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Computational Risk Assessment Methods for Contaminated Sites in Finland

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ABSTRACT

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The thesis work was written in cooperation with Taratest Oy to develop the quality and competence of the environmental department. The thesis is divided into two parts. There is a theoretical part and a practical part. This includes case studies and other literature.

This thesis aimed to gain insight into the risk assessment of contaminated soil to improve the analysis process of risk assessment. This study focuses on identifying different risk assessment models to identify risk assessment processes and provide a better understanding of the use of risk assessment of contaminated soil. This study compared various risk assessments of contaminated soil models to evaluate risk analysis methods. Taratest Oy selected a suitable risk assessment model for the company. In this case, the model chosen was PIRTU eco-efficiency tool.

The thesis introduces the environmental legislation relating to contaminated soil and groundwater and presents the general objectives and methodology of risk assessment for contaminated soil. Also, in the literature part, the thesis offers a variety of different computational risk assessment methods tools according to the various organizational needs.

Two different cases were used to utilize the PIRTU eco-efficiency tool in the practical thesis part. The research methodology consists of the analyses of each case study separately, each the following case studies to carry out a site-specific risk assessment. Based on the outcome, tools can be used to compare different remediation methods and identify the most significant impacts on a site. The analysis results included health risks, environmental impacts, groundwater, and other social impacts. The results can be used to justify choices in the decision-making process during the remediation planning phase.

Key words: contaminated soil, risk assessment, risk assessment models

CONTENTS

1 INTRODUCTION

Soil materials are one of the most significant material flows in Finland's natural resource use. Removing contaminated soil requires substantial resources, primarily from municipalities and other public actors. Most sites are treated by excavating the contaminated soil and by replacing with clean soils. This increases the use of natural resources, soil transport, environmental emissions, and costs (Jylhä, Alhola, Antikainen & Pyy 2021, 3).

In Finland, 250-300 contaminated sites are remediated every year. Construction and land-use change are the fundamental driving forces. A significant number of sites still need treatment or other risk management measures. The National Strategy for Contaminated Land Risk Management has a national vision on how to handle the risk management and remediation of contaminated sites in Finland cost-effectively and sustainably, considering health and environmental protection in the best possible way (Ympäristöministeriö 2015, 7).

Sustainable risk management of contaminated soil is a multidimensional issue that requires a range of actors and stakeholder groups to form a shared vision, address and communicate risks realistically, and make choices that balance environmental, social, and economic impacts. Sustainable risk management is not a single solution but a process, the outcome of which has broad social acceptance. Sustainable soil risk management is based on recognizing the value of soil and defining risks and objectives in a broader context. When properly designed and implemented, sustainable risk management creates value for both land development and land use for contaminated soil (Ramboll n.d.).

The purpose of the thesis, in cooperation with Taratest Oy, was to identify various methods and models for the sustainability assessment of contaminated soil risk management and thereby support the adoption of sustainable risk management methods for contaminated soil. Different risk management methods for contaminated soil models, and tools used in Finland and other countries for sustainability assessment of contaminated site remediation was collected.

Assessments of the sustainability of contaminated soil risk management strive to steer the planning and decision-making of remediation projects in a more sustainable direction. The purpose is to determine remediation methods that maximize the overall benefits, considering the three dimensions of sustainability: environmental, economic, and social impacts. Two case studies illustrate key steps in the risk assessment process. A step-by-step research student conducting cases provides the overall strategy and methods, and risk assessment methods were applied.

2 SOIL CONTAMINATION AND REMEDIATION

Contamination is examined in areas where harmful substances may have entered the soil. If the toxic substances have the potential to cause significant harm to the environment or health, the site must be remediated. Such decontamination may have other objectives and prevent damage to the environment and health (Vepsäläinen, Pyy, Sjölund, Nikunen, Rajala & Reinikainen 2016, 9).

2.1 Activities that cause pollution and toxic substances

Soil and groundwater can be contaminated by activities involving the usage, production, handling, transporting, or storing of harmful substances (chemicals) or waste. Contamination can be caused by a single accident or by long-term discharges from everyday activities. Soil can also be contaminated by air and water pollution outside the site or by imported fill or waste. In most areas under investigation and treatment, environmental contamination occurred decades ago (Vepsäläinen et al. 2010, 9).

2.2 The purpose of a soil investigation

Contamination is usually investigated based on a history of activities in an area that is suspected of contamination, usually when the use or ownership of the area changes, when construction takes place, or when industrial activities cease. Observations of contaminants, for example, during groundwater monitoring or when underground pipelines and tanks are removed, may also trigger the need to determine the site's status. The contamination assessment is carried out by investigating the presence of harmful substances in the soil of the site and, where appropriate, in other environmental compartments such as groundwater and indoor air in buildings. The aim is to determine the concentrations, total amounts, and location of harmful substances in the area under investigation, the transformation and transport of the substances, and identify persons and organisms potentially exposed to them through different environmental compartments.

Based on this information, the contaminants potential environmental and health effects and the need for further decontamination of the area (risk assessment) will be assessed (Vepsäläinen et al. 2010, 9-10).

If investigations carried out at the site show that the concentrations of contaminants measured in the soil exceed the threshold values and background concentrations set by the Government Decree (VNA 214/2007, Government Decree on the Assessment of Soil Contamination and Remediation Needs, so-called contaminated soil Decree), the contamination of the site and the need for its decontamination must be assessed. Other reasons, such as elevated concentrations of contaminants in groundwater, may also trigger the need for an assessment (Vepsäläinen et al. 2010, 10).

Background concentrations refer to naturally occurring concentrations of harmful substances in soil or contaminants that occur over a wide area in the surface of an area due to artificial activities and that originate from several different emission sources, e.g., elevated concentrations in the surface soil of the urban regions, road and railway areas or large industrial sites due to industrial and transport air emissions, also there are natural contaminants or naturally occurring contaminants. For example natural soils and bedrock may have naturally occurring high concentrations of some heavy metals (Vepsäläinen et al. 2010, 10).

2.3 Why and when is soil remediation required

Decontamination is necessary whenever a risk assessment shows that harmful substances in soil or groundwater pose a significant risk to the environment or health. In such cases, the primary objective of decontamination is to remove the contaminants, modify their properties or limit their transport to an acceptable level to reduce environmental and health risks (Vepsäläinen et al. 2010, 11).

