type and sea sediment map of the Olkiluoto site.

Spatial data service	GTK	NLS
Web or download service	• Hakku service	• File service of open data
Data	• Superficial deposits 1:20 000 • Seabed substrate 1:100 000 • Seabed substrate 1:250 000 • Seabed substrate 1:1 000 000	• Shaded relief 32 m (Hillshade) • All features (Topographic Database)
Modifications	• Rocky soil, stony soil and outcrop combined to “Rocky soil” • Gyttja and gyttja clay combined to “gyttja” • Sand and fine sand combined to “sand” • Sedge peat and sphagnum peat combined to “peatland” • Water areas turned into “No data” • “Mud” from Seabed substrate data turned into “Gyttja”	• Transparency of the soil type layer increased by 40%
Link to data	https://hakku.gtk.fi/en/locations/search	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en

The results indicate that the map representing soil types and sea sediments of Olkiluoto Island (Figure 4.) is correspondent to the previous studies of Posiva. Sandy till and sand occurring in the island, and gravel occurring in the vicinity of the island, can be considered as mixed or coarse-grained soil types. On the other hand, sand can be considered also as fine-grained soil depending on its grain size. Silt occurring in the surrounding areas of the island is counted as fine-grained soil. In addition, according to the soil type data there occur clay, peatlands and rocky soils on the island and this supports the results of the previous studies. According to the sea sediment data used in the map, sea sediments include mixed sediments, gyttja, sandy gyttja, rock and coarse-grained sediment. It has not been defined in the sea sediment data what mixed or coarse-grained sediments are composed of. However, according to the EEA (Littoral mixed sediments 2019) mixed sediments are poorly sorted and composed of varying sorts of matter. Mixed sediment can consist of, for example, gravelly or sandy muds, or they can be stony sediments with gravel, sand and mud. Coarse-grained sediments are composed of coarse sand, gravel and stones (EEA: Sublittoral… 2019). Thus, it is observed that mixed sediment and coarse-grained sediment are comparable to some of the sea sediment types studied by Posiva, however, the open data is more simplified than the former results. The hillshade data represents the relief of terrain but no exact information on the elevation, such as the height above sea level is included. However, when comparing the relief displayed in the soil type and sea sediment map to the terrain map of the Olkiluoto site (Figure 1.), it can be observed that the relief matches with the altitude contours on the terrain map. Power lines, roads and buildings are represented similarly in both maps as well.

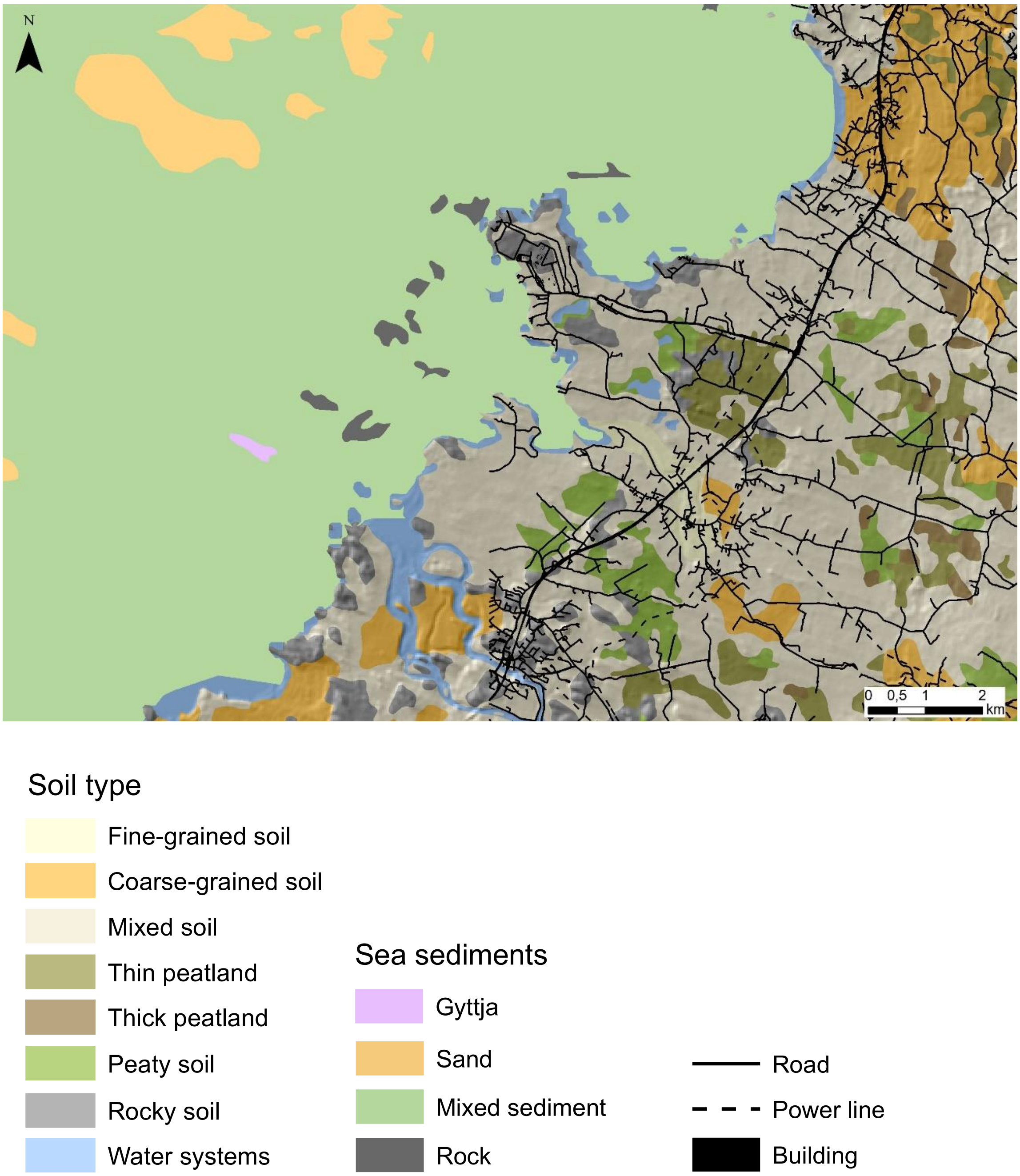

Figure 5. Soil type and sea sediment map of the Hanhikivi site.

Table 6. Information of the soil type and sea sediment map of the Hanhikivi site.

Spatial data service	GTK	NLS
Web or download service	• Hakku service	• File service of open data
Data	• Superficial deposits of Finland 1:200 000 (sediment polygons) • Seabed substrate 1:100 000 • Sea substrate 1:1 000 000	• Shaded relief 32 m (Hillshade) • All features (Topographic Database)
Modifications	• Rocky soil, stony soil and outcrop combined to "Rocky soil" • "Mud" from Seabed substrate data turned into "Gyttja"	• Transparency of the soil type layer increased by 50%
Link to data	https://hakku.gtk.fi/en/locations/search	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en

When observed the soil type and sea sediment map of the Hanhikivi site (Figure 5.) it can be noted that the prevailing soil type at the site is mixed soil. There are also areas covered with rocky soil, peaty soil, thin peatland, thick peatland, fine-grained soil and coarse-grained soil. According to Ronkainen (2012: 9), fine-grained soils are considered as clays and silts. Coarse-grained soils are considered as sands, gravels, stones and boulders. Mixed soils are, for example, tills that consist of various soil types. Thus, it is concluded that the soil in the Hanhikivi site and its surrounding areas can consist of these soil types. The "Superficial deposits of Finland 1:200 000 (sediment polygons)" data contain detailed information on peatlands in its metadata. In the metadata, peatlands are categorised according to their stage of development and thickness to thick peatlands, thin peatlands and peaty soils. Thick peatland contains over 60 cm of peat, thin peatland contains 30-60 cm and peaty soil 0-30 cm. According to the sea sediment data, the sea sediments in the adjacent sea of the Hanhikivi site consist of mixed sediment, gyttja, sand and rock. The mixed sediments can be assumed to be composed of the same sediments as in the case of the map on the Olkiluoto site: muds with gravel or sand, or stony sediments with gravel, sand and mud (EEA: Littoral… 2019). When observing the hillshade data and shapefiles representing power lines, roads and buildings, it is noted that they are correspondent to the altitude contours and other landmarks on the terrain map of the Hanhikivi site (Figure 2.).

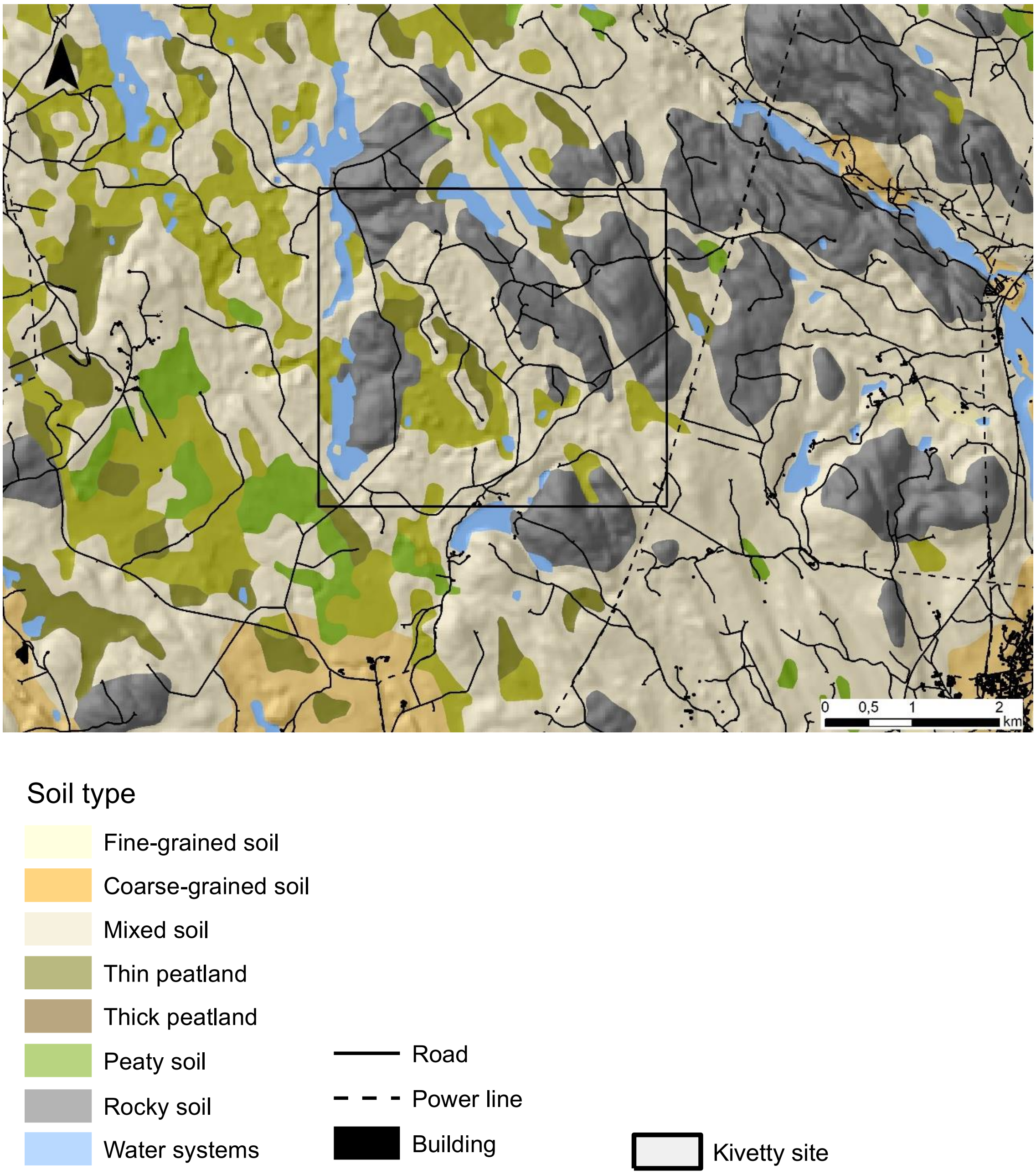

Figure 6. Soil type map of the Kivetty site.

Table 7. Information of the soil type map of the Kivetty site.

Spatial data service	GTK	NLS
Web or download service	• Hakku service	• File service of open data
Data	• Superficial deposits of Finland 1:200 000 (sediment polygons)	• Shaded relief 32 m (Hillshade) • All features (Topographic Database)
Modifications	• Rocky soil, stony soil and outcrop combined to "Rocky soil"	• Transparency of the soil type layer increased by 30%
Link to data	https://hakku.gtk.fi/en/locations/search	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en

The soil type map of the Kivetty site (Figure 6.) shows that the soil is on the area that consists of mixed soil, rocky soil, thin peatland and thick peatland. The hillshade data stands out well on the map. The data is comparable to the altitude contours in the terrain map of the Kivetty site (Figure 3.) as well as shapefiles displaying power lines, roads and buildings. The shapefiles are slightly more detailed compared to the terrain map. When observing the map, it can be noted that the human activity is low in the area.

In summary, the soil types can be represented by open spatial data. The soil type data is rather informative since some of their properties can be deduced, for example, by the grain size. When the grain size is known, it is even possible to hypothesize the vegetation types, which usually occur on certain types of soil. It is also possible to draw conclusions on the vegetation growing on peatland by knowing the thickness of peat layer. For example, according to Isotalo et al. (1982: 23) and Tamminen et al. (2007: 21), pine forests occur on thin peatlands and on coarse-grained soils. When combining multiple sea sediment data together, the sea sediments can be represented, even though they are represented in slightly different way than in the former results of Posiva. Using the data individually does not provide as much information on the sea sediments as using multiple data. Hillshade data and shapefiles displaying power lines, roads and buildings are corresponding to the same features represented on other maps.

