CHALMERS

Comparison of the processes in Sweden and Denmark for remediation of contaminated sites

Master's Thesis in the Master's program Industrial Ecology – for a sustainable future

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Department of Civil and Environmental Engineering
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CHALMERS UNIVERSITY OF TECHNOLOGY
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Examensarbete 2010:4
Department of Civil and Environmental Engineering
Division of GeoEngineering
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
Picture from Luleå municipality homepage about contaminated sites, responsible contact person is Michael Öhman.

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ABSTRACT

Remediation of contaminated sites is an important environmental issue in Sweden and other countries. The processes for managing contaminated sites have developed somewhat differently in different countries in Europe. The main purpose of this study was to compare the Swedish process with the process in Denmark. The study comprised of an evaluation of the methods, structure and organisation of the remediation process in order to identify the main differences between the two countries. The guidelines for remediation projects, together with additional material from both countries and interviews with workers in both countries have been analysed as a basis for the comparison. The study shows that the environmental protection issues considered in the risk assessment and the environmental objectives in Sweden is one significant difference between the two countries. This was early put aside in the Danish work as resources were found to be more efficiently used in other ways. The focus on volatile substances in Denmark is another big difference, affecting especially the approaches for investigations and remedial measures. In Sweden the main focus is still on heavy metals and identification of volatile substances is not well developed. The Danish process seems more flexible and focuses more on actual reductions of risks to humans and ecosystems. The whole process seems more structured and organised in Denmark with a review organisation, extensive national registers for data on sites and information relevant for remediation projects. The statistics on remediation projects and costs also confirm a more efficient process in Denmark. Many of the differences are depending on legislation and organisation by the authorities. Denmark has more centralised responsible authorities, resulting in a more efficient work during the entire remediation process compared to Sweden with its many local authorities.

Key words: remediation, contaminated sites, remediation process, comparison, differences, Sweden, Denmark, remedial measures, remediation project, risk assessment, contaminated, soil, legislation, investigation, development.

Jämförelse av riskbedömningsprocessen för förorenade områden i Sverige och Danmark
Examensarbete för Mastersprogrammet *Industriell Ekologi- för ett hållbart samhälle*
STINA ROSÉN
Institutionen för Bygg- och miljöteknik
Avdelningen för Geologi och Geoteknik
Chalmers Tekniska Högskola

SAMMANFATTNING

Förorenade områden är en stor miljöverksamhet i Sverige och andra länder. Utvecklingen har de senaste åren sett annorlunda ut i Sverige än andra länder i Europa. I Danmark har utvecklingen gått åt ett annat håll, och frågan är om vi har något att lära från vårt grannland. Genom att jämföra metoder för efterbehandlingsprojekt i de två länderna har likheter och skillnader identifierats vad gäller värderingar, metoder och tillvägagångssätt. Danmark har utvecklat sitt arbete med förorenare områden snabbt och effektivt och har idag en delvis annorlunda process för provtagning, riskbedömning, åtgärdsutredning och åtgärder. Bland annat finns en större fokus på flyktiga föroreningar och särskilt klorerade kolväten.

Processen är i Danmark generellt mer flexibel för enskilda projekt och fokuserar på effektivt skydd av människa och grundvatten. Genom beslut att inte skydda markmiljön och en i övrigt väl organiserad process åtgärdas betydligt fler objekt i Danmark varje år till samma kostnad som i Sverige. Stora skillnader finns i organisationen och strukturen för arbetet nationellt med centraliserad organisation med Danmarks fem regioner som ansvariga myndigheter. Sveriges 290 kommuner har delvis samma ansvar, och inte ett lika utbyggt samarbete kommuner och regioner emellan.

Nyckelord: förorenade områden, förorening, efterbehandling, riskbedömning, jämförelse, skillnader, Sverige, Danmark, metod, utveckla, riskbedömningsprocess, projekt, sanering, lagstiftning, utredning.

Contents

Preface

This study has been performed on initiative from Sweco Environment in Göteborg. It has been carried out at the Sweco Environment office in Göteborg during the spring of 2009. The employees at Sweco were helpful giving advices and contacts to people with expertise on the Danish process for contaminated sites.

I would like to thank the employees at Sweco Environment for good support and company. The Danish employees that I was interviewing I would also like to thank for being very helpful. Finally this project would not have been conducted without my supervisors Lars Rosén, Staffan Kaltin and Sven Ardung, thanks for your help. Also I would like to thank David, my family and friends for great support.

Göteborg December 2009

Stina Rosén

Definitions and abbreviation

Acute toxicity Observed effect of poison on organism after short term exposure

Background level Natural level with anthropogenic diffuse accretion

BTEX Acronym that stands for benzene, toluene, ethylbenzene, and xylenes.

Cadastre Index of buildings

Chronic toxicity Negative effects of a substance giving long term effects on species

Contaminated site An area contaminated with substances to an extent that background levels are exceeded.

Dose response relation Relation between dose and frequency of a certain effect within a population

EC50 Effect concentration 50%, level substance giving effect on 50% of the tested organism

DKK Danish Crowns

Ecosystem Natural unit consisting of all plants, animals and micro-organisms in environment

Feasibility study An assessment to identify and investigate appropriate remedial measures

Filling material Anthropogenic moved material, normally built waste, excavated soil, wood etc.

EPA Environmental protection agency

GC Gas chromatograph

Generic guideline value Level of a substance ensuring no negative effects will occur.

Genotoxic Substance that harm the genetic material (DNA)

Geological map Map showing the extent of soil types and rocks

Ground water The natural occurring water in the saturated zone in the ground

Landuse The purpose that land or water area are or will be used for

LO(A)EL Lowest Adverse Effect Level (Dose response- relation)

Medium In this report the ground, groundwater, sediment or surface water that might be contaminated

MTBE Methyl tertiary butyl ether

NOEC No Observed effect concentration, The highest concentration with no effect on organism

NO(A)EL No (Adverse) Effect Level (dose response- relation), The highest dose with no effect on organism

PAH Polycyclic aromatic compounds (e.g. Benzene)

PID Photo ionisation detector

Point source A source effecting the environment locally

Protective value Selected sensitive species or ecosystem that are given protection

Recipient Human or ecosystem effected by contamination

Risk Probability and consequence for a scenario origin from a contaminated site

Risk assessment Identification and quantification of the risk caused by a contaminated site.

Risk classification An assessment of the potential risk from a site both probability and negative effects. A way of classify the risk.

Risk evaluation Evaluation of the best possible solution for the remediation project

Remedial measure Action to prevent negative effects to recipient

Remediation Action to prevent negative effects from contaminated sites to recipient

Remediation process The process to identify, quantify, evaluate and adjust the risks caused by contaminants on a site

Remediation project A contaminated site. A contaminated area with levels of substance exceeding the background levels. In focus for investigation

Remediation goal The aim set up for the remediation project, Used to evaluate the remedial measures

Screening methods Fast overview investigation

SGI Swedish Geotechnical Institute, national authority on geotechnical issues

SGU Swedish Geological investigations, National authority on soil and groundwater

SEK Swedish Crowns

Soil type The classification of soil into classes, e.g. Clay, moraine, sand, gravel, mud.

Source The source of a substance or contamination

SPIMFAB Project for remediation of old contaminated gas stations in Sweden

TCE Trichloroethylene

TDI Tolerable daily intake

Toxicity The degree to which a substance is able to damage an exposed organism

Quality criteria Equal Generic guideline value, a level of a substance ensuring no negative effects will occur.

1 Introduction

1.1 Context for the study

The work with contaminated sites is a big issue in Sweden as well as in other countries. During industrialisation many substances, both natural and non-natural, were produced and spread in high concentration. As a result, the concentrations in soil and water can be very high and many of the substances are harmful to humans and the environment. Today this is a problem. To avoid negative effects from contaminated soil, investigations and assessment of the risks from contaminated sites are performed to evaluate the need of remedial actions to eliminate negative effects on humans and ecosystems.

The work with contaminated sites started in the middle of the 1970s in Sweden. Many countries in Europe and USA started around the same time or earlier, but approaches and methods have developed differently. Sweden is not one of the leaders in this sector. USA, Holland, Canada and Denmark have developed methods and models for remediation that we have adopted and adjusted for our conditions. Today there are still differences and as the remediation costs are often very high it is interesting to evaluate how the Swedish methods and the process for investigating and remediating contaminated sites have developed. The focus on a sustainable society in Sweden is a major driving force in the work with contaminated sites.

The knowledge and methods for contaminated sites have been developed for a while, and some differences within Europe can be identified. It is interesting to study these differences and evaluate how they affect the process. How can we deal with these issues in a sustainable and efficient way to minimize the harm to humans and the environment?

This study will look into details on the procedure for the remediation process in Sweden and compare this with similar procedure in Denmark to identify the differences. Are there methods and models in the neighbouring country that are more efficient than the Swedish methods? What can we learn from Denmark to develop our work?

1.2 Aim of the study

The aim of the study is to compare the methods and processes for the work with remediation of contaminated sites to see what differences there are in the strategy, methods and outcome of remediation projects in Sweden compared to Denmark. Denmark has developed well in this field and the possibility of application of their methods in the Swedish process is evaluated.

1.3 Delimitations

This report will analyse the work with remediation of contaminated sites. The focus will be on the phases influencing the choice and outcome of remedial measures. This includes legislation, investigation and methods available for evaluation and choice of remedial measures, as well as the outcomes of the chosen measures. The elements for analysis are: Regulation, Inventory phase, Investigations, Risk assessment, Feasibility Study, Risk Evaluation, Remedial measures and Organisation of the work with contaminated sites within the countries. The Swedish and Danish remediation processes are described and analysed to identify differences and similarities. Evaluation of the process after remediation will not be included, and the development of quality criteria will not be analysed in detail.

1.4 Method

This master thesis project has been performed in collaboration with Sweco Environment in Göteborg, department for Environmental Techniques. The study is based on literature reviews of guidelines and reports published by the Swedish and Danish environmental protection agencies and other stakeholders. Interviews have been carried out with Danish consultants and authorities as well as Swedish consultants at Sweco Environment. Differences between the remediation processes have been evaluated according to several criteria. Two Swedish case studies have been analysed with hypothetical implementation of the Danish remediation process in order to illustrate the differences. The focus has been on guidelines for remediation projects. In addition practical experiences from consultants have been considered.

The project was carried out as follows:

1. Literature studies of Danish and Swedish guidelines on the remediation processes.
2. Discussion with Swedish and Danish expertise, interviews with Danish authorities and consultants.
3. Resume of the Swedish and Danish remediation processes according to several criteria: Legislation, Structure of the process, Investigations, Protective values, Prioritized substances, Mapping of contaminants, Landuse criteria, Exposure models, Risk assessment; levels, methods and assessment of effects and contaminants, Quality criteria, Use of software, Feasibility study, Risk evaluation, Remedial measures including statistics and Organisation of the remediation work.
4. Comparison of the process and the criteria given the above for the two countries.
5. Two Swedish case studies at ongoing remediation sites with implementation of the Danish process in order to investigate the differences in outcomes for the two processes.
6. Discussion and conclusions.

2 Legislation and regulations

Legislation and regulations are influential for the development of the remediation process. Authorities are an important actor and put pressure on stakeholders to care about contamination issues. In Sweden and Denmark the authorities on the national level are responsible for organising the work with remediation of contaminated sites.

2.1 Sweden

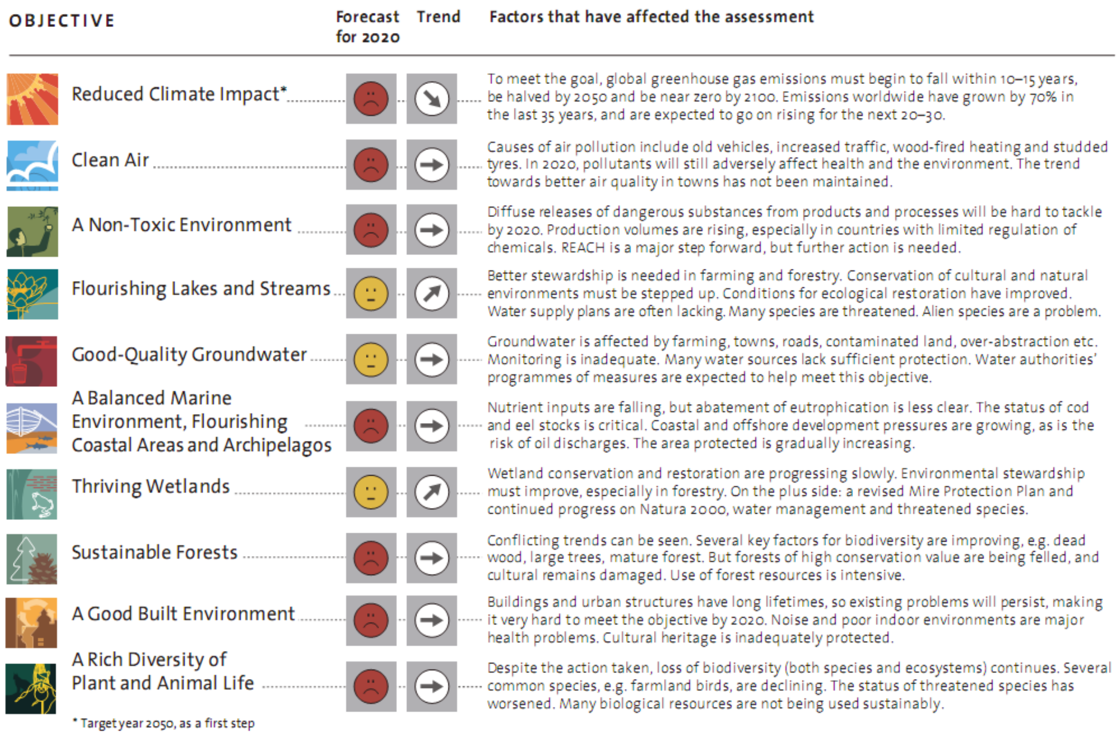
The work on remediation started in the 70s and 80s in Sweden. In the 90s guidelines for investigations, risk assessment and remediation technology were produced by the Swedish Environmental Protection Agency (EPA). The first specialised environmental law for contaminated sites came into force with the *Environmental Code* on the 1st of April 1999. The Environmental Code constitutes a modernised, broadened and more stringent environmental legislation aimed at promoting sustainable development. The same year the Environmental Quality Objectives were launched. In consensus with the Bruntland commission *16 Environmental quality objectives – for a sustainable society* are defined for a sustainable environment (Swedish Environmental Objectives Council 2008). These were adopted by the Swedish Parliament 1999 and intend to solve the major environmental problems until 2020.

The Environmental code put pressure on polluters. The Polluters Pays Principle make the polluters liable for remediation for activities that have a negative effect on the environment or health and that were still on-going after 30 June 1969. For serious environmental damage a new regulation give stakeholders the responsibility for emissions occurring after 1 August 2007. The main responsibility lies on the operation owner, i.e. the manager of the industry that pollutes the ground. If there is no responsible operation owner, or he/she cannot pay, the land-owner can be responsible if he/she knew that the area was contaminated and it was sold after December 31, 2008. Several factors influence the decision of responsibility, e.g. the time since the contamination occurred and if several operators contributed to the contamination (Östlund, 2006).

For the work with environmental questions in Sweden the *Environmental quality objectives* are an important factor. The objectives are created to (Swedish Environmental Objectives Council 2008):

- Support people's health,
- Enshrine the Biological diversity and nature-environment,
- Take care of Cultural and historical values,
- Protect the ecosystems long term productivity and
- Ensure a sustainable use of the resources.

The most relevant objective for contaminated soil is the objective for a *Non-toxic environment*; there are furthermore nine relevant objectives for contaminated soil according to the Swedish EPA (2007), the ten relevant objectives are presented in Figure 1.



OBJECTIVE	Forecast for 2020	Trend	Factors that have affected the assessment
Reduced Climate Impact*			To meet the goal, global greenhouse gas emissions must begin to fall within 10–15 years, be halved by 2050 and be near zero by 2100. Emissions worldwide have grown by 70% in the last 35 years, and are expected to go on rising for the next 20–30.
Clean Air			Causes of air pollution include old vehicles, increased traffic, wood-fired heating and studded tyres. In 2020, pollutants will still adversely affect health and the environment. The trend towards better air quality in towns has not been maintained.
A Non-Toxic Environment			Diffuse releases of dangerous substances from products and processes will be hard to tackle by 2020. Production volumes are rising, especially in countries with limited regulation of chemicals. REACH is a major step forward, but further action is needed.
Flourishing Lakes and Streams			Better stewardship is needed in farming and forestry. Conservation of cultural and natural environments must be stepped up. Conditions for ecological restoration have improved. Water supply plans are often lacking. Many species are threatened. Alien species are a problem.
Good-Quality Groundwater			Groundwater is affected by farming, towns, roads, contaminated land, over-abstraction etc. Monitoring is inadequate. Many water sources lack sufficient protection. Water authorities' programmes of measures are expected to help meet this objective.
A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos			Nutrient inputs are falling, but abatement of eutrophication is less clear. The status of cod and eel stocks is critical. Coastal and offshore development pressures are growing, as is the risk of oil discharges. The area protected is gradually increasing.
Thriving Wetlands			Wetland conservation and restoration are progressing slowly. Environmental stewardship must improve, especially in forestry. On the plus side: a revised Mire Protection Plan and continued progress on Natura 2000, water management and threatened species.
Sustainable Forests			Conflicting trends can be seen. Several key factors for biodiversity are improving, e.g. dead wood, large trees, mature forest. But forests of high conservation value are being felled, and cultural remains damaged. Use of forest resources is intensive.
A Good Built Environment			Buildings and urban structures have long lifetimes, so existing problems will persist, making it very hard to meet the objective by 2020. Noise and poor indoor environments are major health problems. Cultural heritage is inadequately protected.
A Rich Diversity of Plant and Animal Life			Despite the action taken, loss of biodiversity (both species and ecosystems) continues. Several common species, e.g. farmland birds, are declining. The status of threatened species has worsened. Many biological resources are not being used sustainably.

* Target year 2050, as a first step

Figure 1 The environmental objectives relevant for the work with contaminated soil (The environmental objectives council, 2008)

The forecast for the first period, until 2020, does not seem optimistic. To develop this field the Swedish Environmental Protection Agency (the Swedish EPA) has an important role to guide and organise the work in this field. Many reports are published for better knowledge and distinctiveness, and new guidelines are under development. 2003-2009 a special program called "Sustainable Remediation" was started to gather and spread knowledge in this field.

The Objective for Non-toxic environment

The aim of this objective is to have an environment that is free from man-made or extracted compounds and metals that could harm human health or biodiversity. This means that the concentration of natural occurring substances should be close to the background concentrations and non-natural substances should be close to zero. Within one generation is the time-span set to achieve the aim (Swedish EPA 2009).

Within the directive for Non-toxic environment there are special prioritized contaminants with negative environmental effect. These are hazardous, long lived and easily bio-accumulated substances. Especially carcinogenic substances, substances with genetic, hormonal or reproductive effects, and also hazardous metals like mercury, lead and cadmium are prioritized, with the ultimate goal to faze them out (Swedish EPA 2005).

2.2 Denmark

In Denmark there have been regulations about contamination of soils since 1983, when the first law about chemical waste sites was adopted. The revised and stronger version came in 1990 as the Waste landfill regulation (Affaldsdepotloven). In year 2000 this was replaced by the Law for Contamination of soils (Jordforureningsloven). In 2006 it was reversed to be more efficient (Danish EPA 1990, 2009). The Law for contaminated sites in Denmark aims to prevent, delimit and limit the soil contaminations or prevent harmful effects from contaminated soil to humans, groundwater and the environment.

Mapping of contaminated sites is an important issue and started by the first law in 1983. The law allows publication of this information for public interest. This put pressure on land-owners as contamination decrease the real estate value or limited the use for the area. In 2007 the directive for mapping was changed to not include areas that have low contaminant levels, typically older cities where diffuse emissions are present. These areas should be area-classified as *Area of minor contamination* and should not be mapped as a starting point. 1 January 2008 the law for Area-classification came into force aiming to prevent soil from areas of minor contamination to be removed to non-contaminated areas (Danish EPA 2009).

Groundwater is of major importance as drinking water source in Denmark. There is a water directive for clean drinking water in Denmark that aim to ensure that the groundwater is available and possible to use as drinking water source (Kiilerich 2009).

The Polluters Pays Principle is valid since 2000. This means that the polluters have the full responsibility for cleaning up the contaminated areas, and the government can enforce them to clean up. In reality this is hard to follow as remediation can be very expensive and the property owners may have difficulties to pay. The public service can take the responsibility for remediation and payment also if a polluter is identified (Danish EPA 2009; Dall-Jepsen 2009).

In Denmark, the regions have the public responsibility for reduction of risks from contamination in soil. They are responsible for their own drinking water resources, mapping of contaminations and investigations and remediation of contaminated sites. According to the newest regulation from 2007 they are also responsible for the official work with contaminated sites. The regions perform the mapping of contaminants, give advice about use of the site, and also take responsibility for remediation or other actions.

3 Managing contaminated sites in Sweden

3.1 Introduction

Humans and environment exposed to contaminations are at risk. Models have been developed to estimate the potential effects to humans and environment from contaminated soil. Possible measures to eliminate the risk have been identified and developed. The Swedish models are an adjustment of similar models from the Netherlands, USA and Canada. Every country develops the model after its own environmental conditions and legislation. Hence, the Swedish EPA had to evaluate and accommodate the method to Swedish conditions (Swedish EPA 1997). The Swedish EPA is mainly responsible for the development of the Swedish method and the first guideline was published in 1996, together with generic guideline values for contaminated soil.

For assessment of the risks and need for remedial measure analyses are made as the actual exposure from contaminations cannot be known. These analyses are called the remediation process. In this Chapter the remediation process will be described with main focus on the following elements:

- Inventory phase
- Investigations
- Risk assessment
- Feasibility Study
- Risk Evaluation
- Remedial measures
- Organisation of the work with contaminated soil in Sweden

Field investigations give knowledge about quantity, localization and possible spreading of contaminants. To assess the risk to recipients, knowledge about toxicity, exposure, transport, contamination media etc are important.

The Swedish remediation process assesses risks at different levels, from an overview to detailed assessment. As a tool for the assessment quality criteria are developed to compare the level of detected contaminations with reference values. The reference value or quality criteria are guiding and mark the highest acceptable level of contamination and risk to humans and ecosystems. The quality criteria are developed from data, models and assumptions from the “average” situation in Sweden.

In Sweden there are over 80 000 potentially contaminated sites identified (Swedish EPA 2008). Around 17 000 are classified according to the risk classification method developed by the Swedish EPA (reference!).

3.2 The remediation process

3.2.1 Introduction

To assess the risk for exposure to humans and ecosystem and to mitigate unacceptable risks from a contaminated site the remediation process is created. The aim is to, with reasonable certainty, determine the risks, how they can be reduced to avoid negative effects. Identification and quantification of the risks are important to evaluate if there is a need for action.

In the early 1990s the Swedish EPA started the development of a guideline for organising the work with remediation projects in Sweden. They came to the conclusions that a guideline and quality criteria for comparison with the contamination levels are important. The aim of the guidelines is to rationalize the work, make the risk assessments effective for correct decision making and prioritization (Swedish EPA 2007).

The remediation process for Swedish use contains eight main elements. The structure is presented in Figure 2 and is established by the Swedish EPA. The process is iterative and some elements may be repeated. The order and distinction of the elements are not always clear (Swedish EPA 2007). In this project the focus will be on element 2-5.

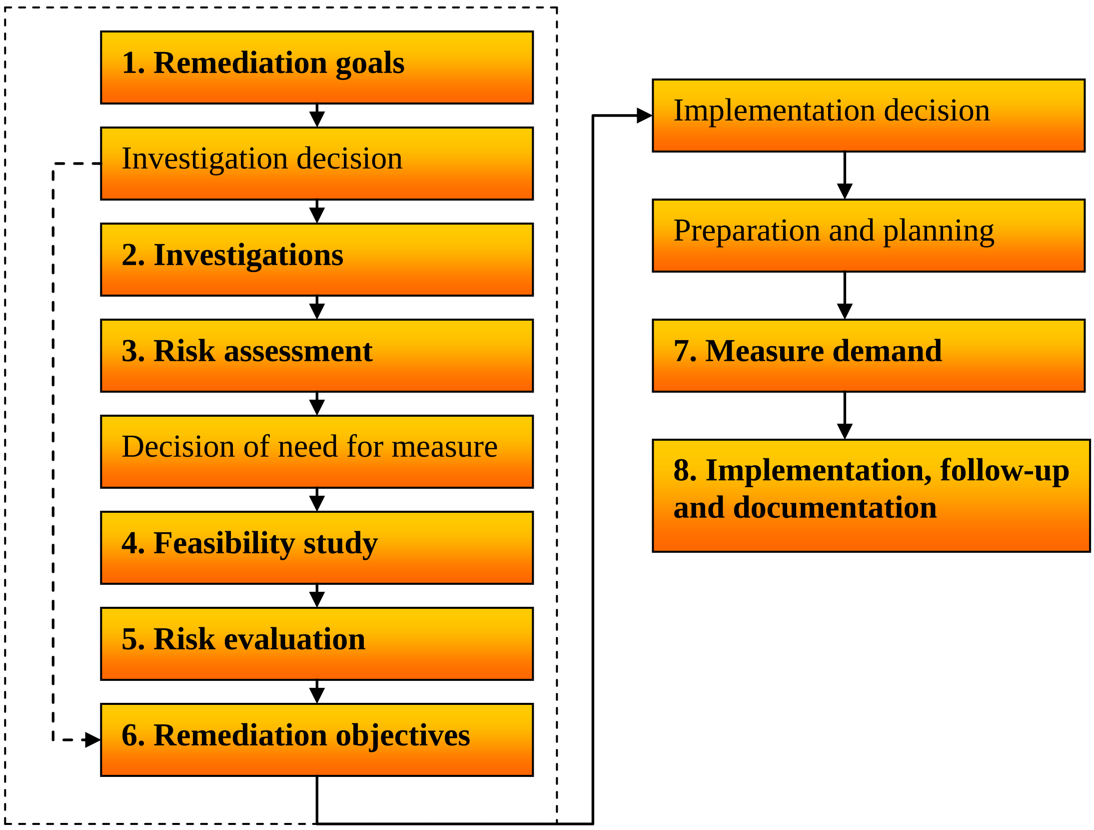


Figure 2 Elements included in remediation project process. The dotted square illustrates elements determining the choice of remedial measure (Swedish EPA 2007).

The remediation process is designed for old contaminated sites, e.g. industrial sites or contaminated filling material, but could also be used for new urgent situations like accidents. The time horizon for assessment of risks is normally 100 to 1000 years. This includes the demands for today as well as for the future (Swedish EPA 1996, 2007). In Figure 3 the elements in focus for this project are presented.

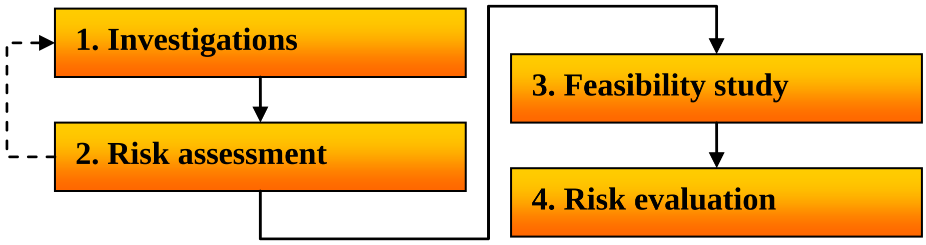


Figure 3 Main elements in the remediation process (Swedish EPA 2007)

3.2.2 Levels of risk assessment

The Risk assessment in Sweden is repeated and performed at three (or four) major levels; Risk classification, Simplified risk assessment and In-depth risk assessment. The same strategy is used for all levels, but the level of detail and quantity of information is increased for every level. In Chapter 3.3.7 detailed descriptions of the levels are given.

3.2.3 Investigations

Investigations are carried out to provide data for the risk assessment, feasibility study and risk evaluation. The site-specific features decide what investigations are needed. Investigations are carried out in several steps to provide data for the topical level of assessment. Investigations include collection of information about historical use, soil conditions, hydrology, buildings and the occurrence of contaminants. In the Inventory phase the background information is gathered from maps, interviews, pictures and other literature. This background helps to identify the contaminated areas and to construct a plan for taking samples. Sampling is carried out to provide information about the occurrence and levels of contamination for the Simplified and In-depth assessment.

3.2.3.1 Establishing sampling plan

With information from earlier activities on the site, geological and hydrological maps, construction maps and old pictures, an overview of the site is shaped. A geo-map for the geological characteristics is also important. This will be the starting-point for creation of the sample plan. The sample plan is important to optimize the sampling and ensure quality and rational field investigation. Motivations of all choices are desired. The plan for sampling should include a description of:

- What media should be sampled?
- Where the samples should be taken?
- What method should be used for sample-taking?
- How should the samples be prepared and analysed?

The choice of media for sampling is important to identify the contamination with as few samples as needed. Preferably, the samples are taken in the contaminated media. Soil, pore air, ground water, sediment and buildings are possible media for sampling. The sampling points are chosen to verify the contamination and contaminant transport and assess the background levels. The number of sample points depends on the type, size, and magnitude of the project as well as economic aspects. For heterogeneous areas five samples per hectare are suggested. Soil and groundwater samples are preferable taken at the same spot. The most important is to take samples at the suspected most contaminated areas, so-called hot spots.

3.2.3.2 Sampling methods

Methods for field investigations of soil in Sweden are mainly drilling and sampling-pit sampling. Drilling is the most used for overview investigations and preferable as the method is simple, fast and only need limited area. A disadvantage is that the samples may be disturbed when the samples are taken trough the upper soil. Samples should be taken down to uncontaminated media, or a few meters depth depending on the circumstances. As a starting-point one sample should be taken every half meter, in reality it often is reasonable to sample every meter. Many soil layers give preferable closer sampling. Sampling in pits is performed with an excavator down to the groundwater surface or to an appropriate depth up to six meters. It is a good method as the layers of soil or colour changes from contamination can be easily detected. The disadvantage is that the method demands large areas and the excavated soil has to be refilled again.