The remediation process can also involve, for example (Vepsäläinen et al. 2010, 11):

- the removal of clean-up liabilities relating to pollution of the site,
- increasing the value and prestige of the site,
- reducing restrictions on land use and the developability of the site; or
- social pressure to remove a potential source of concern and fear. The importance of the different factors varies from project to project. The objectives of remediation may also change as the contaminated soil project progresses

3 ENVIRONMENTAL RISK ASSESSMENT OF SOIL CONTAMINATION

3.1 The objective of risk assessment

The risk assessment aims to identify harmful substances and their sources related to the risks. Potential pathways and exposure scenarios should also be identified. According to the Environmental Protection Act, damage related to soil contamination may affect human health, the environment, public amenity, and public or private interests. When there is no precise information on the actual occurrence of harm or hazard, it is referred to as a risk. Its magnitude is determined by the severity and likelihood of the damage (Ympäristöministeriö 2007, 21 & Ympäristöhallinnon yhteinen verkkopalvelu 2013).

Environmental and health risks are influenced by factors such as (Ympäristöhallinnon yhteinen verkkopalvelu 2013):

- the soil- and groundwater conditions,
- harmful substances and their amounts, concentrations, and properties,
- the current and planned use of the land, its environment, and the groundwater,
- exposure to harmful substances over long and short periods

Health risks

The health risk is defined as the adverse effects on human health that may result from exposure to harmful substances. Health effects can take many different forms and manifest themselves in many ways, such as skin rashes or respiratory diseases. Risk assessment requires an estimate of the amount and duration of exposure and information on the effects of the harmful substances (Ympäristöhallinnon yhteinen verkkopalvelu 2013).

Environmental risks

Environmental risks increase the probability of adverse effect that soil contaminants can have on the organisms in the affected area. These effects can be manifested at different levels, such as reducing groundwater or indoor air quality and soil microbe activity. Results may also include disturbances to the reproduction of a particular species or a reduction in the number of species (Ympäristöhallinnon yhteinen verkkopalvelu 2013).

3.2 Risk assessment methods

The need for a soil contamination assessment is determined by the operational history of the site and the observations made at the site. If this information indicates that the site may be contaminated, investigations and other surveys should be carried out to determine the presence of contaminants. The assessment methods discussed in this work can be used when the harmful substance is known to contaminate the soil and/or groundwater. If the pollutant is not known, the assessment procedure may be different. The way the assessment is carried out and the methods used to determine it will be chosen on a case-by-case basis. In practice, the evaluation will be based on concentration measurements, other pollutant and target studies, and the comparison of the results of the calculations based on these with soil guidance values and different reference values (Ympäristöhallinnon yhteinen verkkopalvelu 2013).

At its simplest, the assessment can be made by directly comparing the concentrations measured in the area with the threshold and guideline values set out in the contaminated soil regulation. In this case, however, it must be ensured that the guideline values can be applied at the site and that the measured results from the site are representative of the baseline condition of the site. The lower and upper guideline values are used as reference values for contamination, depending on the site's land use (Ympäristöhallinnon yhteinen verkkopalvelu 2013).

Upper guideline values are used in an area used as an industrial, storage, transport area, or other corresponding areas if the concentration of one substance or several substances exceeds the prescribed upper guideline value, and lower guideline values are used if the concentration of one substance or several substances exceeds the prescribed lower guideline value (Ympäristöministeriö 2007, 1).

Lower guideline values are set at a concentration level representing the maximum generally acceptable risk under general land use. The upper guideline values define the maximum acceptable risk at less sensitive land uses, such as industrial and storage property areas. The lower and upper guideline values are based on ecological or health risks (Reinikainen 2007, 9)

Soil is considered contaminated, and remediation is often necessary when land-use guidelines are exceeded. However, a more detailed assessment shows that the risks are acceptable despite the elevated concentrations. Soil decontamination may sometimes be found necessary even if the guideline values are below the limits. For example, in such cases, there may be a risk of groundwater contamination (Ympäristöhallinnon yhteinen verkkopalvelu 2013).

If the assessment shows that all relevant adverse effects and risks are negligible, i.e., acceptable, then the soil and groundwater in the area are not contaminated and do not require remediation. Depending on land use and contaminant concentrations, soil and land-use restrictions may remain for sites of this type (Ympäristöhallinnon yhteinen verkkopalvelu 2013).

Consultants and other experts carry out soil surveys and assessments of soil contamination and the need for treatment. The Centre for Economic Development, Transport, and the Environment (ELY Centre) reviews the appraisal and decides on the remediation of the soil and its objectives (Ympäristöhallinnon yhteinen verkkopalvelu 2013).

According to the Ministry of the Environment's Guide 2/2007, there are three stages in the assessment procedure (Ympäristöministeriö 2007, 22):

- identifying the need for assessment,
- baseline assessment
- extended assessment

These three steps are used to identify, define, describe, and assess the acceptability of risks. The step-by-step approach to the assessment is provided to support data collection, processing, and documentation. However, it is not always intended to be presented step-by-steply (Ympäristöministeriö 2007, 22).

3.2.1 Identification and need of soil assessment

In the first stage of the assessment process, the need for an assessment is determined based on the site's historical data. The site history will mainly consist of information on activities that may have resulted in the release of harmful substances to the soil. In addition, the need for assessment will be determined based on concentration measurements and comparison with the threshold/background concentrations laid down in Government Decree (214/2007) (Ympäristöministeriö 2007, 22).

3.2.2 The basic (or primary) assessment

The threshold value corresponds to the concentration level at which the risks posed by the harmful substance in the soil can be considered negligible, regardless of where the soil is located or used. Background concentration means the natural concentrations of an undesirable substance in soil or topsoil from several different emission sources and not from activities at the site. If the threshold values and background concentrations are exceeded, or if an assessment is deemed necessary for other reasons, including elevated levels of pollutants in the indoor air of the building or groundwater, the evaluation will move to a baseline assessment. For those pollutants with no threshold value that has been set, the need for the assessment will be determined separately.

In other cases, the soil may be found to be uncontaminated, and no clean-up measures are required. In this case, no further assessment is required (Ympäristöministeriö 2007, 22-27).