5.3 Biotopes and land use

The maps are representing biotope types and land use at the Olkiluoto (Figure 7.), Hanhikivi (Figure 8.) and Kivetty (Figure 9.) sites. To bring more information on the maps, polygons displaying power lines, roads and buildings have been added to each map. In addition, sea depth data has been added to the maps of the Olkiluoto and Hanhikivi sites. The inland location of the Kivetty site limits the use of sea depth data on the map representing the site. The details of the information of used data, sources of the materials and modifications of the maps are represented in Table 8. (Olkiluoto site), Table 9. (Hanhikivi site) and Table 10. (Kivetty site).

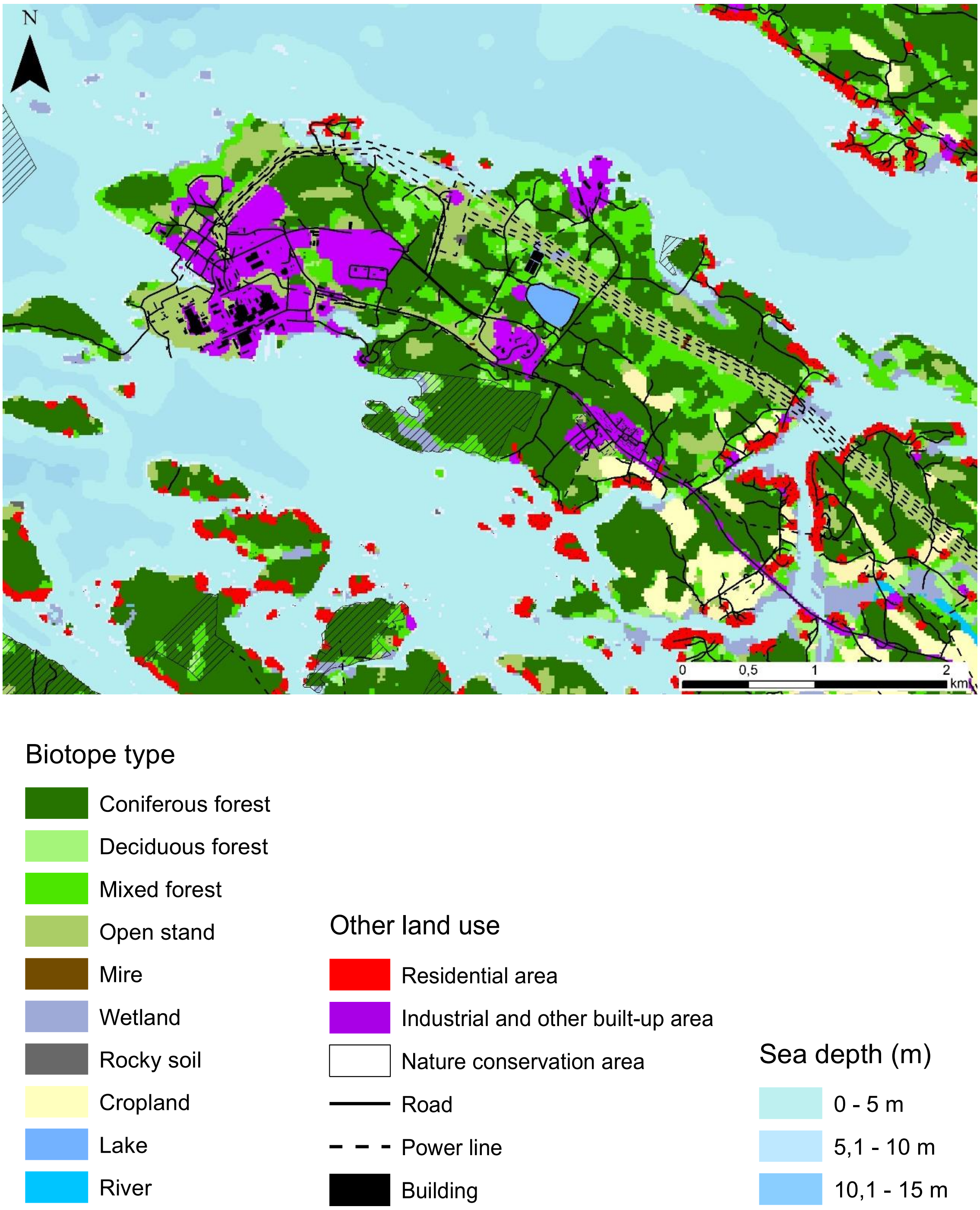

Figure 7. Biotope type and land use map of the Olkiluoto site.

Table 8. Information of the biotope type and land use map of the Olkiluoto site.

Spatial data service	SYKE	NLS
Web or download service	• List of data file packages	• File service of open data
Data	• CORINE maanpeite 2018 20 m • VELMU Syvyysmalli	• All features (Topographic Database) • Topographic map 1:100 000
Modifications	• Residential areas and recreational dwellings combined as "Residential area" • Industrial area, service area, traffic area, harbour area and landfill combined as "Industrial area" • Marine and inland wetlands combined as "Wetland" • Coniferous forests on mineral soil, peatland and rocky soil combined as "Coniferous forest" • Deciduous forests on peatland and mineral soil combined as "Deciduous forest" • Mixed forests on mineral soil, peatland and rocky soil combined as "Mixed forest" • Open stands, open stands on mineral soil, peatland, rocky soil and under the power lines combined as "Open stands"	-
Link to data	https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot/Ladattavat_paikkatietoaineistot	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en

The biotope type and land use map of the Olkiluoto site (Figure 7.) represents biotopes and land use forms at the site and in its surrounding areas and the depth of the sea areas. In addition, power lines, roads, buildings and nature conservation areas are displayed. The biotope types represented on the map are correspondent to the results of the former surface environment studies of Posiva. Observing the map, it can be noted that the prevailing forest type on the island is coniferous forest and the second most common forest type is mixed forest. Deciduous forests grow as small areas around the island. No tree species are specified in the data. However, when the soil type is known, the forest or vegetation type growing on it can be ascertained. For example, it can be observed that the croplands on Olkiluoto Island occur on clay soils when compared the biotope and land use map (Figure 7.) to the soil type and sea sediment map (Figure 4.). In addition, wetlands occur commonly on gyttja when observed the two maps. According to ELY Centre (Pohjois-Pohjanmaan… 2014) clay soils are generally used as croplands, which supports the observation on the maps. In the biotope map, most of the forests grow in areas covered by sandy till, which can be considered as mixed or coarse-grained soil type. According to Haapanen et al. (2011: 24), the characteristic tree species thriving in sandy till are spruce, pine, birch and alder. This supports the previous results that indicate spruce-dominated forests and mixed forests are the most common forest types on the island (Miettinen et al. 2002: 33). Open stands occur mostly in areas with some human activity. On the map it is clearly visible how the area of open stand follows the power lines through the island. Open stands occur also in the areas covered by rocky soil. This can be seen when the biotope and land use map is compared to the soil type and sea sediment map of the Olkiluoto site. The land use forms represented on the map are residential areas, industrial areas and other built-up areas, nature conservation areas, roads, power lines and buildings. It can be observed that the residential areas occur in coastal areas of the island and in the adjacent islands and continent. Industrial and other built-up areas occur mostly at the nuclear power plant site, Posiva site, harbour and accommodation village when the biotope and land use map is compared to the terrain map of the Olkiluoto site (Figure 1.). Also, nature conservation areas, roads, power lines and buildings match those on the maps. These observations correspond with the previous studies that have been conducted, for example, by Ikonen et al. (2013). The sea depth data displays the water depth contours as ranges of five metres. According to Lahdenperä et al. (2011: 7-8), the sea depth near the

Olkiluoto Island varies mostly between 0-10 m but there are also areas where the depth reaches up to 15 m. When observing the sea depths on the biotope and land use map, it can be noted that the depth of adjacent sea is mostly 0-5 m, the second most common areas where the depth is 5,1-10 m and lastly, there are a few areas where the depth is 10,1-15 m. Thus, the data matches the results obtained from the previous studies.

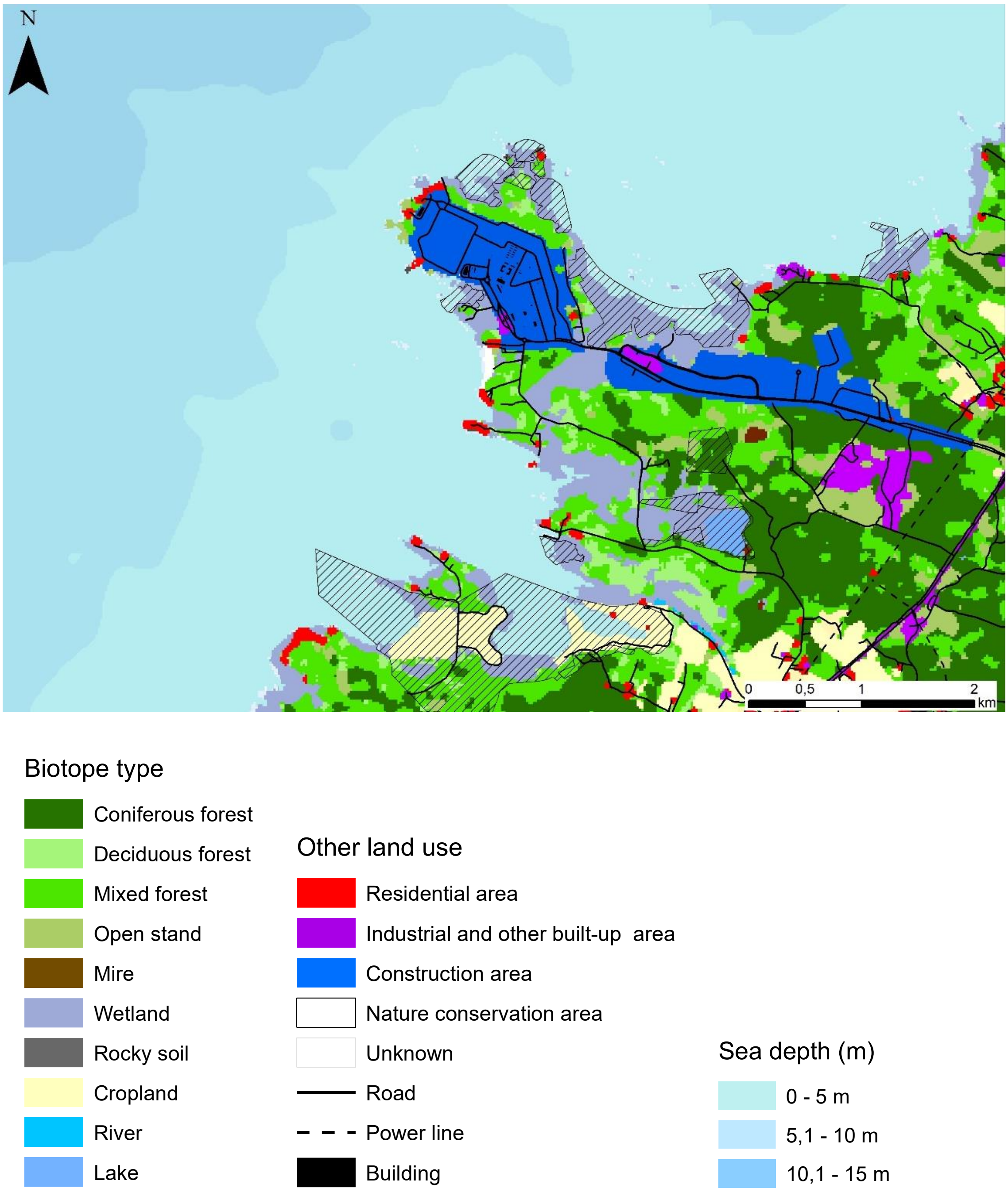

Figure 8. Biotope and land use map on the Hanhikivi site.

Table 9. Information of the biotope type and land use map of the Hanhikivi site.

Spatial data service	SYKE	NLS
Web or download service	• List of data file packages	• File service of open data
Data	• CORINE maanpeite 2018 20 m • Luonnonsuojelualueet: yksityisten mailla • VELMU Syvyysmalli	• All features (Topographic Database)
Modifications	• Residential areas and recreational dwellings combined as "Residential area" • Industrial area, service area, traffic area, harbour area and landfill combined as "Industrial area" • Marine and inland wetlands combined as "Wetland" • Coniferous forests on mineral soil, peatland and rocky soil combined as "Coniferous forest" • Deciduous forests on peatland and mineral soil combined as "Deciduous forest" • Mixed forests on mineral soil, peatland and rocky soil combined as "Mixed forest" • Open stands, open stands on mineral soil, peatland, rocky soil and under the power lines combined as "Open stands"	-
Link to data	https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot/Ladattavat_paikkatietoaineistot	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en

The biotope type and land use map of the Hanhikivi site (Figure 8.) indicates that the dominating biotope type at the site is wetland and the second most common biotope type is mixed forest. Coniferous and deciduous forests and open stands occur only as small areas, but further from the site there are larger areas of coniferous forests. When comparing biotopes to the soil type and sea sediment map of the Hanhikivi site (Figure 5.), it can be noted that the most common soil type at the site is mixed soil, which can be medium- or coarse-grained till. Tree species thriving on such soils are spruce, pine, birch and alder (Haapanen et al. 2011: 24). Open stands occur only as small areas, mainly on rocky soils. Wetlands occur on coastal areas of the site and near water systems, which is characteristic of the biotope type. Croplands occur mostly on fine-grained soil and near water systems, which is, according to Tattari et al. (2015: 9), a common location for croplands. However, according to other maps, there is a small lake at the Hanhikivi site, which is not represented in this data, as it has been represented as wetland. The possible reason may be that the lake is too shallow or overgrown and it is counted as wetland. Other land use forms occurring at the Hanhikivi site and in the surrounding areas are construction areas, residential areas and industrial and other built-up areas. There is also displayed the roads, power lines, buildings and nature conservation areas. Construction areas are large and occur near the roads. Residential areas occur mostly in the coastal areas at the site. When compared the biotope type and land use map to the terrain map of the Hanhikivi site (Figure 2.) it can be observed that land use data matches to the features represented on the terrain map. The sea depth data represents the water depth in the adjacent sea of the Hanhikivi site in the range of 5 m. According to the data, the depth increases from the coastal area’s 0-5 m to 10,1-15 m in the open sea. In the middle, there is an area where the depth is 5,1-10 m.