Groundwater screen wells can be implemented in drilled holes for groundwater sampling. These are placed in the lower part at groundwater level. Most used are plastic groundwater tubes with slits. Purging should be performed before the samples are taken.

Sampling of volatile substances like petroleum products are detected qualitatively with photo-ionic detectors, PID. Gas chromatography is used to detect organic volatile substances. Detailed methodologies for soil and groundwater sampling as well as sampling of surface water, pore air and sediment are described in report 4311 published by the Swedish EPA (1994).

The analysis methods are important to get an overview of the contamination situation. For many sites the components of contaminants are unknown or complex, especially for land-filled areas. A complete analysis of the chemical conditions is impossible due to theoretical, practical and economical reasons (Swedish EPA 1999).

3.3 Risk assessment

3.3.1 Definitions

3.3.1.1 Contaminated soil

Contaminated soil refers to land-filled sites or areas where point sources are contaminating the soil, groundwater or sediment to a level that significantly exceeds background levels, and poses a threat to humans and/or environment.

3.3.1.2 Occurrence of Risk from contaminated soil

A risk is occurring if hazardous substances at a site are transported and admitted by the recipients. If there are contaminants in the ground and there is a possibility for transportation of the substances through medium exposure occurs and pose a threat to humans and/or the environment risk. Possible negative effects are illness or injury to humans or damage to sensitive ecosystems. The model in Figure 4 illustrates the process (Swedish EPA 2007).

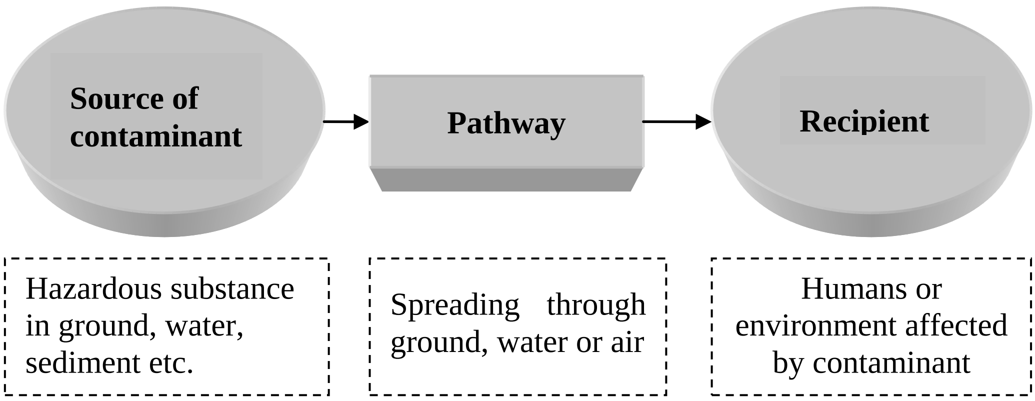


Figure 4 Model for occurrence of risk from contaminant to recipient

3.3.2 Protective values

In Sweden the effects on humans and ecosystems are seen as the major threat from contaminated soil. To avoid negative effects protection is given to recipients. Assessments are performed to evaluate the risks and how to reduce them. Protective values are: humans, environment with ecosystems, ground and surface water.

3.3.2.1 Humans

Health risks to humans are assessed on individual level; the risk is not changed due to the number of people exposed. Protection is given to humans with standard manner of life and normal sensitivity, not humans with extreme habits. Humans are categorised after how often and how long time they are estimated to be exposed. For carcinogenic and genotoxic substances a risk corresponding to less than one cancer patient per

100 000 exposed persons over a lifetime exposure is accepted. In case of specific carcinogenic substances and site-specific values the level of risk should not exceed 1 per 1 000 000. Urgent risks should be prioritised, this include accidental toxicity with effects like diarrhoea or vomits (Swedish EPA 2007).

3.3.2.2 Environment

Environment protection is given to the functions of ecosystems. Flora and fauna is protected at population level, which is assumed to give protection also to the function of the ecosystem. A contaminated site should not have intolerable negative effect on endangered animals or plants. For individual protection of endangered species the environmental risks are especially analysed.

The soil profile is seen as one ecological system and is given the same protection regardless depth. The ecological functions are dependent of the whole ecological system and protection is given at all depth according to the Swedish EPA. The ecological functions are though expected to decrease with depth.

Acceptable effect levels on ecosystems are established for protection of the ecosystem. For *Sensitive landuse* 75 % of the species are given protection and for *Less sensitive landuse* 50 % are protected. For protection of specific species, biodiversity or endangered species an individual assessment has to be carried out (Swedish EPA 2007).

3.3.2.3 Ground water and sediment

Protection of ground water is given for protection of humans, ecosystems and plants dependent on the water. Sediments are given protection for ecosystems, similar to ground water ecosystems. (Swedish EPA 2007)

3.3.2.4 Surface water

No severe disturbing of the aquatic environment should take place. The quality criteria for water and drinking water should not be exceeded. Besides the Swedish standards the European Environmental Quality Standards, EQS, are used. Surface water with sensitive species or inland water used as drinking water source have high protective values. (Swedish EPA 2007)

3.3.3 Assessment of contaminants

Many chemical compounds with harmful effects to humans and ecosystems occur at contaminated sites. The National Inspectorate’s directives and classification has several thousands of chemical substances listed with information about their effects on health and environment. The list is used to evaluate effects and toxicity from substances due physical, chemical and toxicological characteristics of the contaminants, as these factors determine the effects on bioavailability and transport, and where in the ecosystems the effects may take place

3.3.3.1 Hazardous substances

There are two categories for the prioritising of hazardous substances; substances phased out and the risk prioritized substances. The toxic features are determining the categorisation. Especially dangerous are heavy metals like lead, mercury and cadmium as well as organic compounds like DDT, PCB and dioxins (Swedish Administrative Development Agency 2009).

3.3.3.2 Classification of substances

There is a risk classification established by the Swedish EPA to categorize and evaluate hazardous substances at contaminated sites. Four categories are defined, Low to Very high risk. Very high risk holds the most dangerous substances for humans and exposure should be avoided. The hazard classification list is given in Table 1. This categorisation is the base for the Environmental Objectives and for the work with contaminated sites (Swedish EPA 1999).

Table 1 Hazard classification of chemical substances, products and mixtures (Swedish EPA 1999)

Low Risk	Moderate Risk	High Risk	Very high Risk
Iron Calcium Magnesium Manganese Paper Wood	Aluminium Metal scrap Acetone Aliphatic hydrocarbons Wood fibre Tree Zinc	Cobalt Copper Chromium (no Cr VI present) Nickel Vanadium Ammonia Aromatic hydrocarbons Phenol Formaldehyde Glycol Conc. acids Conc. bases Solvents Styrene Petroleum ashes * Petroleum prods. Aviation fuel Heating oil Waste oil Lubrication oil Hydrogen peroxide Paint and dye Cutting oil Petrol Diesel oil Wood tar	Arsenic Lead Cadmium Mercury Chromium (Cr VI) Sodium (metallic) Benzene Cyanide Creosote (old) Coal tar PAHs Dioxins Chloro benzenes Chlorophenols Chlorinated solvents Organochlorine compounds PCBs Tetrachloroethylene Trichloroethane Trichloroethylene Pesticides/herbicides

Quality criteria are used to compare the level of detected substances to evaluate the risk. In lack of quality criteria similar criteria from other countries are used, European standards of LOEC-values divided by 1000, for a description of the use of quality criteria and LOEC-values see Table 2.

Table 2 Principles for prioritization of hazardous substances in soil and water (Swedish EPA 1999)

Principles for prioritization of hazardous substances				
Medium	**Less serious**	**Moderately serious**	**Serious**	**Very serious**
Ground, sediment and groundwater: if quality criteria is available	<quality criteria	1-3 times quality criteria	3-10 times quality criteria	>10 times quality criteria
Groundwater (no quality criteria)	<quality criteria for drinking water	1-3 times quality criteria for drinking water	3-10 times quality criteria for drinking water	>10 times quality criteria for drinking water
Surface water	<quality criteria	1-3 times quality criteria	3-10 times quality criteria	>10 times quality criteria
Toxicity data	< LC50/1000	< LC50/1000 - LC50/300	< LC50/300 - LC50/100	> LC50/100

3.3.4 Mapping of contaminated sites

Mapping of contaminants are mainly performed and organised by the county authorities and often performed by the local authorities. National programs are also initialized for the identification of contaminated sites. The mapping includes identification and classification of potential risk objects; this is made according to MIFO or as possible contaminated industrial object.

The local and regional authorities in the municipality and regions are responsible for the information about risk classified areas, and can provide information at interest. The MIFO-classification is available from the local authorities and complementary information may be available. The organisation and history of the local authorities influence the extent of information available. No official register for contaminated soil is available in Sweden. (Swedish EPA 1995; 2007; 2008)

3.3.5 Sensitivity for landuse

In Sweden there are two categories of landuses; *Sensitive landuse* and *Less sensitive landuse.* The categories are based on substances toxicity, possible exposed groups and exposure time and have specific restrictions of use of the site. The actual exposure for a site is also affected by geological and physical conditions. Quality criteria are developed for general use for both categories (Swedish EPA 2007).

- *Sensitive landuse (SL)* gives the highest protection for humans and environment and allows all kind of use of the ground. It can be used for different purposes, i.e. dwellings, farming, groundwater intake, forest, parks etc. Exposed groups are expected to be children, adults and older people permanently settled in the area for life-time. Children's exposure is mostly the limiting factor. Most ecosystems are protected as well as ecosystems close to surface water.

- *Less sensitive landuse (LSL)* gives protection to ecosystems and groundwater and humans not living on the site. The quality of the ground is limiting the use to office buildings, industries or roads. Exposed groups are expected to be professionals working in the area and children and older persons temporarily visiting the area. Also protection for animals visiting the area and growing of ornamental plants is given for this classification as well as ecosystem close to surface water. Groundwater can be taken out at a certain distance from the site. This classification does not give protection to humans drinking ground water from the site (Swedish EPA 2007)

In the guidelines for remediation there is no in-depth division stated, the environment should be given the same protection regardless depth (Swedish EPA 2007). Depending on the project, the economical factors and level of knowledge there can be a division in depth. In the city-regions many of the projects administer in- depth division to decrease the cost and quantity of soil removed. By showing that the risk will remain low excavation of the upper soil layer can be sufficient (Börnell 2009).

3.3.6 Model for exposure

Humans exposed to contaminants from sites are subject to a risk. A model created to evaluate the risk from exposure includes six pathways from direct and indirect exposure. These are listed below and illustrated in Figure 5. For *Sensitive landuse* all pathways are included and *Less sensitive landuse* include the first four. All pathways should be included or well motivated if not (Swedish EPA 2007):

- Direct intake of contaminated soil
- Dermal contact with contaminated soil and dust
- Inhalation of dust from the contaminated site
- Inhalation of vapours
- Intake of contaminated groundwater
- Intake from plants and vegetables grown on the contaminated site (10% of the total intake of vegetables is assumed to be grown in the garden)

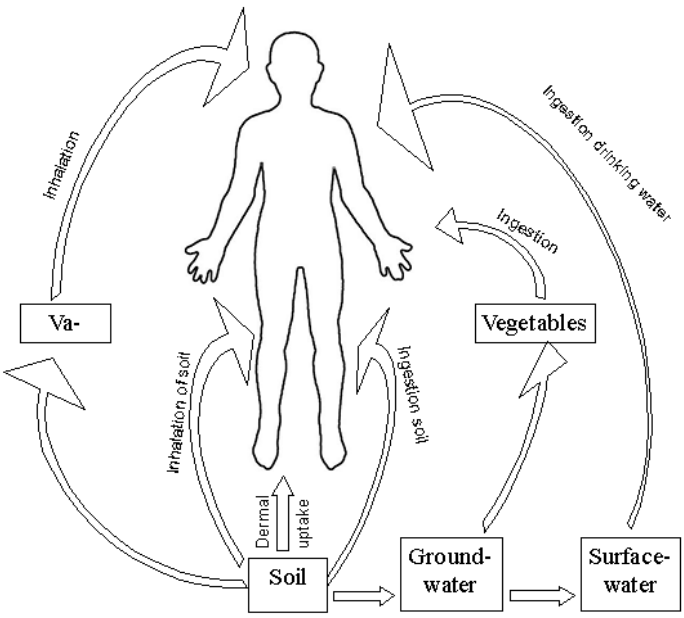


Figure 5 Conceptual model for possible medium and exposure pathways (Swedish EPA 2007).

The acceptable exposure to humans' values is evaluated with data for the tolerable daily intake (TDI). These values are assessed for every day exposure a full lifetime. As a base a contaminated site should not contribute to more than 50 % of the total TDI for each of the contaminants. The share is chosen to avoid multi exposure and ensure that no effects will occur.

There are several media and ways that contaminants spread within or between (Swedish EPA 2007):

- Groundwater
- Surface water
- Day-water and pipes
- Irrigation
- Dust
- Vapour
- Free phase transport
- Transfer among the levels in the food-chain
- Transport among generations (e.g. through uterus and breast milk)

3.3.7 Risk assessment

The Risk assessment process consists of four main elements, see Figure 6. A similar approach is the base for the risk assessment models developed in USA and Canada (USEPA 1998, Environment Canada 1997):

1. Problem definition
2. Assessment of contamination levels, transport and exposure
3. Assessment of effects
4. Comprehensive risk assessment

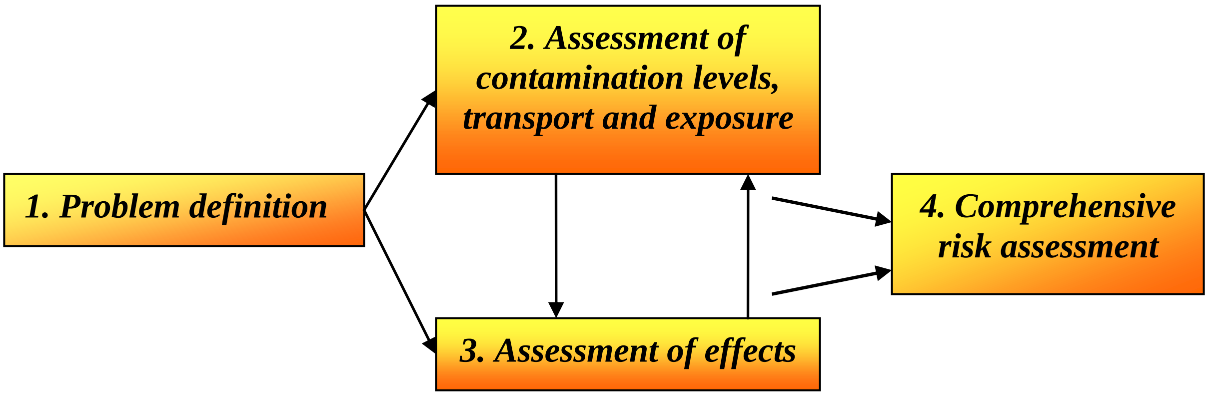


Figure 6 Main elements in the Risk assessment process in Sweden (Swedish EPA 2007)

3.3.7.1 Levels of risk assessment

There are three or four levels of risk assessment in the Swedish guidelines for contaminated sites. Depending on the situation, the complexity of the case and the remediation goals the investigations have to be more or less detailed. For every new level of investigation the demand of further studies are evaluated, including the costs for investigations and expected cost for remediation measure. The levels with corresponding need of information are described in Figure 7 (Swedish EPA 2007).

Investigation	**Inventory**	**Synoptic**	**Detailed**	
(earlier)	MIFO Tier 1	MIFO Tier 2	Pre-study	Main study
Risk assessment	**Risk classification**	**Simplified assessment** →	→	**In-depth assessment**
Data type	Qualitative →	→	→	Quantitative
Data set	Little →	→	→	Bigger
Certainty	Low →	→	→	Higher
Investigations	Literature	Simple tests	More tests	Detailed tests

Figure 7 Overview of the levels for risk assessment with corresponding data and certainty (Swedish EPA 2007).

Risk classification

The first step of the risk assessment is the inventory phase which aims to identify possible contaminants occurring at the site and categorise them. This is the risk classification and is made according to MIFO Tier 1. The method used is an overview assessment of the risk with accessibly data mainly from literature. Information is available from local and regional authorities as well as from industries is useful, often used are old maps, photos and registers. A field visit is included to identify visible indications at the site. The quality and quantity of information vary a lot between cases. A similar risk classification is carried out in Canada (Swedish EPA 1999; 2007; Börnell 2009).

With the available information a classification of the possible risk regarding toxicity, level of contamination, possibility of transportation and the sensitivity of the area is made. The results are weighted together in a Risk classification scheme and results in one of the four risk classes, see Figure 8:

1. Very great risk
2. Great risk
3. Moderate risk
4. Slight risk

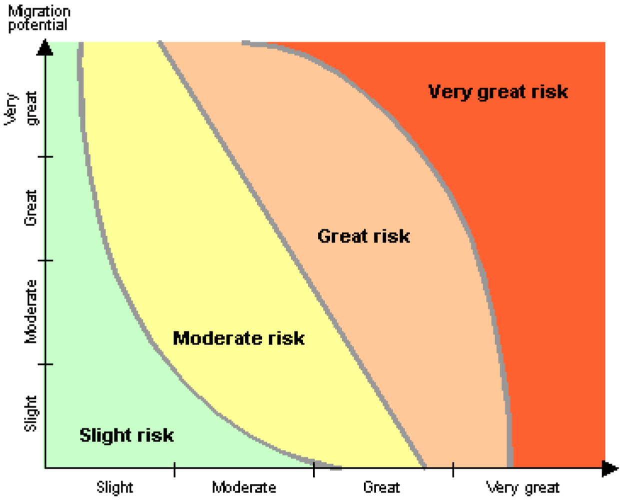


Figure 8 Risk classification scheme (Swedish EPA 2002)

The risk classification is an indicator for how urgent the risk is and is often used for prioritizing of objects. Risk class 1 and 2 should be further investigated to avoid urgent effects; slight risk will be less prioritised. The inventory phase and Risk classification is a qualitative assessment often used for mapping of contaminated sites. The Risk classification is revised if new information is available. The result is presented as a Conceptual Model, a good way to visualize the system, and can be used to explain the situation for involved stakeholders (Swedish EPA 1999).

Simplified Risk assessment

If the inventory phase and risk classification is indicating high risk or big uncertainty a simplified risk assessment is carried out. The simplified risk assessment is based on more or less detailed field investigations and consists of four steps:

- Check if detected substance have quality criteria for relevant medium
- Check the qualification to use the quality criteria
- Comparison between quality criteria and data from field study, if available
- Estimation of contaminant load

Quality criteria are preferable used for the risk assessment and the measured values are compared to the effect based quality criteria. If the values for the contaminations are higher for one or more substances remediation might be needed. A load based assessment can also be performed to survey that the total pressure, the levels in ground or surface water are not too high. The results in the simplified risk assessment normally have high variability and uncertainty in the data used. To deal with this the highest measured values and mean values are compared with the quality criteria (Swedish EPA 2007).

In-depth Risk assessment

If the simplified risk assessment is not giving certain enough answers, an in-depth risk assessment is needed. The reason could be lack of quality criteria for the observed substances, or that the situation is very different to the general case which means the requirements for the quality criteria cannot be fulfilled. Big uncertainties about the actual risk can also motivate a detailed assessment. An in-depth assessment should always be performed if the health and environmental risks are suspected to be underestimated. Several criteria are available to check the need for in-depth risk assessment:

- *Transport*
  - Geological, hydrological or chemical situations are differing from the assumptions (pH, organic substance, dilution etc.)
  - Existence of substance in free phase
  - Other transport pathways (day water, erosion, landslip, irrigation etc.)
- *Exposure*
  - More exposure pathways (inhalation of fumes from contaminated ground water, fish or other food)
  - Other exposure times, or missing exposure pathways
  - Acute health and environmental risks are expected
- *Protective object*
  - The exposed humans have higher sensibility or other manner of life that increase the exposure.
  - Threatened or endangered species or ecosystems in the area.
  - Risk for unacceptable pressure on important ground and surface water resources.

The procedure for performing the in-depth risk assessment is similar to earlier stages, but with more detailed investigations and quantitative data. The site-specific situation is important and considered, if needed new site-specific quality criteria are established. A revised problem description and conceptual model is carried out if needed, further steps are carried out as detailed as necessary. Both short and long term perspectives should be taken into consideration. The detailed risk assessment will look different in the single cases; the extent will depend on the earlier knowledge and lack of information identified.

There are generally two possible procedures for the detailed risk assessment; forward and backward. For both approaches the possible pathways for exposure are important, and the same models for assessing this are often used. Toxicological reference values used are based on the TDI values for health (Swedish EPA 2007):

1. The assessment is starting from the actual situation with descriptions of the risk from the possible conditions for exposure
2. Assessment starting from the effect based low risk levels and from the conditions for exposure acceptable levels of contaminations are calculated (quality criteria)

3.3.7.2 Risk assessment methodology

The risk method gives the structure of the assessment and contains four main elements, the second and third is often performed in parallel, see Figure 9.

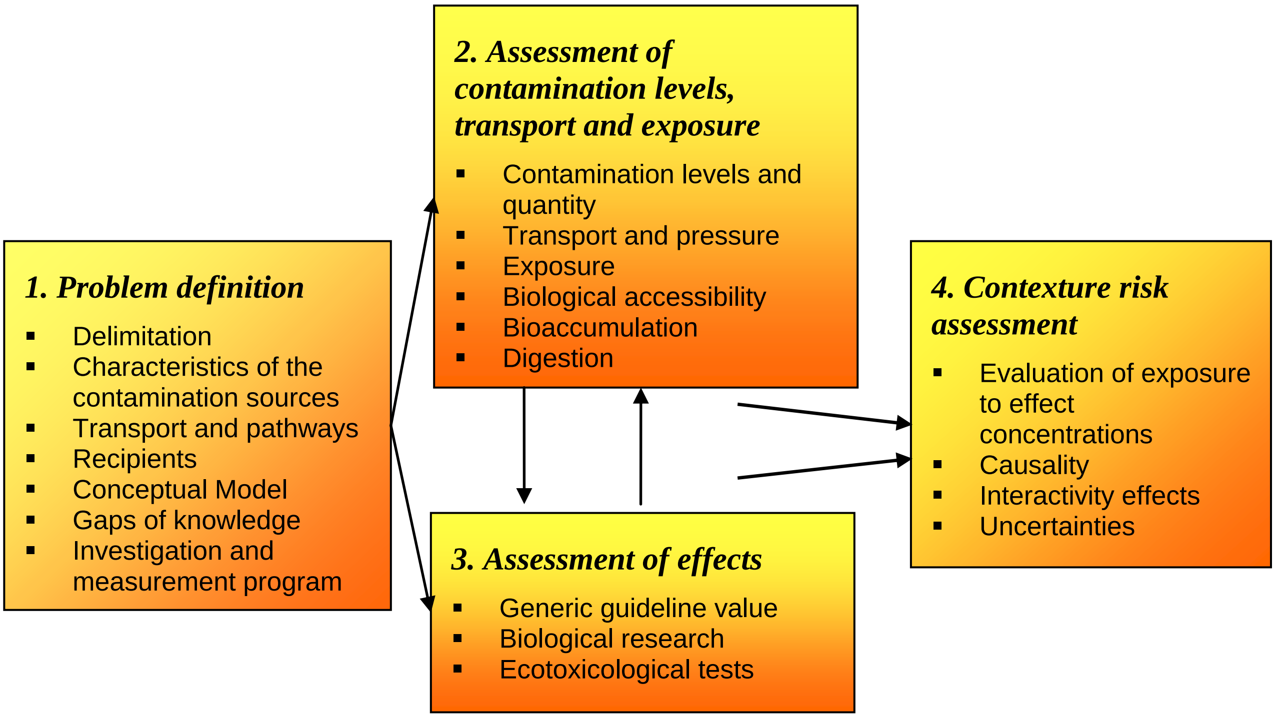


Figure 9 Phases for the Risk assessment method (Swedish EPA 2007)

1. Problem definition

The Problem definition is first carried out in the Inventory assessment. It aims at describing the risk situation and deciding if and what further investigations are needed. In this step the structure for the additional work and the need for information and data should be identified. The result from the problem definition is presented as a conceptual model and a risk classification. The results can be modified later in the process when additional information is gathered. Early discussions with relevant actors are recommended (Swedish EPA 2007).

Delimitations

Definition of future use for the area in time and space are defined. Factors to identify and consider in delimitations and definitions:

- Time perspective- normally 100-1000 years, special cases use near future or 50-100 years.
- The spatial distribution, e.g. economic area, dwelling borders etc.
- The use of the area, current and future utilizing
- Current and future use of adjacent areas possible affected
- Policy and regulations effecting the presumptions for environmental assessment

Characteristics of the contamination sources

Information about historical operation and activities at the site can be valuable to evaluate what substances are present and where they are localized and other information.

Transport and pathways

The possible pathways for transport of the substances are identified. Physical and chemical properties as well as geological and hydrological properties are important for assessment of the dispersal and distribution of the contaminants.

Recipients

Possible effected recipients are identified; an assessment of probable recipients for the situation is made.

Results

The results in the Inventory phase are presented in a Conceptual model. Delimitations should be stated and if possible different scenarios should be included. Gaps in knowledge and uncertainties should be stated (Swedish EPA 2007).

2. Assessment of contamination levels, transport and exposure

In the assessment of contamination levels, transport and exposure detailed investigations and assessments are carried out to identify the possible contaminants, the levels and possible effects. This step is carried out in the simplified and in-depth risk assessment.

Contamination levels and quantity

Levels of contamination can be assessed directly from measurements, or through mathematical modelling. The contamination levels are calculated for the possible mediums and pathways identified possible for exposure. For more complex studies detailed investigations and measurements and development of models are preferable to increase the certainty.

Modelling is used for estimations on a long-term perspective and for media that are difficult to analyse. Direct measurements give more reliable results for present and short term assessments. Modelling and measurements are often and best used in combination. Maximum levels are used to determine the acute toxicity. Statistical analysis is useful to estimate the mean value and variations of the contamination levels. With deterministic models a representative level of contamination can be assessed. Models can be used to calculate if quality criteria for acute toxicity are exceeded. Difficulties in this phase are that levels of contamination should to be set as a profile in time and space (Swedish EPA 2007).

Transport and Contamination load

The transport of substances is important to evaluate the exposure to recipients. Processes and models available to evaluate the transport include:

- The distribution between the levels in water and solid phase (K_d, K_{oc})
- Transport between soil and groundwater
- Transport to sediments
- Contamination load

The distribution of substances between the liquid and solid phase is determining the transport. Distribution varies for different substances and depends on the chemical-physical properties. To analyse the distribution leaching tests are performed. The results should be treated with care as there are several uncertainties. In the model it is assumed that the leaching and K_d –value (distribution of metals between the soil, water and solid phase) is constant over time, and the system is in equilibrium.

The transport of contaminants between soil and groundwater is assumed not to be effected by sorption or dispersion. Transport between groundwater and pore air is calculated as this influence the risk for intake of groundwater and fumes from chlorinated hydrocarbons. For sediments, the transport looks different as it can spread through molecular diffusion, re-suspension or biological transportation in the food-chain.

Detailed investigations are a good basis for assessment of the total contamination load from the site. With several methods and models in parallel the result can be even better, both present and future pressure can be assessed. For transport to water there is a model available for calculation of contaminant levels in surface- and groundwater (Swedish EPA 2007)

Exposure

The exposure is assessed from the exposure time and the contamination levels at the point of contact. The substances' bio accessibility is an important factor influencing the total dose of exposure and bioaccumulation is used to evaluate the accessibility. The model for exposure is presented in Chapter 3 especially Section 3.6 (Swedish EPA 2007).

Biological availability

The effects of exposure depend on the amount of available for up-take. Intakes via food, respiration or direct diffusion through skin are considered. The direct intake via inhalation of dust and ingestion of soil are most hazardous, but low in quantity. There is a lack of data in this field why the accessibility for many cases is set to 1 of precautionary reasons. Some of these are; leaching tests, chemical fractioning, biometric methods, measure of up-take and levels in organisms (Swedish EPA 2007).

Digestion

The models for contaminated soil in Sweden do not consider digestion or transformation of substances in the ground. For organic compounds the levels normally decreases over time, but for some chlorinated aliphatic hydrocarbons other carcinogenic substances are formed. The transformation and digestion of substances have an effect on the risk as the transportation and exposure are changed. Models are under development to describe the digestion of organic compounds of petroleum, but are still not verified for general use (Swedish EPA 2007).

3. Assessment of effects

Assessments of effects aim to produce background data for assessment of levels and exposure of contamination where negative effects will occur. The most used method is comparison with the human toxicological and ecotoxicological quality criteria available nationally and internationally. Data from databases and scientific literature can be used in addition.

To assess effects on humans the toxicity analysis is performed aiming to identify toxic effects and create toxicological reference values. This is unitized with dose-response relations from exposure analysis. For effects on the environment comparison with ecotoxicological effect values, mainly the Canadian and Dutch values are used. The ecotoxicological field needs further development as there are many uncertainties and no standard method available. The uncertainty of the method and limited knowledge for the whole biological system is compensated with uncertainty factors, normally 10, 100 or 1000. Biological research and ecotoxicological tests are normally used to develop a background for the site-specific conditions to assess the probable risks. These can be carried out *in-situ* on exposed organisms or at contaminated media. Tests for acute and chronic effects are therefore carried out. Biomarkers or indicators can be used to observe early signals. For best results, a combination of several methods should be used. Lack of knowledge on environmental effects is problematic when creating site-specific quality criteria as no certain data is available for the assessment (Swedish EPA 2007).

4. Comprehensive Risk Assessment

In the comprehensive risk assessment a quantification and evaluation of the health and environmental risks is performed. The risk is assessed for each substance and the total risk will be based on the individual results. Comparison with the quality criteria or other toxicological reference values as well as establishment of risk quotas are common procedures. The results from several independent investigations are weighted together and presented as an overall results about the expected risk, need for risk reduction and demands for remediation measure. Uncertainties and consequences of the assessed risk should be included (Swedish EPA 2007).