The baseline assessment evaluates the contamination and the need for decontamination based on the site's land use and environmental conditions and the information on the contaminants found at the site. The baseline assessment describes the site's characteristics that may contribute to ecological and health risks from pollutants in the soil or transported to other parts of the environment. Factors include transport, exposure sources, exposure pathways, and harmful effects. The necessary information is gathered from the literature and existing data such as maps, land use and planning data, research reports, soil, bedrock, groundwater and waterbody data, etc., available at the site. The site is also visited, and, where necessary, information is obtained through various field surveys such as groundwater wells and boreholes. Based on the site data, a conceptual model of the presence of contaminants in soil, their potential pathways, and the target groups exposed to them can be established (Ympäristöministeriö 2007, 22-32).

The type and scale of risks to the environment and health from harmful substances depend on the transport of the pollutants, the exposure of organisms and humans to these substances, and the effects of exposure. These are assessed based on environmental concentrations chemical and physical properties such as transmissibility, bioaccumulation, persistence, and toxicity. The total amount of harmful substances affects their dispersion and perseverance in the environment (Ympäristöministeriö 2007, 34-35).

The level of risk is obtained by comparing the levels of contaminants measured in the soil and, where appropriate, other environmental compartments of the site with the guideline and reference values. If the values are exceeded, the soil or other environmental elements such as groundwater or surface water are considered contaminated, and clean-up is necessary (Ympäristöministeriö 2007, 22, 35).

Comparing measured levels of contaminants with guidelines and reference values is insufficient to determine risks at all sites. This is partly due to the criteria used to determine the importance and the associated uncertainties. In such circumstances, a more refined assessment is carried out even if the guideline and reference values for contaminants are not exceeded at the site. The baseline assessment identifies and describes the factors that influence whether the risks can be defined at the guideline and reference values (Ympäristöministeriö 2007, 22).

The baseline assessment must identify not only environmental and health risks, but also other harms according to Section 7 of the Environmental Protection Act, such as a reduction in amenity or deterioration in well-being, and, if necessary, assess their impact on the contamination of the site and the need for clean-up. Any suspicion of contamination of the site will reduce the value and appreciation of the property and its surroundings. Contaminants may also affect structures and building materials (Ympäristöministeriö 2007, 22, 47-48).

The sources and studies used in the assessment are always subject to uncertainty. At all evaluation stages, careful attention must be paid to the representativeness of the environmental samples taken and the reliability and integrity of the source data. The most common uncertainties relate to the contamination history of the site, the distribution of contaminants in the target area, the studies' adequacy, and the results completeness (Ympäristöministeriö 2007, 41).

3.2.3 Comprehensive assessment

If the baseline assessment cannot provide sufficiently reliable conclusions on the contamination of the site and the need for clean-up, the assessment will be revised. The comprehensive assessment goes beyond the baseline assessment in how it treats and applies the baseline data. More information is needed on the site, for example, on the presence and behavior of contaminants in soil and other environmental compartments. Data is also required on groundwater and surface water conditions in the area and other factors affecting the transport and exposure of the pollutant. The comprehensive assessment is often supported by migration and exposure models. Where appropriate, the assessment may be supplemented by different exposure tests (Ympäristöministeriö 2007, 22-23).

The assessment may be stopped if the soil or other part of the site's environment is remediated or the soil containing harmful substances is excavated, for example, because of construction. In this case, however, it must be demonstrated that the concentration of toxic substances in the soil and the potential risks arising from them will be at an acceptable level after decontamination of the soil (Ympäristöministeriö 2007, 23).

The objectives and limitations of the extended evaluation will be set and justified on a case-by-case basis. The setting of goals will always be influenced by the level of environmental protection required and the long-term objectives, which are mainly based on environmental legislation. The overall framework includes the definition of the risks and pollutants to be considered, the spatial and temporal delimitation of the assessment and the choice of assessment methods. The comprehensive evaluation will focus on the most relevant pollutants in terms of risk, the most pertinent exposure routes and situations, and the most likely and likely to be exposed target groups. It also focuses on risks that cannot be adequately identified by the generic guideline and reference values or for which the baseline assessment indicates that the risks are not at an acceptable level. Qualitative and quantitative methods will be used to determine the evaluation. The procedures and the conclusions drawn from results are described in the assessment, considering the degree of uncertainty (Ympäristöministeriö 2007, 23, 49-50).

The assessment methods will be chosen on a case-by-case basis. They may be based on the environmental fate of the pollutants, exposure to humans and organisms, or computational modelling of the effects. Computational modelling software includes SOILIRISK, Caltox, SSL, RAIS, CLEA, etc. In addition, assessment methods may be based on environmental studies and measurements, such as contaminant solubility tests, groundwater flow patterns, and soil properties. The use of mathematical models can predict to a large extent the damage caused by soil contamination.

They can be software specifically used for risk assessment in the form of calculation tools based on statistical data and theoretical or empirical equations. The use of modelling requires that the assessor understand the computational theory of the model and the input data from the assessment site to the model, such as soil, groundwater, and site use data. Models can estimate the transport of pollutants and the change in concentrations from one part of the environment to another, such as from soil to groundwater. Most models can also predict human exposure and ecological changes in the background (Ympäristöministeriö 2007, 51-55).

The reliability of the evaluation is assessed utilizing qualitative or quantitative uncertainty analysis. Uncertainty is increased by the lack of variability of the assessment data and the limitations of the methods used. Uncertainties associated with lack of data include the choice of parameters used in the assessment, the representation and inadequacy of the transport and concentration data for the pollutant, the assumptions made in the transport and exposure pathways, and their combined effects. Uncertainties associated with the assessment methods include their suitability for the site and for describing the phenomena under consideration. All these uncertainties can be reduced by further refinement through additional studies and measurements and by using more than one method for the assessment (Ympäristöministeriö 2007, 58).

Risk mapping is the final step in the assessment process. It provides an assessment of the risks' magnitude, type, and acceptability. The risk characterization is based on the studies and determinations that have been made (qualitative and quantitative risk assessments). It concludes with an assessment of soil contamination and the need for decontamination. The concept of risk includes an assessment of the likelihood of harm, which means that the risk can never be eliminated. However, risks may be acceptable, but this is always decided on a case-by-case basis (Ympäristöministeriö 2007, 62).

4 RISK ASSESSMENT METHODOLOGIES

4.1 GoldSET – Sustainable evaluation tool

GoldSET is a commercial program that can be used as an assessment tool developed by Golder Associates. It can be used to compare and select treatment methods for contaminated soil. GoldSET includes several modules for various projects, including wastewater treatment, mining, and contaminated soil remediation. The program is intended to support project planning, decision-making, and reporting. The contaminated soil module consists of five steps: project description, development of remediation options, selection of indicators, evaluation of remediation methods, and review of results. The tool includes four areas of sustainability to be considered: social and economic impacts, technical factors, and environmental impacts (Nihtilä 2016, 35).