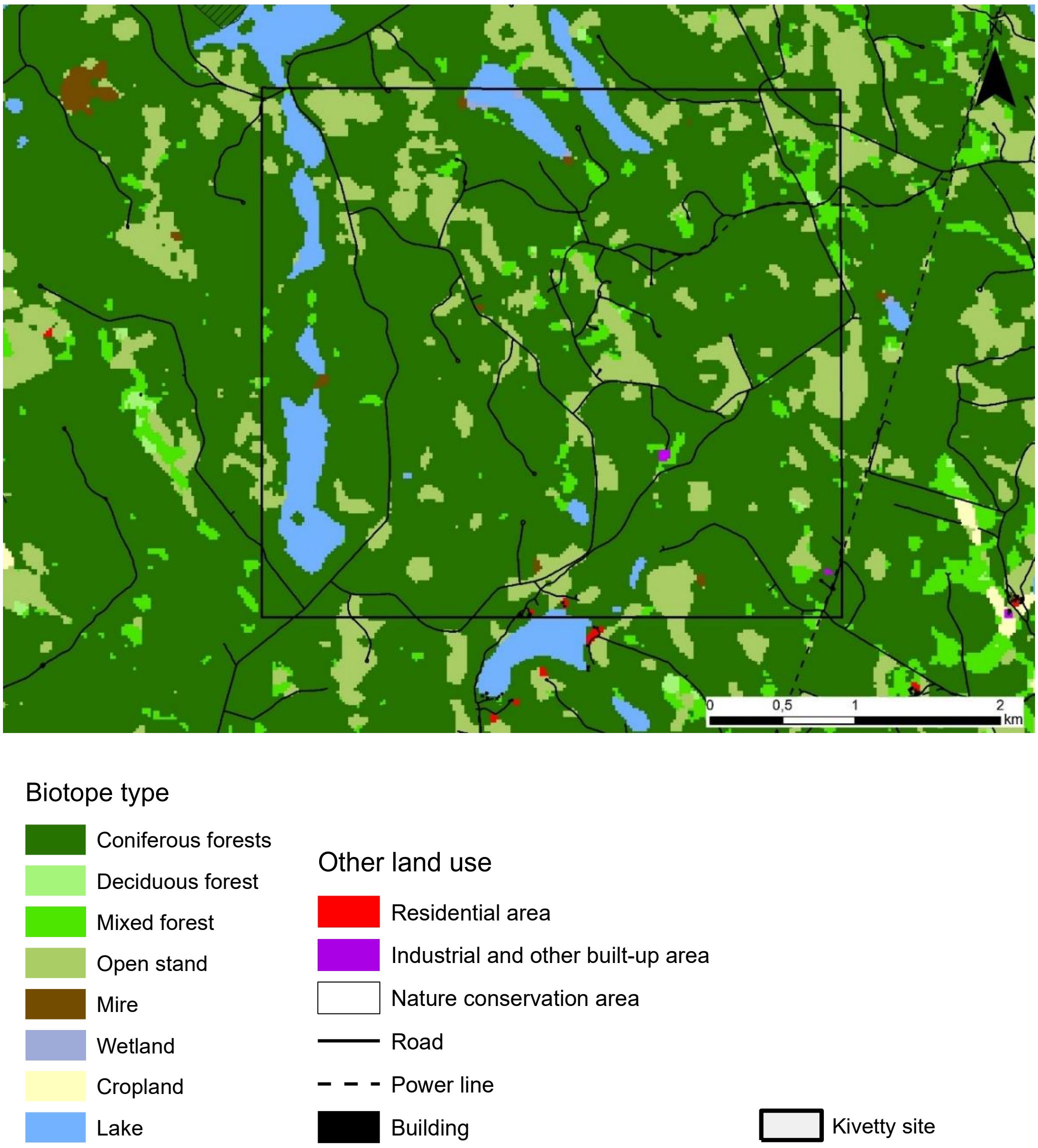

Figure 9. Biotope and land use map of the Kivetty site.

Table 10. Information of the biotope type and land use map of the Kivetty site.

Spatial data service	SYKE	NLS
Web or download service	List of data file packages	File service of open data
Data	• CORINE maanpeite 2018 20 m • Luonnonsuojelualueet: Valtion omistamat	• All features (Topographic Database)
Modifications	• Residential areas and recreational dwellings combined as “Residential area” • Industrial area, service area, traffic area, harbour area and landfill combined as “Industrial area” • Marine and inland wetlands combined as “Wetland” • Coniferous forests on mineral soil, peatland and rocky soil combined as “Coniferous forest” • Deciduous forests on peatland and mineral soil combined as “Deciduous forest” • Mixed forests on mineral soil, peatland and rocky soil combined as “Mixed forest” • Open stands, open stands on mineral soil, peatland, rocky soil and under the power lines combined as “Open stands”	-
Link to data	https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot/Ladattavat_paikkatietoaineistot	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en

The biotope type and land use map of the Kivetty site (Figure 9.) displays biotopes and land use forms. In addition, roads, power lines buildings and nature conservation areas are represented. When observing the biotopes, it can be noted that most of the area is covered by coniferous forest. There is also areas of open stands and small areas of mixed forests, mires, wetlands and croplands. By comparing the biotope and land use map to the soil type map of the Kivetty site (Figure 6.), it can be observed that most of the soil in the area is mixed, consisting of, for example, medium- or coarse-grained till. Characteristic tree species on mixed soil are spruce, pine, birch and alder (Haapanen et al. 2011: 24). When observing the map, it can be deduced that the forest and soil types are matching as the dominating forest type is coniferous forest. Also, the mixed forest occurring in the area supports the deduction. Open stands occur partly on rocky soil and mires on thick peatland. Thus, it can be observed that the data is reliable. Land use at the site is very minor. There are a few residential, industrial and other built-up areas. Roads, power lines, buildings and nature conservation areas are displayed in detail and match the terrain map of the Kivetty site (Figure 3.). The roads are even more detailed than in the terrain map, which may be due to different updating cycles.

In summary, biotopes, land use forms and sea depth can be represented with open spatial data. The biotope data is detailed and is corresponds to previous results of Posiva. Soil type occurring in an area can be assessed, if observed the vegetation. In addition, vegetation type growing on peatland can be assessed according to thickness of peat. The data representing biotope and land use and sea depth is thus informative, and suits for the characterisation of the surface environment.

5.4 Catchment areas

The catchment area maps represent the catchment areas of the most significant water systems adjacent to both Olkiluoto and Hanhikivi. To bring more information onto the maps, soil type data has been added to each map. The catchment area maps have been made only for the Olkiluoto (Figure 10.) and Hanhikivi (Figure 11.) sites due to the small area of the Kivetty site. In the case of the Kivetty site, only one map has been created that combines catchment areas, soil types and water quality and it is introduced in section 5.5. The details of the information of used data, sources of the materials and modifications of the maps are represented in Table 11. (Olkiluoto site) and Table 12. (Hanhikivi site).

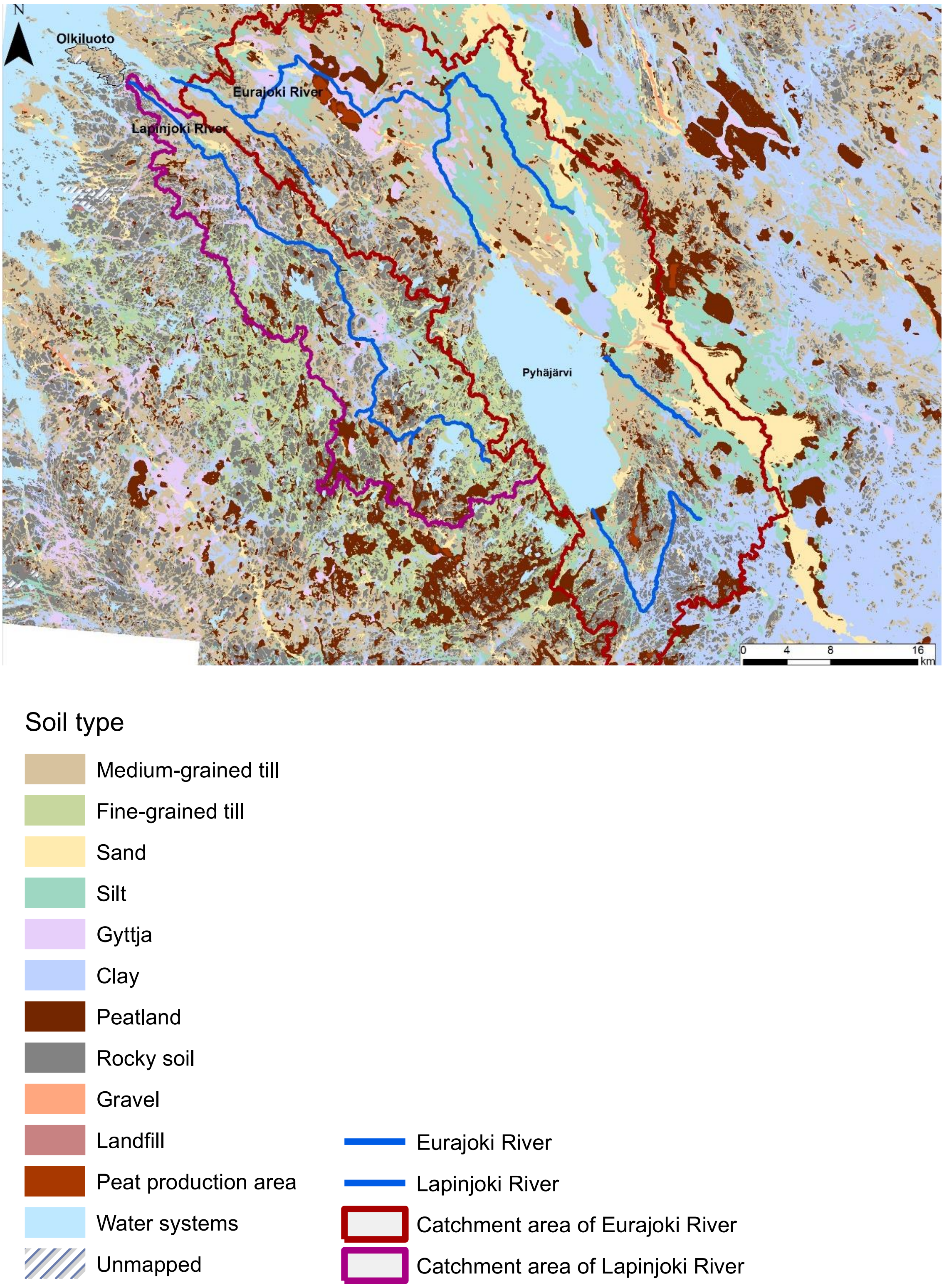

Figure 10. Catchment area map on the Olkiluoto site.

Table 11. Information of the catchment area map of the Olkiluoto site.

Spatial data service	SYKE	GTK
Web or download service	• VALUE tool • Vesikartta service	• Hakku service
Data	• Catchment areas • Rivers	• Superficial deposits 1:20 000
Modifica-tions	-	• Silt, fine silt and coarse silt combined as "Silt" • Sedge peat and sphag-num peat combined as "Peatland" • Rock, stones, boulders, boulder field and weath-ered bedrock combined as "Rocky soil" • Gyttja, gyttja silt, gyttja clay and gyttja sand combined as "Gyttja"
Link to data	• http://paikkatieto.ympar-isto.fi/value/' • http://paikkatieto.ympar-isto.fi/vesikarttaview-ers/Html5Viewer_2_11_2/In-dex.html?con-figBase=http://paik-katieto.ymparisto.fi/Geocor-tex/Essen-tials/REST/sites/Vesikart-taKansa/viewers/Vesikart-taHTML525/virtualdirec-tory/Resources/Config/De-fault&locale=fi-FI	https://hakku.gtk.fi/en/loca-tions/search

In the catchment area map on the Olkiluoto site (Figure 10.), it can be observed that the catchment area of the Eurajoki River is larger than the area of the Lapinjoki River. There are some lakes in the catchment areas the largest being the Pyhäjärvi Lake in the catchment area of the Eurajoki River. The Eurajoki River locates to the north of Olkiluoto Island and it flows to the Eurajoensalmi Strait. The Lapinjoki River flows to the narrow strait between the Olkiluoto Island and the mainland, below the Eurajoki River. The soil is dominated by fine-grained till, silt, clay, gyttja and medium-grained till. Fine-grained soil types are thus prevalent in the catchment areas. Croplands are not represented on the map, but according to ELY Centre (Pohjois-Pohjanmaan… 2014) croplands often occur in the lands covered by fine-grained soils, such as clay and silt.