3.3.7.3 City–specific quality criteria

A project initiated by the three main cities in Sweden lead by Sweco Environment (Leback el al 2009) is developing a method for risk assessment for major city regions. City-specific quality criteria and guidelines will consider the special demands for urban areas. This include higher contamination levels, diffuse sources and bigger projects and a different landuse than in rural areas. Establishment of quality criteria involves definition of exposure pathways and sensitivity of landuse. *Sensitive landuse* is the regular suitable landuse in cities as many houses are built for residences. This landuse includes exposure pathways not normally present in cities, e.g. intake of home-grown vegetables. The new guidelines and quality criteria will simplify and clarify the remediation process for city projects.

The main differences to the regular guidelines are change of protection of the environment, and landuse categories. Soils in cities are often contaminated from filling material or other sources, and the ecological activity is limited. The protection of ecosystems is giving protection to 10% of the ecosystems. To deal with the home-grown vegetables and other exposure pathways new landuse alternatives are created. This means that only houses with large gardens are assumed to grow vegetables at home. Landuse groups for city uses are (Leback et al 2009):

- Residential building with large garden, possibility of growing vegetables
- Residential building with small garden, no growing of vegetables
- Houses with flats – no gardening
- Flats blocks
- Activity area, including small industry, business centre etc.
- Square, parking lots, roads
- Parks, green areas

3.3.8 Quality criteria

The Swedish quality criteria or generic guideline values are established for easy assessment of effects from contaminants at sites. The quality criteria are recommendations and set the level where no unwanted effects are expected. The quality criteria do not consider big scale effects or airborne diffuse contaminations. The quality criteria are created for general cases of local limited areas with point source contaminations. Important to consider by use is;

- They are calculated to be used nationally for a variety of situations.
- The level set for a quality criteria describes where no unwanted effects will occur, this does not mean that such effects will automatically occur above this level.
- It does not describe an acceptable level to where it is allowed to contaminate.
- They are recommendations and not legally binding.

The detected values are compared to the quality criteria. In Table 3 the current condition can be seen for different outcomes:

Table 3 Risk quotas from comparison of assessed values and the quality criteria (Swedish EPA 2007)

Current conditions	**Level in relation to quality criteria or corresponding value**
Not very serious	< quality criteria
Moderately serious	1-3 time the quality criteria
Serious	3-10 times the quality criteria
Very serious	> 10 times the quality criteria

3.3.8.1 Soil quality criteria

Soil quality criteria are established on basis of knowledge on toxicological and ecotoxicological effects. The quality criteria are constructed for two levels of protection; *Sensitive landuse (SL)* and *Less sensitive landuses (LSL)*. Today there are quality criteria available for 52 substances in the Swedish model. Revised criteria were published in 2008 (Swedish EPA 2009). In case of absence of Swedish quality criteria, corresponding values from other countries or environmental quality standards for the European Union can be used. The Swedish soil quality criteria are presented in Appendix 3 and a selection of criteria are found in Table 4. Cases where exposure, transport and protective values deviate from the general case it is motivated to calculate site-specific quality criteria, see this chapter, section 3.10 (Swedish EPA 2007).

Table 4 Selection of Quality criteria for contaminated soil in Sweden (Swedish EPA 2008)

Table for the quality criteria for contaminated sites		
Substance	**SL**	**LSL**
Arsenic	10	25
Barium	200	300
Bly	50	400
Cadmium	0,5	15
Cobalt	15	35
Copper	80	200
Chromium (VI)	2	10
Mercury	0,25	2,5
Molybdenum	40	100
Nickel	40	120

3.3.8.2 Groundwater quality criteria

There are high demands on the quality of groundwater in Sweden as the National Environmental Objective "Groundwater of good quality" and the EU water framework directive put pressure on this. The quality criteria for soil include the levels of contamination acceptable to avoid effects on groundwater at a contaminated site. There are several criteria available for groundwater protection published by SGU. National criteria from the Netherlands and Canada are used by lack of Swedish references (Swedish EPA 2007).

3.3.8.3 Surface water quality criteria

The quality criteria for effects in surface water show the level of contamination acceptable in the ground for a given level in the watercourse. For most substances the levels for surface water is lower than the levels for groundwater. This implies that the quality criteria established for protection of surface water also give protection to human health. A project within the EU is working on establish of effect based Environmental Quality Standards, EQS, for surface and ground water, also sediment and biological variables are included (Swedish EPA 2007).

3.3.8.4 Establishing Quality criteria

The model for establishing quality criteria includes direct and indirect effects on human health and environment. The quality criteria are established for general conditions and site-specific quality criteria should be created when other conditions occur. The health based and environmental based risk values are carried out separately, the lowest value is then chosen as the Quality criteria. The toxicological effect levels developed by WHO and USEPA are used for determining the health risk. The method for establishing quality criteria is described schematically in Figure 10.

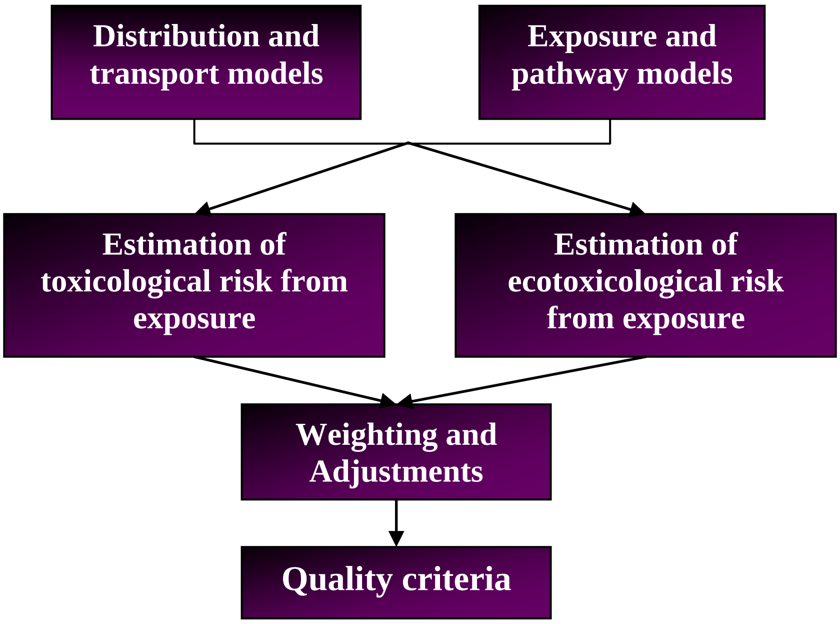


Figure 10 Schematic picture of the model for establish of quality criteria (Swedish EPA 2007)

There are many formulas and calculations for establishing quality criteria. Some of the formulas are presented in Appendix 4, which also present data for the calculations of effects to humans. A more complete collection of the formulas can be found in the literature published by the Swedish EPA (Swedish EPA 2002, 2005).

Assumptions

When calculating the quality criteria basic assumptions are made about how the contaminants are distributed and transported in the environment. Many of the assumption are conservative to avoid unexpected effects. The most important are described below (Swedish EPA 2007).

Distribution and transportation of contaminants

The distribution of substances between the phases in the soil influences the transportation to nature media (see Section 3.3.6 in this Chapter). In Sweden the fugacity model is used to calculate the distribution between phases (MacKay and Peterson 1981), most quality criteria calculations are based on this. Several assumptions are made for the calculations:

- All contaminants are seen available for transport and exposure.
- The concentration of contaminants in the ground is assumed to be constant over time. Sorption and degradation of the substances are assumed to be none. The motivation for the assumption is that the transport is limited, and the big uncertainties about digestion for organic substances. This assumption is conservative especially degradable substances and long term exposure.
- The distribution of contaminants between solid soil particles and pore water solutions, free organic coal and pore air, is assumed to be in equilibrium. The fugacity model is used for calculating the equilibrium concentrations. This model is conservative as equilibrium is not always attained in the ground.
- The concentration of a dissolved substance is assumed to be proportional to the sorption level of the substance by the medium, the constant K_d is used. For organic substances the K_d -value is proportional to the level of organic coal in the soil.
- The K_d –value is used for calculating of leached contaminants. It is based on the total level of contamination in the ground, and not only the absorbed part.
- The model assumes that all analysed contaminants will be available for transport over time, i.e. the bioavailability is equal to 1. No attention is given to contaminants that are in forms that are not available for leakage.

3.3.9 Background levels

Various substances are spread in the environment. There is a natural variation with higher or lower levels of substances in certain places. Variations are caused either by natural reasons or as a consequence of anthropogenic diffused emissions of substances. For these areas the ecological system is assumed to be adjusted to the natural conditions. These levels are defined as *background levels*. The background level reflects the environmental situation, and is not always the preferred level.

If the levels of substances at the site are at the same level or below the background level no further investigations or remediation is needed. There are data available for background levels in soil, groundwater, air, food items and drinking water etc. Further information is available from Swedish EPA and SGU (Swedish Geological Investigations), SMHI (The Swedish Meteorological and Hydrological Institute) and IVL (the Swedish Environmental institute) etc (Swedish EPA 2007).

3.3.10 Site-specific assessment – use of software model

When the quality criteria are not preferable to use as the site specific conditions are differing too much from the average case, site-specific quality criteria are calculated. Conditions that motivate the establishment of site-specific criteria are:

- The ground involves other exposure pathways for humans
- Other requirements for protection of environment are needed
- The difference in transportation conditions is big
- Other ground water conditions
- Different size and/or residence times in the surface water
- Other sensitivity or protective value for the recipient

A calculation sheet in Excel-format published by the Swedish EPA in 2007 is used to calculate the new quality criterion for the specific cite. Earlier this was made by the individual consultant individual. This step is performed in the detailed risk assessment. New assumptions about exposure pathways, time for exposure, groups of humans exposed, medium involved etc. are made. Human based criteria and surface and groundwater values are calculated. There is still lack of data to calculate new ecotoxicological values (Swedish EPA 2007). In reality the economic factor is important for when to calculate site-specific criteria. Big projects that generate high costs for remediation are more often calculating site-specific criteria. Projects demanding high certainty or level of knowledge are other examples. With site-specific criteria the expected risk at the site is assessed (Kaltin 2009).

3.3.11 Principles for dealing with uncertainties

In Risk assessment estimations are needed to evaluate the risk and possible effects to recipients. Uncertainties will remain also after a detailed investigation regarding:

- Sources of pollution can be hard to locate and analyse - all contaminants in an area are difficult to define.
- The transport of contaminations can be spread out in time and space, and is therefore difficult to measure.
- The exposure can be difficult to predict.
- Negative effects from many contaminants are not fully reviewed.

To deal with this the precautionary principle is used. This is adopted by the EU-commission to deal with these questions. By considering the possible bad but less expected scenarios in a risk assessment, and choosing safe values on the sensitive parameters, the risk assessment try to cover these uncertainties (Swedish EPA 2005).

3.4 Feasibility study

The feasibility study aims to identify possible remedial measures for contaminated sites. Several objectives influence the choice of remedial measure and five base criteria are available:

1. Fulfilment of the measure goals (Established in the beginning of the process)
2. Technical feasibility
3. Acceptable results according to investigation criteria and risk reduction
4. The best result according to risk assessment criteria
5. Fulfilment of other qualifications

The technical conditions are very important to investigate as they limit the possible alternatives. Both single methods and combination of methods should be investigated. The site-specific situation with contaminations, hydrological and geological features and other factors are evaluated as they determine the possible remediation action. The information gathered in the investigation and risk assessment phase is the basis for the feasibility study. The main aspects to consider are:

- Exposure pathways to environment and humans
- The Contaminants form, media, level and amount
- Distribution of contaminations
- Effects on the ground ecosystem
- Geological and hydrological features
- Effects on the aquatic environment

The feasibility study gives the basic data for the risk evaluation, where the final action is decided. The risk evaluation use information collected in the feasibility study and also considers economic and practical factors; see Chapter 3.5 (Swedish EPA 2007).

3.4.1 Kinds of measures

Three kinds of measures are possible for remediation and can be used separately or combined. Reduction of the contamination source is preferred; protective measures can be chosen as a second solution. The third, administrative measures should not be used as a permanent solution if other actions are possible, but it can be good as a temporary solution. The measures are (Swedish EPA 2007):

1. Reduction of the contamination source.
2. Protective measures - contamination is remaining in the ground fully or partly, transport and exposure is limited to acceptable levels.
3. Administrative measures - restrictions of the use of the area

3.4.2 Methods for reducing contamination

There are several different methods for reducing contamination source available; excavation, destruction, deposit, separation etc. The remediation measures are divided after where and when the action is performed; *On site* or *Off site,* and *In-situ* or *Ex-situ* (Swedish EPA 2007). On site treatments are carried out on the site with or without removal of the soil. In-situ treatments mean the soil is treated where it is, without any removal. In Ex-situ remediation the soil is removed for cleaning at another place (off site), on the site (on site) or transported for deposit. The relations between the measures are illustrated in Figure 11. The methods can also be combined for better efficiency (Swedish EPA 2007; Helldén et al 2006).

On site	**Off site**
In-situ	Ex-situ
Ex-situ	

Figure 11 On/Off site and In/Ex-situ relationship (Swedish EPA 2007)

3.4.3 Checklist for risk assessment and remediation

The Swedish EPA has developed a checklist with several principles and requirements for the risk assessment and remediation, including (Swedish EPA 2007)

- The risk should be reduced as much as technically and economically possible
- Actions should provide permanent solutions
- Damages created during the remediation and investigations should not exceed the damage from the contaminations
- Best available technology should be used, low energy consuming techniques are preferable
- Contamination of decontaminated parts should not be re-contaminated by left contaminants
- Further remediation cannot be made impossible because of new-building
- Left contaminants should be covered as if they were put on a landfill
- The remediation action should be implemented so that no risk for further demand of remediation is needed
- Sites with allowance from the Swedish environmental protection agency should be serving as a model for other remediation projects

3.5 Risk evaluation

After the feasibility study there are several possible remedial measures identified and now the best alternative for remediation is evaluated. The risk evaluation is made at the end of the remediation process, but it is important to consider this aspect earlier to collect information and create a dialogue with involved stakeholders. The ambition level is important for the outcome of the risk evaluation.

The process for risk evaluation contains six main elements. For complex cases a repetition of the process and especially the first three elements is needed. The evaluation elements are;

1. Definition of evaluation criteria
2. Grading and evaluation of the criteria
3. Weighting of criteria
4. Proposal of remediation measure
5. Determine of remediation goal
6. Communication of risk evaluation results

Depending on the complexity, size and number of possible remediation measures, there might be a need for mathematical models for risk evaluation. From the European organisation CLARINET (Contaminated Land Rehabilitation Network for Environmental Technologies in Europe, 1998-2001) several useful methods are listed:

- Environmental Risk Assessment (ERA)
- Cost- Benefit analysis (CBA)
- Cost- Effectiveness Analysis (CEA)
- Life Cycle Assessment (LCA)
- Multi- Criteria Analysis (MCA)
- Multi Attribute Techniques (MAT)

CBA and CEA are seen as most useful for cost evaluations, and ERA is used as the environmental and health aspects are the core in the method. In Sweden the most common method for risk evaluation is a simple evaluation of various factors, an adjustment between costs, benefits, the environmental aspects and the technical risks are made for the most advantageous alternatives. The most beneficial alternative is preferable. The risk evaluation also includes societal aspects and need for permits for remediation. Criteria for the relevant interests are compared and analysed, this is the base for the final decision (Swedish EPA 2007).

3.6 Remedial measures

There are many methods available for remediation. Methods used in Sweden are presented below. In Appendix 1 a more detailed presentation of the methods is given. Statistics for the use of methods are given in Chapter 3, Section 6.2.

3.6.1 Remediation of contaminants

There are several methods available for treatment of contaminated soil, groundwater and sediments. The methods are presented in Table 5 and described more in detail in Appendix 1.

Table 5 Available methods for remediation of contaminants in Sweden (Helldén et al 2006)

Ex-situ methods	**Destruction methods (in-situ and ex-situ)**
Excavation and sorting Dredging of contaminated sediment Transport-elimination methods	Biological treatment (anaerobe in bioreactor or aerobe by digestion) Combustion
Concentration methods (in-situ and ex-situ)	**Immobilisation methods**
Soil vapour extraction Air sparging Soil washing Thermal desorption Filter technique and reactive barrier Pump and treat	Stabilisation and solidification Enclosing and barrier technique (in-situ) **Other methods** On site treatment of contaminated water Administrative measures Measures for contaminated buildings and facilities

3.6.1.1 Ex-situ methods

Excavation and sorting is the most used method for remediation in Sweden. Advantages are that this method is quick, reliable, and can be used for all kind of contaminations. After excavation the soil can be treated ex-situ or put on land disposals. The price for disposal has been low in Sweden in the last years and disposal has been commonly used. Dredging of contaminated sediment is a kind of excavation method for sediments used under water. It is especially developed for loose and highly water containing sediments (Swedish EPA 2007).

3.6.1.2 Concentration methods (in-situ and ex-situ)

Soil vapour extraction or Vacuum extraction is an in-situ method used for volatile or half-volatile hydro compounds. This method is mainly used for old gas stations in Sweden, where this is the most common in-situ method. The vacuum extraction is often combined with excavation to ensure the fulfilment of measurement goals. In combination with biological digestion it can be even more efficient. .

Air sparging is an in-situ method for treatment of volatile or half-volatile organic substances in the groundwater zone, especially trichoroethane, triethylene, benzene, toluene, xylene, light oils and gasoline. The method was introduced in 1980 and is still mainly used in the US. In Sweden it has been used for several projects for remediation of gas stations. Best effect is given on loose and relatively dry soils but can be used also for more compact soils it with longer treatment time. Despite the age there are very few cases documented with good results (Marksaneringsinfo 2009).

Soil washing is used in Sweden since 1997 and is mostly used for concentrating contaminations to less volume. It can be used for both inorganic and organic compounds, as well as complex combinations. Normally 75-80% of the soil can be reused after the treatment. Pump and treat is a method widely used abroad, especially in the US. In Sweden a pilot-treatment is performed and it shows that the treatment duration for soil in Sweden can be very long, up to 10 years. The method is implemented for treatment of groundwater. Pump and treat is mainly used for treatment of organic compounds in groundwater (Helldén et al 2006).

Thermal desorption is another method using heat to drive low boiling substances away from the contaminated soil. The method is used for solvents, PCB, dioxin, PAH and mercury etc. The advantage for this method is the lower demand of energy compared to combustion. This method has had limited use in Sweden. Filter technique and reactive barrier is used for cleaning of metals, PAH, dioxiner and PCB relatively efficient with filters in the saturated zone. Some cases are tested in Sweden and internationally (Marksaneringsinfo 2009).

Extraction with solvents (On site) is in Sweden mostly used for PBC, VOC and halogenated solvents and oil/petrol products. By using solvents hazardous organic contaminations can be separated from the contaminated media. The extraction increases the concentration for further treatment, or reuse. This method is good for extraction of hazardous substances from innocuous, mainly used for separation of organic compounds, wood preservation waste, pesticides and oil containing waste (Marksaneringsinfo 2009).

3.6.1.3 Destruction methods (in-situ and ex-situ)

Destruction methods are only possible to use for organic substances. The most used methods are ex-situ treatment with:

- Biological treatment (anaerobe in bioreactor or aerobe by digestion)
- Combustion

These are often combined with separation or concentration methods to minimize the quantity for remediation.

3.6.1.4 Immobilisation methods

Stabilisation and solidification is a chemical method where adding of chemicals gives a reaction with the contamination that prevents the transportation of the substance. The toxicity may also be reduced. Solidification is a method for casing the contamination or transforms it to a low-leaching structure. In Sweden the method is mainly used for treatment of ashes from combustion (ex-situ) and of in-situ treatment of mercury in the ground. Enclosing and barrier technique (in-situ) is in Sweden used only if no other method is available for treatment. By enclosing the contaminated soil with low hydraulic conductivity (< $5*10^{-10}$ m/s) material the transportation of contaminations is reduced. It can be used for small amounts of high-contaminated soil are present. Internationally membranes and bentonite have been used, but in Sweden most tests have been with natural material like clay and rest ashes (Helldén et al 2006).

3.6.1.5 Other methods

On site treatment of contaminated water is in Sweden used for cleaning of contaminated water. For example after dredging of contaminated sediments when ground or surface water is collected by excavation pits or when contaminations are diluted in water. The method for cleaning is dependent of the type of substance and the form of the contaminations (Marksaneringsinfo 2009).

3.6.2 Statistics of remedial measures

An analysis by Helldén et al 2006 of 226 remediation projects in year 1994-2005 showed the most common used methods for remediation in Sweden. The analysed projects correspond to 15 – 20 % of the total remediation of 1 200 – 1 500 projects during these years. 90 of the projects were from the Spimfab program for remediation of closed gas stations, the remaining 136 projects were remediated by governmental or private stakeholders. Of the analysed Non-Spimfab projects the *Ex-situ* method dominated and was used in 88% of the cases. *In- situ* methods was used for 10% and on site in 13% of the projects. Half of the in-situ and on site remediation measures were combined with ex-situ methods. For all 226 objects around 75% used off-site treatment or land-fill (Helldén et. al 2006). Statistics of remediation methods and in-situ methods used are presented in Figure 12. Note that some projects used several methods.

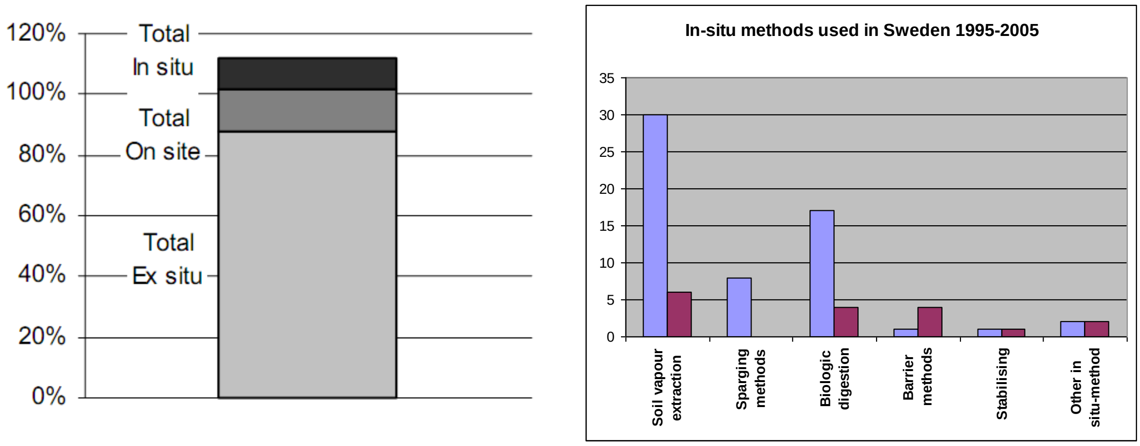


Figure 12 Remediation methods used (left) and In-situ methods for the 136 analysed non-Spimfab projects 1994-2005 (Helldén et al 2006)

There were totally 1 780 000 tonnes of contaminated soil excavated for the 226 objects. This correspond to 8 000 tonnes per object or 160 000 tonnes per year. This also produced emissions of carbon dioxide and other substances (Helldén et al 2006; Swedish EPA 2009).

3.7 Remediation projects

3.7.1 Identified contaminated sites

The work with remediation and investigations of sites has developed the last years and the number of contaminated sites identified increased. The identification is assumed to be finished in year 2015. In 2008 statistics were, also presented in Figure 13:

- 80 000 potentially contaminated sites are identified
- 17 000 are risk classified, of which 13 000 according to MIFO
- 60 000 sites are classified as industrial sites
- 800 Risk class 1, acute objects are identified. Totally around 1 400 are suspected to be found in this class.
- 4 300 Risk class 2 objects are classified, 16 000 sites are estimated to be Risk class 2 objects.

Figure 13 Remediation objects identified in Sweden (Swedish EPA 2009)

From 1999-2008 there were 3800 sites investigated and 1300 sites adjusted, of these 100 were prioritized sites. The local authorities are obligated to finance 10% of the total cost and the government pays 90%, which can be increased only under special circumstances. The governmental financing for remediation is important for this work. Totally the Swedish EPA gives around 500 million SEK in grants for remediation annually (Swedish EPA 2008).

In 2008 there were around 580 ongoing remediation projects for contaminated soil. The mean cost for the governmental granted projects was 40 million SEK per project, with a span from a few millions for small projects to over 200 million for the largest ones. The cost for remediation of remaining objects is estimated to 45-60 billion SEK (Swedish EPA 2008, 2009).

3.7.2 Frequency of detected contaminants in Swedish soils

Analysis of the most common contaminations is Swedish soils show that mainly oil and metals like copper, lead, zinc and arsenic as well as PAH is present, see Figure 14. The figure shows the contaminants occurring on sites not including the Spimfab project (for old gas stations) (Helldén et al 2006)

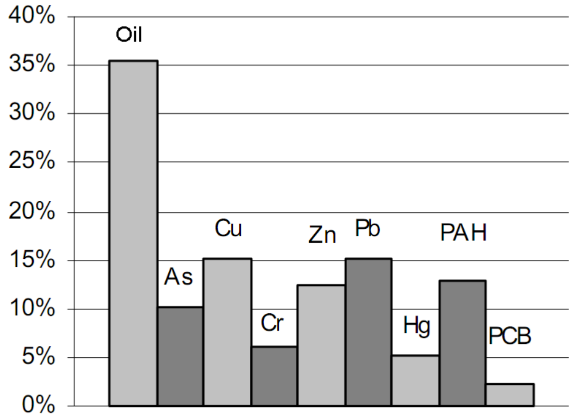


Figure 14 Contaminants occurring in Swedish contaminated soils non-Spimfab (Helldén et al 2006)

3.8 Geology

The geological conditions are influential for the transport and possible exposure of the contaminants. It also influences the possible remedial measures. The Swedish soil and bedrock conditions were highly affected by the last ice-age. The unconsolidated materials consist of mainly till/moraine, peat, glaciofluvial sediments and fine-grained sediments, e.g. marine clays. In the southwest there are extensive areas of thin soil cover and large areas of exposed crystalline bedrock. A Swedish geological soil map is presented in Figure 15.

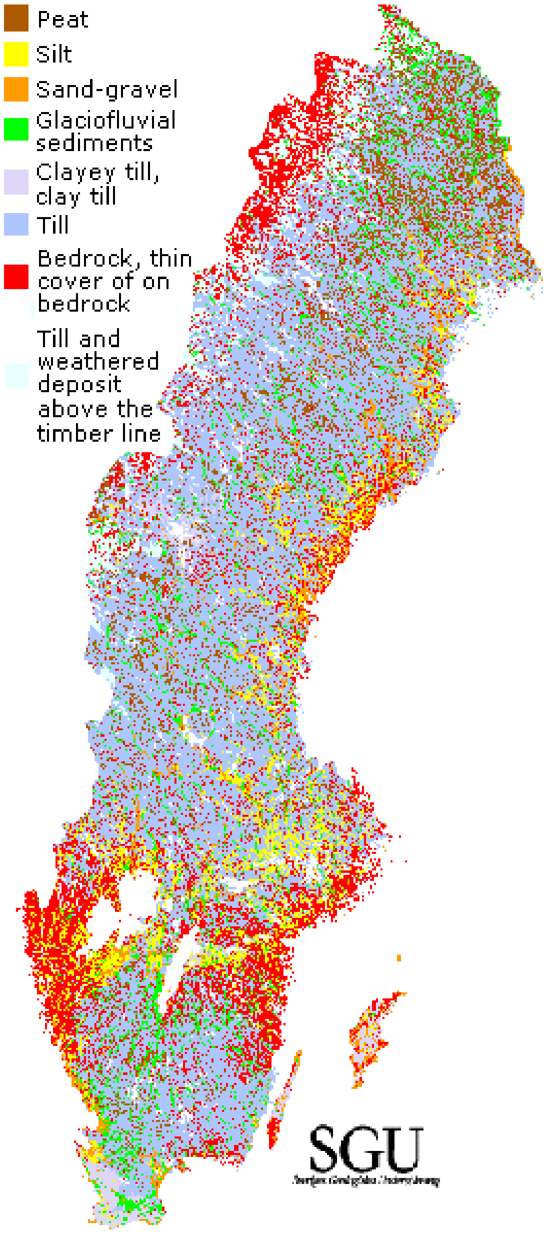


Figure 15 Swedish Geological map with soil types (SGU 2009)

3.9 Organisation of the work with Remediation projects

3.9.1 Administrative tools

The work with contaminated sites in Sweden is structured and organised by the Swedish EPA. At regional and local level the authorities are responsible for the organisation of the work. The environmental court also has an important role in juridical questions and appeals. The structure is illustrated in Figure 16.

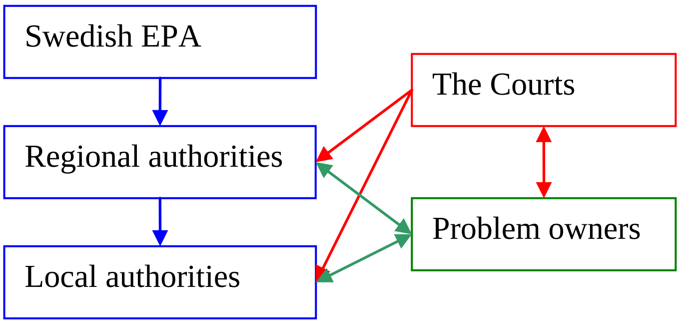


Figure 16 Structure of responsibility and work with contaminated sites in Sweden (Swedish EPA 2009)

The Swedish EPA works nationally and internationally and gives advice for the work with contaminated sites. EPA is also responsible for developing guidelines and quality criteria for contaminated soil. Today the Swedish EPA has three-four employees for the work with structure, development and distribution of financing etc. for remediation projects. They are also responsible for producing a review of the work every year. In addition there are four persons at the Swedish Geological Survey (SGU) that work directly for the Swedish EPA and support from SGI giving advises to local authorities in remediation issues. The Swedish courts are responsible for setting legal disagreements between authorities and companies. They implement the environmental code and other laws (Swedish EPA 2008, 2009).