The purpose of the project description is to describe the objectives of the treatment and provide a description of the condition and constraints of the site. It then identifies the remediation methods to be compared and their respective remediation durations. It is also possible at this stage to carry out a preliminary shortlisting of methods if it is known that one of the methods is not worth further consideration (Nihtilä 2016, 35).

The GoldSET indicators describe the environmental, social, economic, and technical impacts of remediation. The indicators can be computational or qualitative. The indicators are selected based on their relevance to the site and weighted according to their importance. A module on the remediation of contaminated soil is available in the program's framework, which provides a set of indicators suitable for the remediation of contaminated soil. In addition, indicators can be added from other modules, and completely new ones can be created. The indicators selected can be weighted according to their importance. The user can create the weighting coefficients either by selection or by distribution methods. Selection means that the user chooses a factor from a menu with a range of factors, for example, from one to three, according to the importance of the indicator.

In the distribution method, the user assigns a selected number of points to the indicators in a sub-area, with the most significant ones receiving more points. The total number of points allocated to each sub-area is the same (Nihtilä 2016, 35-36).

The indicators selected for the evaluation of the remediation methods are assessed either qualitatively or computationally. For quantitative indicators, such as the amount of waste and total costs, the estimated quantities are provided. The program includes a carbon footprint calculator to determine the treatment methods energy consumption and greenhouse gas emissions. The calculator is fed with estimates of the equipment used in the treatment methods and their utilization rates. For example, in the case of transport, the number of trucks used and the distance travelled are entered into the calculator. For qualitative indicators, scoring is done by selecting each rehabilitation option. For each indicator, the scoring criteria are predefined, together with a description of the indicators used. The scoring should be done to allow for as many relevant stakeholders perspectives as possible to be considered. In the GoldSET program, the results for each component are presented as a percentage, with 100% indicating the most favourable option. The percentages are calculated as a weighted average of the results for each indicator in each component. The results for the quantitative indicators are scaled on a scale from 0 to 100, with the best treatment option scoring 100 and the worst option scoring 0. The qualitative indicators are scored on the same scale (0-100) (Nihtilä 2016, 36).

Additional information about the application can be founded on Golder Associates construction engineering company's main webpage golder.com.

4.2 The PIRTU tool

The PIRTU eco-efficiency tool was developed in the "Eco-efficiency of risk management solutions for contaminated soil and groundwater" project, coordinated by the Finnish Environment Institute. The PIRTU tool is intended as a tool for planning and decision-making in the risk management of contaminated soil. The

tool allows a site-by-site comparison of the sustainability of different remediation methods.
PIRTU is a Microsoft Excel-based calculation tool consisting of four sections: risks, environmental impacts, costs, and other factors. It is based on the Dutch REC (Risk Reduction, Environmental Merit and Costs) calculation tool, which has been adapted to Finnish conditions (Nihtilä 2016, 37).

The "risks" section identifies the reductions in health risks, ecological risks, and groundwater risks from treatment under different treatment options. The risks are determined by comparing the baseline and the final post-treatment situation for the different treatment options. In terms of environmental impacts, the loss of soil and groundwater, energy consumption, air emissions, waste, and land use are determined for the different treatment options being compared. The software calculates energy consumption and air emissions from input data, such as the amount of contaminated soil, the distance transported, or the processing power. The results for energy consumption and air emissions are expressed in per capita equivalents, where emissions are related to emissions per capita in Finland. Costs - the section estimates the costs of the different remediation methods for the project. The costs are broken down by the different stages of the remediation project into baseline costs, clean-up costs, monitoring costs, disposal costs, and other costs. If the costs of the 38 remediation options are set over a long period, they can be discounted to present value (Nihtilä 2016, 37-38).

Other impacts - this section identifies the social impacts of the treatment methods. These include psycho-social impacts, ecological impacts, impacts on image, impacts on site appreciation, and impacts on soil quality. Other social impacts can also be added. Impacts are assessed by scoring the impacts from -3 to +3 (Nihtilä 2016, 38).

The tool's summary section provides an overview of the evaluation results. The results of all sections have been combined, and different graphs of the results are presented within each section. This section also provides the goodness-of-fit scores for the remediation options based on the results and weights of each section. The PIRTU-program allows for weighting of each of the four main sub-sectors and individual indicators for each sub-sector. The weighting is done by multiplying the weight coefficient of each sub-component by the sum of the weight coefficients of all sub-components (Nihtilä 2016, 38).

4.3 The CalTOX risk assessment model

CalTOX is an Excel-based program developed by the California Department of Toxic Substances Control agency of the government of California to assess human exposure and set soil clean-up targets. The program can be used to assess the contamination of soil and adjacent air, surface water, groundwater, and sediment layers. The program and its instructions for use are freely available at. CalTOX is user-friendly and clear, but it contains very large spreadsheets and the data used for the calculation are presented in a scattered way. However, the program is particularly well suited for preliminary risk assessment (Kuusela-Lahtinen, Mroueh, Vahanne, Kling, Kapanen, Priha, Laine & Rossi 2010, 41).

4.4 MMSoils

MMSoils is a DOS-based health risk assessment tool used to some extent in Finland in previous years. The programme has been included in a comparison of risk assessment programs by Esko Rossi. Nowadays, risk assessment has moved mainly to more user-friendly Windows-based programs (Kuusela-Lahtinen et al. 2010, 42).

4.5 RISC – Health risk assessment for contaminated sites

RISC is a Windows-based health risk and transport risk assessment software. It was developed by Bp Oil International Ltd. and is based on the American Society for Testing and Materials (ASTM) Risk Based Correction Action (RBCA) method. The original objective was to provide a consistent and transparent review of the risks associated with company-owned assets. However, the model has spread to wider use. It has the most comprehensive spill risk assessment element of all the options studied, with the possibility of probabilistic modelling. The software cost from 400 up to 860 dollars (Kuusela-Lahtinen et al. 2010, 42).

4.6 The RISC-HUMAN – model for calculating site specific human exposer

The RISC-HUMAN is a software developed in the Netherlands to assess human exposure to contaminants in soil, groundwater, and sediments. The software is based on the CSOIL model developed by the National Institute of Public Health and Protection (RIVM) for human risk assessment of contaminated soil, which has been extended to include the effects of meat and milk from animals exposed to contaminants. The software is available for a fee. If desired, an operating grant is also available (Kuusela-Lahtinen et al. 2010, 42).