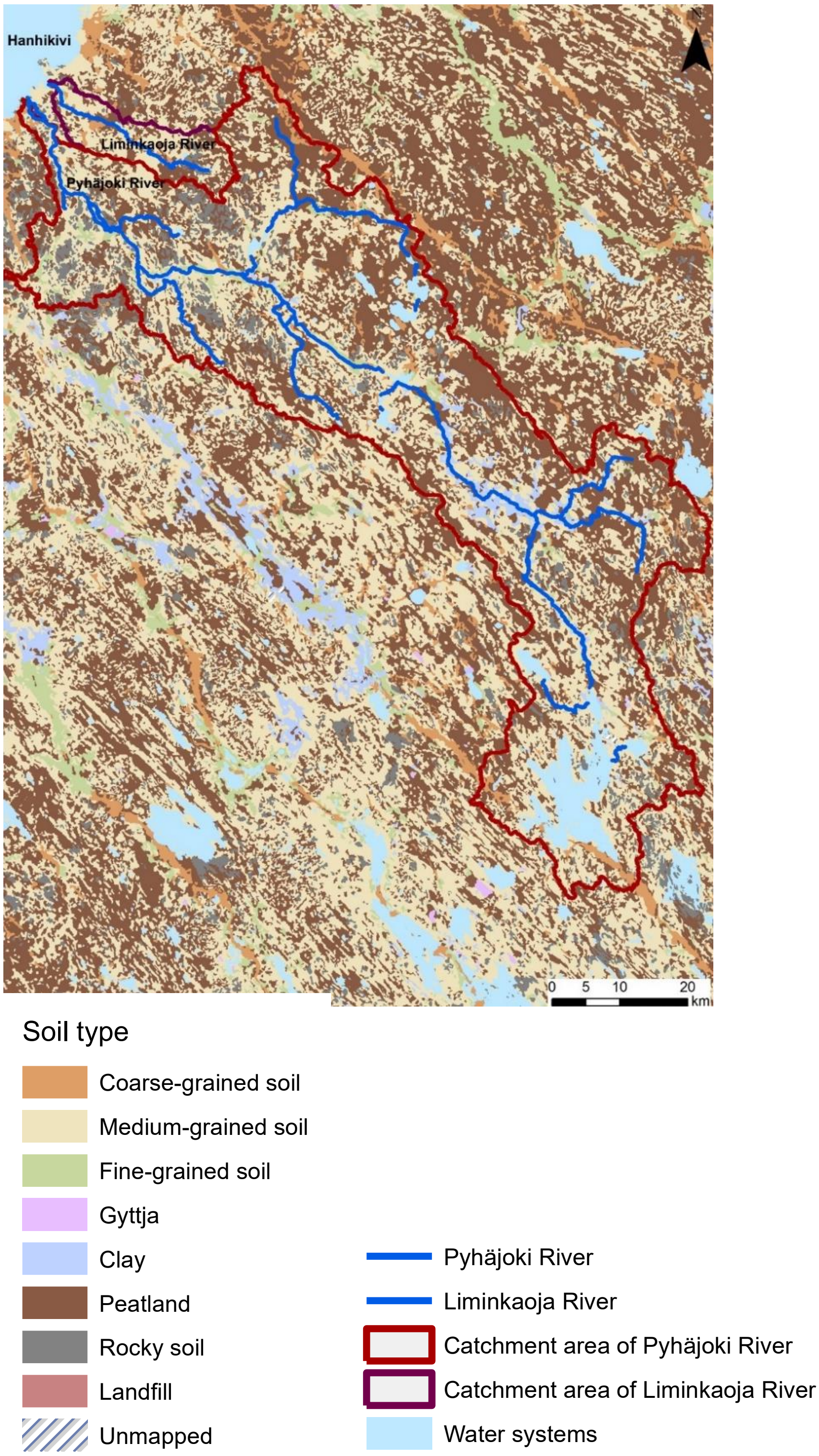

Figure 11. Catchment area map of the Hanhikivi site.

Table 12. Information of the catchment area map of the Hanhikivi site.

Spatial data service	SYKE	GTK
Web or download service	• VALUE tool • Vesikartta service	• Hakku service
Data	• Catchment areas • Rivers	• Superficial deposits of Finland 1:200 000 (sediment polygons)
Modifications	-	• Rocky soil, outcrop and stony soil combined as "Rocky soil" • Thick peatland, thin peatland and peaty soil combined as "Peatland"
Link to data	• http://paikkatieto.ympar-isto.fi/value/' • http://paikkatieto.ympar-isto.fi/vesikarttaview-ers/Html5Viewer_2_11_2/In-dex.html?con-figBase=http://paik-katieto.ymparisto.fi/Geocor-tex/Essen-tials/REST/sites/Vesikart-taKansa/viewers/Vesikart-taHTML525/virtualdirec-tory/Resources/Config/De-fault&locale=fi-FI	• https://hakku.gtk.fi/en/lo-cations/search

The catchment area map on the Hanhikivi site (Figure 11.) represents the catchment areas of the Pyhäjoki River and the Liminkaoja River, and the soil types occurring in the catchment areas. Both rivers occur south of the Hanhikivi site, the Liminkaoja River being located closer to the Hanhikivi site. Also, both rivers flow to the Bay of Bothnia. According to Ekholm (1993: 87), the total area of the Pyhäjoki River's catchment area is approximately 3712 km^2 and Liminkaoja River's approximately 187 km^2 so the size difference is large. The catchment area of the Liminkaoja River shares a boundary with the catchment area of the Pyhäjoki River. When observing the map, it can be noticed that the catchment area of the Pyhäjoki River is much larger than that of the Liminkaoja River, and the catchment areas share the same boundary. The Pyhäjoki River is long and has multiple side streams whereas the Liminkaoja River does not have any side rivers. The dominating soil types in the catchment areas are medium-grained soil, peatland and rocky soil. In addition, there are smaller areas with clayey soil, coarse-grained soil and fine-grained soil. According to Regional State Administrative Agencies (AVI) (2019: 10-11), the soil in the catchment area of the Pyhäjoki River consists of sandy till with stones that can be considered as coarse-grained soil, and silt, which can be considered as fine-grained soil. There are also rocky soils and peatlands.

In summary, it is possible to characterise catchment areas and rivers with open spatial data. The data is representing the catchment areas and rivers correctly in realistic sizes and forms. The data is easy to combine with any data and create versatile maps characterising different topics. Therefore, the data suits for the characterisation of the surface environment.

5.5 Water quality

The water quality maps represent the quality of the adjacent sea and the most significant water systems' catchment areas near the Olkiluoto (Figure 12.), Hanhikivi (Figure 13.) and Kivetty (Figure 14.) sites. The catchment areas are calculated using SYKE's VALUE tool, and on the maps of the Olkiluoto and Hanhikivi sites the catchment areas are the same as on the catchment area. In the case of Hanhikivi, the nearest large water system, Keitele Lake, has been selected for displaying the catchment area. The Kivetty site extends partly into its catchment area, which has been the main reason for selecting it. The details of the information of used data, sources of the materials and modifications of the maps are represented in Table 13. (Olkiluoto site), Table 14. (Hanhikivi site) and Table 15. (Kivetty site).

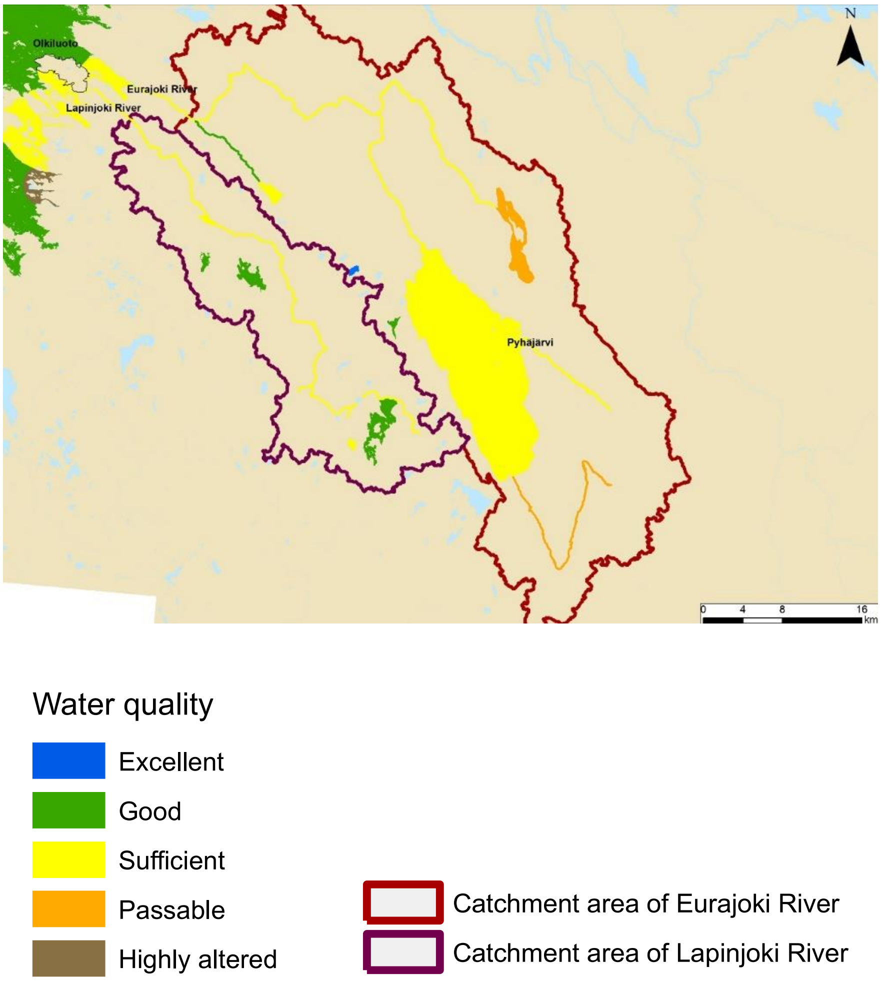

Figure 12. Water quality map of the Olkiluoto site.

Table 13. Information of the water quality map of the Olkiluoto site

Spatial data service	SYKE	GTK
Web or download service	• Vesikartta service • VALUE tool	• Hakku service
Data	• Water quality • Catchment areas	• Superficial deposits 1:20 000
Modifications	-	• The subjects have been turned into the same colour
Link to data	http://paikkatieto.ymparisto.fi/vesikarttaviewers/Html5Viewer_2_11_2/Index.html?configBase=http://paikkatieto.ymparisto.fi/Geocortex/Essentials/REST/sites/VesikarttaKansa/viewers/VesikarttaHTML525/virtualdirectory/Resources/Config/Default&locale=fi-FI	https://hakku.gtk.fi/en/locations/search

The water quality map on the Olkiluoto site (Figure 12.) represents the catchment areas of the Eurajoki and Lapinjoki River and the water quality of the two rivers and the lakes occurring in the catchment areas. Vesikartta service does not cover all the water systems occurring in the catchment areas. The water quality data is mostly based on the biological quality factors (Ymparisto: Pintavesien… 2019). It can be observed that the quality of the Eurajoki River varies from good to passable, being mostly sufficient. The Pyhäjärvi Lake's quality is sufficient. In addition, there are a few lakes in the Eurajoki River's catchment area, whose water quality varies from excellent to passable. Lapinjoki River's water quality is sufficient. There are also a few lakes, whose quality varies from sufficient to good. The quality of the coastal sea water is sufficient in the areas that are nearest to the mainland, near to Olkiluoto Island. In addition, there occur areas south to Olkiluoto Island where the water quality is highly altered or good. In the open sea, the water quality is good. The sufficient and passable quality of the Eurajoki River may be due to the load originating from croplands in the catchment areas (ELY Centre: Pohjois-Pohjanmaan… 2014) and the industrial concerns in the upper reach of the Eurajoki River (Sojakka et al. 2018: 31). Also, the Lapinjoki River's sufficient quality may be due to the load originating from croplands. It can be concluded that the sufficient condition of the coastal waters near Olkiluoto Island is partly due to the load from the two rivers and cooling and waste waters of the nuclear power plant site. The highly varying water quality is due to the harbour.

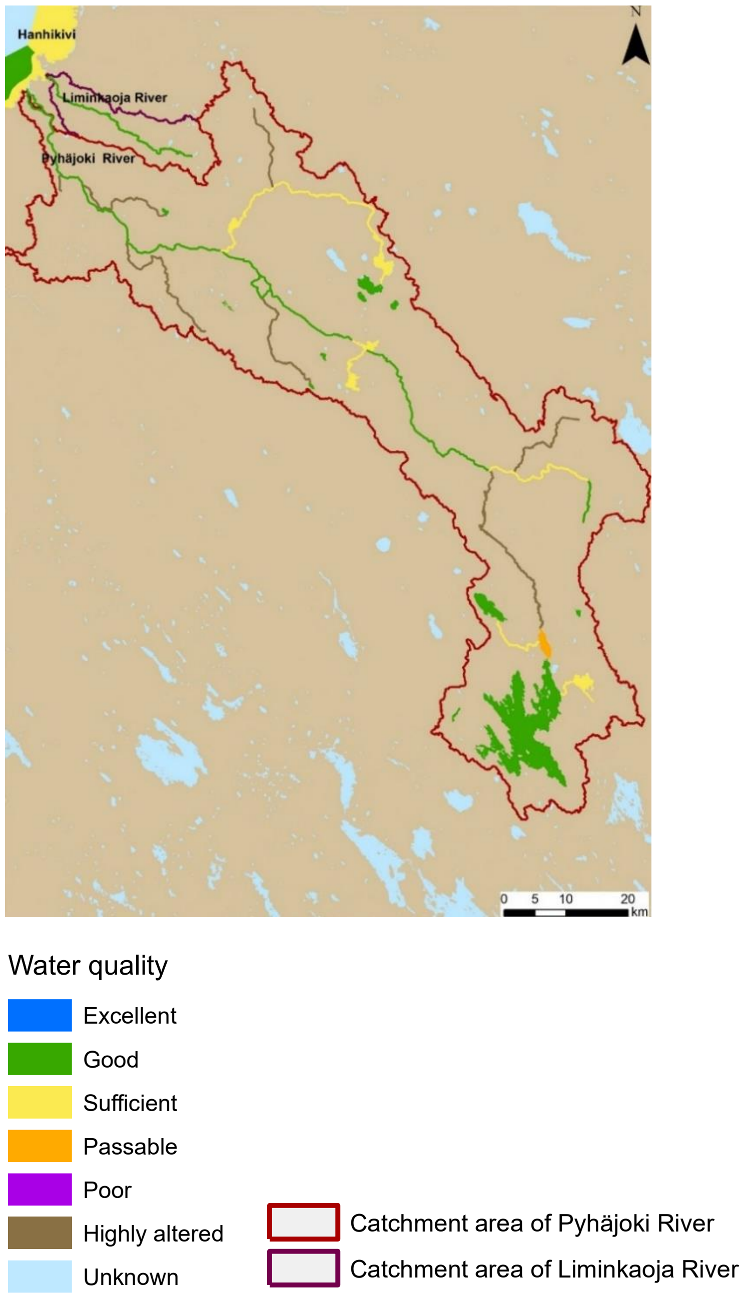

Figure 13. Water quality map of the Hanhikivi site.