The regional authorities (Länsstyrelserna) are responsible for implementing and planning the work in the region. They answer for allowance, investigation supervision and assays on environmental questions. Local authorities, totally 290 municipalities, are responsible for the local environment and contaminations, and have the main responsibility for smaller industries. In Sweden the municipalities are the regulatory agency and contaminated areas have to be reported to the local authorities. They are also responsible for the prioritising, organisation and information about contaminations. Information about the contaminated areas is organised by the local authorities, but no official register is available (Swedish EPA 2009, Göteborg Stad 2009). In total, the work with contaminated soil involves more than 1000 employees at the authorities, consultants and other stakeholders in Sweden (Swedish EPA 2008)

3.9.2 Juridical tools

For all remediation projects permission from the local or regional authorities is needed. The permission authority is an important actor as they are available for discussions and can act if a project needs more structure. The juridical document on the remediation process is found in 2 Chapter 8§ (The environmental code) and the instance for permission are important to make sure it is followed (Swedish EPA 2008)

In Sweden there is a network for the work with contaminated sites called Renare Mark (Cleaner Soil), the work for development of knowledge within the field of contaminated soil. In this organisation there are members from local, regional and national authorities, consultants and other actors in the field (Swedish EPA 2009).

Also other smaller networks are collaborating for more a robust and effective work with the remediation process. Local authorities in the Gothenburg region and other places collaborate to increase the efficiency in their work. A city-region group was created for communicating and exchanging experience for risk assessment in the major cities (Stockholm, Göteborg, Malmö), as the situation is different with big projects in cities compared to other areas. Creation of similar values and methods for a more effective work is developed at several places (Swedish EPA 2009).

Development

During the years 2003-2009 the Swedish EPA financed a program named *Sustainable Remediation*, to develop and spread knowledge about remediation and risk assessment projects. According to the EPA the lack of knowledge about risks with contaminated sites and how to handle them are barriers for an effective remediation work. Projects and research is ongoing on Universities and by other stakeholders' continuously (Swedish EPA 2009). In 1999 Methods for inventory of contaminated sites (MIFO) was developed, and in 2009 a revised and extended guideline for the process will be published for a more efficient work. (Swedish EPA 2006, 2009)

Local work

In Gothenburg there are local environmental goals for prioritizing and structuring the work with environmental questions. One goal concerns contaminated sites: Gothenburg should be free from contaminated sites in year 2050 (Gothenburg City 2009).

4 Managing contaminated sites in Denmark

4.1 Introduction

High levels of substances occurring in the ground may pose a risk to humans and environment. To evaluate the risk and assess the need of remedial measures the process for remediation of contaminates sites is developed by the Danish EPA. The process is mainly influenced by similar processes in US and Netherlands. The work with contaminated sites started in the 1980s and the first guidelines were published in 1992. Guidelines are continuously updated to ensure an efficient and effective work. Also the environmental regulation is updated continuously. Mapping of the contaminated sites was introduced for public interest in the beginning of 1990s to stimulate identification of contaminants in the soil. The focus for the remediation process in Denmark has been to ensure human health and the supply of clean groundwater for drinking water (Danish EPA 1999; 2002).

The remediation process aims to evaluate the risk for human health, groundwater and ecosystems to identify appropriate remedial measure. The process contains four phases, where the first three will be analysed in this Report, see Section 4.3.

- Initial survey
- Investigation phase including risk assessment,
- Remediation as well as
- Operation and evaluation

The Danish remediation process separated the work with; Landuse, Evaporation and Groundwater. There is quality criteria developed for all three categories, and the risk assessment is performed separately. A calculation sheet is used for the assessment of contamination levels and risks to humans and groundwater, which are the main recipients considered (Danish EPA 1999; 2002).

There are today 55 000 identified contaminated sites in Denmark, and the work with contaminated soil is a big business in Denmark financially. There are about 2000 employees and around 8 000 projects with remedial measures in 2005, to a cost of around one million Danish Crowns each (Danish EPA 2009).

4.2 The remediation process

4.2.1 Introduction

The remediation process aims to understand and prioritize between risk-objects to avoid negative effects on human health and ground water. The time-span considered is 50-100 years as buildings and infrastructure is expected to last that long (Danish EPA 1990). An overview of the remediation process used in Denmark is given in Figure 17.

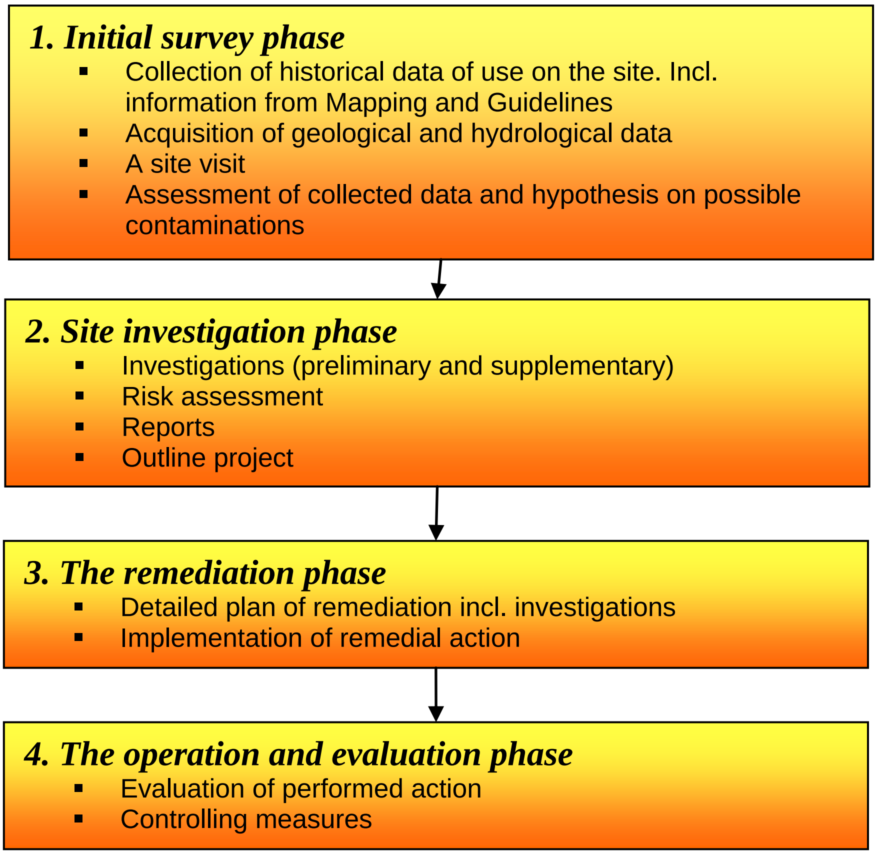


Figure 17 An outline of the process for remediation of contaminated sites (Danish EPA 2002)

4.2.1.1 The initial survey

In Denmark the collection of data and mapping of contaminated sites is the first step in a risk assessment. This phase is aiming at obtaining the best basis for implementation of the investigations. It includes collection of information from charts, maps as well as historical activities on the site. The historical overview can give a hypothesis of what contaminants are present on the site. In several cases mapping is performed separately and replaces the work of collecting information in the initial survey and investigation phase (Danish EPA 2002).

4.2.1.2 The site investigation phase

The site investigation phase includes investigations, risk assessment and reporting. Preliminary investigations are performed to test the hypothesis stated in the initial survey and to understand how contaminated the site is. A strategy plan for sampling is established based on information collected in the initial survey phase. If the site is found to be contaminated detailed information may be required, then supplementary investigations are proposed. In cases when remediation is necessary one or more outlines of the project should be included, where several proposals of remediation techniques including estimates of costs and a timetable are stated (Danish EPA 2002).

Risk assessment is carried out to assess the possible consequences from the detected contaminants. The objective of the risk assessment is to establish the need for remediation for a specific situation (Danish EPA 2002). Data is required for contamination transport, exposure pathways and specific groups of recipients. The risk should be assessed independently for landuse, groundwater and evaporation. For all three cases there are quality criteria developed to compare the levels. For landuse there are two criteria; soil quality and the cut-off criterion. For evaporation both indoor and outdoor air could be affected by soil or groundwater contaminations. The contribution from evaporation to overlying air must not exceed acceptable contribution. Ground water criteria have been established for use in risk assessment, both soil and upper groundwater aquifers containing contaminations are analysed.

In the risk assessment all present and potential landuse conflicts should be identified. Often different interests, for example future or present uses are giving different requirements. Based on the risk assessment the present landuse conflicts should be eliminated (Danish EPA 2002).

4.2.1.3 The remediation phase

The remediation phase is where detailed plans and implementation of the required remediation takes place. Remediation aims to remove the contaminants, limit the exposure or prevent transport of contaminants to soil, water or air. The techniques of remediation vary, and a detailed planning and supplemental investigations may be necessary to ensure a good result. There are three main solutions to a contaminated soil: Clean-up, Replacement and Advisory measures. The remediation phase includes establishment of a detailed plan for the action as well as a measure program to ensure that the levels set for the clean-up are reached (Danish EPA 2002).

4.2.1.4 The operation and evaluation phase

The objective for the evaluation phase is to ensure that the goal, formulated as a stop criterion, is reached and to evaluate and document the effect of the remedial measure. The stop criterion and a monitoring program are always established before starting a remedial measure. The operation and evaluation phase is important to verify the effects from the remediation actions. The operation and evaluation phase for a remediation object will look different depending on the chosen remedial measure. For excavation the process is quick and evaluation takes place almost simultaneously with the excavation. Other methods, especially in-situ methods, are long term processes with long term evaluation (Danish EPA 2002).

4.2.2 Levels of risk assessment

Risk assessment can be carried out in different stages. Starting with a simple risk assessment and if the evidence of the risk are too weak, more investigations and calculations are needed. There are no specified levels of risk assessment but there might still be several levels depending on the complexity and character of the projects. Investigations are carried out at two levels, registration investigations to understand if a site is contaminated and detailed investigations, gives the background for place specific assessment. After the investigations the risk assessment is performed to assess the best measures. The program Jagg is used to calculate the risk and transport and is an important tool for risk assessment in Denmark. Depending on the size and cost of the object the extent of investigations are chosen (Kiilerich Danish EPA 2009).

4.2.3 Information

Information is an important element in the Danish remediation process. Residents possibly affected by the contaminants should be informed about the hazard and how to avoid to be affected. Information should be integrated through the whole remediation process to ensure that the activities can proceed as smooth as possible. The importance of information as a protective measure increased with the new classification of city areas as low contaminated. There are several guidelines for citizens in lower contaminated areas published by the Danish EPA to minimize the effects and exposure of hazardous substances (Danish EPA 2002)

4.2.4 Initial survey phase

Within the initial survey phase relevant information about the object should be obtained. It is the base for the following work and sets the qualification for further investigations. The initial survey phase is therefore important and should be executed with great care. Potential sources of contamination should be identified; both the characters and physical location. The initial survey uses literature and data for several databases to create an overview of the object. A site visit is included in the initial survey phase.

4.2.4.1 Data sources

There are several important data sources used within the remediation process. The most important are the primary sources including local historical and authority records, company records etc. All data sources are presented in Table 6. The local authorities maintain records from areas in databases. Mainly from construction activates, but also records from environmental inspections and approvals. There are extensive national databases available for use through internet including information about previous buildings, factories and wells. Also information from the Environmental Permit Acts is stored for acts from 1974-present.

Table 6 Sources of data for preparation of investigations and risk assessment (Danish EPA 2002)

Primary data sources
Local authority records Local historical records Background material on equipment and processes Interviews and investigations Company records Land Registry Office The police and fire departments
Secondary sources
Register of Companies etc. The Working Environment Service The Royal Library The Danish National Business Archive in Aarhus National Survey and Cadastre

Local historical records can be old maps, information booklets and telephone directories as well as photos and newspapers. Personnel with good knowledge working in the archives are very helpful. Interviews with current and previous employees can give supplement information to records and literature. A site visit is included to check collected data and to observe signs of contaminations, e.g. plant growth, and the locations of existing buildings and installations. Company Records can give relevant information about raw materials used, products produced and pictures and drawings. The Land register office may provide information about previous owners of individual sites.

Background material on equipment and processes implicate collection of relevant information about soil and groundwater. Detailed data has been prepared for a number of sectors and enterprises. Production and potential sources of contamination with parameters for analyse and references from earlier investigations and experiences are collected. General information about techniques, processes, raw materials and chemicals can be found in specialist literature and sector organisations (Danish EPA 2002).

The extensive information available for the initial survey helps the identification of contaminations. With good background information a good picture of the case is created, and the field investigations can be constructed from this (Falkenberg 2009).

4.2.4.2 Geological and hydrological data

The geological and hydrological conditions are important for the preliminary vulnerability assessment. An overview of water abstraction, ground water flow and surface water recipients in the area should be created. Collection of data includes;

- Typographical maps
- Geological basic data maps
- Maps of groundwater's potentiometric surface
- Water abstraction plans
- Water supply plans
- Geological literature
- Other investigations in the area

4.2.4.3 Results

The result from the initial survey should be presented clearly and comprehensibly including all data collected. It should be assessed and related to the original hypothesis of possible contaminating activities on the site.

4.2.5 Site investigations

The site investigation phase includes investigations, risk assessment, reports and project outline. The scope is dependent on the results and information from in Initial survey phase.

The sampling aims at describing the contamination in soil and ground water to an extent that risk analysis can be performed. The investigations are performed in two stages, the registration investigations to indicate if the area is polluted and the intensive investigations that are the background for the site-specific assessment (Dall-Jepsen 2009). According to Danish EPA (2002) elements in the investigation phase are: Sampling soil and water, Sampling of air, Methods of analysis, Collection of data on buildings and Geology, hydrogeology and hydrology.

Sampling of soil

The sampling is performed to understand and describe the extent and details of contamination. This is the background for the risk assessment and planning to execute a remediation measure. Historical data is important to understand and plan the sampling and help to predict location and type of contamination. Also hydrological data and information at the site, e.g. plant growth, is helpful for the forecast (Falkenberg 2009)

The location of the soil borings are planned and carried out differently depending of previous knowledge.

- In areas where contaminations are expected, e.g. hot spots, the soil borings are planned from knowledge of landuse and previous and existing plants.
- Near boundaries of know contamination, to determine the extent of contamination.
- Areas with contamination- sensitive landuse, known or suspected. Relatively high intensity of borings.
- The rest of the site. To localize possible more hot spots and spills in the area.

Borings are normally carried out from a scheme of rules to obtain the best results; some statistical knowledge can be used to ensure the data, for example sample grids/fields/nets are used. To localise unknown hot spots with certainty there are different number of sample points needed. Table 7 shows the probability of finding a hot spot by sampling in a specific area. If 24 samples are taken on a 400 m^2 area, there is a 95% probability of finding a hot spot with diameter of 5 m.

Table 7 Number of borings needed to verify a hot spot with known certainty (Danish EPA 2002)

Diameter of hot spot	% contaminated site %	Probability of localising a hot spot			
		50%	90%	95%	99%
10	20	2	5	6	7
7	10	5	10	12	15
5	5	10	20	24	29
3	2	28	54	65	81
2	0.8	62	122	147	183
1	0.2	249	488	589	731

Smaller hotspots are financially impossible to localise with high certainty. Therefore it is not possible to assume that all small hot spots have been localised. It is important to stress that each boring point only represents a point of measure. An absolute minimum representative samples should be taken which correspond to a rough screening. Single values which exceed the quality criteria does not declare a hot spot, a hot spot must be verified by several analysis. More specific descriptions of borings are available from the Danish EPA and Videncentre (The knowledge centre for soil).

Sampling pits are carried out to obtain representative samples and to determine geological and contamination conditions horizontally and depth-wise. Close to the surface excavations are to prefer for borings, normally performed with trench diggers. They are used especially where contaminants are distributed unevenly, for example on landfills or if investigations of other geological conditions are desired. Excavation should only be performed if permission to refill the trench with the soil is given.

Location borings are made to describe contaminations in the upper soil layers or groundwater aquifers, normally executed up to 3-4 meters in depth. For detection of metals and contaminants close to surface shallow borings are usually used, up to 1 meter. Then also the material can be filled back. Borings at depth of 3-4 meters or deeper should usually use dry rotation boring or other casing to avoid cross contamination. Samples are usually taken two at each depth; one for categorisation and one for chemical analysis. According to guidelines sample sets are collected every 0.5 meters up to 4-5 meters depth. As a minimum one set per soil layer is collected (Danish EPA 2002).

Sampling of groundwater

Sampling of water aims to obtain a sample from the well representative for the aquifer for the investigated parameters. Usually collection of the samples is performed from screens in wells. The boring screens are normally installed in the upper saturated zone, but may vary due to hydrological conditions. Three main steps are important (Danish EPA 2002):

- Purging
- Sampling
- Sample storage

To ensure that the collection of sample represents the groundwater aquifer, purging should be carried out before the sampling. Different types of pumps are used for water sampling and purging depending on the nature and hydraulic conditions.

Well development is carried out to obtain the best possible efficiency on the well by pumping direct after the well is finished. This can be performed as a part of a stepwise pump test. By obtaining water samples from an aquifer via a well there are some important factors to consider. The equipment should not contaminate the sample, it should not be made by materials that ad/absorb substances and the method should not bias the contaminant content of sample. The storage of samples during transportation from the site to laboratory should affect the sample as little as possible. Water samples for organic substances should be stored in glass bottles and metal samples in plastic bottles. Dark and cool place is used, and the time for storing should be kept at minimum (Danish EPA 2002).

Samples are taken from the ground water from the source and in a potential well at a distance from the source. This indicates the transportation and help to understand the relation of contamination in the soil and groundwater. The level of contamination in a possible well at a distance of 100 m from the source for quick transportation (1 year of transport for slow moving substances) is assessed and compared with the levels at the source, see Figure 18. Sampling in the pore gas is also important as high levels in the pore gas compared to the ground water indicate higher risk (Dall-Jepsen 2009; Falkenberg 2009)

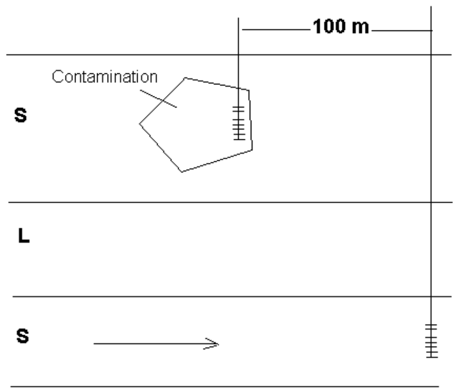


Figure 18 Sampling of groundwater and at the (Dall-Jepsen 2009)

Sampling of air

There is a focus on volatile substances in Denmark and the sampling of air is an important measurement to assess the risks from volatile substances. It is often carried out as the first measure before the soil is disturbed. Volatile hydrocarbons are mainly detected; especially benzene, toluene and chlorinated solvents, also other kinds of substances like naphthalene and hydro cyanide are detected through air sampling.

Soil contaminations in the unsaturated zone are distributed in three phases; absorbed on the soil, dissolved in the water and dissolved in the soil gas. The chemical and physical properties are determining the distribution of the substances. For all volatile compounds a greater part will be in gas form, a soil gas measurement is advantageous for detection of these compounds. The gas measurements are particularly useful for risk assessment of sensitive landuse areas, especially for indoor air, preliminary investigations were volatile compounds are suspected and to localise point sources.

Soil gas measurements are taken in the unsaturated zone, the depth is normally 1-5 meters depending on the objects, geology and expected contamination. The soil gas is pumped up and collected for analyse. Analysis can be performed in field but give higher certainty if made in a laboratory. Gas investigations are used at landfills to detect if methane gas which percolates might lead to explosions. Depending on the geology the transport of substances very, critical distances are given in Table 8 (Danish EPA 2002).

Table 8 Potential critical distance from landfills (Danish EPA 2002)

Boulder clay	10 m
Fine sand	25 m
Coarse sand	250 m

Analysis

To identify the degree of contaminations in the investigated area, analysis is important. There are various methods available which vary in price, speed and kind of substances possible to analyse. Analysis of unknown substances needs a broad analysis to identify and describe many substances, normally with screening methods.

Approved laboratories should analyse and identify potential contaminations and the quantity of contamination. There are regulations for acceptable accuracy (10-20%) and detection limits (the detection limit should not be higher than 1/10 of the acceptance criteria). Both screening and substance specific analysis are carried out (Danish EPA 2002).

Geology, hydrogeology and hydrology

The geological and hydro geological conditions are important for the investigations of contaminations. The soil strata should be described geologically and a description on basis of geological characterisation of soil samples from the soil borings. If needed geotechnical tests i.e. pumping and geophysical measures are performed as a supplement. Groundwater aquifers are assessed using geological descriptions and observations in wells. Flow direction, gradient, potentiometric surface and hydraulic parameters as well as leakage are determined from the groundwater aquifer.

Surface water recipients should be mapped, if they are located closely to the contaminated site complementary investigation may be needed. Contamination can occur from groundwater flow, which are most critical, and from surface run-off (Danish EPA 2002).

4.3 Risk assessment

4.3.1 Definitions

4.3.1.1 Contaminated soil

Contaminated soil is defined as soil with toxic substances to an extent that it may pose a risk to humans. It does not tell if the substances are natural or produced by humans, or if they occur in a harmful form for humans. A non-toxic bad smell could be unacceptable for residence (Danish EPA 1990).

4.3.1.2 Occurrence of risks from contaminants

Occurrence of risk is assessed for specific circumstances. Information about actual contamination, transport and exposure pathways as well as target recipients is the base for the assessment and determines the risk; see Figure 19. In Denmark the sources of contaminants are commonly diffuse sources like traffic and industries as well as landfills from industries (Danish EPA 2002).

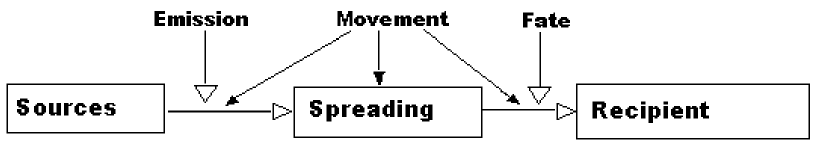


Figure 19 Schematic picture of risk occurring from contaminated sites (Danish EPA 1990)

4.3.2 Protective values

4.3.2.1 Humans

Human health is protected for both chronic, harmful effects and acute harmful effects. The acceptable risk is set to effect on 1 person out of 1 000 000 humans affected for lifetime exposure. To ensure human health acceptable tolerable daily intake, TDI, is calculated at a level that no harmful effect on humans should occur.

4.3.2.2 Environment

In the beginning of the work with contaminated sites in Denmark protection was given also to the environment. Very soon the need of remediation was found too big to make it possible to consider also environmental protection. As the resources are limited it was found more efficient to put the effort on protection for human and groundwater. Legislation was changed not to prioritise environment protection as a benchmark. For special projects environmental aspects are taken into consideration. One reason for not giving protection to environment by remediation is that the money can be used in more urgent and effective ways for protection of environment, e.g. eutrophication caused by the pig industry is giving more harm and should be in prior for investigations (Danish EPA 2002; Kiilerich 2009).

There are eco-toxicological criteria available to assess risks to ecosystems. The criteria are developed from NOEC values and the protection value is set so that 95 % of the species are protected to 95 % uncertainty. The criteria are published for several substances and groups of substances.

4.3.2.3 Groundwater

Groundwater is important as drinking water source in Denmark and has the highest priority for protection. The protection of groundwater has been one of the driving forces for the work with remediation of soil and is still a very important issue for the country. The map in Figure 20 shows areas with drinking water interest. Almost the whole country is important as source of groundwater for drinking water supply (Danish EPA 1990).

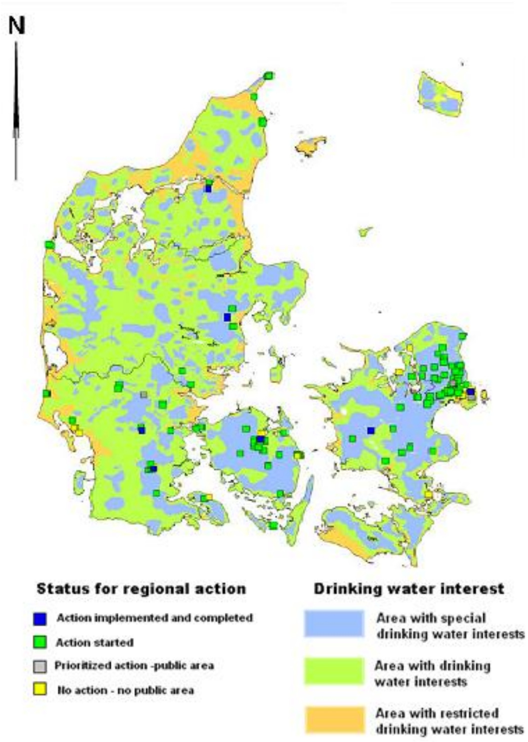


Figure 20 Areas with groundwater interest in Denmark (Danish EPA 2007)

4.3.2.4 Sediment and surface water

Effects on surface waters have had low priority in Denmark. This is due to small dependence on surface water as a drinking water source, and is also due to the fact of limited resources. The main threat to surface water has been seen as eutrophication. Since the new European Water directive there might be changes of priority in Denmark. Sediment has until now not been prioritized and the Danish EPA is not planning to change it in the near future (Kiilerich 2009).

4.3.3 Assessment of contaminants

To evaluate the effects of hazardous substances to humans' assessment are performed to understand substances effects on the biological systems. This includes valuation of the hazard of the substances, exposure of recipients and duration of exposure. There are several steps that have to be carried out to ensure effects from contaminants. To assess the effects from contaminated sites a risk assessment is the common method. Danish scientists were analysing the difference between risk and hazard assessment and concluded that the main difference between the two methods is the starting point. Risk assessment assesses the risk from the perspective of a specific situation, whereas hazard assessment stars from the specific substance and assesses the effects of that. Figure 21 illustrates the differences. Results from hazard assessments can often be used in a risk assessment as the same situation occurs. According to OECD a hazard describes the features of a substance that are causing a threat to organisms and environment. This includes the exposure analysis, an assessment of recipients' exposure and an effect assessment, assessing if the substance will cause the unwanted effects (Danish EPA 1990).

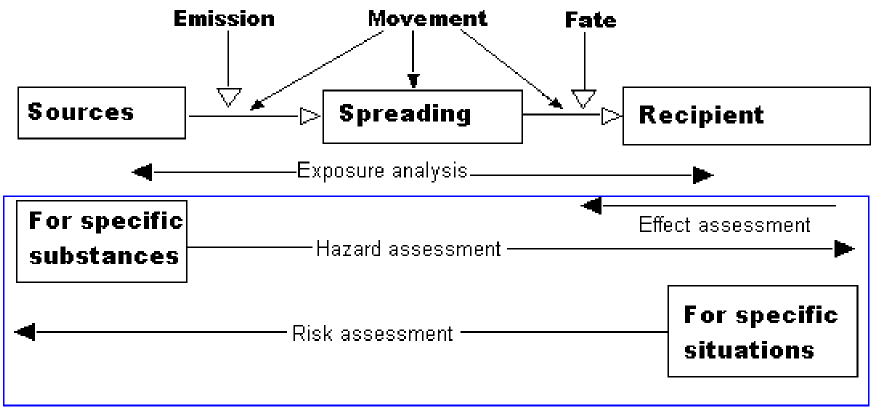


Figure 21 Schematic picture describing differences of hazard and risk assessment (Danish EPA 1990)

4.3.3.1 Hazard identification and hazard assessment

The hazard identification focuses on the qualitative combinations of exposure pathways and effects that may harm the recipients. It may contain several qualitative elements and commonly used is the dose-response relations (Danish EPA 1990).

Hazard assessment is a review of the characteristics of the contaminants. The hazard is described qualitatively as carcinogenic, corrosive, toxic etc. and the effects are characterised as acute, long term or chronic effects. Often a qualitative description is made characterising if the substance is harmful or not to humans (Danish EPA 2002). Hazard assessments primarily consider the chemical and physical features of substances and what effects this will have in relation to biological systems. Indications are normally dose-response relationship; No-effect level (NOEL) and no-observed effect concentration (NOEC). Totally there were 83000 substances in the RTECT database in 1983, where 80 % had values for acute toxicity but only 5 % had values for irritation and effects on reproduction. (Danish EPA 1990).

There are three main characters analysed in Danish hazard assessment; what chemicals are present, if the chemicals may transform in the environment and the distribution of the substances in nature. These are determining the major hazard to humans. Two main aspects are further assessed given by the Danish EPA 1990:

1. Whether the target groups can be exposed to the contamination → *Exposure assessment*
2. Whether the contaminants can cause toxic effects on target groups → *Effect assessment*

4.3.3.2 Hazardous substances

Chemical substances are not always found hazardous, but several are very hazardous and especially important to identify. The work with contaminated soil in Denmark has main focus on chlorinated volatiles as they are very harmful to humans and groundwater. Further there are several hazardous substances to be phased out; DDT, PCB, Trichloroethylene and MTBE (Kiilerich 2009). Other harmful prioritized substances are; PVC, phthalates, dioxin, lead, hormonal effecting substances, ozone corrosive substances and bromide flame retardants. In the beginning of the work with contaminated soil substances like lead, dioxin and PAH were prioritized, but the focus have changed due to knowledge, cost effectiveness and focus on protective values. Hazardous substances have been divided into two categories; those with chronic effects to humans e.g. lead, cadmium, benzapyrene and PAH, and those with acute harmful i.e. arsenic and nickel. The substances are chosen according to certain criteria and hormone affecting substances is found as a main threat. There are about 6 400 substances listed in Danish EPA's database for substances with unwanted effects, including the EU prioritized substances. They are all published for public interest (Danish EPA 2009).

4.3.4 Mapping of contaminated sites

The Danish mapping of contaminated soil started 30 years ago and is extensive. Mapping has put pressure on land owners to clean the land as public registers are available for contaminated areas and may affect the value of the site. The mapping is performed at two levels of knowledge:

1. Level 1. There is knowledge about the activity that may have caused the contamination on the area. No full mapping is performed.
2. Level 2. There is documentation of the contaminations on the area, fully or partly.