4.7 SOILIRISK model

SOILIRISK is an assessment model for site-specific risk assessment of small areas (e.g., a gas station area) of soil and groundwater contaminated with petroleum products, commissioned by Oil Sector Service Centre Finland. The model can be used to assess health and transport risks. The program is Excel-based and is based on the so-called RBCA equations recommended by ASTM but modified to be more appropriate for the intended use. The software is available for a fee (Kuusela-Lahtinen et al. 2010, 42).

4.8 SNV's Risk Assessment Programme

SNV's Risk Assessment Programme is an Excel-based software commissioned by the Svenska Naturvårdsverket, the final version published in autumn 2009 and revised after two rounds of comments. It is a model for the calculation of site-specific acceptable concentrations of soil contaminants based on the calculation principles of the Swedish Soil Guideline Values. In addition to the health risk assessment, the software calculates acceptable concentrations for ecological and groundwater protection of the site. The program is simple and easy to use. (Kuusela-Lahtinen et al. 2010, 42-43).

4.9 ConSim

ConSim is software developed by Golder Associates on behalf of the Environment Agency in England to assess the migration of pollutants, which can be based on the results of dissolution tests or soil concentrations. ConSim has been used to some extent in risk assessments in Finland. The software is available for different audiences, and prices vary from 425 to 850 British pounds (Kuusela-Lahtinen et al. 2010, 43).

4.10 SURE by Ramboll model

SURE by Ramboll is a free online tool developed for assessing the sustainability of contaminated soil treatment. The agency provides a model and methodology to determine the environmental impact of a remediation project and the economic and social impacts. SURE by Ramboll - online tools for guiding sustainability in contaminated soil remediation projects (Ramboll 2021).

SURE by Ramboll provides information on the most sustainable treatment methods to support decisions on the objectives of the project. The tool also enables dialogue between different relevant stakeholders during the remediation project (Ramboll 2021).

SURE includes 18 sub-categories and 70 sustainability indicators, and the top sustainability categories (environment, society, and economy), which support the 17 UN Sustainable Development Goals (SDGs) (Ramboll 2021).

The sustainability assessment of the decontamination project and its results will also produce an assessment report that will support national guidelines and international standards, bringing transparency and reproducibility to the decontamination project decisions (Ramboll 2021).

The starting point for sustainable remediation is to maximize the benefits and minimize the harm. Considering values other than economic ones makes the whole picture more complex.

SURE by Ramboll, an open and free cloud service, makes it easier for everyone and brings transparency to sustainability reporting (Ramboll n.d.).

If the soil on the site is contaminated, it must be replaced or remediated. However, vast quantities of soil are also excavated and transported without any pressing environmental or health risks. It is, therefore, a good idea to stop and think about what matters from an economic, social, and ecological perspective in every excavation project (Ramboll n.d.).

The idea behind sustainable decontamination is that it is economically viable but generates as little soil and aggregate waste as possible. Natural resources are used in a resource-wise manner, and the chosen method does not damage natural ecosystems or biodiversity. Furthermore, the decontamination method must not degrade the quality of the surrounding human environment (Ramboll n.d.).

SURE by Ramboll has all 17 UN Sustainable Development Goals (SDGs) built-in. They create a coherent and internationally recognized set of criteria for assessing the sustainability of treatment methods. In addition, we have considered international practices in the field, such as the Sustainable Remediation Standard (ISO 18504:2017). More than 70 decision criteria are included, covering a wide range of ecological, social, societal, and economic responsibilities (Ramboll n.d.).

One of the main objectives in developing the SURE tool is to help practically promote sustainability. Many municipalities, cities, and companies already have carbon neutrality and sustainability goal and a roadmap to achieve it. Getting started with measures is more complicated. SURE by Ramboll can provide a tool to help. Sustainable soil treatment can be an essential tool for achieving climate goals, from the circular economy to the carbon footprint (Ramboll n.d.).

SURE automatically logs information at each stage of the evaluation process. This facilitates transparent and objective sustainability reporting. For example, the documents generated by the tool directly show which UN Sustainable Development Goals (SDGs) the remediation activities have supported. This assures that sustainability has been sufficiently considered (Ramboll n.d.).

5 CASE 1: An industrial site, Tampere

5.1 Location description

This thesis aimed to conduct a site-specific risk assessment of the environmental and health risks of contaminated soil residues in the Tampere industrial area. In the land-use plan, the area is designated as an industrial block. In previous decades, a rubber factory was located in the factory building on the site. The rubber industry has been active in the area since 1963. Taratest Oy investigated from December 2020 to October 2021. Contamination by several different contaminants has been found in the area, and efforts have been made to determine the extent of the contamination.

The environment of the study area is relatively flat. The survey points are located inside the 160 m long and 50-70 m wide industrial building and outside the hall in the southern part of the property. The soils observed at the survey points inside the factory building were gravel, sand, clay, and sandy loam. The clay/silt layer, generally about 2 m thick, was mainly sandy gravel at the exterior locations. According to the GTK Geodata Service, the soil in the southern part of the property and the south of the property is sandy gravel. The soils in the northern parts of the property have not been mapped. The groundwater on the site was not under pressure. Groundwater is generally present immediately after the sub-contact of the clay layer in moraine or sand at a depth of about 2-3,5 m (in highly conductive layers). Groundwater wells generally had high yields if the borehole had penetrated a lot of sand or till. In the machine pits, the water was pressurized because the bottom of the machine pits was below the water table.

5.2 Risk-based monitoring and the measures taken

In December 2020, nine boreholes were drilled in the factory building for contamination investigations and concrete sampling. The sample was carried out using a tube sampler with an Atlas Copco Cobra Combi hand crawler. Holes 1 to 6 were made at the deepest levels of the machine excavations. From points 3 to 6, water flowed into the machine trenches due to pressurized groundwater.