Table 14. Information of the water quality map of the Hanhikivi site.

Spatial data service	SYKE	GTK
Web or download service	• Vesikartta service • VALUE tool	• Hakku service
Data	• Water quality • Catchment areas	• Superficial deposits of Finland 1:200 000 (sediment polygons)”
Modifications	-	• The subjects have been turned into the same colour
Link to data	http://paikkatieto.ymparisto.fi/vesikarttaviewers/Html5Viewer_2_11_2/Index.html?configBase=http://paikkatieto.ymparisto.fi/Geocortex/Essentials/REST/sites/VesikarttaKansa/viewers/VesikarttaHTML525/virtualdirectory/Resources/Config/Default&locale=fi-FI	https://hakku.gtk.fi/en/locations/search

The water quality map of the Hanhikivi site (Figure 13.) represents the water quality of the Pyhäjoki River and the lakes occurring in its catchment area, and the Liminkaoja River and the lakes occurring in its catchment area. In addition, the map represents the quality of the adjacent sea of the Hanhikivi site. The quality data is based mostly on the biological quality factors (Ymparisto: Pintavesien… 2019). According to AVI (2019: 10-11), the water quality of the Pyhäjoki River depends on the perspective and the part of the river: the biological factors in the lower and middle reaches indicate that the quality is sufficient. The result is mainly based on fish stock studies. The algae samples and benthic fauna monitoring indicate that the water quality is excellent. The physical and chemical factors also indicate that the water quality in the Pyhäjoki River is sufficient. The results are based on the average concentrations of total phosphorus and nitrogen. Nutrient load originates from, inter alia, agriculture and forestry. In the lower reaches of the river occur fish passes and hydropower dam. When observing the map, it can be noted that the water quality of the Pyhäjoki River varies from good to highly altered condition. In addition, there are lakes in the catchment area, whose water quality varies from good to passable. The water quality of the Liminkaoja River is good. No other quality data is available from its catchment area. The quality of coastal sea water near the Hanhikivi site is sufficient, whereas further from the coast it is good. In the results of AVI (2019: 10-11), the water quality of the Pyhäjoki River is sufficient, but according to the data of the Vesikartta service the quality is mostly good. There are a few side rivers, whose water quality is sufficient and a few with a highly altered condition. The highly altered side rivers refer to the fish passes and power dams that are man-made. The sufficient quality refers to the nutrient load that originates from agriculture and forestry. Sufficient condition of the coastal sea areas may be due to the load originating from the rivers. The water quality is good in the sea areas further from the coast.

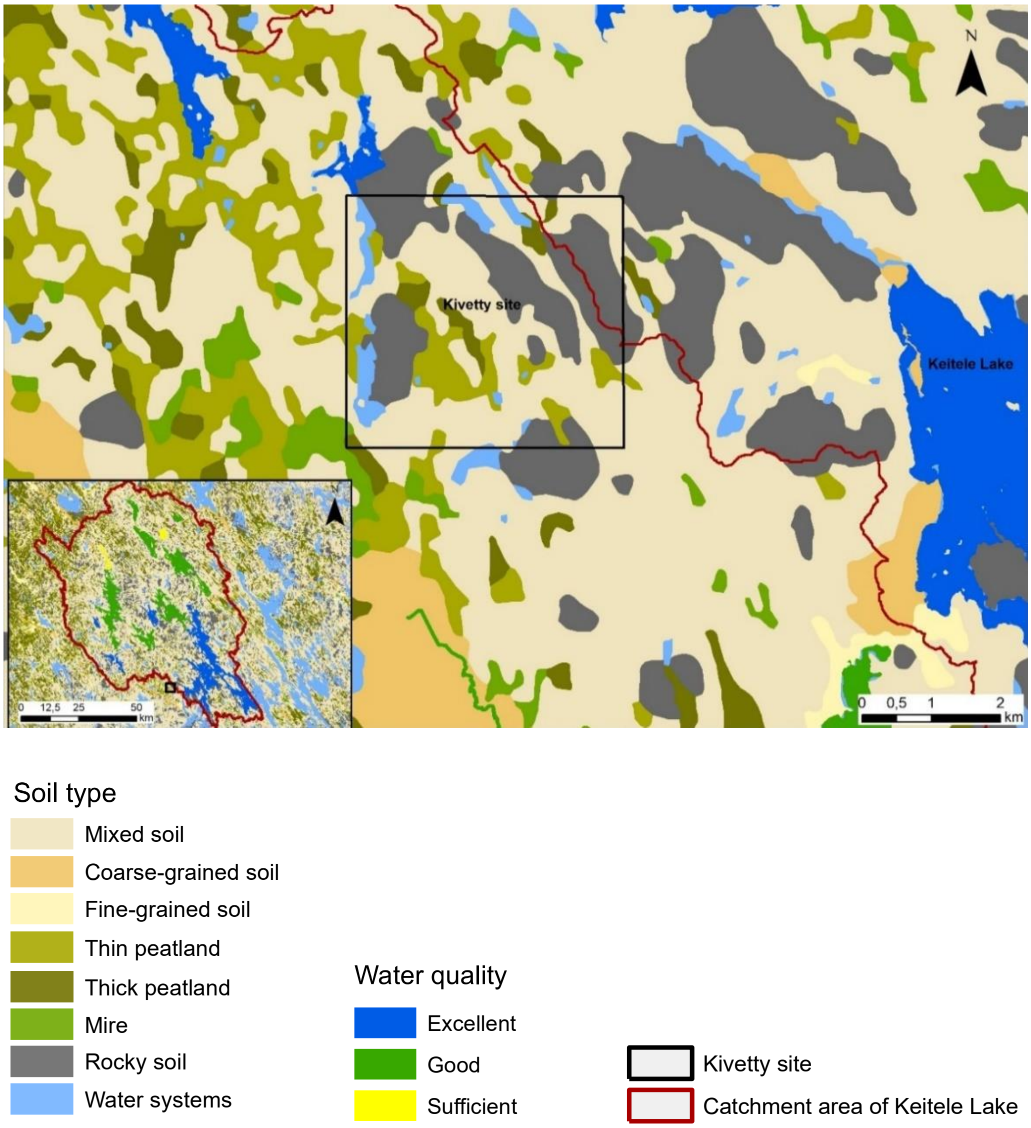

Figure 14. The water quality and catchment area map of the Kivetty site.

Table 15. Information of the water quality and catchment area map of the Kivetty site.

Spatial data service	SYKE	GTK
Web or download service	• Vesikartta service • VALUE tool	• Hakku service
Data	• Water quality • Catchment areas	• Superficial deposits of Finland 1:200 000 (sediment polygons)”
Modifications	-	• Rocky soil, outcrop and stony soil combined as “Rocky soil”
Link to data	http://paikkatieto.ymparisto.fi/vesikarttaviewers/Html5Viewer_2_11_2/Index.html?configBase=http://paikkatieto.ymparisto.fi/Geocortex/Essentials/REST/sites/VesikarttaKansa/viewers/VesikarttaHTML525/virtualdirectory/Resources/Config/Default&locale=fi-FI	https://hakku.gtk.fi/en/locations/search

The water quality map on the Kivetty site represents the water quality of the water systems in the catchment area of Keitele Lake. The map differs from the maps of the Olkiluoto and Hanhikivi sites due to the site’s small area and lack of water quality data for the site. On the other hand, it was possible to add more data on the map, and in this instance the soil type data was added on the map. The catchment area of the Keitele Lake was selected to be displayed on the map since the Kivetty site extends partly into it. The catchment area and water quality data are displayed both in the larger picture and in the smaller picture to provide more information.

According to Council of the Central Finland (2005: 35-38), the water quality in Keitele Lake is excellent and the catchment area is large the area being approximately 6265 km^2 (Ekholm 1993: 39). There are also other large lakes in the catchment area. Mires and peat production in some areas are common, and human activity is low. When observing the catchment area and water quality map for the Kivetty site, it can be observed that the catchment area of Keitele Lake is large. According to the data of the Vesikartta service, the water quality in Keitele Lake is excellent, and in the other large lakes it is mostly good. There are also a few smaller lakes, whose conditions are classified as excellent, good or sufficient. Peatlands are common in the catchment area, but the most prevailent soil type is mixed soil. In general, the water quality varies from excellent to good in Keitele Lake's catchment area. There are also a few lakes, whose condition is sufficient. The overall good and excellent quality of the lakes may be due to there being little human activity in the catchment area (Council of the Central Finland 2005).

In summary, the water quality data is rather simple, but it gives regional overview on the water quality of the sites. Therefore, the data in the Vesikartta service is suitable for regional and general characterisation of the water quality, but for more specific studies, such as quality variation within one lake, it is too rough. The water quality data of the Eurajoki River's catchment area on the map is rather correspondent to the former results of Posiva, and thus the data is suitable for regional observation on the water quality. The data representing the water quality of the Hanhikivi site is not fully correspondent to other studies made at the area. The data on Kivetty site is correspondent to other studies.

5.6 Watershed delineations

Watershed delineation maps have been created using the Spatial Analyst Tool's Hydrology tool and its functions in ArcMap 10.6. The details of data used in the maps are represented in Table 16. All three maps – the Olkiluoto (Figure 15.), Hanhikivi (Figure 16.) and Kivetty (Figure 17.) sites – have been created using the same method.

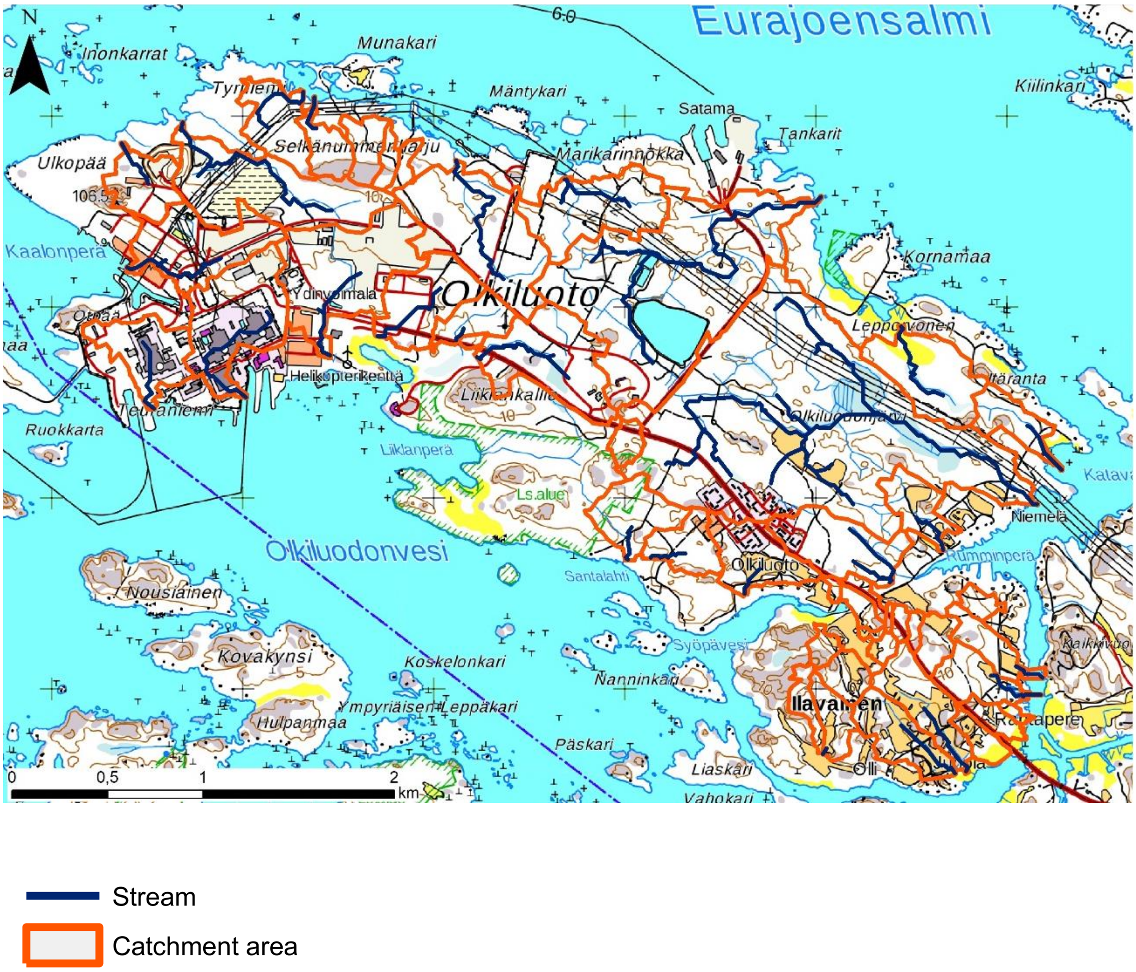

Figure 15. Watershed delineation map of the Olkiluoto site.