In 2006 around 23 000 contaminated sites were mapped according to knowledge level 1 or 2. Totally or partly 11 000 sites were investigated and had proven contamination according to Knowledge level 2. At 12 000 sites knowledge about the activity that may have caused the contaminants were documented, and some investigations made, Knowledge level 1. The mapping of contaminations is performed by the regions, and can be found at the homepage for *National Survey and Cadastre*.

The contaminations in soil that may affect ground water are not yet fully mapped. This mean more contaminated sites will be added to the list of mapped sites. Until now the focus has been on big areas where ground water have major importance and areas planned for building of dwellings and residential houses (Danish EPA 2009).

City classification

City areas are since January 2008 classified as *Area of minor contamination*. Cities have been contaminated during a longer time period and are exposed from many different sources. They have other types of contaminations compared to industrial areas or similar and should be treated differently. No mapping has to be carried out and investigations are performed only for suspected areas. To minimize the risks from contaminated soil for humans the Danish EPA publish general advises to deal with the risks, see Information in Chapter 4.2. The city classification aims to prevent that lower contaminated soil is not moved to places that are not contaminated. If the soil is moved from an Area of minor contamination a permit is needed from the municipality. The city classification prevent the mapping of around 90 000 contaminated areas (Danish EPA 2009).

4.3.5 Sensitivity for landuses

In Denmark there are three categories for landuse purposes:

- Highly sensitive landuse (HSL)
- Sensitive landuse and (SL)
- Non-sensitive landuse

The highly sensitive landuses allow farming and children playing on the ground. This includes possible ingestion of soil and or inhalation of fumes from volatile contaminants. Sensitive landuse includes parks and park-like areas. Non-sensitive landuse is land used for industries and other non-sensitive areas. Specific landuse sensitivity is stated in Appendix 5. Quality criteria are stated for HSL and there are no further levels for other less sensitive landuse purposes. An assessment and discussion is deciding the possible use and levels acceptable for less sensitive area (Danish EPA 2002).

The exposure to humans applies to the depth of landuse. For HSL and SL the protection of humans is specified with a depth-wise. The minimum depth for certain landuse should be:

- 1 m, where landuse is highly sensitive, i.e. in the garden of private homes and in day-care facilities. The soil may be frequently worked or crops may be grown
- 0.5 m, in park areas and other public accessible areas permanent planted
- 0.25 m, where the area is permanently covered with grass, thus excluding further earth works.

For circumstances where the soil will be worked at lower depth than stated above this will be taken into consideration. Risk for contamination of groundwater may demand deeper remediation. Landuse for future uses the soil quality criteria should be met down to about 3 m depth or higher if the groundwater level is higher. The level of landuse can be used to regulate the exposure, administrative regulations, pavement or permanent grass cover ensures that the depth of landuse will be nil.

It is acceptable to let residual contaminations remain at depth below the landuse depth. Replacement of the upper 30 cm of soil with non-contaminated soil is an option to avoid exposure. Separation of the contaminated layer from the clean soil is needed, usually geotextile and/or identification net is used (Danish EPA 2002).

Various soil types are considered for landuse: contaminated undistributed soil, excavated soil that is either contaminated or non-contaminated and soil conveyed from an external source. Distinction is also made between different kinds of soil (Danish EPA 2002):

- Soil which is used in excavations on the site,
- Topsoil, the uppermost layer and most sensitive layer regard to surface-related activities. The thickness typically varies from 0.25 to 1 m.
- Subsoil, the soil below the topsoil but above the ground water level.

There is a difference between governmental and private objects for remediation. For objects with private responsibility there is no distinction in depth, and the whole contamination should be taken away (Dall-Jepsen 2009).

4.3.6 Model for exposure

Contaminated soil can be a threat to humans, plants and animals in case of landuse at ground level. Primarily the contaminated topsoil is a threat to humans. The exposure pathways to humans are, also illustrated in Figure 22:

- Ingestion of soil
- Eating crops grown on the soil
- Skin contact with soil
- Inhalation of soil particles
- Inhalation of fumes from soil
- Ingestion of crops

Exposure pathways to environment and animals are also; exposure of plants and animals as well as water abstraction.

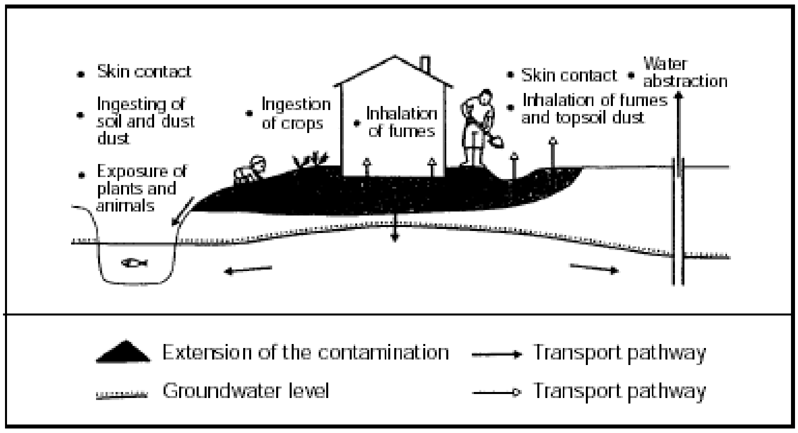


Figure 22 Exposure pathways for humans (Danish EPA 2002)

4.3.7 The risk assessment

The risk assessment analyses a specific situation with target groups and exposure. Important elements are identified for definitions and data requirements and risk assessment is carried out for landuse, evaporation and groundwater separated see Figure 23. According to Kiilerich there is no general procedure for risk assessment and the assessment will vary for different projects and demands from authorities. Indoor air is often determining the risk as this is a main threat to human health (Danish EPA 2002).

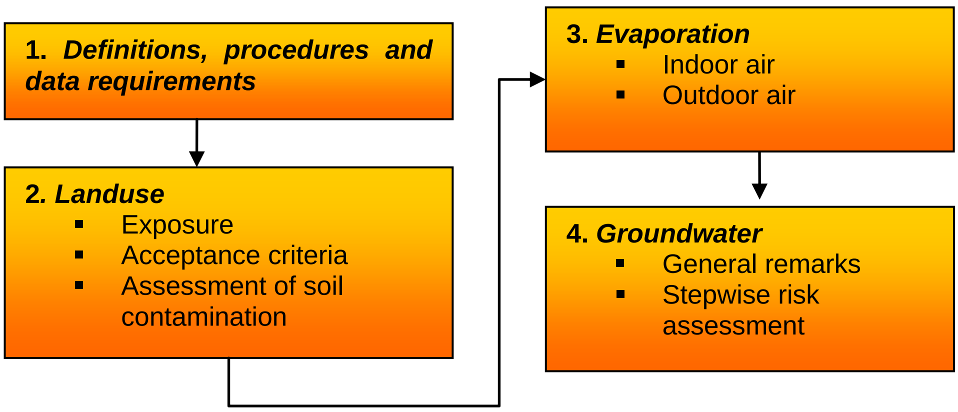


Figure 23 Elements in the Risk assessment (Danish EPA 2002)

Risk assessment aims to evaluate the risk to humans and assess the need for remedial measures. The risk assessment is based on the hazard assessment where a review of natural characteristics of the potential contaminants is carried out. The toxicity, bioavailability and mobility of the substances are important for the assessment of risk and the three most important considerations are health considerations connected to the expected landuse, identification of groundwater protection and considerations regarding surface-water recipients and soil. The risk assessment must be based on:

- The result from the investigations
- Hazard assessment of relevant contaminants
- A survey of possible pathways for transportation and exposure
- Knowledge of target groups exposed

4.3.7.1 Landuse

Risk Assessment for landuse includes definition of exposure, acceptance criteria and assessment of soil contamination. The possible exposure pathways should be identified and the minimum depth of landuse is determined to ensure that the exposure does not exceed the acceptable level; see Chapter 4, section 3.5 and 3.6 (Danish EPA 2002). For assessment of risk for less sensitive landuse there are no certain criteria or procedures. The assessment is carried out on basis on exposure patterns for various landuses presented in Appendix 7 but is also influenced of the demands from responsible authority (Kiilerich 2009).

Establishing acceptance criteria

Establish of acceptance criteria for the contaminant with respect to the sensitivity of landuse is an important element in risk assessment. There are no general differentiated acceptance criteria with respect to exposure time and specific landuse developed for the remediation project. The acceptable risk level should be defined for every project according to expected exposure and landuse, including landuse depths. The acceptance criteria should be robust so the project can last for 50-100 years that a building is expected to remain.

The acceptance criteria should not be based only on toxicological parameters. Other issues like smell and bad visible contamination of water may be unacceptable. In the risk assessment potential landuse conflicts, both present and potential, must be identify. The present landuse conflicts should be eliminated.

There is a difference between the limit of value and acceptance criteria. It is important to delimit the exposure and a general limit value would for all sources give a very low criteria. An acceptance criterion is the landuse depth at which the soil quality criteria must be met. Qualitative criteria are used to delimit the exposure of soil, for example to decide how deep the soil should be excavated. It is acceptable to let residual contaminations remain at depth below the landuse depth. It is not always practicable and economically feasible to remediate all contaminated areas with the acceptance criteria. Administrative regulations could be used to ensure that the exposure of the contamination will be limited (Danish EPA 2002).

Assessment of soil contamination

Contaminations can occur as hot spots (a specific point source) or in more diffuse concentrations. Hot spots are determined by investigations with falling concentrations from a highest concentration as the source. An identified hot-spot needs an action if the contaminations are posing a hazard to humans or groundwater. For more diffuse sources with single high concentrations but no hot spot identified, investigations and action are not prompt performed. Identification of contaminations should include identification of hot-spots to ensure the source of the substances. A single value is not enough to declare a hot-spot, and mapping and investigations are not prompt needed for single high detection. For fill layers with identified contaminations mapping and remediation actions are necessary.

For diffuse contaminations the assessment will depend on whether the substances give acute or chronic effects. For substances with chronic effects (e.g. cadmium, lead and PAH) these are the determining factor in setting the quality criteria. Highly sensitive landuse is allowed only if the average of all tests is below the soil quality criteria. For substances where acute harmful effects (arsenic and nickel) are determining the quality criteria, an area can be used for highly sensitive landuse if the following criteria are met (Danish EPA 2002):

- The average of all samples lies below the quality criteria
- A maximum of 10 percent of the samples exceeds the soil quality criteria
- No of the test results exceed the quality criteria with more than 50 %

4.3.7.2 Evaporation

Assessment of the evaporation effects in buildings and outdoor air is performed for indoor and outdoor air individual. The risk is greatest form highly organic solvents including chlorinated volatiles. Several models for assessments of air contamination are developed, from simple to complex models. They provide a conservative estimation of the contribution to outdoor and indoor air. The methods will not be described in detail in this report. Factor influencing the evaporation of substances are:

- Depth of contamination
- Porosity and water content of soil layers
- Building design and construction materials
- Temperature and pressure gradients surrounding the building
- Building ventilation

4.3.7.3 Groundwater

The risk assessment for groundwater aim to evaluate if there is a risk of exceeding the groundwater criteria. Also possible contribution from secondary groundwater will be evaluated. Leaching of contaminants is defined as the source term. Sorption is considered in the saturated and unsaturated zone. Dispersion and natural degradation influence the transport time and is assessed in the saturated zone.

The methods developed for evaluation of groundwater contaminations are extensive in Denmark. The method is performed stepwise with three main elements:

- Step 1. Near source mixing model
- Step 2. Downgradient mixing model
- Step 3. Downgradient risk assessment with dispersion, sorption and degradation

This method includes extensive calculations and is performed mainly with programs; JAGG is used for several parts. More details are given in Chapter 4, Section 3.10 (Danish EPA 2002).

4.3.8 Quality criteria

The Danish Quality criteria or guideline values state a secure level of contamination, where no negative effect will occur for recipients. These are not strict limits and give the level of contamination that can be accepted in all contexts. Independent quality criteria are designed for soil, water and air. This means compliance with one of the criteria does necessarily imply compliance with another. For soil there are two criteria, the *Soil quality criteria* and *Cut-off criteria* (Afskæringkriteriet). For dust and evaporation from soils there are the *Air quality criteria for evaporation* and for affects on ground water the *Ground water quality criteria*.

The quality criteria do not represent a risk analysis as there are no local geological conditions or sensitivity of landuse taken into consideration. The aim of the quality criteria is to eliminate harmful effects on humans, but also to have a clean surrounding. Soil that is moved because of excavation is replaced by other, clean soil. It is unacceptable to mix clean soil with the contaminated soil at a site to comply with the criteria, as this is in direct conflict with the intention of the environmental legislation (Danish EPA 2002).

4.3.8.1 Soil quality criteria

The soil quality criteria are developed for highly sensitive landuse, for example gardens and day-care centres. The quality criteria specify the highest levels of contaminants that can be present in the ground without giving negative effects on recipients. If the levels are below the criteria the soil is clean and no restrictions for landuse are needed. For most quality criteria the daily acceptable intake (TDI) from the top soil is the background for establish of criteria, either acute effect or chronic effects. Children's direct exposure is a main influence on the soil criteria.

The soil quality criteria are stated for protection of human health. Ecotoxicological criteria are available for protection of environment, see Appendix 6B. These are not considered for normal projects according to the Danish laws. The health based soil quality criteria; eco-toxicological soil quality criteria and corresponding background levels for a selection of substance are stated in Table 9. A list with all the Soil quality criteria is available in Appendix 6A.

Table 9 Selection of Soil quality criteria and background levels (Danish EPA 2008)

Substance	Soil quality criteria	Eco-toxicological soil quality criteria	Background level
Acetone	8		2-6
Arsenic	$20^{1(2)}$		
Benzene	1.5^{*2}		
BTEX, total	10^{*2}	10	
Cadmium	0.5^{2}	0.3	0.03 – 0.5
Chloroform	50^{*2}		
Chlorophenols	3^{*2}	0.01	
Chromium, total	500	50	1.3 – 23
Chromium (VI)	20	2	
Copper	500^{1}	30	13

Units are; mg/kg dry weight (DW). Note:

There are areas where the soil quality criteria are slightly exceeded, especially in cities. This is not directly harmful and advises are given for citizens' to avoid negative effects. Since 2008 these areas are classified as Area of minor contamination and should only be mapped and treated if higher levels of contamination are suspected. Advises to reduce the risk are given, for example washing children's hands after playing outside and cleaning of vegetables, fruit and berries before eating. If there are several sources suspected that contribute to the exposure of a substance, e.g. food or air, this is compensated when applying the criteria to ensure that the total tolerable intake (TDI) is not exceeded (Danish EPA 2002).

4.3.8.2 The Cut-off criteria

There are additional soil quality criteria for harmful immobile and slow degradable substances, the Cut-off criteria (Afskæringkriteriet). These criteria indicate the level where no contact with upper soil is allowed. If the levels are exceeded the area is considered as contaminated; investigations and necessary remedial measures should be implemented to avoid damage to humans or environment. Currently there are ten substances with cut-off criteria, all listed in Table 10.

Table 10 The cut-off criteria for soil (Danish EPA 2008)

Substance	Cut-off criteria for soil (mg/kg DW)
Arsenic	20^{1}
Cadmium	5^{2}
Chromium	1000
Copper	1000^{1}
Lead	400^{2}
Mercury	3
Nickel	30^{1}
Zinc	1000
PAHs	40^{2}
Benzo(a)pyrene	3^{2}
Dibenzo(a,h)anthracene	3^{2}

[1]. Based on acute harmful effects, [2]. Based on chronic harmful effects

4.3.8.3 Quality criteria for groundwater

This criterion is composed for areas where ground water is used for or might be used for drinking water. After a simple cleaning the water should fulfil the criterion for drinking water. Apart from the health based criteria smell and taste are taken into consideration when establishing ground water quality criteria. In Denmark ground water is the main drinking water resource and to protect it the pollution is held as low as possible. The quality criteria for groundwater are in some cases lower than for drinking water, as there are other sources that are taken into consideration. A selection of the criteria is presented in Table 11. (Danish EPA 2002; 2007)

Table 11 Selection of Quality criteria for drinking water (Danish EPA 2008)

Substance	Groundwater quality criteria, µg/l	Background level, µg/l
Acetone	10	
Arsenic	8	0.1->8
Benzene	1	
Boron	300	10->300
Butyl acetates	10	
Cadmium	0.5	0.005->0.5

The quality criteria for ground water must be fulfilled for the major aquifers. Also for minor upper groundwater aquifers compliance is demanded as they may spread contaminations or will be used for drinking water supplies in the future. Important in the risk assessment is to establish an acceptable level of residual contamination in relation to an influence on the groundwater at the site. (Danish EPA 2002)

4.3.8.4 Air quality criteria for evaporation

The Quality criteria for air quality is dealing with the risk that evaporation from volatile contaminations can affect humans via inhalation. Outdoor air and indoor air could be contaminated by volatile substances, which should be avoided. There are two criteria and a distinction is made between *evaporation criteria* (quality criteria) and *limit values for air*.

Evaporation criteria Air-quality criteria for evaporation to air are a contribution value which is generally set equal to the limit value for air.

Limit value for air The Danish EPA publish limit values for air on basis of toxicological assessments. These are used for setting maximum permissible contributions of contaminating industries to air as emissions (B-values). These are also used for setting air-quality criteria for evaporation into the overlying air.

The evaporation of chemical substances from contaminated sites should not contribute to higher levels to the overlying air than the evaporation criteria, as a general rule. Limiting values for evaporation have been established for several substances and a selection is given in Table 12, all are presented in Appendix 6A. The Danish EPA are regularly revising the criteria (Danish EPA 2002; 2008).

Table 12 Selection of substances with Air-quality criteria for evaporation (Danish EPA 2008)

Substance	Air-quality criteria for evaporation to the overlying air [mg/m3]
Acetone	0.4
Aromatic hydrocarbons	0.03
Benzene	0.00013
Butylacetates	0.1
Chloroform	0.02
Cyanides, volatile acidic	0.06
Diethylether 1	1
Isopropanol 1	1

Apart from the Quality criteria for evaporation a list with around 150 B-values for air quality are developed for additional important air pollutants. These are extracted from the background documentation, and four categories based on acute effects, smell and immediate acute effects are used for implementation (Danish EPA 2002).

4.3.8.5 Establishing quality criteria

Establishing quality criteria include collection of data, performing research and many calculations are needed to set the levels. The process is described below and more details and data are given in Appendix 8. An overview of the process is given in Figure 24.

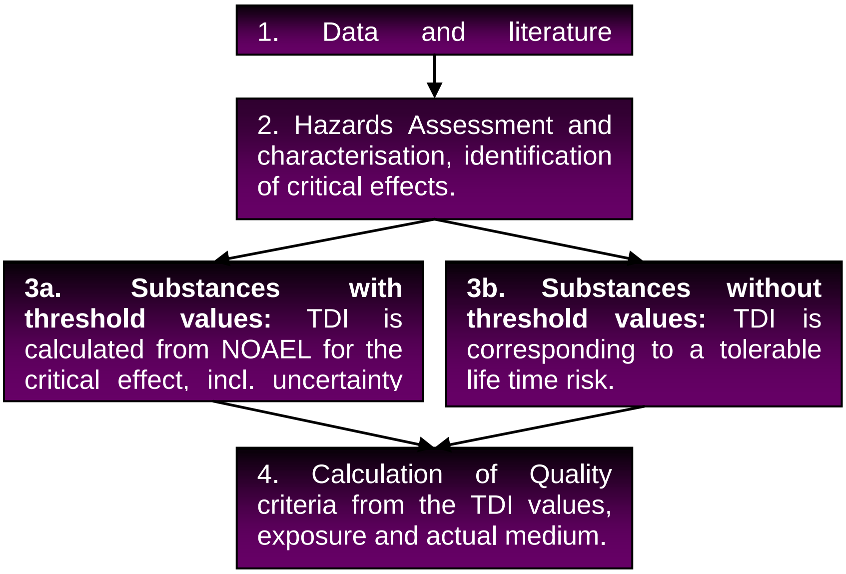


Figure 24 Process for establishing quality criteria for soil, air and groundwater (Danish EPA 2006)

1. The literature research and collection of data use international and national data bases and research to assess information about the substances and their effect on humans. WHO's guidelines for risk assessment and quality criteria for several chemical substances in water and air is a part of the work. Also guidelines and principles from the European Union and their risk assessment program are used.

2. Hazard Assessment and characterisation of hazards and identification of critical effects, are structuring and assessing the hazard effect, and level of effect where there will be an effect on humans.
3. The TDI values are developed for every substance. In these calculations it is assumed that 100 % of the intake comes from the exposure of the contaminated site. If other sources for exposure of the same substances are known, the exposure from the site will be given a percentage of the total TDI.
4. Finally the quality criteria are developed with knowledge of TDI, exposure, transport pathways, medium for transport and exposure etc.

The establishment of the quality criteria in Denmark is assuming (Danish EPA 2006):

- The accepted risk to humans is harm to 1 out of 1 000 000 humans for lifetime
- Specific allowance are taken for children
- A lifetime of 70 years is expected for a human
- A time-span of 50-100 years

4.3.9 Background levels

The background levels are used for comparison with measured contamination levels in the investigations. General background levels are stated for many of the substances and may also be detected in the investigation phase to identify if the background levels are differing from the general values. The general background levels are presented by the Danish EPA (Danish EPA 2002).

4.3.10 Site-specific assessment – use of software

In Denmark the software Jagg is used as a main tool to assess the level of contamination available for spreading that may affect the surrounding. This is a site specific assessment and the program is developed to assess what level of substances that may be spreading for several categories including several calculations for soil, groundwater and indoor air. A discussion is normally held in the report about the reasonable levels of contamination in the area. For industrial sites the quality criteria are not necessary to comply with, but in gardens there are important. When assessing risk in ground and water the relationship of gas and groundwater is important, when the levels are higher in the pore gas there is a higher risk (Falkenberg 2009)

4.3.10.1 Jagg

The program Jagg is a calculation sheet used for all kinds of risk assessment of contaminated soil. It is developed by the Danish EPA with influence from the US-EPA. The current version, 1.5, will be updated and the new version 2.0 will include more functions for the calculations (Danish EPA 2009). Jagg is very conservative in the calculations to deal with uncertainties and avoid unwanted effects from the contamination. This means that the result from the program will overestimate risks, and additional evaluations and assessments can be needed to understand the real risk (Danish EPA 2000). A disadvantage with Jagg is that it is constructed to deal with relatively small quantity of data. Projects with very extensive investigations cannot be used with good results (Kiilerich 2009). Jagg have eight main functions presented below. An overview plat of the program is given in Figure 25.

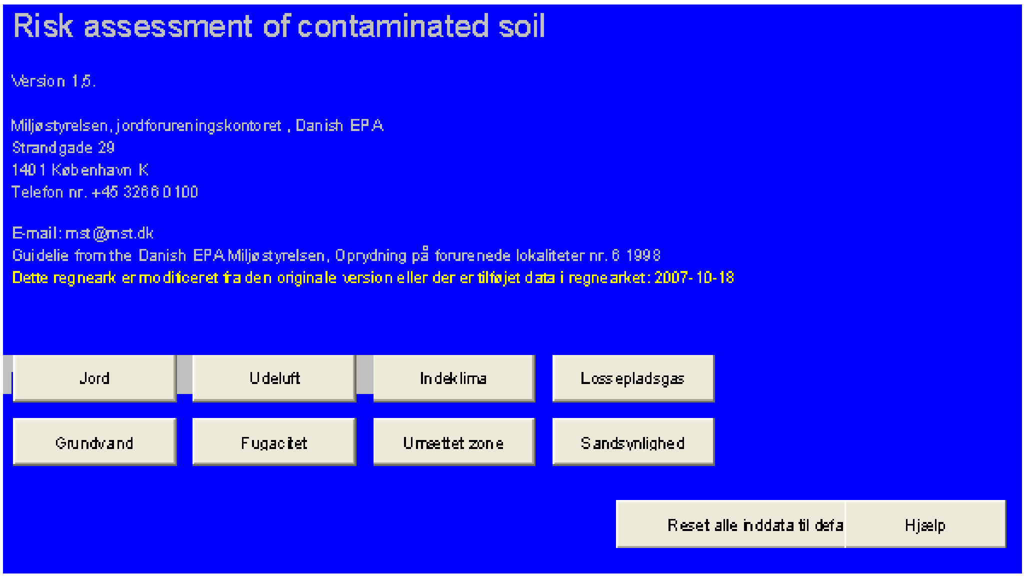


Figure 25 JAGG - the first page with functions (In Danish, Danish EPA 2009)

Soil

Assessment of diffuse soil contamination can be used to determine whether a site can be used for very sensitive landuse. A distinction is made between contaminations that give decisive chronic effects or acute effects.

Outdoor air

Vaporization to outdoor air calculates the diffuse transport of pore gas from a contaminated area to the surface and mixing with outdoor air. The calculation is conservative and made on basis of the measured or calculated pore gas concentration, soil features and size of the contaminated area.

Indoor air

Vaporization to indoor climate is used for calculations of the diffuse transport of contaminated pore gas to buildings and indoor air. Calculations are similar to those for the outdoor air, but calculated for the lower side of the floor in the house and the sum of diffusive and convective transport is included. Data of the buildings and floor is needed as well as chemical parameters.

Landfill gas

On basis of half time values and total gas production calculations are made for the annual rate of gas production. Also the relationship between pore gas concentrations of the landfill and the indoor concentrations can be calculated. These calculations represent a worst case scenario where assumptions about frozen and water-saturated topsoil and where all gas from the landfill are transported into the building.

Groundwater

Risk assessment in relation to ground water is performed divided into three steps.

1. “Mixing model close to the source area”. The infiltrating contaminated pore water is mixed with the groundwater in a 0.25 m wide vertical zone of the top of the aquifer (Danish EPA 2000)

2. “Mixing model downstream of the source area”. The thickness of the vertical zone is the aquifer is determined on the basis of the distance corresponding to one year of travel time, or a maximum of 100 meters from the source, see Figure 26. The further the groundwater flow the grater the mixing zone thickness will be with lower concentration as a consequence (Danish EPA 2000).

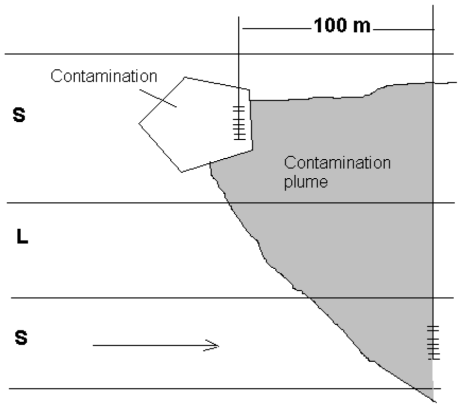


Figure 26 Calculation of the contamination plume at a distance from the source (Dall-Jepsen 2009).

3. “Downstream model based on dispersion, sorption and natural degradation” This calculation includes the effect of sorption and degradations of the contaminants. As this is difficult to predict measurements and monitoring is needed to confirm the degradation rate. On the basis of the measured values the program can calculate the actual degradation (Danish EPA 2000; Falkenberg 2009)

Fugacity calculations

The fugacity equilibrium is calculated i.e. the distribution of the substance in the three phases pore air, pore water and soil is assumed. The maximum values in the three phases are calculated with data input about soil type and contamination components (Danish EPA 2000).

Mitigation in the unsaturated zone

The mitigation of substance by can be calculated by means of pore water transport through the unsaturated zone. The pore water concentration may be presented as a function of time and depth. There are still big uncertainties in this area and the results should be considered with great reservation. In the new upgraded version this is one of the improved areas (Danish EPA 2000; Kiilerich 2009)

Probability

The probability of encountering contamination at a given site can be calculated. Data is needed about how many samples are taken and the diameter of a hot spot or percentage of the contaminated site containing the substance (Danish EPA 2000).

4.3.10.2 Other programs

In Denmark several programs are available for risk assessment and contaminated soil; Geoproc, KRIPP and GISP are most used. GISP is a program developed to look at what kind of contaminations there are, and were they are located. KRIPP is constructed for detailed assessment where lots of data is available. This is a complement to Jagg as it is produced for assessment with limited access to data. KRIPP can be used for very detailed investigation and for prioritising between objects (Flyberg 2009). With Geoproc the natural degradation is indirectly evaluated; also the speed of a contamination in soil can be assessed. The main functions of the program are according to Danish EPA 2009:

- Evaluate if groundwater contamination will decrease due to digestion or dilution
- Evaluate the effect of degradation in the unsaturated zone
- Assess if hypothesis about biochemical processes are true
- Quality control on the analysed data
- Assess local degradation constants for the ground water assessment with Jagg

4.3.10.3 Strategies for remediation of contaminated sites

The regions in Denmark have started with a new approach for prioritizing of the contaminated sites. Instead of looking at each object separately the objects in an area are identified and a prioritising for all objects is carried out. For an area the program GISP can be used to calculate how much the different sites contribute to the total pressure. This helps the prioritizing between objects. In Figure 27 an overview is given about programs needed to deal with the prioritizing between objects (Flyberg 2009).

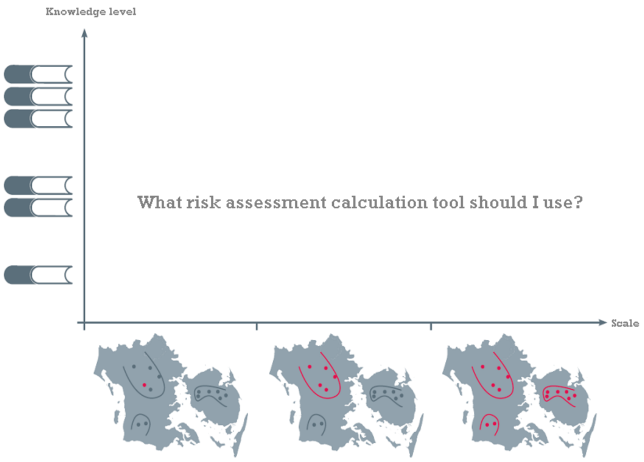


Figure 27 New programs for assessment and prioritising between remediation objects are under development (Flyberg 2009)

4.3.11 Principles for dealing with uncertainties

There are no specific regulations for precautionary principles in Denmark. In reality this is implemented in many of the laws. For suspected hazards to humans or the environment the principle will be important until scientific principles are identified. For contaminated soil the principle is applied when setting the quality criteria. By choosing the criteria at levels that give higher certainty the chances are smaller for unexpected effects, the security for the public is higher. As the risk assessment process involves several uncertainties within all levels assumptions are made that ensure a high protection to humans and the environment. For example are the calculations within Jagg are conservative to ensure low uncertainty (Danish EPA 2005).