Water samples from points 3-6 were taken from the upward flowing water inside the concrete section of the study holes using a Bailer groundwater sampler. Narrow aquifers were sampled using a hand pump. No further drilling was carried out because continuing the drilling would have resulted in the oil passing through the floor and soil. During the drilling, groundwater wells were installed nearby boreholes. Soil samples were taken through the concrete floors of the machine excavations at sample points. At some sample points, the pits were made after the machine excavations at the floor level of the factory building. A total of 6 concrete samples were taken from different points. A diamond core sampler was installed in the hand auger to obtain a sample of concrete approximately 5 cm in diameter, which penetrated the entire floor. The samples were analyzed for petroleum hydrocarbons >C10-C40 in 6 samples.

The concrete samples were sent to the laboratory of ALS Finland Oy for analysis. One concrete sample contained petroleum hydrocarbons above the level of the MARA Regulation 843/2017. Six groundwater samples were taken from sampling points 3-8. Soluble metals were analyzed in 5 samples, petroleum hydrocarbons C5-C40 in 5 samples, oil content >C10-C40 in 1 sample, polycyclic aromatic hydrocarbons in 5 samples, and volatile organic compounds in 3 samples. The analyses of the groundwater samples were performed in the laboratory of KVVY Tutkimus Oy. Water samples were taken at points 3-6 from upward flowing water inside the concrete section of the study holes using a Bailer groundwater sampler. Sampling results from groundwater sampling represent contaminant concentrations in the water accumulated at the borehole points than in the groundwater.
The groundwater pumps did not fit into a 25 mm hole, so pre-pumping could not occur. The installed groundwater pipes were iron pipes.

Investigations in May 2021 had still not reliably outlined the contamination, and the source of groundwater concentrations above the quality standard in southern groundwater well remained unclear. The new investigation program aimed to address these problems and provide additional information for the clean-up plans. In October 2021, survey points additional were excavated, and two extra groundwater wells were installed.

Samples were subjected to field XRF measurements for metals and PID measurements to identify petroleum hydrocarbons. Where PID measurements showed elevated levels of petroleum hydrocarbons, Petroflag field analysis was also performed. The purpose of the field measurements was to reduce the number of samples sent for research and identify contamination quickly so that additional sampling points could be planned immediately to limit the contamination.

The XRF analyzer measures the elemental concentrations of different materials. XRF analyzer can be used to determine various samples, including minerals, sediments, rocks, and soil samples. XRF is commonly used to detect the heavy metal content in soil samples. The PID meter can be used for various organic and some inorganic to detect compounds. In multiple applications, PID meters can detect volatile organic compounds (VOCs) and other airborne compounds (Tiusanen 2019, 19).

Samples were taken from six different groundwater monitoring wells. The yield was high in the new groundwater wells, and the water level did not drop much despite pumping. Groundwater samples were analyzed for metals, petroleum hydrocarbons, and chlorinated aliphatic hydrocarbons. Both soluble and total concentrations were analyzed for metals to provide information on metal transport. In addition, the pH, redox potential, oxygen content, and sulphate content of two groundwater wells were investigated for the cost estimation of in situ purifications.

5.3 Risk assessment methods

The objective of the site-specific risk assessment in this study was to determine the contamination of the site and thus assess the need for soil decontamination. The site-specific risk assessment was carried out as a calculated refined assessment for groundwater and qualitative assessment based on VNA 214/2007. According to the guidance document 2/2007 of the Environment Agency, an Advanced evaluation is necessary when significant amounts of volatile compounds are present in a site's soil.

The risk assessment took into account the properties of the contaminant, the pathways of transport, and the health and ecological risks. The calculated contribution to groundwater was carried out for petroleum hydrocarbons using the Excel-based PIRTU eco-efficiency tool. The calculation was based on the site-specific data. The program calculated the risks of the contaminant, the risks, environmental impacts, other factors, and groundwater based on measured concentrations of petroleum hydrocarbons and different fractions of petroleum hydrocarbons in soil and groundwater. The risk assessment was based on existing baseline data and research results. The risk assessment focused on the contaminant's pathways, health, and ecological risks.

The target values used for soil remediation in the area were the lower guideline values for the medium distillates found in the area. The concentrations of petroleum hydrocarbons detected in the area consisted almost entirely of medium distillates of petroleum hydrocarbons. High levels of petroleum hydrocarbons, vinyl chloride, and heavy metals were found in the soil and high concentrations of metals and VOCs were found in groundwater.

According to the surveys, the soil and groundwater on the property are considered contaminated in some areas. The contamination may have spread from underneath the factory building to the surroundings.

6 CASE 2: Commercial services, Helsinki

Soil surveys were carried out in October-November 2018 to determine the possible presence of soil contamination from past activities in the area. The site is located in Helsinki area. The site is currently occupied by a florist/garden shop and a detached house. Most of the site is covered with asphalt.

The site is not located in an area with groundwater. The nearest groundwater body is the Järvenpää groundwater body, located about 1 km to the south (class 2 groundwater body). Investigations show that clay soil starts about 0,5-1 m below the layer of fill gravel.

The 1964 aerial photograph shows that small-scale woodworking activities have been carried out. According to the information received, saturated wooden poles would also have been stored on the site. The 2003 aerial photo shows the same industrial hall as the 2017 aerial photo

The investigations aim to determine whether the site has been contaminated by past use. The aim is to ensure soil cleanliness for future construction projects.

In October-November, sampling for the contamination studies was carried out with a drilling machine tube sampler at seven sampling points. Samples were taken at depths of 1 m, 2 m, and 3 m. According to the research program, samples were selected for laboratory testing based on historical data and sensory evaluation.

After sampling, the samples were packed in gas-tight sample bags and stored in a refrigerator before being submitted to the laboratory for analysis. The laboratory analyzed six samples for petroleum hydrocarbons, eight samples for heavy metals, 1 sample for PAHs, 1 sample for pesticides, 1 sample for chlorophenol, and 1 sample for broad-spectrum contaminants.

In the case of study 2, heavy metal concentrations above the upper guideline values of (VNA 214/2007) were found at three different points, and a concentration above the lower guideline value was found at one sampling point.

Also, heavy metal concentrations above the threshold values were found for two other sampling points. Samples from the rest of the sampling points did not exceed concentrations above threshold or guideline values. Laboratory analyses of the case study indicate the possible presence of high contaminants resulting from past activities in the area. Remediation of the contaminated soil on the property is required. Metals are generally impervious to soil migration and are usually soluble at low pH. Based on the assessment, there is a low chance that the contaminant will occur in groundwater, waterways, or surrounding areas. But it's essential to look at heavy metals as a potential risk. All the different types of heavy metals and their variations might cause health problems and harmful effects on plants. For example, ecological risk varies according to the toxicity/harmfulness of the contaminant. For example, nickel and cadmium are dangerous in different ways.