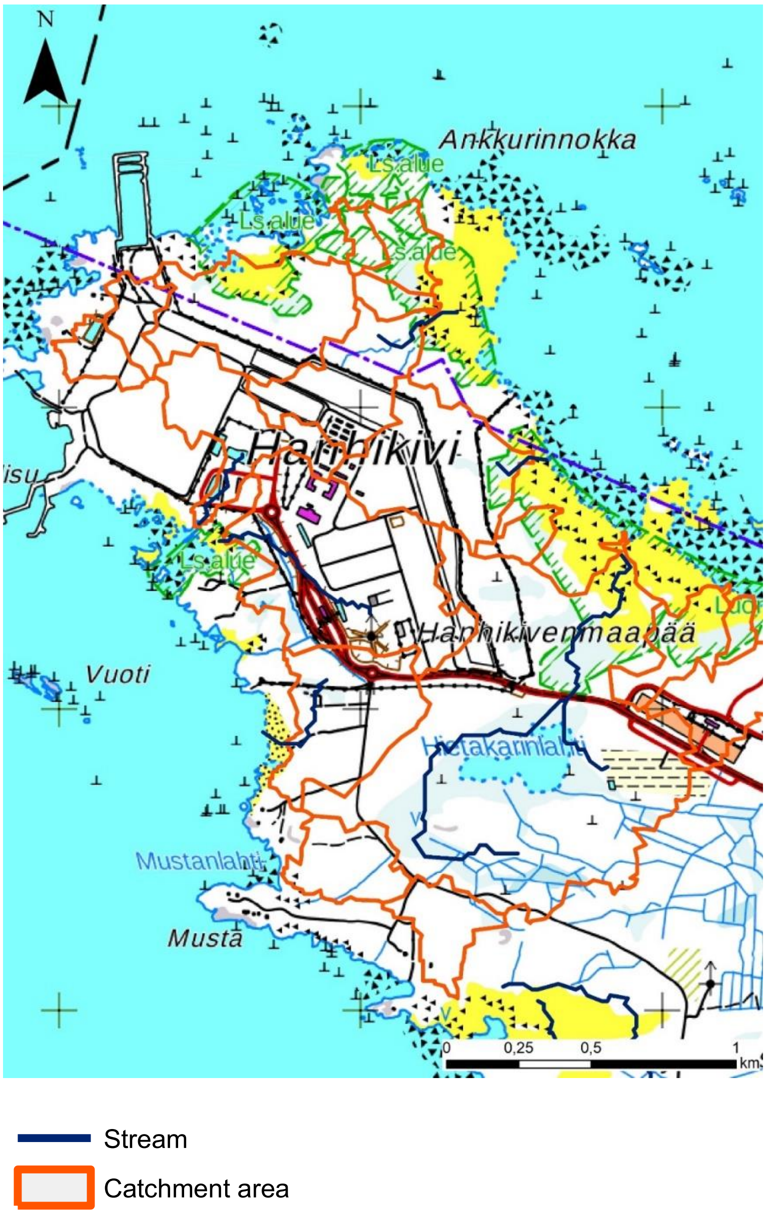

Figure 16. Watershed delineation map of the Hanhikivi site.

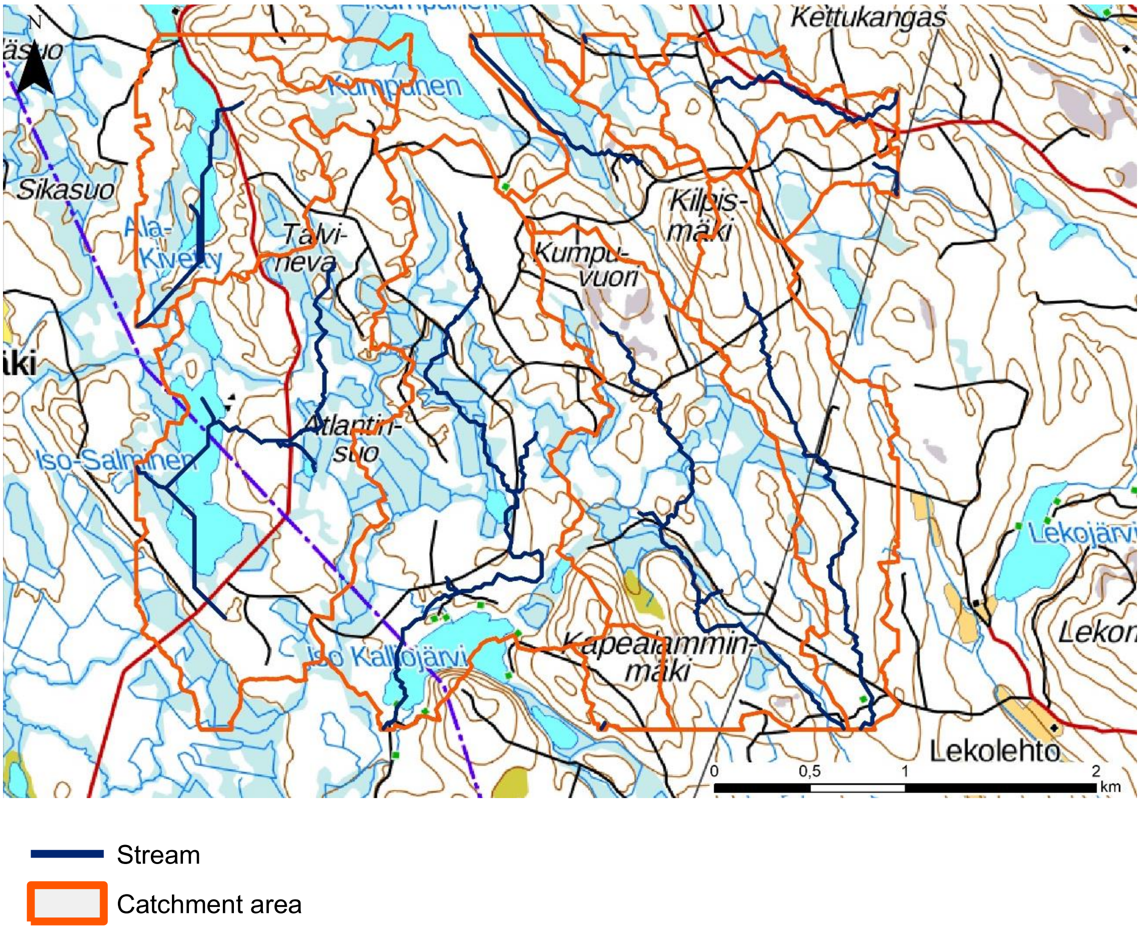

Figure 17. Watershed delineation map of the Kivetty site.

Table 16. Information of the water delineation maps of the Olkiluoto, Hanhikivi and Kivetty sites.

	Olkiluoto site	**Hanhikivi site**	**Kivetty site**
Spatial data service	NLS		
Web or download service	File service of open spatial data		
Data	• Elevation model • Topographic map raster 1:50 000		
Link to data	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en		

Watershed delineation is an artificial subdivision of a catchment area, which is based on a digital elevation model (DEM). The delineation is modelled using the Spatial Analyst Tool’s Hydrology tool in ArcMap. The watershed delineations have been discussed by, for example, Ojala et al. (2006). There is an example of the watershed delineation (Figure 18.) in the Posiva Report 2012-30 (Karvonen 2012: 32). When created watershed delineation, the sinks in the used raster formed DEM data were first filled with the Fill tool. Then, flow direction raster was calculated with the Flow direction tool. The tool determines flow direction from each cell to its steepest fall neighbour. Next, rasters of accumulated flow into every cell were calculated with the Flow accumulation tool. Lastly, Basin tool determines the boarders of every watershed. Watersheds were converted to polygons and the area represented in the map was clipped. Streams were calculated using the Raster calculator and were converted to polylines (ArcGIS Desktop: An overview… 2020).

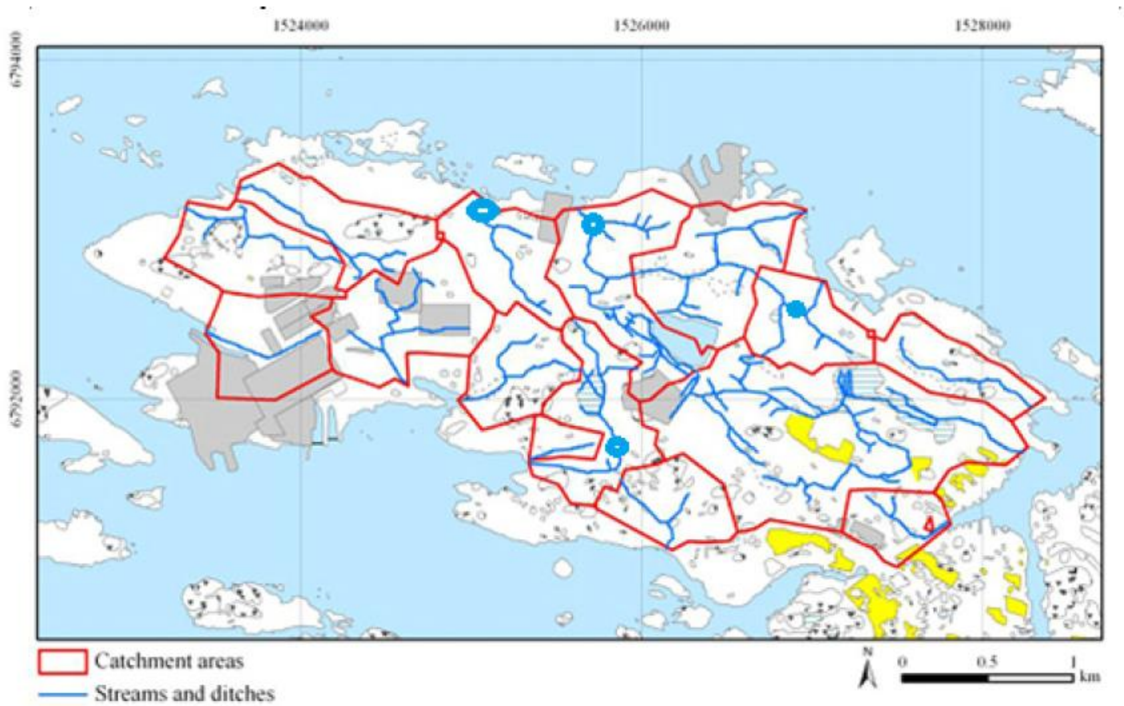

Figure 18. Watershed delineation in the Posiva Report 2012-30 (Karvonen 2012: 32). Figure published with permission of Posiva.

When comparing the map of the Olkiluoto site (Figure 15.) to the watershed delineation in the Posiva Report 2012-30 (Figure 18.), it can be observed that the artificial catchment areas are rather similar. The map created for this study is slightly more detailed due to slightly altering values and cropping of the area while working on it. It can be observed that the streams are following the altitude contours and they flow from upper altitudes to lower ones. Catchment areas also cover, for example, the artificial lake, mire and ditches correctly on the map.

There are no former watershed delineations on the Hanhikivi or Kivetty sites created by Posiva. When observing the map (Figure 16.), it can be noted that the artificial catchment areas cover, for example, the Hietakarinlahti Lake correctly. Also, the streams flow to the sea from the upper altitudes. Also, in the watershed delineation map on the Kivetty site (Figure 17.) the artificial catchment areas cover the lakes correctly and the streams flow from upper altitudes to lower ones.

In summary, the use of the Hydrology tool from Spatial Analyst Tool in ArcMap 10.6 is a suitable for creating the watershed delineation. Open elevation model data can be used as a base data in study. The working method used in this study suits for the characterisation of watersheds.

5.7 The assessment of success of the study, sources of errors and inaccuracies

The model characterisations conducted by using open spatial data have been successful as the surface environment characterisation has been proved to be possible in various topics. The model characterisations also contain versatile information on the topic they represent. To obtain the most comprehensive information possible and comprehensive comparison between data and characterisations, the study has been conducted on three sites. Each site has its special characteristics, which provides versatile viewpoint on the study. Each separate characterisation is informative, but the greatest benefit of the characterisations is obtained when they are observed together. Versatile conclusions can be drawn, for example, by observing the biotope and land use maps and soil type and sea sediment maps together. In addition, it has been proved that the results of model characterisations correspond to the previous results obtained by Posiva.

However, the use of open spatial data may also lead to sources of errors in the study. There has been an attempt to avoid this using only the open spatial data produced and provided by the major open spatial data producers and service providers, such as NLS, GTK and SYKE. When creating maps with open spatial data it is recommendable to be aware that the data can be produced and provided by anyone. Also, the characterisations themselves may contain inaccuracies. For example, all the data used in characterisation is not updated at the same time. Combining data from multiple sources may influence the interpretation of the map. For example, hillshade data changes the colours of other data, and thus may cause errors in interpretation. In watershed delineations, the result of the Hydrology tool's calculation partly depends on the mapmaker's choices in values and croppings.