In the feasibility study the possible choices for remediation are analysed and information to compare them are collected. Depending on the specific circumstances for the object different remedial measure are appropriate to use. The feasibility study aims at investigating which remedial measure that is possible and most efficient to use and decrease the identified risk and an acceptable risk level for humans and environment. The feasibility study and risk evaluation is carried out together in the Danish process. Factors that will influence the choice of remedial measure are;

- Type of contamination
- Location of contamination
- Soil type
- Geology and hydrology
- Time available for clean-up
- Effect on the clean-up and acceptable residual contamination
- Landuse and layout
- Working environment during remedial measures
- Cost of the methods
- Documentation of methods application

The feasibility study can be carried out in steps, from an Overview in the Outline project to detailed Tender documents. In Appendix 7 the possible remedial measures for various types of contaminations and soil types are stated. With base in this table and the factors presented above the possible measures are identified and evaluated (Danish EPA 2002).

4.4 Feasibility study

In the feasibility study the possible choices for remediation are analysed and information to compare them are collected. Depending on the specific circumstances for the object different remedial measure are appropriate to use. The feasibility study aims at investigating which remedial measure that is possible and most efficient to use and decrease the identified risk and an acceptable risk level for humans and environment. The feasibility study and risk evaluation is carried out together in the Danish process. Factors that will influence the choice of remedial measure are;

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4.4.1 Strategies for remediation

In relation to the expected landuse the contaminants needs to be removed, cut-off or prevented from being transported. Several strategies are available to deal with this according to the Danish EPA 2002:

- Excavation with subsequent off-site or onsite treatment
- In-site treatment of soil and ground water
- Pumping groundwater near the surface
- Construction measures to reduce effects to indoor air
- Equipment to prevent or reduce exposure in the outdoor environment
- Limit of landuse to avoid exposure

4.4.2 Feasibility study and risk evaluation

The structure for the feasibility studies is based on the US EPA guideline on feasibility studies and consists of five main elements (Englöv et al. 2007):

1. ***Formulation of goal***: Identification and formulation of specific remediation goals.
2. ***Identification of general measures***: Identification and evaluation of general measures and their possibility to achieve the formulated goals.

3. ***Initial method screening***: Identification of methods for evaluation in detail. Screening of a broad spectrum of know and new methods for remediation for chosen measure strategy.
4. ***Intensive method analysis***: The chosen methods from 3. are studied and evaluated in detail. Parameters to assess are: Implementation, possibility for mass reduction, possibility to achieve the measure goals, probability for action success, timescale and costs.
5. ***Preparation and evaluation of measure option***. Collocation of object specific measure actions based on the methods in 4. The alternatives are evaluated and ranked according to criteria so the best alternative can be chosen.

1. Formulation of goals

This step includes: 1) Identification of objects for protection and 2) Production of remediation criteria for soil and/or groundwater and pore gas. Reduction of risks to humans is usual as measurement goal, but other factor can be included. Specific remediation objectives are the base for assessment of remediation alternative. Acceptable contamination levels or intervals for the exposure pathways are stated (Englöv et al. 2007).

2. Identification of general measures

General remediation actions achieving the remediation goals should be identified and evaluated. Methods should be evaluated, and the reason for out rule from further evaluation should be well motivated and documented. General categories are (Englöv et al 2007):

- ***No action*** **-** If it can be proved that the risk to recipients is low enough and the goals are reached also with no action, this is a possible alternative.
- ***Administrative protective measure*** **–** By protection of exposure trough administrative measures that will eliminate usage that give unacceptable risks.
- ***Technical protective measure*** **-** This method is designed for protection of indoor climate for volatile compounds and treatment of drinking water. Ventilation actions are usual for buildings.
- ***Long term follow-up*** **-** Used to follow up that the goals are met in long-term.
- ***Monitoring of natural digestion*** **-** This strategy is based on natural processes like biological, sorption, sedimentation, evaporation and dispersion that reduce the concentrations over time.
- ***Enclosing*** **-** With physical measures the transportation of contaminations is eliminated or limited to an extent that the goals are reached.
- ***Mass reduction*** **-** By reduction of the levels of contamination through in-situ or ex-situ methods to the measure goals.

3. Initial method screening

When the possible remediation actions are identified the remediation methods and techniques in the respective categories should be identified and assessed. The screening aims to sort out the most appropriate methods for the site from the less appropriate ones. Tables can be used as a help in the process to evaluate the possible methods certain soil and contaminations (Englöv et al 2007).

4. Intensive method analysis

To identify the most appropriate remediation methods for the specific site an intensive method analysis is performed. A template is used to evaluate the effects for the implementation and documentation including the criteria; Practicability, Capacity to reach the goals, Time required to reach the goals, Technique maturity, Time required for remediation, and Cost. (Englöv et al 2007).

5. Preparation and evaluation of measure option

The highest prioritised methods from 4 are used to compile site-specific remediation measures. Only a few alternatives or a combination of alternatives are chosen. The final evaluation include nine criteria; Protection of human, Fulfilment of authority requests, Long time effects and permanence, Reduction of toxicity, mobility and quantity, Short term effect, Practicability, Costs, Acceptance by authorities and Public acceptance (Englöv et al. 2007).

4.5 Risk evaluation

The risk evaluation is integrated in the Feasibility study as the last part. The evaluation aims to reach the best result for the specific remediation object. For many cases the cost of remediation is very high, and it is important to evaluate the demand and limits for the remediation. Remediation should be carried out as far as technically possible, it should also be economically reasonable for society and stakeholders. The risk should be reduced to acceptable levels, which give benefit to the public. Ideally a Cost-Benefit Analysis, CBA, should be carried out, but in reality a discussion about pros and cons and what is found most advantageous is common used (Flyberg 2009).

There is a difference in the view if remediation for private and public stakeholders. Public remediation projects focus on the reduction of risk to humans and groundwater to a reasonable level. Cost-benefit models are preferable to evaluate the motive for remediation and the focus is on efficient remediation and to minimise the impact on recipients to a reasonable cost for society. Private stakeholders have the responsibility to remove the contaminations on the site completely. As this is very costly it is often hard to convince them to remove everything. The last 5% is often left as the risk is not potentially reduced by cleaning this part, see Figure 28 (Killerich 2009).

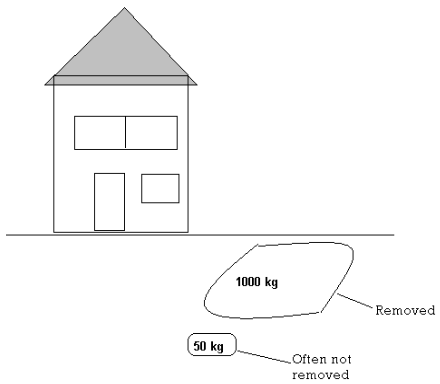

Figure 28 Remediation of private objects is often made partly as the last part is very expensive to clean (Kiilerich 2009)

4.6 Remedial measures

A distinction is made for remediation of the three contaminated media in Denmark: soil contaminations, groundwater contamination and soil gas or gas contamination. Different contaminants can be treated with different methods, and new methods can replace or be used as a complement to more verified measures. The location specific factors influence the choice of possible measures as well as the type of contamination. Methods available for remediation in Denmark are under rapid development and there is lack of documentation of the effects of the newer methods (Danish EPA 2002). Detailed descriptions of available remedial measures are given in Appendix 1.

4.6.1 Remediation of soil contamination

There are some principal methods used for remediation measures; in-situ, onsite and off-site (ex-site) methods. The well-known methods are:

- Excavation and disposal of soil at the central treatment facilities (ex-site)
- Excavation and soil disposal at landfills (ex-site)
- Excavation and soil disposal at treatment facilities (on site)
- Soil Vapour extraction (in-situ)
- Forced leaching (in-situ)
- Methods using construction techniques and equipment (on site, in-situ)

For the newer not fully tested methods there are among others (Danish EPA 2002);

- Bio ventilation
- Biological soil treatment (inoculation technique)
- Detergent leaching
- Immobilisation (vitrification, stabilisation)
- Electro kinetics
- Steam stripping
- Chemical treatment
- ‘Pneumatic fracturing’

Excavation is the most common method for remediation of soil contamination. According to the Danish EPA there was no real alternative to excavation and landfill until the 1990’s. Now treatment of excavated soil is possible and there are several central soil treatment facilities in use. Most of the facilities treat organics with microbiological degradation. Also thermal treatment is possible for especially heavy metals, cyanide or tar content. Chemical treatment (one facility in 1997) treats soil for tar, pesticides, cyanides and heavy metals in addition to lighter contaminations. Stripping is used to a limited extent for highly volatile contaminations. Finally landfill disposal is possible, used mainly for heavy metals, but need permission from both landfill authorities and the local authority where the soil originate (Danish EPA 2002).

Treatment of excavated soil on site is possible by several treatment firms using the same principles as for central plants (land farming and stack compositing). These methods have been tested to a very limited extent in 2002. On site treatment is performed to a small extent as large amounts of soil are preferable and mainly sandy soil with lighter organic contamination is efficient. Drawbacks for on site treatment are large space and time requirements, odour and noise problems and expensive constructions. The local authorities in Denmark have the responsibility for assigning the disposal and a subdivision into classes is often made to be able to reuse the soil afterwards (Danish EPA 2002)

Soil Vapour extraction is the most frequently applied in-situ method used in Denmark is the soil vapour extraction. It is primarily a physical extraction (stripping) method for highly-volatile xenobiotic organic substances. Bioventilation is in operation in Denmark but is still not fully documented; it does have good potential though. Greatest potential are with lighter anaerobic degradable organic contaminants such as mineral-oil products and solvents but not chlorinated solvents in permeable soil types (Danish EPA 2002).

Forced leaching is most efficiency in combination with other methods like remedial pumping. It is used for a few projects in Denmark but it is still not fully documented. Total remediation seems impossible with this method, and some operational problems have been observed. Immobilisation is a method where the contaminations are kept in place in the soil. The area can be used without removing the contamination. Constructional methods are often used in Denmark, e.g. asphalt or paving to decrease the transport of the contaminations. Another method, Vitrification, is now tested in a few projects in Denmark. Sealing is also used to stabilise the contaminations in the ground, but still in small scale (Danish EPA 2002).

Bioremediation is under development with a suggested pilot project for biological remediation. Detailed investigations and planning are taking place and the conditions for this site are identified as appropriate for this method. Electro-kinetic soil remediation is a method still not for commercial use, but pilot project show the big potential for heavy metals. Stream stripping is evaluated as no potential in Denmark. Infiltration of active substances to degrade toxic substances is another method, still not tested in Denmark (Danish EPA 2002)

4.6.2 Remediation for groundwater contamination

Methods available or under development are under development. The most common remedial methods for groundwater in Denmark are according to Danish EPA 2002:

- Pump-and-treat from screened wells.
- Separation pumping from specific levels.
- Pumping with multiple pumps in several phases.
- Skimming LNAPL contamination from screened wells.
- Pumping from drainage systems.
- Pumping from suction-probe equipment (including ‘bioslurping’).
- In-situ methods including:
    - Air sparging
    - Adding oxidising agents
    - Reactive barrier and filter techniques

Pump and treat is a way to bring contamination under hydraulic control to with a pumping strategy, and the treatment can be performed with several different methods. Methods in use are; screened wells, separation pumping, skimming, injection recirculation etc. Air sparging includes several methods with good potential for use in Denmark. It was recently introduced and will mainly be used in combination with other methods (Danish EPA 2002).

Reactive barrier and filter techniques are under development with several full scale research projects in Denmark. Barriers for cleaning of groundwater contamination is mainly tested, and may have a future in Denmark (Helldén et al 2006).

4.6.3 Remedial measures for soil gas contamination

To avoid effects from soil gas there are several strategies. New buildings should be planned and build so they are not affected by the fumes. This can be made by choice of location construction. Contaminated areas should not be used for very sensitive landuse. Radon is one threat, and new buildings have to be conducted according to the guidelines. For outdoor areas frequently visited remedial measures are needed to protect humans from exposure. Examples are cover by asphalt or replacement of the upper layer of soil (Danish EPA 2002).

Ventilation is a method used for existing buildings. Ventilation pipes or drains under the floor can eliminate the air flow of volatile substances into the house. This method is very widespread and can be used for all types of contaminations. As a supplement or alternative diffusion inhibiting synthetic membranes can be used.

Remediation of land fill gas is performed to limit the contamination and the effects to recipients. Remedial measures to prevent the flow of gas towards buildings are;

- ***Gas barriers.*** Constructed between the source of gas and the building, and normally comprising a gas-tight cut-off membrane placed in a ditch on the side of the ditch that is closest to the building. Synthetic and natural membranes are used.
- ***Permeable ditches***. Established between the source of gas and the building, and normally comprising a cut-off ditch with coarse material and possibly a gas-tight membrane in the side of the ditch closest to the building. The gas is vented either passively or actively (in drains).
- ***Venting drains.*** The gas is vented between the building and the source of gas either passively or actively).
- ***Venting wells***. The gas is vented between the building and the source of gas either passively or actively.

The following methods are used to prevent gas from entering into buildings;

- ***Sealing buildings***. The building is sealed against gas convection, for example by using membranes and sealing cracks in concrete).
- ***Changing the pressure gradients.*** Buildings can be slightly pressurised above atmospheric pressure. This method is not recommended, however, for buildings which are damp.
- ***Ventilated drains.*** Drains under the building are ventilated on the same principle as used for preventing other volatile contamination described in Section 9.4.2, or ventilation is established around the buildings and in dead space and sewers. The system can work either actively or passively.

(Danish EPA 2002)

4.6.4 Statistics of remedial measures

Remediation techniques used is still dominated be excavation. In 2005 there were 671.000 tons of soil excavated for ex-situ treatment and deposit. Pump and treat methods and Soil vapour control are also much in use. For details see Figure 29. The dominance of excavation with 68% of the projects is clear. This includes in-situ combinations (Danish EPA 2006).

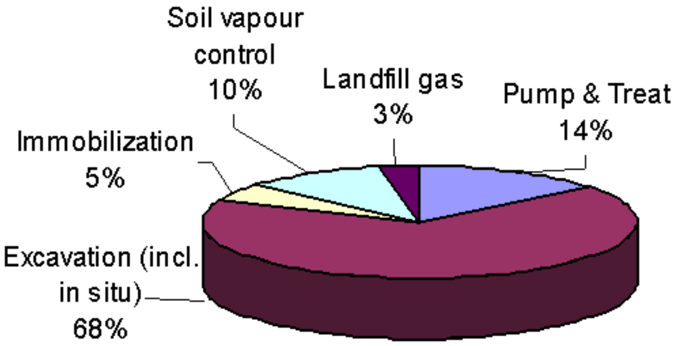

Figure 29 Remediation measures used in Denmark 2005 (Kiilerich 2006)

4.6.5 Classification of excavated soil

After the remediation there is often soil left contaminated to a certain extent. There are regulations and a classification to handle and use this soil. The classification includes four classes, Class 1 soil, not contaminated and below the quality criteria; can be used for all purposes. Class 2 soil is used for land filling and filling material, for example to noise barriers. Class 2-3 can be placed on certain landfills, and Class 4 soil has to be placed in certain landfills because of its harmful substances (Dall-Jepsen 2009)

4.7 Remediation projects

4.7.1 Identified sites

In Denmark remediation involves many employees and is an economically important business. There are many remediation projects going on and the work with this is extensive. In 2005 the status for contaminated sites in Denmark looked like this;

- Possible contaminated sites: 55 000 (estimated)
- Sites with proven contamination: 10,991
- Sites with risk of contamination: 11,852
- Estimated costs of additional sites: 14.3 billion DKK (incl. remediation)

Of the identified objects 35 000 are actually contaminated and from these 14 000 are in priority for remediation. Groundwater contamination are the reason for 4 000 of the prioritized sites and human health for 10 000 sites. In Figure 30 the remediation objects in Denmark are presented per industry. In 2005 there was in around Denmark 8 400 sites with remediation activities. This gave an average cost of 0.6 – 1.4 million DKK/ site (0.85-2.0 million SEK/site) (Kiilerich 2006).

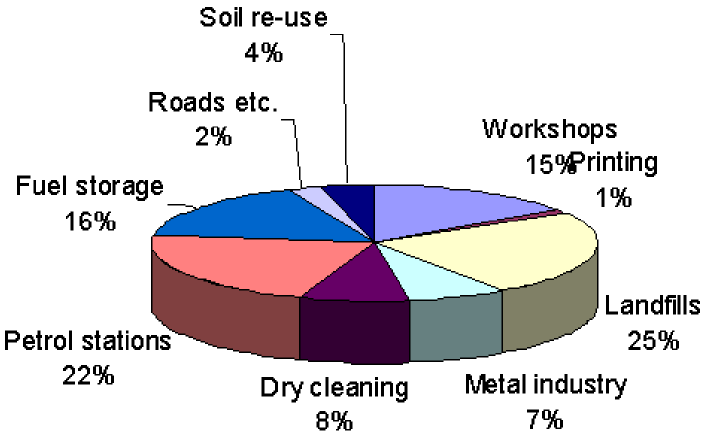

Figure 30 Remediation objects in Denmark (Kiilerich 2006)

4.7.2 Frequency of detected contaminants

The frequency of contaminations accruing in contaminated soils in Denmark is presented in Figure 31. Mainly oil, heavy metals, tar and chlorinated solvents are detected (Dansk Miljörådgivning 2006).

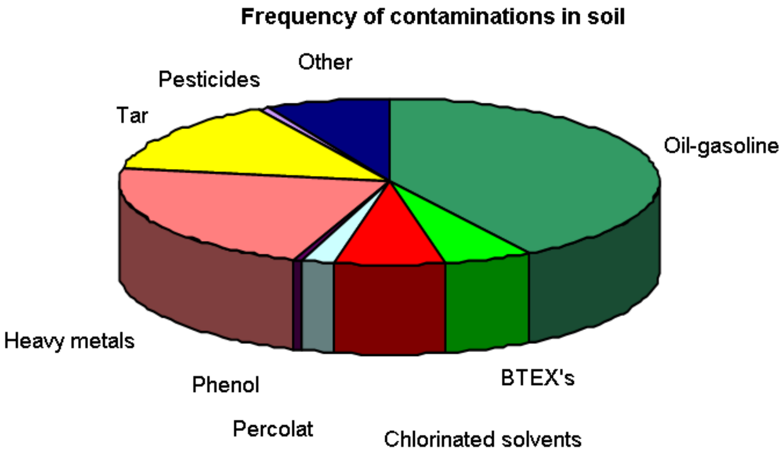

Figure 31 Contaminants occurring in contaminated soil in Denmark (Dansk miljörådgivning 2006)

Contaminants found in groundwater are mainly oil products and substances occurring from petroleum derivates, chlorinated solvents and BTEX. Groundwater contaminants are illustrated in Figure 32.

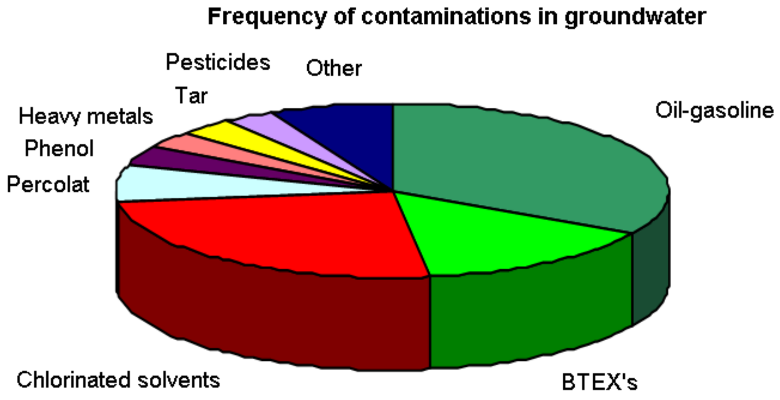

Figure 32 Frequency of contamination in groundwater (Dansk miljörådgivning 2006)

4.8 Geology

The Danish geological soil map show that glacial till, glaciofluvial deposits and gaciomarine deposits are major soil types. Sand is present to a large extent which has a high permeability for water. Sand deposits are also good as drinking water aquifers. For details see the geological map in Figure 33 (Kupa 2009).

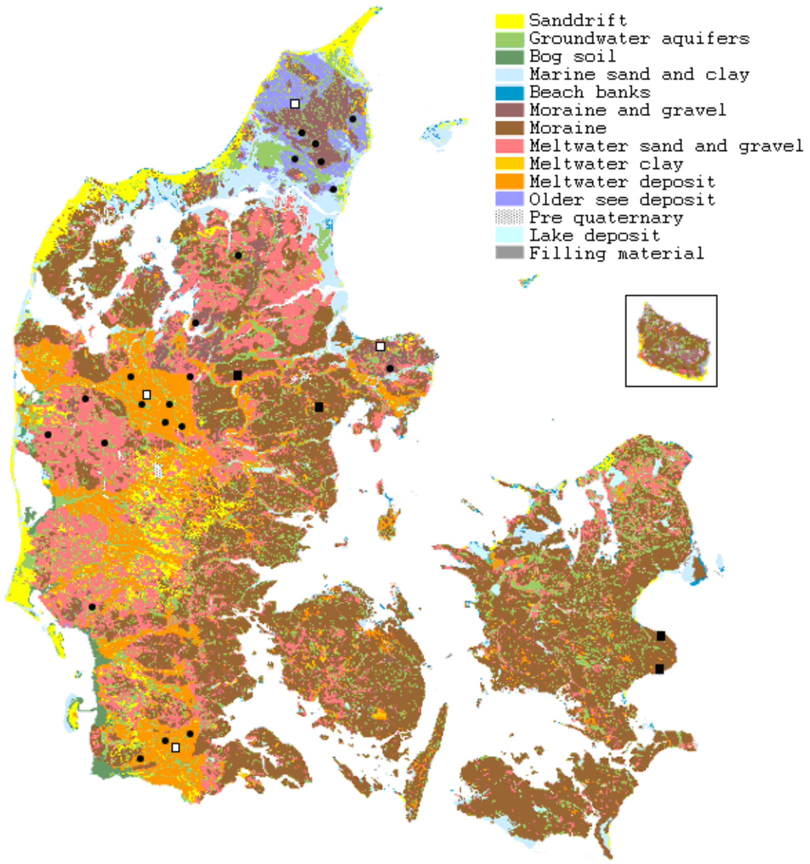

Figure 33 Danish geological map with soil types (KUPA 2009)

4.9 Organisation of the work with Remediation projects

4.9.1 Administrative tools

In Denmark the Ministry of Environment, Miljøministieriet (Danish EPA), is working for the government on environmental issues. There are several departments and institutions in the Ministry of Environment and the Environmental Council (Miljøstyrelsen) is responsible for issues on Soil, Waste, Chemicals, Air and several other issues. Totally the EPA has about 200 employees; around 50 are working at the department for Soil and Waste issues. Of these 13-14 mainly work with contaminated soil. In Demark totally around 2000 people are expected to work with contaminated sites (Kiilerich 2009).

The departments of the Danish EPA are responsible for setting goals, development and implementation of strategies and plans and for the work with environmental issues overall. Contaminated soil is an important issue, and the department for Soil and Waste do collaborate with several other departments and institutions to reach best results. Together with regional and local authorities, universities and consultants as well as the EU commission they work for developing the procedures for mapping of contaminated sites, investigations, risk assessment and remediation measures (Kiilerich 2009). The Danish EPA administrates several codes; the "*Contaminated soil directive"* is one of the more important codes together with the law about chemical compound and law about the Environment and gene technology. (Danish EPA 2009)

The five regions in Denmark are official responsible for the work with contaminated soil, see Figure 35. Mapping and prioritizing of sites as well as consulting and financing are their responsibility. The regions have an important role in structuring the work and prioritizing what sites are urgent for investigations and actions (Danish EPA; Kiilerich 2009). The local authorities are responsible for smaller projects, for example indoor climate and earth excavation, most decisions and organisation are made on region level (Danish EPA 2009).

Figure 34 The 5 regions in Denmark (Danish EPA 2009)

Depotrådet is an extensive instance that reviews the work with contaminated soil in Denmark. Every year a written report is published that resume the work and knowledge for the year. Depotrådet consist of several stakeholders including representatives from the Industry, the Regions and the Danish EPA who are also leading the council. The aim with the council is to review the work and to point out important improvements, lack of certain techniques, knowledge or special needs in the sector (Kiilerich 2009).

The Knowledge Centre for Soil Contaminations (Videncenter for Jordforurening) is working for greater experience and knowledge about inventory to remedial measures. This is collaboration with representatives from the five regions and was established in 1996. They gather, arrange and distribute informative reports for interested stakeholders. Arrangement of courses and conferences are ongoing. Important is also the spreading of information between the regions and municipalities. On their homepage all kinds of industries are listed with necessary information for a remediation process; possible contaminants, needed investigations etc. Standard descriptions informing how different kinds of risk assessment should be performed and handbooks for soil and groundwater sampling are also published (Videncenter 2009; Falkenberg 2009)

4.9.2 Financial tools

Financing of the work with contaminated are mainly governmental, but local and regional authorities are also important. The grants given for this work the last years are totally around 370 million DKK or 500 million SEK, similar to Swedish grounds. All numbers are presented in Table 13. In Denmark there is a financed funding for technology development through the Teknologipujen. This is financed by the government with 5 million DKK/ year (~7.2 million SEK/yr) and is a collaboration between universities, authorities, consultants and the Danish EPA (Kiilerich 2009).

Table 13 Allowance for remediation in Denmark (Depåtrådet 2009)

Financing (in millions)	**2004**	**2005**	**2006**	**2007**
Allowance Regions	200	205	212	337
Allowance municipalities	11	12	12	12
Regional financing	130	115	106	-[1]
Governmental	21	29	22	22.1
Technology development	5	5	5	5.4
National defence	6.6	5.6	3.6	8.9
Total DKK (millions)	**373.6**	**371.6**	**360.6**	**385.4**
Total SEK (millions)	**512**	**509**	**494**	**528**

[1] The regional financing do not longer exist due to change in organisation.

Local work

The cost of remediation in the Capital Region Copenhagen is estimated to 4 – 6 billion Danish crowns (~ 6 – 9 billion SEK). With today's economic situation it may take up to 100 years to eliminate all contaminants. The yearly cost is 100 million whereof 22 millions are used for protection of 100 contaminated areas with administrative regulations (Region capital city 2007).

5 Differences between the Swedish and Danish remediation processes

The overall method for remediation projects in Sweden and Denmark is similar. Both countries have developed the methods and models from the US, Canadian and Dutch models. The national authorities have the responsibility for adjustment and development of guidelines and establish of quality criteria and they distribute financial allowance for remediation projects. The regional and local authorities have responsibilities in both countries. In Denmark more of the responsibility is localized to the regions that have a more advising position. In Sweden the local authorities have more responsibility themselves; the different tasks are given more too local than regional authorities.

The development of the work with contaminated soil started about the same time in Sweden and Denmark. The first guideline was published earlier in Denmark, in 1992, whereas the first guideline for Swedish conditions was published in 1996.

Denmark and Sweden are geographically different. Sweden is ten times bigger with large natural areas, forest and lakes and rivers. Denmark is flat with few lakes and few undeveloped areas and the groundwater is important as source for drinking water; in Sweden surface water also is used as drinking water source. The geographical conditions have been important for the development of procedures to handle contaminated sites.

In Sweden with large undeveloped areas the focus is on protection of the environment. Programs and development of environmental objectives are prioritized to create a sustainable development. In Denmark the protection of nature is not as extensive. To limit the pollution, regulations prohibit contaminated soil to be put at non-polluted areas. This gives higher pressure on remediation investigations and measures to avoid large volumes to be disposed at landfills.

5.1 Legislation

The binding laws for contaminated soil were implemented earlier in Denmark than in Sweden. In 1990 came the first law for waste including contaminated soil. Already in 1983 the first regulation was implemented allowing mapping of contaminated areas and buildings for public publication. The environmental law in Denmark early clarified the responsibility for investigations and remediation with connection to year and type of contamination. A governmental responsibility for contaminations from earlier was also stated (Englöv 1999). The Danish law gives protection to humans and groundwater primarily and environment secondary. According to Danish law contaminated soil should not be moved to clean areas.

In Sweden the environmental law came into force later, in 1999. This law was implemented together with environmental objectives to create a clean and sustainable environment. No corresponding goals for environment are present in Denmark. There is still no official register for contaminated soil in Sweden, and the responsibilities are sometimes weak. Swedish legislation gives protection to humans, ground and surface water as well as the function of ecosystem with species similar to Canada and the US.

The environmental objectives are in many situations the basis for decisions in Sweden. Sites should preferably be free from contaminations and excavation is for most project the only way to ensure this. For the work with contaminated soil it can be challenged what consequences the environmental objectives has for the long term development and sustainability. When sites are cleaned with excavation large quantities of contaminated soil is often put on landfills. Clean soil is taken from clean areas and put in a surrounding with contaminated areas. Removal of the contaminated soil does not only eliminate the contaminations if the soil is cleaned afterwards, but as this is very expensive landfill is the preferable option.

In Denmark the regulations prohibit that contaminated soil is put on clean areas to limit the contamination. No similar rule is stated in Sweden, and it would be interesting to evaluate the consequences of excavation in a broader perspective. As remediation is an expensive process and prioritizing has to be carried out it can be challenged at what level protection should be given to reach the best result in a broader perspective. Both countries have implemented the polluter pays principle.

5.2 The remediation process

The risk assessment processes in Denmark and Sweden are both developed from US EPA and Dutch models, and have major similarities. The first guideline for contaminated sites was published in Denmark in 1992 and the Swedish equivalent in 1996.