The risk assessment took into account the properties of the contaminant, the pathways of transport, and the health and ecological risks. This study used hazard index and PIRTU eco-efficiency tools to assess soil heavy metal pollution. Among all the examined heavy metals in the surveyed area, the content of chromium (Cr) was the highest, and arsenic (As) and copper (Cu) were the lowest. Heavy metals are a critical concern in their pollution in ecosystems because of their persistence and environmental toxicity. The heavy metals results showed that all the heavy metals concentrations were higher than the standard guideline values for soil by about three times. Arsenic is naturally present in the soil and groundwater in certain regions. Soil with high arsenic concentrations can lead to severe health problems. Chromium is toxic in high amounts to the environment and humans. Chromium exposure can have severe consequences, and a high quantity of Cr leads to cancer and death. High concentrations of Cu in the soil can lead to toxicity problems for plants and humans and cause various diseases. Rain leads to great releases of soil intensification of precipitation, which could accelerate the leaching of heavy metals. Therefore, heavy metal remediation in soils is required to reduce the associated risks.

7 DISCUSSION

This study focused on the different risk assessment tools used to assess environmental risk due to contaminated soil. Risk assessment is an essential part of good environmental management. Many risk assessment tools are available on the market to analyse risk components and make risk conclusions. The risk assessment tools do not progress towards your objectives but will give better understand appropriate risk-related information needed to inform and guide. The thesis represents two cases of environmental risk assessment of contaminated soil. Risk evaluation assesses that such a high concentration of chemicals present in the environment has significant health and ecological effects. Many different risk assessment tools are not for free and are required to pay for each program application. PIRTU eco-efficiency tool is just one available option on the market and is accessible to everyone. Therefore, PIRTU eco-efficiency tool is user-friendly and affordable. The only downside of PIRTU tool is the risk index calculation which should be performed before risk assessment. Risk assessment cannot be calculated without further operations, so extra calculations are required. The PIRTU eco-efficiency tool is recommended for the risk assessment of contaminated soil, but knowledge is needed for an overall process or method for suitable and sufficient assessment. In the case of study two, the thesis author did not conduct a site-specific experimental investigation and, therefore, lacked the risk assessment information to identify possible details to get a considerably more useful overview. There was lack of available information on scale of pollutants.

7.1 Summary of PIRTU eco-efficiency tool

The PIRTU calculation tool consists of four components (risks, environmental impacts, costs, and other impacts). The PIRTU analysis assesses the risks, environmental impacts, and other factors for two different case study sites. In the section on the environmental effects, the environmental impacts of the treatment methods compared were determined. The indicators selected for each component are relevant to the case studies, and analysis results include health risks, environmental impacts, groundwater, and other social impacts.

The PIRTU method is an Excel-based tool, making it easier for those who have used Excel before. The easy customizability of the PIRTU spreadsheet tool is based on the simple editing of the Excel spreadsheet tool. It may be possible to integrate other software such as statistical tools. The data used can be easily updated in the cells of the spreadsheet. The tool comes with a set of predefined treatment methods and their data. It is also relatively easy to add new ways if their environmental impacts are known. With PIRTU, the code is visible to the user in Excel, making it easier to follow the calculation flow. The program is unambiguous, and all the data used is displayed to the user. On the other hand, the program's usability as an Excel spreadsheet is somewhat confusing. There are several tabs and moving from one account to another can sometimes be challenging. PIRTU mainly involves quantitative calculation. Only the social impacts are assessed qualitatively. The PIRTU tool contains pre-defined information on remediation methods. However, some information would need to be updated, and new information on new remediation methods could be added. With PIRTU eco-efficiency tool can compare different remediation methods and identify the most significant impacts on a project. The whole evaluation process and the justified results obtained are essential. The results can be used to justify choices in the decision-making process during the remediation planning phase (Nihtilä 2016, 80).

There were challenges in calculating the site-specific hazardous index (HI). The challenge was that the post-remediation condition is rarely known precisely at the assessment stage.

For example, the concentration of contaminants in the soil after remediation must be estimated when determining ecological risks. Assuming guideline values for the concentration of contaminants for each method, only the duration of the remediation will impact the reduction of risks. However, sometimes, it is sufficient to achieve the target level when planning remediation. For example, maximizing the risk reduction may lead to excessive remediation measures.

7.2 Case studies summary

For the case study 1 statements found elevated levels of contaminants in the area due to past activities, including the presence of oil under the floor. Based on analyses of soil samples, the primary contaminants present in the soil at the site are heavy petroleum hydrocarbons, cobalt, copper, and vinyl chloride. In groundwater, the most significant contaminants are metals, oil fractions C10-C21 and TCE. Based on the surveys, the elevated concentrations of contaminants in the soil are located around the northern machine excavation to the full depth surveyed and below the bottom of the southern machine excavation.

Under and around the northern machine trench, the soil was found to be mostly clay and silt. The clay in the soil layers potentially acts as a barrier to transporting petroleum hydrocarbons, heavy metals, and vinyl chloride. In addition, the heavy hydrocarbon fractions are sparingly water-soluble, moderately volatile, and non-transferable. Under and around the southern machine excavation, the soil is mostly observed to be gravel and sand. However, after filling the area around the pit, the surface is generally clay with a clay layer of 2-4 m, followed by sandy gravel.

Harmful substances have been found underneath the concrete floor inside the factory building, so it is not considered possible that the pollutants could be transported by dusty soil. However, airborne transport in the dusty soil is possible if excavation is done.

The soil samples detected vinyl chloride, which is easily transported by water. TCE was detected in soil samples only above the threshold in one sample.
Based on fractionation, the soil materials contain mainly low soluble and non-transferable petroleum hydrocarbons C21-C35. However, medium distillates C10-C21, which are more volatile than heavy petroleum hydrocarbon fractions, were also detected in the results from two groundwater well.

The total metal concentrations in the water samples from groundwater wells have shown relatively high levels of exceedances of the groundwater quality standard for almost all heavy metals. However, insoluble concentrations not exceeding the quality standard were observed except for arsenic. The source of the metals may be in the area of the investigated metal contamination under the factory building. In any case, it appears that the metal-containing sediment has been transported from somewhere nearby.