The research data on the Olkiluoto site is widely available whereas there are less studies conducted on the Hanhikivi and Kivetty site. Thus, the results of model characterisations on the Olkiluoto site are easily comparable to the former results of Posiva and drawing conclusions possible. In the case of the Hanhikivi and Kivetty sites, the results of the model characterisations must be applied to the previous results of the Olkiluoto site. However, this method brings versatile information on the sites as well.

6. Conclusions

The objective of this study was to research the use of open spatial data in the characterisation of the surface environment: what topics can be represented by the open spatial data, how the results can be applied in the studies conducted by Posiva, and is it possible to replace other research methods used in the surface environment characterisation using the open spatial data. The model characterisations' topics have been selected according to the previous surface environment studies conducted by Posiva. The maps have been created by using open spatial data produced and provided by NLS, SYKE and GTK, and the results have been compared to previous results of the surface environment characterisations obtained by Posiva.

As a result of the study, it can be stated that open spatial data is suitable partially for surface environment characterisation. The data available on the service providers sites varies from very detailed to very coarse quality. Particularly informative characterisations were terrain maps, soil type and sea sediment maps, and biotope type and land use maps. The three topics contained the most information as they had the most detailed data on the sites. Soil type and sea sediment maps and biotope type and land use maps were particularly informative when they were compared to each other and observed together. The sea sediment data is rougher than the soil type data, but it is suitable for regional observation of the sites. The data was less detailed than the results obtained by Posiva. However, when observed more closely to the open spatial data on the sea sediments, it has been noted that the data contains the same information, and thus is suitable for surface environment characterisation. Watershed delineation can be created on the sites by using open spatial data as a base since the elevation models are detailed. The Hydrology tool from the ArcMap's Spatial Analyst Tools is suitable method for creating the delineations. Due to the elevation model's accuracy, it can be used instead of the remote sensing methods. Catchment areas can be represented by open spatial data since the VALUE tool covers rather comprehensively data on water systems' catchment areas. Thus, the tool and the data can be used in the surface environment characterisation. Water quality data at the Vesikartta service is generalised data on the quality of water systems, which is based mostly on biological quality factors. The data did not entirely correspond on the previous results of Posiva due to different methods for categorising quality. The data can be used in the regional characterisation on general water quality. The least informative data was soil thickness data that has not been used in the model characterisation. For surveying soil thickness by open spatial data, some other data must be used, such as elevation models, and conclusions drawn according to the information they provide.

In conclusion, open spatial data is suitable for characterising the surface environment and it is possible to partially replace other survey methods. It is possible to draw conclusions by studying the open spatial data used in the study with GIS software. For example, when studying elevation data, it is possible to estimate release locations of radionuclides from the repository, which advances further site studies. The use of open spatial data has plenty of potential in characterisation of the surface environment and in the safety case programme. Not all data is as accurate and informative, but, for example, it is possible to obtain versatile information on the soil and biotope types and land use forms by open spatial data. In addition, terrain maps and elevation models are very detailed and are well suited for surface environment characterisation. As open spatial data is easily available on the internet, its use saves time and costs from other research methods. However, when using open spatial it is advisable to be aware of the producers of the data. The data owned and produced by public administration are more reliable than the data produced and provided by an individual user of GIS.

Further studies could be conducted using the open source geographic information system QGIS as a replacement of ArcMap in the surface environment characterisation. QGIS is widely used in working life and its advantages are free costs and its advanced features. The software can be installed on all operating systems. As the open spatial data has been proved to be suitable for the characterisation of surface environment, the model characterisation could be conducted in further studies by using only open spatial data and open source geographic information system QGIS.

References

Alahuhta, J. (2008). *Selkämeren rannikkovesien tila, vesikasvillisuus ja kuormitus*. Rehevöitymistarkastelu. Lounais-Suomen ympäristökeskuksen raportteja 9/2008. Lounais-Suomen ympäristökeskus, Turku 2008. 111 p.

ArcGIS Desktop: An overview of the Hydrology toolset (2020). <*https://desktop.arcgis.com/en/arcmap/10.6/tools/spatial-analyst-toolbox/an-overview-of-the-hydrology-tools.htm*> 11.3.2020

Aro, L., J. Derome, H-S. Helmisaari, H. Hökkä, A-J. Lindroos, P. Rautio (2010). *Results of Forest Monitoring on Olkiluoto Island in 2009.* Working Report 2010-65, November 2010. 68 p.

Bank, E. (2004). *Importance of open spatial data infrastructure for data sharing*. Commission TS-PS-WG IV/4.

Broed, R., R. Avila, U. Bergström, T. Hjerpe, A.T.K. Ikonen (2008). *Biosphere Analysis for Selected Cases in TILA-99 and in KBS-3H Safety Evaluation 2007.* Working Report 2007-109, December 2008. 186 p.

Centre for Economic Development, Transport and the Environment: Maatalouden vesien suojelu (2013). <*https://www.ymparisto.fi/fi-FI/Vesi/Vesiensuojelu/Maatalous?f=KeskiSuomen_ELYkeskus*> 9.10.2019

Centre for Economic Development, Transport and the Environment: Pohjois-Pohjanmaan maaperä (2014). <*https://www.ymparisto.fi/fi-FI/PohjoisPohjanmaan_ymparistohistoria/Luonnonolot_ilmasto_ja_aluekehitys/Maapera_ja_kasvillisuus*> 17.10.2019

City of Helsinki (2007). *Helsingin monimuotoinen luonto.* Ympäristökeskus, Helsinki. 35 p.

City of Jämsä: Kartasto ja paikkatietopalvelut (2020). <*https://www.jamsa.fi/palvelut/kaavoitus-ja-rakentaminen/kartat-ja-mittaus/kartasto-ja-paikkatietopalvelut*> 31.5.2020

City of Tampere: Ympäristöverkko - Metsätyypit (2019). <*https://www.tampere.fi/ytoteto/yva/ymparistoverkko/bl_mt.html*> 8.10.2019

CSC: About us (2019). <*https://www.csc.fi/about-us*> 12.8.2019

CSC: Open GIS Data (2019). <*https://research.csc.fi/open-gis-data*> 13.8.2019

Ekholm, M. (1993). *Suomen vesistöalueet.* Vesi- ja ympäristöhallinnon julkaisuja - sarja A 126. Vesi- ja ympäristöhallitus, Helsinki. 166 p.

European Environment Agency (2011). *About us - INSPIRE*. 5 p.

European Environment Agency: Littoral mixed sediments (2019). <*https://eunis.eea.europa.eu/habitats/439*> 12.11.2019

European Environment Agency: Sublittoral coarse sediment (2019). <*https://eunis.eea.europa.eu/habitats/2500*> 13.11.2019

Fennovoima.fi: Tietoa Hanhikivi 1 -hankkeesta (2019). <*https://www.fennovoima.fi/hanhikivi-1/tietoa-hanhikivi-1-hankkeesta*> 6.11.2019

Finnish Environment institute: Avoin tieto (2019).

<*https://www.syke.fi/avointieto*> 19.8.2019

Finnish Environment institute: Kalliot ja kivikot (2019). <*https://www.ymparisto.fi/fi-FI/Luonto/Luontotyypit/Luontotyyppien_uhanalaisuus/Kalliot_ja_kivikot*> 4.10.2019

Finnish Environment institute: Ladattavat paikkatietoaineistot (2019). <*https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot*> 14.8.2019

Finnish Environment institute: Monivaikutteiset kosteikot (2019). <*https://www.ymparisto.fi/fi-FI/Vesi/Vesien_kaytto/Maankuivatus_ja_ojitus/Luonnonmukainen_peruskuivatus/Monivaikutteiset_kosteikot*> 3.10.2019

Finnish Environment Institute: Pintavesien luokittelun periaatteet (27.8.2019). <*https://www.ymparisto.fi/fi-FI/Vesi/Pintavesien_tila/Pintavesien_luokittelu*> 19.11.2019

Finnish Environment institute: Suomen vesien tila-arvio: Järvien ja jokien tila pääosin ennallaan, rannikkovesien tila heikentynyt (2019). <*https://www.syke.fi/fi-FI/Ajankohtaista/Tiedotteet/Suomen_vesien_tilaarvio_Jarvien_ja_jokie(51384)*> 26.11.2019

Finnish Environment institute: SYKEn avoimet rajapinnat (2019). <*https://www.syke.fi/fi-FI/Avoin_tieto/Avoimet_rajapinnat*> 31.5.2020

Haapanen, R. (2005). *Results of Monitoring at Olkiluoto in 2004 – Environment*. Working Report 2005-31, July 2005. 127 p.

Haapanen, R., L. Aro, H. Ilvesniemi, T. Kareinen, T. Kirkkala, S. Mykrä, H. Turkki, A-M. Lahdenperä, A. T. K. Ikonen (2007). *Olkiluoto Biosphere Description 2006*. Posiva 2007-02, February 2007. 34 p.

Haapanen, R., L. Aro, J. Helin, T. Hjerpe, A.T.K. Ikonen, T. Kirkkala, S. Koivunen, A-M. Lahdenperä, L. Puhakka, M. Rinne, T. Salo (2009). *Olkiluoto Biosphere Description 2009*. Posiva 2009-02, August 2009. 68 p.

Haapanen, R., A-M. Lahdenperä (2011). Olkiluodon maalta merelle -linjaston maa osuuden inventointi vuonna 2008 ja Olkiluodon ympäristön ruovikkotutkimukset vuosina 2007-2008. Working Report 2011-67, Lokakuu 2011. 112 p.

Hakku: Portti Suomen geologiseen tietoon (2019). <*https://hakku.gtk.fi/fi/locations/search*> 16.8.2019

Hakku: Tietoa palvelusta (2019). <*https://hakku.gtk.fi/tietoa-palvelusta*> 15.8.2019

Heikkinen, P. (2000). *Haitta-aineiden sitoutuminen ja kulkeutuminen maaperässä.* Tutkimusraportti 150. Geologian tutkimuskeskus, Espoo. 74 p.

Helin J., A.T.K. Ikonen (2009). *BIOPROTA Theme 3.* Contribution from Posiva, 20 February 2009.

The Helsinki Term Bank for the Arts and Sciences (2019). Biologia: afoottinen. <*https://tieteentermipankki.fi/wiki/Biologia:afoottinen*> 27.11.2019

The Helsinki Term Bank for the Arts and Sciences (2019). Biologia: foottinen. <*https://tieteentermipankki.fi/wiki/Biologia:foottinen*> 27.11.2019

The Helsinki Term Bank for the Arts and Sciences (2019). Biologia: runsasvaloinen. <*https://tieteentermipankki.fi/wiki/Biologia:runsasvaloinen*> 27.11.2019

Hertta © 2019: Hertta (2019). <*https://www.syke.fi/avointieto*> 21.8.2019

Hirvonen, A, K. Koski (2016). *Kanta-Hämeen maatalouden kannalta hyvät ja yhtenäiset peltoalueet*. Hämeen liitto, Hämeenlinna 2016. 51 p.

Hjerpe, T. (2006). *Overall Strategy for Management of Parameters and Data in the Biosphere Assessment Portfolio.* Working Report 2006-109, December 2006. 45 p.

Hjerpe, T., A.T.K. Ikonen, R. Broed (2010). *Biosphere Assessment Report 2009*. Posiva 2010-03, March 2010. 186 p.

Hämäläinen, T. (2017). Tarkka tieto savikoista auttaa maankäytön ja rakentamisen suunnittelussa. *Geofoorumi 1/2017, Geologian tutkimuskeskuksen sidosryhmälehti.* Geologian tutkimuskeskus. 10-11 p.

IAEA (2006). *Geological disposal of radioactive waste: Safety requirements.* Safety Standars Series WS-R-4, May 2006. International Atomic Energy Agency, Vienna. 49 p.

IAEA (2012). *The safety case and safety assessment for the disposal of radioactive waste. Specific safety guide*. Safety standard series No. SSG-23. International Atomic Energy Agency, Vienna. 120 p.

Ikonen, A.T.K., L. Aro, R. Haapanen, J. Helin, T. Hjerpe, T. Kirkkala, S. Koivunen, A-M. Lahdenperä, L. Puhakka, T. Salo (2010). *Site and Regional Data for Biosphere Assessment BSA-2009. Supplement to Olkiluoto Biosphere Description 2009*. Workin report 2010-36, June 2010. 242 p.

Ikonen, A.T.K., L. Aro, R. Haapanen, J. Helin, V. Kangasniemi, A-M. Lahdenperä, T. Salo, K. Smith, M. Toivola, T. Hjerpe, T. Kirkkala & S. Koivunen (2013). *Olkiluoto Biosphere Description 2012*. POSIVA 2012-06, April 2013. 299 p.

Ikävalko, O., J. Huitti (2008). *Maaperän rakennettavuusselvitys: Nurmi-Sorila ja Tarastenjärvi, Tampere.* Geologian tutkimuskeskus, Espoo. 4 p.

Ilmarinen, K., J. Leinikki, P. Oulasvirta (2009). *Seafloor Mapping at Olkiluoto, Western Coast of Finland.* Working Report 2009-12, February 2009. 48 p.

Isotalo, T., R. Kuusiniemi, E. Loukola, & E. Rönkä (1982). *Maaperän rakenteesta ja maastotutkimusmenetelmistä*. Vesihallitus, Helsinki. Tiedotus 219. 117 p.

Jokela, S. (2017). QGIS kiinnostaa kaupunkeja*. Positio 1/2017, Maanmittauslaitos*. 26-27 p.

Kaihovaara, A., V. Härmälä, V. Salminen (2016*). Mitä ovat innovaatioekosysteemit ja miten niitä voi kehittää?* Policy Brief 15/2016. Näkökulmia ajankohtaisiin yhteiskunnallisiin kysymyksiin ja poliittisen päätöksenteon tueksi. Valtioneuvoston selvitys- ja tutkimustoiminta. 9 p.