5.2.1 The remediation process structure

The main steps in the process are similar in Denmark and Sweden with A first survey (literature study), Investigations, Risk assessment, Feasibility study and evaluation and finally Operation and evaluation. The order and presented structure may look clearer in the Danish version, with four major steps. The Swedish method contains more elements and is not as easily overviewed. Comparisons of the two processes starting from the Danish process show that the same steps are carried out in both countries. The comparison of the main elements is given in Figure 35.

In the description of the Swedish process the investigations are placed before the Problem definition. This might be confusing as the problem definition aims to identify and plan the investigations. The need for a problem definition before the investigations is not clearly described. The acquisition of geological and hydro geological data is performed in both countries as an initial step.

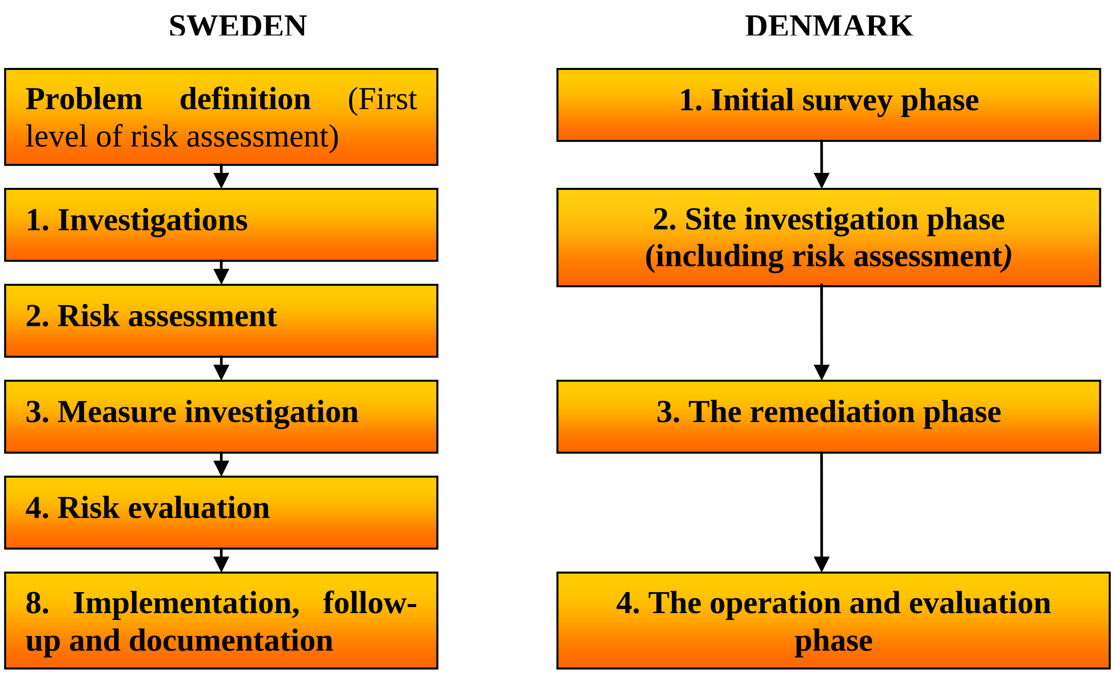

Figure 35 Comparison of the main elements in the Remediation process in Sweden and Denmark

Quality criteria are used in both countries, with the difference that the Swedish criteria provide one single value including toxicological, ecotoxicological values as well as protection for ground- and surface water. In Denmark there are different quality criteria for different purposes; soil, groundwater and evaporation, and a fourth quality criterion for ecotoxicological values is available but regularly not in use. The number of substances with quality criteria is two times higher in Denmark than in Sweden. The importance of information as a protective measure in Denmark is not found in Sweden. With information about routines to avoid exposure especially in city areas citizens are given a basic protection in Denmark.

5.2.2 Levels of Risk Assessment

The several levels of risk assessment that are defined in the Swedish process do not occur in the Danish process. Only the first step; Risk Classification is performed in mapping and identification of contaminated sites in Denmark. Further there are no corresponding levels of risk assessment in Denmark but in some projects the investigations and assessment are repeated.

5.2.3 Overview investigation

The first step in the Danish process is the Initial survey phase (see Chapter 4.2.1). The corresponding procedure in the Swedish process in the Problem definition performed in the Risk assessment (see the Risk assessment methodology in Chapter 3.3.7). This is the first overview investigation aiming to identify relevant information and data for the project to structure the work and plan the field investigations etc.

The main elements in the procedure are compared below in Figure 36. The aim and main elements are very similar with collection of data from historical photos and literature, identification of possible contamination and a field visit. The importance of data sources from maps and historical register is more developed in Denmark with well structured and central organised registers for data. These sources are very important for the Initial survey outcome in Denmark. The corresponding data sources in Sweden are of varying quality, very good for some projects and rare for several projects. They are not as comprehensive and easy overviewed as the Danish internet data bases.

Sweden - Problem definition

- Delimitation
- Recipients, Transport and pathways
- Gaps of knowledge
- Geological and hydro geological data
- Investigation and measurement program
- Characteristics of the contamination sources
- Conceptual Model

Denmark- Initial survey phase

- Collection of data
- Acquisition of geological and hydrological data
- A site visit
- Assessment of collected data and hypothesis on possible contaminations

Figure 36 Comparison of the initial steps in the remediation process

5.2.4 Site Investigations

The investigations are important to assess the contamination levels, type of contaminants and form the basis for the risk assessment. First a sample plan is created from the initial information to ensure that the sampling is correctly performed. Similar procedure is performed in both countries. The level of details for the sample planning seems higher in Denmark, partly due to higher levels of knowledge about previous actions on the site. The identification of hot-spots is important in Denmark as single high values are not seen as a major threat. Hot-spots are not identified in the same way in Sweden. This may be partly because of the different geological conditions.

For sampling of soil there are no main differences as the same methods are used. Mainly excavation pits and location borings are used down to 4-5 m or to natural soil occur. Samples should be taken every 0.5 meters according to both guidelines. Sampling of groundwater is in both countries performed with screen wells in a similar way.

The focus on pore air sampling is well developed in Denmark, but not much used in Sweden. One reason is the focus on volatile hydrocarbons and especially chlorinated solvents in Denmark. These substances are very harmful to humans and as the solvents could have negative effects occurring in outdoor and indoor air they are well investigated to avoid damage. To identify the volatile compounds air sampling is performed as the first measure at several depths. Pore air sampling is in Sweden described in the guidelines but not prioritized for investigations. The analyses can be performed with screening methods and laboratory test, the latter is preferable in both countries. Many of these hazardous compounds are derivates from petroleum product and oil is the major identified contaminant in Sweden. Presence of these harmful volatile substances is highly probable also in Sweden, and detection should be prioritized. A higher level of background knowledge on contaminated sites may give higher certainty of the detection and analysis in Denmark than in Sweden. The sample methods are overall more developed in Denmark mostly due to well developed air and water sampling.

5.3 Risk Assessment

5.3.1 Definitions

The basic definitions of contaminated soil show that both Denmark and Sweden consider it a risk with substances that poses a threat to humans and ecosystems. The definition of the occurrence of risk show that Sweden put more focus on the fact that there are sources of contamination that can be transported for exposure to humans and ecosystems. In Denmark the identification of hot spots and actual contamination levels, possible transport and exposure is seen important. More diffuse sources and single values are not found as a direct threat and investigations takes place only if hotspots are suspected by our neighbour.

5.3.2 Protective values

In Sweden protection is given to humans, ecosystems, groundwater and surface water. For environmental protection organisms in soils and waters protection are given for the function of the ecosystem. Ecotoxicological data is a major governing factor for many of the quality criteria. This means that soils can be remediated or excavated to protect the soil or water itself, with its species and ecosystem. Protection is given to 75% of the species for *Sensitive landuse* and 50% of the species for *Less sensitive landuses*. There are many uncertainties in the development of ecotoxicological quality criteria, and the values are very conservative and ecotoxicological risk assessments are also difficult to use for site-specific assessments. Groundwater and surface water is given similar environmental protection. Humans are given protection at the individual level with an acceptable risk for carcinogenic substances set for effects on 1 out of 100 000 persons over a lifetime exposure.

In Denmark the focus for protection are humans and groundwater. Human health is seen very important, and as groundwater is the main source for production of drinking water protection of groundwater is of high priority. The risk acceptable for humans is set to 1 of 1 000 000 effected humans over lifetime exposure, ten times higher protection than in Sweden. Groundwater is protected as drinking water source and gives protection to human health. For protection on the environment there are ecotoxicological threshold values giving protection to 95% of the species with 95% certainty. These are not regularly in use since 17 years as this protection is not found efficient and necessary. Surface water and sediment have not been given protection this far due to few important uses. But the new water directive within the EU may change this.

Denmark has regulations to avoid contaminating of clean areas. This help to keep the existing ecosystems intact. The importance of information to minimize the exposure and effects of human's health are central in the Danish process but not included in the Swedish work.

5.3.3 Assessment of contaminants

To understand the effects substances have on recipients hazard assessments to identify the effects and toxicity is needed. Hazard assessment is identifying effects for a specific substance whereas risk assessments identify risk and effects for specific situation. An analysis performed in Denmark has shown the relationship between the hazard assessment and risk assessment. No similar analysis is known in Sweden. In both countries the dose response relationship and NOEL/ LOEC values are used to assess the effect concentrations. Data for substances are available from international studies and many substances are registered with acute toxicity, but there is a lack of knowledge for irritation and effects on reproduction.

In Denmark the focus seems to be on understanding the effects and levels for effects of substances or groups of substances. They have put big effort in hazard assessments, and have around 83 000 substances in the RTECT database. For unwanted substances there is another database with 6400 substances specially designed from certain criteria and focus on hormone effecting substances. In Sweden the focus is more on finding what substances are prioritized for phasing out and remediation. There are several list presented with unwanted substances and classification of levels for unwanted substances.

There is a difference in the focus on hazardous substances. In Sweden the main focus is on metals; lead, mercury, cadmium and several organic compounds; DDT, PCB, dioxin as well as chlorinated organic substances. These are classified as high risk substances. In Denmark the main focus is on chlorinated solvents as these have bad negative effects on both humans groundwater. Heavy metals have lower priority now but were prioritized 15-20 years ago. Remaining prioritized substances are similar to Sweden; DDT, PCB, phthalates, tri TCE, MTBE etc.

A major difference can be found in the Danish dependence and prioritizing of groundwater and the bigger focus on evaporation as a pathway for exposure. Transport of the contaminations in the ground is more in focus in Denmark; especially for groundwater there are several stages to calculate the "real" level of transported substance. In Sweden the quality criteria are used for prioritising of the substances and the list are many for prioritizing of hazardous substances. My impression is that the assessments in Denmark evaluate the risk and prioritize the remediation in a more realistic way, where the estimated risk is decreased to an acceptable level with remediation.

An interesting difference is the view at digestion of contaminants in the ground. In Sweden all substances are suspected to be available for transport and exposure whereas in Denmark the digestion is considered and calculations are used to assess the possible transport and exposure. The more advanced methods for calculation programs used in Denmark also influence the results.

5.3.4 Mapping of contaminated sites

The mapping of contaminated sites started earlier and has been more extensive in Denmark than in Sweden. In Denmark the mapping started already 30 years ago, and has been official since the 1980s. This has put pressure on the land owners for both mapping and remediation. The regional authorities are mainly responsible for the mapping.

In Sweden the mapping started later, and the last years have been important for the identification and classification of the sites. The local authorities are responsible for the mapping of contaminated sites in Sweden, and they also have the information about identified and classified objects in the area. There is no official register for contaminated sites.

Since 2008 there is a new classification of city areas in Denmark. As there are many diffuse sources of pollutants in the cities these are classified as Area of minor contamination as a benchmark, and information is given to minimize the exposure and effect on citizens.

5.3.5 Landuse sensitivity

In both countries there are several landuse categories. In Sweden there are *sensitive* and *less sensitive landuse*. The quality criteria are developed for the two categories. In Denmark there are three levels; *highly sensitive*, *sensitive* and *non-sensitive landuse*. The quality criteria are set for highly sensitive landuse and for other purposes other methods than comparisons with quality criteria are used. Landuse depths are often used to evaluate the acceptable contamination levels.

There is a difference in the view of landuse. The sensitive landuse category in Sweden includes many variables for exposure; intake of soil, vegetables, drinking water etc. This category is used for all dwellings and public areas, and children's ingestion of soil and the intake of vegetables are often the limiting factor as well as protection of ecosystems. The Danish highly sensitive landuse is given protection similar to the Swedish but highly sensitive landuses include primarily children playing, and farming etc.

A difference between the countries is that there is a depth-wise division in the Danish model, and should be avoided according to the Swedish EPA. In Denmark the remediation should clean the 1 m of topsoil for highly sensitive use, and for future unknown uses 3 meters should be cleaned. For areas with permanent cover, i.e. grass, 0.25 m is replaces with clean soil to avoid contact. In Sweden there is no depth-wise division given and the guidelines are suggesting that the soil should be given protection regardless depth. In reality this is problematic as it is very costly to clean deep in the ground and lots of material has to be removed. Often some kind of in-dept division has to be performed in the end anyway, especially in the cities.

An advantage for the Danish model is the possibility to remediate the areas that are posing the largest threat to humans and for their situation also groundwater. By choosing not to protect the environment and make an in-dept division the cost for every remediation is lower. This also let several more clean-up measures possible to use as these can often remove a part of the contamination. In the broader perspective it may also be important to understand the consequence of removal of soil to other places. If the soil is not cleaned it has to be put somewhere else, and other clean soil are replacing the contaminated soil at the site. This does not lead to less clean soil, but more transportation and areas without access. It is very important to understand what we are protecting, and what effects the way of treating soil give in a long term perspective.

5.3.6 Model for exposure

The models for exposure are similar in Sweden and Denmark. Both countries are evaluating the: Accessibility of contamination, Duration of the exposure, Possible Exposure pathways and the Sensitivity of the recipients. Children playing and ingestion of soil are limiting factors for both countries' methods.
Pathways considered for exposure to humans are:

- Direct intake of contaminated soil
- Dermal contact with contaminated soil and dust
- Inhalation of dust from the contaminated site
- Inhalation of vapours
- Intake of contaminated groundwater
- Intake from plants and vegetables grown on the contaminated site

There are some small variations in the numbers for exposure time, accessibility etc. but no dramatic differences. The intake of vegetables from home gardens might be a little high in Sweden for normal use.

5.3.7 Risk assessment

The risk assessment is described differently in Denmark and Sweden. The Swedish description is detailed and steps and elements are many. The Danish process focuses more on the hazard assessment as the base for risk assessment with adjustment to the specific target groups and exposure. In the guideline from 1990 Risk assessment is presented as examples to illustrate the application of the method, but no specific elements are stated. The connection of risk assessment and hazard assessment is not identified that clear in Sweden.

The main elements described in the Swedish risk assessment model are also performed in Denmark. In both risk assessment processes the importance of quality criteria are found. In Denmark there is also landuse depth stated which is not considered in Sweden.

As the risk assessment is differently described in the two processes only several elements will be compared in this chapter. Additional comparison is made in other parts of Chapter 5.

5.3.7.1 Definitions

Time perspective: In Sweden the remediation should have long term focus at 100-1 000 years according to the Swedish EPA shorter timescales are sometimes used. In Denmark the time perspective is normally 50-100 years.

Use of the area: The landuse of the area should be for long term use in Sweden, no possible future landuse should be delimited due to the contamination. A plan for the present and future landuse is defined. The level of protection is set from the landuse. Construction should not restrict the future possibilities of landuse o remediation. In Denmark the landuse is also defined for the present and future landuse. The long term and permanent solutions are not as important for the decision of remedial action as in Sweden; the time-perspective is set to the lifetime of a building. Current and future landuses that might be affected by the site are identified in both countries.

5.3.7.2 Characteristics and evaluation of the contamination sources

Characterisation of the contamination source is important for the risk assessment as the levels and properties of the substances determine the risk. The aspects considered in both countries are; Contamination level, transport, exposure, biological accessibility and accumulation. Possible transportation is calculated similar with an assumption of equilibrium between the three phases in soil in both countries. No effects of sorption or dispersion are taken into consideration in Sweden. In Denmark these effects are found important. A method for sampling is developed to analyse the probable spreading to groundwater at a certain distance from the source.

Calculations of biological accessibility in Sweden are assuming all contaminations are available for up-take in the simplified assessment. This field is under development in Sweden, but many uncertainties are still present. Biological accessibility is considered in Denmark as an influencing factor for the total exposure. Duration of exposure and exposure pathways are considered similarly, but the exposure time and exposure of soil below the surface is seen as a hazard only in Sweden. There is a higher focus on sensitive groups of people in Denmark. Degradation is found important for the Danish assessment as the substances may change over time. In Sweden this is not considered, and the substances are assumed to be available for exposure at same level in long term.

Characteristics for groundwater contaminations are much more developed in Denmark than in Sweden. Calculations with a “Mixing model” both close to and downstream the source is performed. Also a downstream model based on dispersion, sorption and natural degradation is developed to evaluate the pressure. Most calculations are possible for the saturated zone, and in the new version of Jagg also calculations for the mitigation on the unsaturated zone will be possible.

5.3.7.3 Recipients

The expected recipients for the specific situation are identified. There is one main difference between the countries; Sweden has a high level of environmental protection for contaminated soil. The ecosystems are protected for projects in general. In Denmark environment is no longer seen as a major recipient. Human health is considered important in both countries.

5.3.8 Quality criteria

For both countries the quality criteria are designed to ensure that no negative effects will occur if they are complied with. The detected or calculated levels of contamination are compared with the quality criteria to evaluate if any unwanted exposure will occur. The number of substances with quality criteria is two times higher in Denmark than in Sweden, in Denmark there are criteria available for 110 substances and in Sweden for 52 substances.

There is a difference in the way the quality criteria are developed. In Sweden there are two levels of criteria and each criterion is designed for protection of human health, ecosystems, ground and surface water and sediment. In Denmark there are up to four separate quality criteria available, depending of the properties of the substance. These are for soil, cut-off criteria for soil, groundwater and evaporation criteria. The criteria are developed individual and compliance with one does not ensure compliance with another criteria. All quality criteria are designed for very sensitive landuse. Evaporation is much more considered in Denmark than in Sweden. The quality criteria is one indication of this, and the procedure for sampling also tell that the focus for air-gas in Denmark is seen important.

The cut-off criteria for soil in Denmark do not have an equivalent in Sweden. It is constructed for ten very hazardous substances at levels that will need remedial measures. The levels of the cut-off criteria are for some substances higher and for some lower than the Swedish criteria and no general conclusion can be taken.

Quality criteria are guidelines and are not legally binding. Both countries describe the criteria as guidelines, but the ways they are used seem to differ. The Swedish use is stricter and the Environmental goal “Non-toxic environment” often influence the evaluation or the criteria. In Denmark the criteria are only developed for highly sensitive uses and individual assessment for less sensitive landuses is needed. The compliance with the quality criteria is more individual and not as strict in general in Denmark. In Denmark there are besides the effect based health related levels consideration about smell and visible deviation. Bad smell and back looking water may also need remediation.

There is a calculation program available in Denmark for assessment of the risk and levels of contaminations possible for transportation and exposure. With Jagg the site-specific parameters are input, and the levels accessible for exposure are calculated for comparison with the quality criteria. Jagg is well established and used for all risk assessments. A similar program is available in Sweden since 2007. There are some main differences between the programs; one reason is that the quality criteria look different. This means the Swedish criteria include all exposure pathways and in the program the expected pathways and exposure time are chosen and a new soil criterion is calculated for this situation. The groundwater part is also much more developed in Denmark where the transport of the contamination can be assessed.

In Sweden there are many situations where compliance with the quality criteria is not reasonable as the circumstances with pathways and recipients etc are diverging form that. By creation of site-specific criteria the local factors are considered. In Denmark the depth of landuse is calculated for the specific case and site-specific quality criteria does not exist.

5.3.8.1 Comparison of the levels of quality criteria

The levels of quality criteria in the two countries are compared in Appendix 2. The colours illustrate lower criteria. The Swedish criteria are general at a lower level for the 28 compared criteria. Comparisons of soil quality criteria show lower values in Sweden for sensitive landuse around 10 times lower values for 12 substances and 2 times lower or more for 5 substances. For less sensitive landuse there are 8 of the substances with around 10 times' lower values and 3 substances with 2 time's lower values. The Danish quality criteria are 10 times lower for 2 substances and 2 times lower for 2 substances, see Table 14.

Table 14 Comparison of levels and reason for Quality criteria in Sweden and Denmark

Levels of quality criteria	Sweden	Denmark
Number of substances with lower Quality criteria, comparison of 28 subst.	**12 :~>10 times lower** **8 : ~2 times lower**	**2 :~>10 times lower** **2 : ~2times lower**
Limiting factor for the **SL** compared 28 substances **LSL:**	**11: Ecotox** **9: Groundwater** **12: Ecotox** **10: Groundwater**	Health is the main limiting factor

Analysis of the limiting factor for SL of the 28 Quality criteria in Sweden shows that: Ecotoxicological effects are the limiting factor for 11 substances and groundwater protection for 9 of the substances. Additional there are only single substances where health, ingestion of soil or ingestion of plants are the determining factor. For LSL there are 12 substances with ecotoxicological limitation and 10 substances with groundwater as limiting factor. This means that for almost all the criteria and assessments the protection of environmental ecosystems and groundwater from a private well is determining the risk assessment.

5.3.8.2 Establishing quality criteria

The quality criteria are established to evaluate the levels of contaminants detected in the soil or other contact medium. The developments of quality criteria contain many calculations and assumptions and in this report only a part of this process is analysed.

The main difference is that the Swedish quality criteria are emerged for health and environmental criteria, and all exposure pathways and media whereas the Danish quality criteria are developed individual for soil, groundwater and evaporation.

The dose-response relation is the base for the assessments, TDI or corresponding is used to detect the acceptable exposure. For both countries a similar model is used to calculate these values, but the uncertainty factor can be bigger for Danish cases. In Denmark: $TDI = \frac{NO(A)EL \text{ or } LO(A)EL}{UF_1 + UF_2 + UF_3}$ where UF is an uncertainty factor.

The hazard assessment is the basis for the quality criteria in Denmark. These are the basis for the TDI. In Sweden toxicological effect levels developed by WHO and USEPA are used, which are for many cases the same as in Denmark. Danish quality criteria consider digestion and bioavailability for the calculation of quality criteria.

In Sweden the exposure from the site is considered as one part of the total exposure of the substance. The exposure from the site normally corresponds to 50% of the total acceptable exposure. For lead, cadmium and mercury are only 20% of the tolerable intake is assumed to come from the site and for persistent organic compound, dioxins and PCB corresponding figure is 10 %. In Denmark the exposure from the site normally could be 100% of the total exposure, but for cases with other known sources the share is lowered.

Assumptions are made to calculate the criteria. Values are presented in Table 15. The exposure by inhalation for children seems to be differing, remaining numbers are differing only a little.

Table 15 Comparison of numbers for development of quality criteria

	Sweden	**Denmark**
Lifetime (years)	80	70
Risk accepted	1/100 000 (Carcinogenic substs.)	1/1 000 000
Weight Child (kg)	15	13
Weight adult (kg)	70	70
Children's ingestion of soil (g)	SL: 1.2 (365 days/yr) LSL: 0.08 (60 days/yr)	0.2 (max 10g/day for single intake)
Daily skin exposure child (g)	1	1

There are further assumptions made for the Swedish criteria:

- The concentration in the ground is assumed to be constant over time.
- Changes in the soil from transport from the area, or by digestion are not considered.
- The model assumes that all analysed contaminants will be available for transport over time, i.e. the bioavailability is equal to 1.
- No consideration is taken to sorption or degradation of contaminants during transportation.

5.3.9 Background levels

The background levels are used for comparison with the detected values as high background levels will allow higher levels of substance. These are available as general values in both countries and should be detected to ensure if variations exist.

5.3.10 Site-specific assessment – use of software's

The site-specific assessment is different preformed in the two countries. In Sweden there are site-specific calculations in the detailed risk assessment. Earlier in the process the assessment is more general. If this is satisfying a site-specific assessment is carried out with a program as help. New quality criteria are calculated for the specific use and circumstances with recipients and exposure time at the site.

The use of programs for calculations for contaminated sites stated earlier and is more developed in Denmark. The program Jagg is in Denmark used for all remediation projects to evaluate the levels and effects of contaminations. Similar calculation sheet was developed fir Swedish use in 2007, but is mainly used for the last level of risk assessment, the detailed assessment with establish of site-specific values.

The main difference between the programs is that the Swedish program calculates new quality criteria for the site, where all considered pathways are included. The Danish program calculates the levels of contamination available for exposure to groundwater and air. The soil part is not very developed in Denmark, and the assessment is made with other resources. With Jagg there are eight main functions for different uses, including fugacity calculations, outdoor and indoor air, groundwater, unsaturated zone etc. There is also a possibility to calculate the probability of encountering contamination at a given site. The functions in Jagg are in general more extensive, the function of the program is also differing from the Swedish program. Jagg is conservative and developed for assessment of various kinds of sites. A need of program for more detailed assessment where the quantity of data is large is identified as Jagg is not appropriate for these assessments (Danish EPA 2008).

Other programs in use in Denmark are GISP, Kripp and Geoproc. With Geoprocis natural digestion is indirect evaluated with calculations. GISP is used for prioritizing between projects in a bigger area by calculating the pressure from this site from the area. Instead of analysing the individual sites a broader view of the area is created (Danish EPA 2009).

5.4 Feasibility study

The feasibility study aims to investigate the possible and preferable remedial measures. The criteria and main steps used to evaluate the measures are similar in both countries, but the way the feasibility study is described varies. Technically feasibility, reduction of the risk and fulfil of the remediation goal is important in both countries, 5 major steps are identified:

1. ***The remediation goal*** is the first step in both countries. This is established in the beginning of the Swedish remediation process, and for the feasibility study in the Danish process.
2. ***The identification of general measures***. General overview to identify technically and possible measures. Carried out in both processes.
3. ***Initial method screening***. Sorting of the most appropriate methods for evaluation. A large range of methods should be evaluated to ensure a good choice.

4. ***Intensive method analysis***. Identification of criteria for evaluation of the measures, these are described in both countries. Including cost and effectiveness analysis. Important for the outcome. This is where the process goes over into risk evaluation in Sweden.
5. ***Preparation and evaluation of measure options***. The last step where the best options are evaluated according to the criteria. The social and practicable aspects are also considered.

The structure for the feasibility study is very similar in the two countries. The available measure alternatives are the same; Reduction of the contamination source, Protective measures (contamination is remaining in the ground fully or partly) and Administrative measures. There is a different view of the risk and long term solutions in Sweden prioritising the reduction of contamination to a greater extent than in Denmark. The administrative measure is seen as a temporary solution in Sweden and should be implemented only if no other solution is possible. In Denmark administrative measures are more common. The same with Protective measures, these are often implemented in Denmark as the risk for exposure to humans is found very low also for this measures. In Sweden there is a view that exposure could always be possible if contaminations remain in the soil. The protection of environment is also influencing this outcome.

5.5 Risk evaluation

The risk evaluation is where the evaluation and decision about the best remedial measure is taken. The risk evaluation and feasibility study are not always separated, especially in Denmark they are carried out together. There are some basic methods for risk evaluation available in both countries, the method use often depend on the size of the projects and involved stakeholders.

The risk evaluations in Denmark focus a lot on the cost-benefit method and even though the full CBA is not used the evaluation is affected by this thinking. Reasonable reduction of the contaminants to an acceptable risk level is made. As the costs often are high for the remediation it is important to find the optimal reduction at the site. Total reduction of the risk is not needed for most projects and it preferable to remediate many sites than one.

In Sweden the risk evaluation focus on fulfilment of the remediation goals and the quality criteria is a method for comparison. Also the environmental objectives may influence. The remediation goals are often met only if all contamination is removed as exposure is found possible also at major depth. The evaluation criteria and goals often suggest excavation as the only measure. Advantageous factors are that it is quick, can be used for all contaminations and fulfils the environmental objective "Non-toxic environment". Total removal of contamination is the most secure alternative to avoid risk to humans and ecosystems. It also eliminates need for further administrative measures or control programs.

The risk evaluation in Denmark seems to focus more on reduction of the risk, not the levels of contamination. The need for total remediation is mostly not seen beneficial, and for example are often the last 5% of contamination left as this is too expensive to remediate. Major parts of contamination could also be left in the ground as long as the risk reduction for humans is ensured and the groundwater is protected. The difference between governmental and private remediation projects in Denmark is interesting, only private projects should eliminate all contamination.

5.6 Remedial measures

The remedial measures available for cleaning up are similar in Denmark and Sweden, see Appendix 1. The development with new methods for remediation has been intense in Denmark last years, especially for groundwater and vapour remediation. In Sweden the focus on groundwater has been small. Remediation of sediments is more common, demanding techniques for both sediment and pumped water. The importance of clean groundwater in Denmark have put pressure on the developed of remedial measures for cleaning of the soil and groundwater.

5.6.1 Remediation methods of contaminations

Soil contamination

Excavation is mainly used in both countries. Looking at other soil contamination remediation methods used in Sweden most are expected to have limited use in Sweden. Soil washing is used since 1997 and Air sparging is used for several projects. Air sparging is mainly used for cleaning of groundwater in Denmark.

Soil vapour extraction has been used mainly for cleaning of old soil gas stations in Sweden and is the most frequently applied method in Denmark. Immobilisation methods are used in both countries but in much wider projects in Denmark. Barriers or construction method with pavement are regularly used to limit the transport. Sealing and Vitrification methods are still under development. In Sweden the method is mainly used for treatment of ashes from combustion (ex-situ) and of in-situ treatment of mercury in the ground. Further Bioventilation and Forced leaching are used in small scale in Denmark and Electro-kinetic soil remediation is in pilot project stage.

In-situ methods used in Sweden was mainly soil vapour extraction, sparging methods and biological digestion. The soil vapour control is also used quite a lot in Denmark. The Pump & treat method mainly used in Denmark is still in pilot project in Sweden, the same with immobilisation and landfill gas which are still not developed for use.