Water samples from the north side of the factory were rich in sediment even after pre-pumping. The water conductivity of the coarser layers of the soil was excellent in some places, so it is possible that the sediment could have been transported. However, the risk of wider dissemination of metals in groundwater solids was found to be negligible. This can already be seen from surveys of the surrounding groundwater wells, where the concentrations were very low, even for total concentrations. The highest arsenic concentration was measured in one aquifer.

The arsenic concentrations have likely been transported from under the factory building along the assumed north-south groundwater flow direction. The factory building is located 15-30 m north of the groundwater well. Some arsenic compounds are highly soluble in water, which may explain the elevated soluble concentrations of arsenic in groundwater. Based on the results, it does not appear that vinyl chloride has been significantly transported by water and its presence in the groundwater-saturated soil layer is limited. However, this does not mean that groundwater contamination is not possible.

Concentrations in groundwater above the quality standard appear to be confined to a relatively small area, and the concentrations in the groundwater wells are not very high either.
Considering that the groundwater quality standard concentrations are deliberately very low, the exceedance of such a low-quality standard concentration in the delimited area is unlikely to affect nature, biota, or humans negatively.

Pumping the groundwater under the factory building may have contributed to the transport of contaminants in the groundwater. The groundwater level has been lowered, especially during high groundwater levels. Areas around machine excavation pits that were assessed as risk areas were investigated at the site. High levels of petroleum hydrocarbons, vinyl chloride, and heavy metals were found in the soil at the site. High concentrations of metals and VOCs were found in groundwater. There is a risk for contamination, and hence exposure via groundwater exists as groundwater was observed in the area. Off-site transport of contaminants in groundwater is considered unlikely for all metals except arsenic. The investigations do not provide a definitive assessment of off-site migration via water in the soil, but it is possible. Reducing the concentrations of contaminants in the soil to harmless levels will reduce the risk of leakage.

Based on investigations, the soil and groundwater on the property are considered to be contaminated locally. There is limited contamination inside the factory building. The contamination has not been delineated for groundwater, and the source may be on a different property. The contamination may have spread from underneath the factory building to the surrounding groundwater.

The direction of groundwater flow is probably southwards, but this has not been further investigated through measurements. Contour maps of the water table determined groundwater flow and, therefore, might not be accurate. It is recommended to take measures to prevent the contamination from spreading into the groundwater. Mass replacement inside the factory building is not possible in the facility's current state. Suitable in-situ methods are recommended for risk management and decontamination if the building is retained on the property.
If the building is to be demolished, mass transfer is recommended as a remediation method. Soil and groundwater remediation and other appropriate risk management methods can prevent the spread of contaminants outside the property. By reducing the concentration of contaminants in the soil to harmless levels, migration risk is reduced. If the site's land-use changes, e.g., residential, the contamination must be reassessed.

In case study 2, a site-specific risk assessment aimed to identify risks and determine a path for risk mitigation. This indicates that there has been a leakage of heavy metals containing these metals at specific locations into the soil. Laboratory analyses indicated potentially high levels of contaminants in the area of multiple sampling points, which may have resulted from past activities at the site.

Representative soil concentrations of heavy metals on a site exceed the concentrations of the specified essential substances. Further evaluation and risk assessment based on collected data and calculations established on the obtained data into calculating critical heavy metals exceedance for the site. The target values used for soil remediation in the area were the guideline values. Heavy metals are naturally occurring elements and are considered a part of the soil. Heavy metals are usually insoluble, and the solubility depends mainly on the pH of the soil. At high pH, heavy metals tend to increase their solubility. Although most heavy metals show low mobility in soil, however, they might cause harm to the soil and human health. According to the survey, the soil is considered contaminated based on the high concentration of heavy metals in the soil. Mass exchange provides the fastest and most affordable alternative for remediation and delivers the quickest, and in this case, it was founded to be the cheapest option for remediation.

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APPENDICES

Appendix 1. Hazard index

The hazard index is calculated by HQ = Exposure / Reference value, where exposure is exposure to a single substance, depending on the effect considered. The reference value is usually described as either a daily intake (intake) or a concentration in the relevant environment representing the level of exposure. Exposure data must be in the same format as the reference value to compare. (Opasnet n.d.)

Reference value states exposure level considered safe in terms of non-carcinogenic health effects. The reference level includes the various assessment or uncertainty factors. The magnitude of these factors depends on the uncertainties associated with assessing the adverse impact. (Opasnet n.d.)

The hazard rate should not be interpreted as a statistical probability of the occurrence of harmful effects. Although the health risk increases relative to increasing hazard levels, the likelihood of adverse effects does not necessarily increase linearly with increasing HQ. The HQ calculation does not provide information on the nature of the dose-response of the exposed substance. The nature of the dose-response of a sense must be separately identified from the toxicity data, if necessary. However, as a starting point, it can be assumed that the lower the HQ is below 1, the lower the risk. The more the HQ exceeds 1, the higher the risk.
The effects of long-term exposure should be assessed by comparing the direction over the whole exposure period with the reference value for lifetime exposure.
In principle, short-term exposure (a single dose or a few repeated doses over a short period) should not be compared with the reference value for continuous long-term exposure, leading to an overestimation of health risk. Furthermore, short-term exposure should not be converted into a lifetime exposure level. However, short-term exposure (it has to be repeated exposure over some time, a single dose is not relevant) can be compared to the long-term exposure reference value for a rough assessment of health risk. To the rough evaluation, if HQ ≤ 1, adverse effects are unlikely to occur. If HQ > 1, an appropriate short-term exposure reference value should be used for a more detailed health risk assessment.

The reference value used should always be carefully described and justified. (Opasnet n.d.)

Hazard index (HI) HI = (HQ1 + HQ2 + ... + HQn), where HQn = Hazardous dose rate per exposure. If HI ≤ 1, then an assessed adverse reaction is unlikely to occur and if HI > 1, then an assessed adverse reaction as a consequence is possible. (Opasnet n.d.)

Given the high degree of uncertainty involved in assessing interactions, the numerical risk estimates can only be considered as rough, indicative estimates of the likelihood and nature of interactions. The risk estimates should not be interpreted as a description of the absolute magnitude of the health risk. (Opasnet n.d.)

If endocrine disrupters are present in the mining environment, their interaction should be assessed. Dioxins and PCBs (within a group) have a synergistic effect. There is a specific assessment method for this, whereby the different toxic equivalent factor (TEF) of the individual substances is considered in the harmful equivalency quantity (TEQ). (Opasnet n.d.)