Kaiva.fi: Suomen maaperä (2019). <*https://kaiva.fi/geologia/suomen-maapera/maaperan-erityispiirteet/*> 16.10.2019

Kallio, K., H. Kankaanpää, P. Kauppila, M. Nurmi (2017). *Studies on the Aquatic Environment at Olkiluoto and Reference Area: 4. Olkiluoto Open Sea Area in 2013.* Working Report 2016-65, June 2017. 116 p.

Karvonen, T. (2012). *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto. Surface and Near-Surface Hydrological Modelling in the Biosphere Assessment BSA-2012*. Posiva 2012-30, May 2012. 157 p.

Kirkkala, T., R. Oravainen (2005a). Uudenkaupungin edustalta Merikarvialle. *In* Sarvala, M. & Sarvala, J. (toim.) *Miten voit, Selkämeri? Merialueen tila Satakunnan ja Vakka-Suomen rannikolla*. Ympäristön tila Lounais-Suomessa 4. Lounais-Suomen ympäristökeskus, Turku. 32-47 p.

Kirkkala, T., H. Turkki (2005b). Rauman ja Eurajoen edustan merialue. *In* Sarvala, M. & Sarvala, J. (toim.) *Miten voit, Selkämeri? Merialueen tila Satakunnan ja Vakka-Suomen rannikolla.* Ympäristön tila Lounais-Suomessa 4. Lounais-Suomen ympäristökeskus, Turku. 48-65 p.

Kontula, T. (toim.), A. Raunio, A. Schulman (2008). Uhanalaisuusarvioinnin periaatteet 2. *In* Kontula, T., A. Raunio, A. Schulman *Suomen luontotyyppien uhanalaisuus - Osa 1. Tulokset ja arvioinnin perusteet.* 11-28 p.

Kontula, T., J. Teeriaho, J. Husa, A. Grönlund, J. Gustafsson, R. Juutinen, A. Jäkäläniemi, T. Korvenperä, H. Nurmi, J. Pykälä (2018). Luontotyyppien punainen kirja. Osa 2: Luontotyyppien kuvaukset: Kalliot ja kivikot. *In* Kontula, T., J. Teeriaho, J. Husa, A. Grönlund, J. Gustafsson, R. Juutinen, A. Jäkäläniemi, T. Korvenperä, H. Nurmi, J. Pykälä *Suomen luontotyyppien uhanalaisuus 2018*. Suomen ympäristö 5/2018. Ympäristöministeriö, Helsinki. 575-657 p.

Korhonen, K-H., R. Gardemeister, M. Tammirinne (1974). *Geotekninen maaluokitus*. Valtion teknillinen tutkimuskeskus, Espoo. Geotekniikan laboratorio, Tiedonanto 19 p.

Korte, T. (2014). SmartData Collective: The Coming Wave of Innovation from Open Geographic Information. <*https://www.smartdatacollective.com/coming-wave-innovation-open-geographic-information/*> 29.7.2019

Krebs, C. J. (2014). *Ecology: The experimental analysis of distribution and abundance*. Harlow: Pearson Education. 6th ed. 646 p.

Kumpumäki, T., J. Tuominen, T. Lipping (2018). *Remote Sensing Data Analysis of the Materials Collected Between 2007 and 2016.* Working Report 2017-37, April 2018. 110 p.

Lahdenperä, A-M. (2009). *Summary of the Overburden Studies of the Soil Pits OL-KK14, OL-KK15, OL-KK16, OL-KK17, OL-KK18 and OL-KK19 at Olkiluoto, Eurajoki in 2008*. Working Report 2009-109, December 2009. 88 p.

Lahdenperä, A-M. (2016). *Geochemical and Physical Properties and In Situ Distribution Coefficients of the Deep Soil Pits OL-KK22, OL-KK23 and OL-KK24 at Olkiluoto*. Working Report 2016-12, March 2016. 150 p.

Lahdenperä, A-M., A. Keskinen (2011). *Chemical and Physical Properties of the Surface Sea Sediments at the Olkiluoto Offshore, South-Western Finland*. Working Report 2011-80, Novemver 2011. 150 p.

LAPIO: Ladattavat paikkatietoaineistot (2019). <*https://paikkatieto.ymparisto.fi/lapio/latauspalvelu.html*> 14.8.2019

Lindborg, T. (ed.) (2008). *Surface system Forsmark. Site descriptive modelling. SDM-Site Forsmark.* Svensk Kärnbränslehantering AB. R-08-11, December 2008. 206 p.

Luke.fi: Suomen metsät 2012 (2012). <*http://www.metla.fi/metinfo/kestavyys/*> 8.10.2019

Lundberg, C. (toim.), J. Ögård, M. Ek, M. Snickars (2012). *Pohjois-Itämeren vedenalainen luonto. Huomioon otettavaa merenläheisten alueiden suunnittelussa.* Raportteja 83/2012. Uudenmaan elinkeino-, liikenne- ja ympäristökeskus, Helsinki. 51 p.

Luonnontila.fi: Elinympäristöt (2014). <*https://www.luonnontila.fi/fi/elinymparistot/*> 9.10.2019

Löfgren, A., T. Lindborg (2003). *A descriptive ecosystem model - a strategy for model development during site investigations.* Stockholm, Svensk Kärnbränslehantering AB. SKB R-03-06. 113 p.

MetsäVerkko: Metsäekologia - suotyypit (2019). <*http://virtuoosi.pkky.fi/metsaverkko/metsaekologia/Suotyypit/*> 17.10.2019

Miettinen, N., R. Haapanen (2002). *Vegetation types on Olkiluoto island*. Working Report 2002-54, December 2002. 57 p.

Ministry of the Environment (2007). *Luonnon puolesta - ihmisen hyväksi. Suomen luonnon monimuotoisuuden suojelun ja kestävän käytön strategia 2006-2016. Suomen luonnon monimuotoisuuden suojelun ja kestävän käytön toimintaohjelma 2006-2016.* Suomen ympäristö 35/2007, Helsinki. 162 p.

Mäkinen, K., J-P. Palmu, J. Teeriaho, H. Rönty, T. Rauhaniemi & J. Jarva (2007). *Valtakunnallisesti arvokkaat moreenimuodostumat.* Suomen ympäristö 14/2007. Ympäristöministeriö, Helsinki. 120 p.

National Land Survey of Finland: File service of open data (2019). <*https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en*> 10.7.2019

National Land Survey of Finland: Mikä INSPIRE? (2020). <*https://www.maanmittauslaitos.fi/kartat-ja-paikkatieto/paikkatietojen-yhteentoimivuus/inspire/mika-inspire*> 30.5.2020

Ojala, A.E.K., H. Virkki, J-P. Palmu, K. Hokkanen, J. Kaija (2006). *Regional Development of River Basins in the Olkiluoto-Pyhäjärvi Area, SW Finland, 2000 BP - 8000 AP.* Working Report 2006-113, December 2006. 97 p.

Ormsby, T., E. Napoleon, R. Burke, C. Groessl, L. Feaster (2001). *Getting to Know ArcGIS®. Basics of ArcView®, ArcEditor® and ArcInfo®.* Updated for ArcGIS 9. ESRI Press, Redlands California. 572 p.

Poikola, A., P. Kola, K.A. Hintikka. (2010). *Julkinen data, johdatus tietovarantojen avaamiseen.* Liikenne- ja viestistäministeriö, Helsinki. 94 p.

Posiva Oy (2003a). *Baseline Conditions at Olkiluoto.* Posiva 2003-02, September 2003. 218 p.

Posiva Oy (2003b). *Programme of monitoring at Olkiluoto during construction and operation of the ONKALO.* Posiva 2003-05, December 2003. 92 p.

Posiva Oy (2011). *Olkiluoto Site Description 2011.* Posiva 2011-02, December 2012. 1029 p.

Posiva Oy (2012a). *Monitoring at Olkiluoto - A programme for the period before repository operation.* Posiva 2012-01, August 2012. Report Abstract, 188 p.

Posiva Oy (2012b). *Safety Case for the Spent Nuclear Fuel at Olkiluoto - Synthesis 2012.* Posiva 2012-12, December 2012. 277 p.

Posiva Oy (2013). *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto. Ter-*

rain and Ecosystems Development Modelling in the Biosphere Assessment BSA-2012. Posiva 2012-29, December 2013. 380 p.
Posiva Oy (2014). *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto. Data Basis for the Biosphere Assessment BSA-2012 Part I.* Posiva 2012-28, January 2014. 1446 p.
Posiva: Final disposal (2019). <*http://www.posiva.fi/en/final_disposal*> 17.7.2019
Posiva: Posiva - About us (2019). <*http://www.posiva.fi/en/posiva/about_us*> 28.6.2019
Posiva: Posiva-SKB -reports (2019). <*http://www.posiva.fi/en/databank/posiva_-_skb_reports*> 18.6.2019
Posiva Solutions: Posiva (2019). <*http://www.posiva.fi/en/posiva_solutions*> 1.7.2019
Rainio, A. (2012). Julkinen tieto aukeaa. *Systeemityö 3/2012. Sytyke ry:n jäsenlehti*. 12-13 p.
Rantataro, J. (2001). *Akustis-seismiset tutkimukset Olkiluodon läheisellä merialueella vuonna 2000.* Työraportti 2001-11, Huhtikuu 2001. 62 p.
Rautio, T. (1996*). Syväkairaus KI-KR11 Äänekosken Kivetyssä.* Työraportti PATU-96-19, Kesäkuu 1996. 55 p.
Regional State Administrative Agencies (2019). *Pyhäjoen tulvasuojeluruoppaus, Pyhäjoki.* Ympäristöluvat, Pohjois-Suomi. Nro 150/2019. 35 p.
Ronkainen, N. (2012). *Suomen maalajien ominaisuuksia.* Suomen ympäristö 2/2012. Suomen ympäristökeskus, Helsinki. 57 p.
Sojakka, T., L. Aro, T. Lipping (2018). *Results of Monitoring at Olkiluoto in 2016 Environment.* Working Report 2017-45, August 2018. 162 p.
Söderbäck, B., T. Lindborg (2009). *Surface system Laxemark-Simpevarp. Site descriptive modelling SDM-Site Laxemark.* Svensk Kärnbärnslehantering AB. R-09-01, May 2009. 195 p.
Tamminen, P. (2009). Suomen metsämaiden maannokset. *Metsätieteen aikakauskirja 1/2009*. 74-78 p.
Tamminen, P., L. Aro, M. Salemaa (2007). *Forest Soil Survey and Mapping of the Nutrient Status of the Vegetation on Olkiluoto Island. Results from the Fisrt Inventory on the FEH Plots*. Working Reposrt 2007-78, September 2007. 110 p.
Tattari, S., M. Puustinen, J. Koskiaho, E. Röman, J. Riihimäki (2015). *Valuma-alueen eri lähteistä tulevan vesistökuormituksen arviointi ja vähentämismahdollisuudet.* Suomen ympäristökeskus, 31.3.2015 Helsinki. 52 p.
Tuominen, S., H. Eeronheimo & H. Toivonen (toim.) (2001). Yleispiirteinen biotooppiluokitus. *Metsähallituksen luonnonsuojelujulkaisuja. Sarja B, No 57*. Metsähallitus ja Suomen ympäristökeskus, Vantaa. 60 p.
Turkki, H. (2015). *Olkiluodon lähivesien fysikaalis-kemiallinen ja biologinen tarkkailututkimus. Vuosiraportti 2015.* Lounais-Suomen vesi- ja ympäristötutkimus Oy. 60 p.
Turveinfo: Tiivisturvetta kaatopaikkarakenteisiin (2019). <*http://turveinfo.fi/kayttotavat/turpeen-muu-kaytto/tiivisturvetta-kaatopaikkarakenteisiin/*> 29.9.2019

Turveteollisuusliitto: Mitä on turve ja mihin sitä käytetään? (2019). <*http://turveteollisuusliitto.fi/mita-on-turve-ja-mihin-sita-kaytetaan/*> 29.9.2019

USC University of Southern California: The Top 6 Industries for GIS (2019). <*https://gis.usc.edu/blog/the-6-top-industries-for-gis/*>. 29.7.2019

VALUE tool (2019). <*http://paikkatieto.ymparisto.fi/value/*>. 26.9.2019

Vanhatalo, K., P. Väisänen, S. Joensuu, J. Sved, A. Koistinen, & O. Äijälä (toim.) (2015). *Metsänhoidon suositukset suometsien hoitoon, työopas.* Tapion julkaisuja. 119 p.

Vesikartta - Vesien ekologinen tila (2019). <*http://paikkatieto.ymparisto.fi/vesikarttaviewers/Html5Viewer_2_11_2/Index.html?configBase=http://paikkatieto.ymparisto.fi/Geocortex/Essentials/REST/sites/VesikarttaKansa/viewers/VesikarttaHTML525/virtualdirectory/Resources/Config/Default&locale=fi-FI*> 26.9.2019

Virkkala, K. (1972). *Maaperäkartoituksen maasto-opas*. Opas N:o 4. Geologian tutkimuslaitos, Otaniemi. 37 p.

World Soil Resources Reports (2006). *World reference base for soil resources 2006. A framework for international classification, correlation and communication.* No. 103, 2006 edition. 142 p.

Äikäs, K., A. Hagros, E. Johansson, H. Malmlund, U. Sievänen, H. Ahokas, E. Heikkinen, P. Jääskeläinen, P. Ruotsalainen, P. Saksa (1999). *Kivetyn kallioperän luokittelu loppusijoitustilojen rakennettavuuden kannalta.* Työraportti 99-65. Joulukuu 1999. 158 p.