Groundwater contamination

For groundwater remediation in Denmark Pump and treat methods are commonly used. Filter techniques and reactive barriers are under research. The cleaning of contaminated groundwater is a major business in Denmark to protect the drinking water source. In Sweden groundwater are cleaned sometimes and mostly when it may harm surface water that is used for drinking water.

Soil gas remediation

Remedial measure for soil gas contaminations are more developed in Denmark than in Sweden. Radon is a known problem in both countries, and ventilation is a method used for existing buildings. Ventilation is used for many contamination problems in Denmark, synthetic membranes are used in addition. For remediation of land fill gas is in Denmark performed with; Gas barriers, permeable ditches, Venting drains and venting wells. Especially chlorinated solvents are important to remediate as these pose a threat to humans also at low concentrations. Similar methods and protection is not found in the Swedish guidelines.

5.6.2 Protective and administrative measures

The use of protective measures as a remediation alternative can be effective. Filter or barrier techniques or similar are used to eliminate the transportation of contamination and minimize the exposure. This is more often implemented in Denmark than in Sweden. One reason is the higher acceptance for leaving contaminants in the ground and this kind of methods in Denmark. The focus and assessment of the actual risk to humans at normal circumstances is also a reason.

Another important protective measure used in Denmark is information. Information is given about how to behave if you live at or close to contaminated areas, what the single person can do to minimize the risk for exposure. Since 2008 all city areas are classified as Area of minor contaminations, this mean the importance of information increase for all city areas. Guidelines are available to inform citizens how to avoid exposure from contaminated soils.

Administrative measures are more common in Denmark than in Sweden. There are many areas with need for monitoring with major costs showing that the administrative measure is an accepted measure in Denmark.

5.6.3 Statistics of remediation measures

In Sweden excavation is the main remedial measure and is used for 75% or the remediation projects. For 226 analysed objects (remediate 1994-2005) there was totally 1 780 000 tonnes of contaminated soil excavated. This correspond to 890 000 tonnes per year and 8 000 tonnes per object.

The dominating remedial measure in Denmark is also excavation, 68% of the projects used excavation in 2005. Same year there was 671 000 tons of soil excavated for the 8 400 on-going projects, corresponding to 80 tonnes per project. Statistics of remediation projects are presented in Table 16 and a comparison of remedial methods used in Sweden and Denmark is presented in Figure 37.

Table 16 Statistics for remediation projects in Sweden and Denmark

Comparison of remediation projects	**Sweden (2008)**	**Denmark (2005)**
Projects with ongoing remediation	580	8 400
Share with Excavation	75%	68%
Tonnes of soil excavated per project	8 000	80

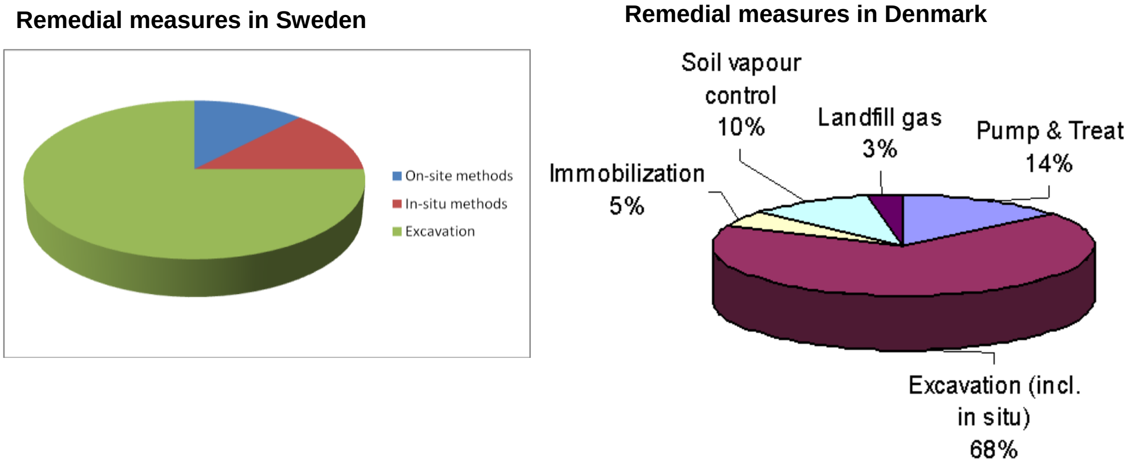

Figure 37 Remediation methods used in Sweden (1995-2005) and Denmark (2005)

A major difference is that 100 times more soil is excavated for every project in Sweden than in Denmark. The number of remediate sites are higher in Denmark with 8 400 sites compared to the 580 is Sweden. This tell that the Swedish projects are bigger and fewer. Interesting would be to identify the reason for this. One difference is the view of depth-division. Danish guidelines propose depth-wise division for excavation, and mainly upper soil excavation to eliminate the risk to humans. The protection of environment and soil ecosystems in Sweden as well as repulsion of depth-wise division give other circumstances for the Swedish projects. Are there much bigger contaminated areas adjusted in Sweden or is the main difference the view of how a site should be cleaned? The main question would be to identify what is reasonable, and what the consequences in long term will be for the different approaches.

5.6.4 Classification of contaminated soil

In Denmark the classification of the excavated soil make it possible to reuse the soil for construction projects. Four risk classes for different uses where the first class, below the quality criteria let the soil to be used for all purposes. Class 2 and 3 is used for construction of roads, noise barriers etc. The fourth class has to be put on deposit. There is no corresponding national classification system in Sweden and the only way to reuse the soil is to use it within the project. For bigger projects with large areas for constructions and storage this is a good solution. Smaller projects or situations where no collaboration is known cannot reuse lower contaminated soil. The soil is put on landfill as no system for reuse of the soil is developed.

5.7 Remediation projects

5.7.1 Identified contaminated sites

The number of identified remediation projects are over 80 000 in Sweden and around 55 000 in Denmark. The number of sites is a little more in Sweden, the reason can be various. For example the new city classification with lower contaminated sites in Denmark decreases the number of mapped sites. The number of prioritized contaminated sites are also similar, 17 500 in Sweden and 14 000 in Denmark. The situation regarding identified, risk classified and prioritized objects are about the same.

The cost for remediation is varying more. In Sweden the average cost for remediation of one site is estimated to 40 million SEK, in Denmark 0.6 – 1.4 million DKK/ site (0.85-2.0 million SEK/site). This is a big difference with around 20 times higher cost per site in Sweden. The cost estimated for remediation of remaining objects is estimated to 45- 60 billion SEK in Sweden and 14.3 billion DKK (~20 billion SEK) in Denmark. An overview is given in Table 17.

Table 17 Overview comparison of numbers for costs and projects in Sweden and Denmark

	Identified sites	**Prioritised sites**	**Cost per remediation** (million SEK)	**Cost for remaining remediation** (billion SEK)
Sweden	80 000	17 500	40	45-60
Denmark	55 000	14 000	0.85-2.0	20

5.7.2 Frequency of detected contaminants

Analysis of the contaminations found in Swedish and Danish soils show that oil contaminations in both countries are most common, second is heavy metals, see Figure 38. PAH is found in oil and tar and should be detected in both countries. Further there are no major similarities. Mainly volatile organic compounds including chlorinated solvents and BTEX (benzene, toluene, ethylbenzene, and xylenes) are identified in Danish soils, but not in Swedish soils. As many of these formulas are volatile organic compounds found in petroleum derivatives these should occur also in Sweden.

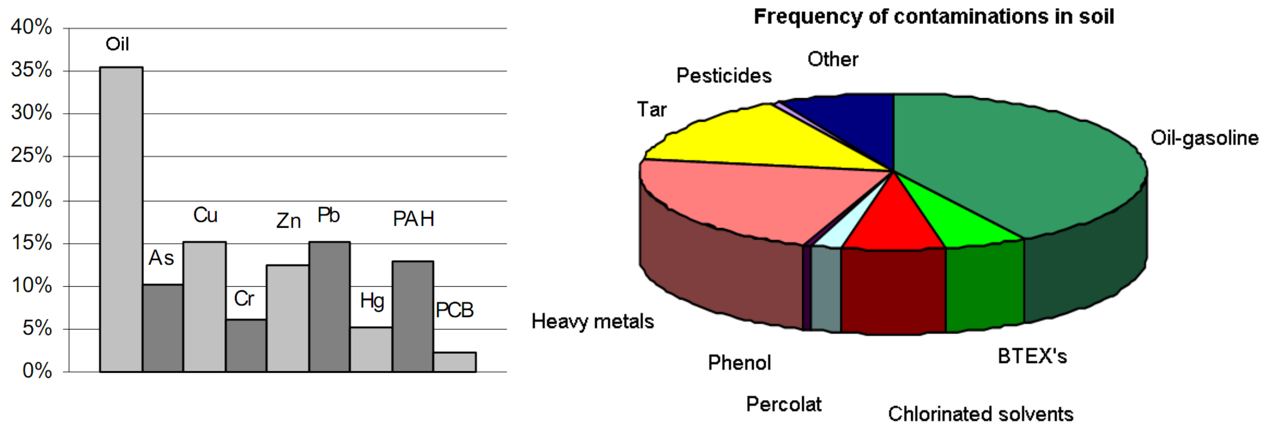

Figure 38 Comparison of detected contaminants in soil in Sweden (left) and Denmark (right)

A main difference can be found in the focus on chlorinated solvents in Denmark. There is overall a higher focus of volatile compounds in Denmark, both for indoor and outdoor air. Both remedial measures and investigation is more developed for volatile substances in Denmark than in Sweden. The question should be why they are not now detected in Sweden and if they are occurring also here? Many of these substances have harmful effects on the central nervous system and are defined as hazardous in both countries.

5.8 Geology

Sweden and Denmark have different geological conditions which have an important influence for the choice of remediation measure. Sweden has more compact sediments with glacial till and glaciofuvial sediment as well as crystalline bedrock. Denmark has more porous soils with different sandy soils but also glacial till. These soil types influence the transport of contaminations and also the possible remedial measures, porous soils are more permeable. Some remedial measures can only be used in permeable and light soils.

5.9 Organisation of the work with Remediation projects

5.9.1 Administrative tools

The administrative tools for the work with contaminated soil in Sweden and Denmark are mainly similar. Some differences are still important and described here. The environmental protection agencies in both countries are working with general guidelines for the sector, quality criteria, programs and other issues.

Employees

In Sweden 3-4 persons on the EPA and 4 at SGU are dealing with these questions. In Denmark the corresponding organisation at the EPA have 13-14 employees mainly working with contaminated soil. The number of employed people in the whole sector is larger in Denmark with over 2000 employees. In Sweden the half, around 1000 are working with contaminated soil.

Responsible authorities

The authorities responsible for the work with contaminated soil are at three levels. The national authorities are creating the guidelines and give grants for remediation projects. This is similar in both countries. The regional authorities are official responsible for the work with contaminated soil in Denmark. The five regions are developing and responsible for prioritising, mapping and financing of the sites. The local authorities are responsible for smaller projects.

In Sweden the local authorities (Totally 290 municipalities) are main responsible for the work with contaminated soil. Depending on the kind of project the local or the regional authorities (21 pieces) have the main responsibility. The main difference here is that the knowledge and experience can be better developed in Denmark. The good overview of the projects makes it possible to prioritize the most urgent objects.

In Denmark there are two instances for development of knowledge and experience. Depotrådet is an independent organisation reviewing the work with contaminated soil in Denmark. It consists of several stakeholders from the sector and aim to identify important improvements, lack of certain techniques and knowledge or special needs in the sector. No corresponding organisation is developed in Sweden.

The Knowledge Centre for Soil Contaminations is working for improved experience and knowledge about the process from inventory to remedial measures. They provide all information at their homepage, and are a good source for relevant information about investigations for certain industries etc. The project Sustainable Remediation created in Sweden may be similar, but the extent and organisation is much more developed in Denmark.

5.9.2 Financial tools

The remediation process is economically big in both countries. The governmental financing is an important tool for the remediation. The responsibility for contaminated sites is in both countries the land owner, but for older contaminated sites the government can be responsible. A difference is that in Sweden the local authorities should provide 10 % of the total cost for the remediation, which sometimes can be difficult to provide, especially for small communities. The Danish government can be fully responsible for an old site if no other actor can be identified.

In Sweden there are 500 million SEK governmental grants available yearly. In Denmark yearly allowance of 370 million DKK or 500 million SEK are given every year by the regions, i.e. very similar numbers. In Denmark these grants are partly financing technology development with 5 million DKK (7.2 million SEK). Developments of remedial measures are performed in collaboration with consultants, universities, regions and other stakeholders. In Sweden there is no development of technology for remediation on long term with governmental financing.

5.9.3 Strategies for remediation of sites

There is a new view of prioritizing of contaminated sites in Denmark. As there are many sites and little money the strategies are becoming more important to eliminate the most hazardous sites. The regions are working with a program called GISP, focusing on identification of the pressure from each sites in the area. With this area-perspective the sites can be prioritized relatively one other. Normally the prioritizing is made on local or regional level, but with a broader view the prioritizing can be safer. No similar method is sill developed in Sweden.

5.10 Overview comparison

An overview comparison of the major differences is presented in Table 18.

Table 18 Overview comparison of remediation projects in Sweden and Denmark

	Sweden	Denmark
Legislation and guidelines		
First law implemented	1999	1990 (1983 for mapping)
First guideline on contaminated soil	1996	1992
Responsible authority	Local/Regional	Regional
Time perspective for remediation (years)	100-1 000	50-100
Data bases for contaminated sites	Local	National
Protective values		
Protective values	Human, Environment, surface-, groundwater	Human, Groundwater
Hazardous substances, given in	Lists	Databases
Prioritized hazardous substances	Heavy metals, DDT, PCB, dioxin	Chlorinated solvents, DDT, PCB, phthalates, MTBE
Landuse		
Landuse categories	2; Sensitive and Less sensitive	3; Highly sensitive, Sensitive, Non-sensitive
Depth-wise division on landuse	No	Yes; 1m, 0.5m, 0.25m
Investigations	Soil and groundwater	Pore air, Soil and Groundwater
Quality criteria		
No of substances with national criteria	52	110
Structure of quality criteria	2 levels of criteria	4 purposes
Number of substances with lower Quality criteria, comparison of 28 subst.	12 :10 times lower 8 : ~2times lower	2 :10 times lower 2 : ~2times lower
Contaminations		
Detected substances	Oil 35%, Cu, Pb, Zu, As 10-15%, PAH 13%	Oil 40%, metals 17%, Tar 15%, BTEX 5% Chl.solv 8%
Identified contaminated sites	80 000	55 000
Remedial measures		
Focus for remediation	Soil	Soil, gas and groundwater
No. Ongoing projects in one year	580	8 400
Share with excavation	75%	68%
Tonnes of excavated soil per project	8 000	80
Contaminated soil classification	No	Yes, 4 levels
Cost per remediation (million SEK)	40	0.85 - 2.0
Estimated cost for remaining remediation	45-55 billion SEK	20 billion SEK
Administrative and financial tools		
Employees at EPA or corresponding	7-8	13-14
Total employed for contaminated sites	1 000	2 000
No. authorities at responsible level	Local: 290 Regional: 21	Regional: 5
Revising instance	No	Yes
Governmental financing (million SEK/yr)	500	500
Technology development	No	5 million DKK/yr
Strategy for prioritizing of sites	No program	GISP

6 Case study

6.1 Remediation process for Bohus Varv, Bohus

The main study for earlier Bohus Varv was performed in 2006 by Consultants at Sweco Viak. The area is situated along the river Göta älv, that is the main drinking water source for Gothenburg and totally 700 000 persons. Today the area is owned by EKA and used for industry, a slip road is planned in west, the north part is nature area and the Main area is covered with grass and gravel. The site of 5 ha with 600 m coastline is covered with filling material that to a large extent is contaminated with metals and oil.

The main study was carried out to understand the level of contamination and possible need of remediation. The main threats identified for this site is the transport of contaminants to the river. Gothenburg's major drinking water intake is situated downstream the site, normal running time there is 6 hours, 4.5 with high flown. There is a risk for slides in this area according to earlier investigations.

An attempt to implement the Danish model of the remediation process will here be carried out to identify probable differences between the Danish and Swedish model.

6.1.1 The initial survey

1. Initial survey phase

- Collection of daa from historical sources, mapping and guidelines
- Acquisition of geological and hydrological data
- A site visit
- Assessment of collected data and hypothesis on possible contaminations

In the initial survey earlier use of the site are identified from background sources. In this case the area is land-filled with contaminated soil, and the activities on the site are known for the period 1970-74. Some activities by EKA were continuing until 1980. This is not well documented. In Denmark the historical documentation may have been more detailed. The hypothesis on possible contaminations would probable look similar, with more focus on volatile compounds. Geological and hydrological data conditions are described.

6.1.2 The site investigation phase

2. Site investigation phase

- Investigations (preliminary and supplementary)
- Risk assessment
- Reports
- Outline project

The site investigations are carried out according to a plan to identify the suspected contaminations. It is carried out in two steps, similar to Swedish investigations. For a land filled site the relations between concentrations are few as point sources are not dominating. According to the Danish guidelines the contaminations should be detected near boundaries to determine the extent. The whole site should be investigated, but as no sensitive landuse is expected very high intensity may not be important. Close to the river the intensity may increase to localize and determine the levels.

As the protective values and model for exposure are similar in both countries no difference are probable here. For this site a Danish landuse would probably be Non-sensitive for human exposure as the site is manly industry area and not visited by many people. The site is very close to a major drinking water source with surface water. As this is unusual in Denmark there will be no guidelines specific for this situation, but a high priority for protection is probable. In Denmark there are no special Quality Criteria for this category and the evaluation have to more individual than a comparison with the quality criteria.

6.1.2.1 Investigation analysis

The method of investigations would be soil sampling and water sampling. Air sampling is normally carried out as a first step in Denmark. In this case the groundwater table is close to surface and contaminated pore air is not probable. For some of the area this might still be possible, dioxins and organic tin compounds could have been detected. .

Water sampling is performed with groundwater wells. Similar sampling is suspected in both countries. For the sampling of soil mainly digging is used, which is also suggested in Denmark. The detected values would probably look similar with Danish sampling procedures.

Several samples are taken in the area to identify the levels of contaminations. Mainly metals are found in very high concentrations, but also oil spills with aliphatic compounds (C12-C16, C16-C32) and PAH are found in very high concentrations.
To have a reference the comparison with quality criteria is made, see Table 19.

Table 19 Result from the investigations including Danish and Swedish reference values (Main study Bohus Varv 2006 and Danish EPA 2007)

Metal	Number of analysis	Min	Mean	Max	Danish Quality criteria		Swedish Criteria		Water samples		Danish Water Criteria
					Soil	**Cut-off**	**SL**	**LSL**	**Mean**	**Max**	
Arsenic	59	<3	65	662	20	20	15	40	-	-	-
Lead	140	22	4050	41487	40	400	80	300	5.6	60.9	1
Copper	59	14	1900	10500	500	1000	100	200	9	40	100
Mercury	59	<1	60	838	1	3	1	7	-	-	-
Zink	140	37	2380	19922	500	1000	120	200	408	4780	100

The quality criteria comparison shows that the detected values are high above the reference values for the five metals; the mean is 2-20 times higher and the max more than 1000 times higher for some substances. By using JAGG the result shows that the concentrations are very high, and exceeding the quality criteria, example of result is given in Figure 39. For this case a very extensive data material is available, which is not suitable in Jagg. Results would look similar also with all data.

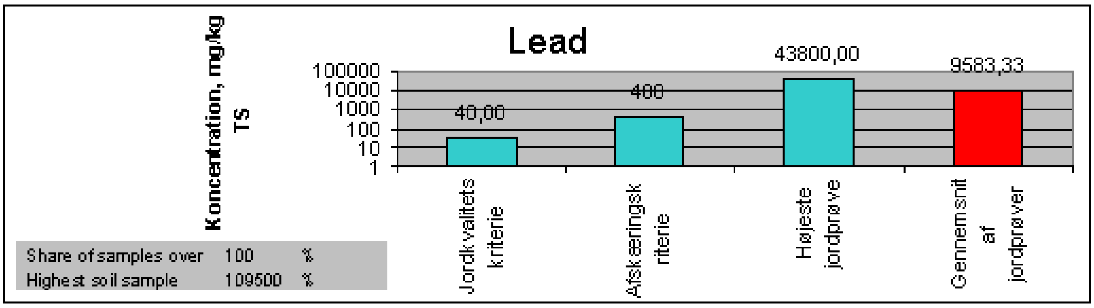

Figure 39 Result from Jagg for a selection of the samples on soil

6.1.2.2 Risk assessment

In the risk assessment an evaluation of the effects on health and environment should be assessed. This is the base for decision of protective measure. For this case the protection of environment is not considered in the Swedish investigation. The main focus for Danish Risk assessment is human health and groundwater, for this case the drinking water source is the River Göta Älv and would be given similar protection. For land filled areas like Bohus Varv, investigations are necessary. No hot-spots can be identified, but the levels of metals are very high.

According to Danish guidelines the expected landuse depth should be stated, i.e. the soil depth used by humans. As the site consist of mainly industry and storage area, the landuse depth would only be surface for human uses. In the Danish guidelines the landuse depth for industrial areas is not presented in number. According to Appendix 5 daily exposure for industrial areas is estimated to 8 hours in buildings with greater likelihood of exposure by inhalation. Minutes of exposure are assumed for car parks and grass, where exposure is slightly likely by inhalation or skin contact. User group is Healthy adults.

Protection of humans

The Swedish Guidelines (Swedish EPA 1997) suggest Site-specific quality criteria for specific circumstances. Expected exposure pathways are; direct intake of soil, skin contact, and inhalation of dust or fumes, see Table 18. The direct intake of soil refers to e.g. oral intake by children or with Swedish snuff. Adults are mainly assumed to visit the site, children in single case. The exposure time for direct intake of soil at surface is set to 20 or 130 days/years, for greater depth 5 days/year is assumed for the work at the site. Denmark do not assume direct intake at industrial sites, see Table 20.

Table 20 Assumed pathways and exposure times with Swedish and Danish guidelines

Exposure pathways	**Sweden** (Days/year)		**Denmark**	
	Surface soil	>0.7 m	Grass	Car parks
Direct intake of soil	129	5	-	-
Skin contact	Adults 27	5	-	Minutes, slight likely
Inhalation of dust	122	5	Minutes, slight likely	Minutes, slight likely
Inhalation of fumes	122	122	Minutes, slight likely	Minutes, slight likely

In Sweden new quality criteria are calculated for the site that is acceptable levels of contamination to avoid effects on humans. The biggest difference to the less sensitive landuse is levels acceptable for Lead: 5300. The comparisons with Danish acceptable values for highly sensitive landuse are shown in Table 21. The comparison shows that the mean is exceeded for all metals, the measured values exceed the criteria both on surface and deeper in the soil.

Table 21 Comparison of Swedish site-specific and LSL criteria with Danish criteria and detected mean (Bohus Varv 2006, Danish EPA 2008)

Metal	**Swedish site-specific**	**Swedish Quality criteria**	**Danish Quality criteria**		**Mean detected**
	Surface soil	**LSL**	**Soil**	**Cut-off**	
Arsenic	37	40	20	20	65
Lead	5300	300	40	400	4050
Copper	-	200	500	1000	1900
Mercury	30	7	1	3	60
Zink	-	700	500	1000	2380

For protection of humans the Swedish result was that the values are exceeding the remediation goals, the levels are not acceptable. Danish analysis would probable show that the surface soil contamination is too high, but as no in-depth landuse is probable, they would suggest changing and the top-layer of contaminated soil and cover the contaminated soil to avoid exposure to humans.

Drinking water protection

For the transport to Göta Älv there are no Danish guidelines for transport to surface water. The Swedish guidelines consider both leakage via erosion and groundwater. The Danish guidelines include definitions of leakage flux in kg substance per year. Definition of the source term concentration is important to evaluate the leakage from the site. This determines of; the concentration in the pore water in the unsaturated zone, the solubility of the substance, the mass of the contaminations. In many cases only the concentration of contaminations in soil is known, and equilibrium between the phases (soil, water and air) is assumed. For big large volumes e.g. from a land fill, a continual stream of contamination is assumed.

Sorption effects the release and for continues contamination release the soil sorption capacity will gradually deplete. Sorption is only considered in the saturated zone. Dispersion is also influential mainly in the saturated zone, with 10-1000 m/year as a typical pore water flow velocity.

For the case the flow rates are calculated from the measured levels of metal in the groundwater and the groundwater formation of 300mm/year in the area. As the Danish guidelines suggest a continuous contamination there may be sorption effects affecting the release. The calculated release to Göta Älv is calculated to be pretty low according to the main study, see Table 20.

Table 22 Quantity of metals on the site and expected release to Göta Älv, with comparison of total transport of metal in the river (Bohus Varv 2006)

	Arsenic	Lead	Copper	Mercury	Zink
Total quantity (kg)	9 000	585 000	275 000	9 000	345 000
Via groundwater (kg/yr)	< 0.1	1	0.5	< 0.1	70
Via erosion (kg/yr)	1	50	20	1	30
Transport in the river (kg/yr)	1 700	2 000	6 900	15	22 500
Release in % of the transport	0.06%	2.55%	0.30%	6.67%	0.44%

The probable releases to the River Göta älv show that most metals are not contributing dramatically to the river, mercury and lead may be a threat. For the release to the river the values would look similar with Danish guidelines.

Slide risk

The main treat to Göta Älv from this site is the risk for slides, which would give a very high contribution of hazardous metals to the river. This would affect both the drinking water supply and river itself including activities and environment extensively. To estimate this risk, and probable consequences, analysis is performed concluding: The raw water intake has to be closed in case of a slide. This would give serious consequences for the raw water supply, both because of a sediment pulse and long term effects on the water quality. Effects on the aquatic species is not investigated, but is suspected to be extensive, especially as the bottom is dredged regularly.

This would probably be important for the Danish risk assessment. As no guidelines are available for surface water the value as drinking water source is the focus. This is very important for the city and humans, and has to be protected to avoid major leakage. A Danish Risk assessment would probable put effort on this including; investigations of possibility of slide, the probable consequences and measures that could minimize the effects on the river.

6.1.3 The remediation phase

3. The remediation phase

- Detailed plan of remediation incl. investigations
- Implementation of remediation action

To assess what action is suitable a feasibility study carried out in Sweden, after that a risk evaluation is assessed to evaluate the preferred action. Similar method is used due to Danish guidelines. In both countries remediation goal are set to specify the objective with the action. The goal is set to:

1) Use of ground as industry and nature area
2) Improved protection of Göta älv as raw water source and other purposes.

The grounds for choice of remedial measure look different according to the landuse sensitivity and other factors. The Danish guidelines suggest replacement of the topsoil with non-contaminated soil. Remaining contamination will be covered to avoid exposure to humans and leakage. To totally avoid leakage to the river further remediation might be needed. For Bohus Varv six remedial solutions are suggested, all described and analysed regarding; technical specification, reduction of risk, consequences and effects on the surrounding, fulfil of the remediation goals for use of soil and Göta älv, and finally estimated costs. Similar analysis would be carried out in Denmark, but the result may differ as the calculations and view on exposure are differing. Analysis of the most interesting alternatives is made below.

Alternative C- Covering and sealing. This alternative include; covering and sealing of the contaminants, actions to increase the degree of stability and erosion protection. The analysis shows that it would partly fulfil the remediation goals for use of ground and the river. The exposure to humans on the area will decrease; also the risk for slide and transport of contamination through erosion will decrease. A Danish analysis would probable find the same, but value the risk reduction to humans enough. There is a future risk for harm on the sealing layer and demand for control of the sealing. This may be too high also with Danish guidelines.
Estimated Cost 10 million SEK

Alternative D- Partly excavation and off-site treatment/depositing. Excavation of 0.7 meter of soil, actions to increase the degree of stability and measures to decrease erosion, refilling with clean soil. This measure gives similar effects to Alternative C, but with decreased potential of contamination. This alternative is assumed to partly fulfil the remediation goals, and restrictions of landuse. With Danish values the risk to humans would be eliminated, also with less depth of excavation, e.g. 0.25 m, the landuse options would be less defined than in Sweden. The risk to the river is decreased substantial, but the exact risk for slide and emission to the river in case of a slide is hard to estimate. Estimated Cost: 45 or 65 million SEK.

Alternative E- Excavation of soil (90%) and off-site treatment/ depositing. Removal of contaminated soil, refill with acceptable soil, actions to increase the degree of stability and creation of erosion protection. Swedish remediation goals are fulfilled for both landuse and Göta älv. The process includes risk with the excavation work, dusting and noise as well as emissions to air is extensive. Refilling with non-contaminated soil demand large clean soil and remediation of the soil is more costly than depositing. Estimated cost 85 or 140 million SEK

The three alternatives are all reducing the risk for landuse and the raw water source Göta älv. According to Swedish guidelines the only acceptable alternative is 90% excavation, where both goals are fulfilled. The main impacts for leaving the contaminants accept for the risk to the river is that; future ground work can harm the sealing surface, there is risk for harm and sagging on the sealing, and the limited possibilities of future landuse. These impacts are limited according to a Danish view. As no future plans for development are topical the landuse and ground work should not be a limitation. For the sealing regular control is possible to minimize the risk or erosion and risk in case of a slide.

Danish remediation goals would be similar, and probably met for Alternative D and C. Excavation give very high cost for the process and off-site treatment or depositing. In Denmark there is a regulation to avoid transport of contaminated soil to non-contaminated areas, which would lead towards less excavation.

In the risk evaluation the cost for the different alternatives would influence the choice of action in Denmark. The advantage gained from remediation is important for the decision of action. In this project the consequences of a slide is major, which would allow pretty high costs for the action. There is an uncertainty according the slide risk and the effects of a slide. The main focus is to reduce the risk to an acceptable level, and with the background for this study Alternative D or maybe also with C would reduce the risk to acceptable levels. With this solution limited amount of material will be removed and refilled, and the risk for excavation work and emissions from transportation will be limited. Alternative E is very costly and excavation of the whole site is preferable only if this is the only way to get an acceptable risk.

6.1.4 Results and differences

The main difference in the remediation processed is the view of landuse and exposure from existing landuse. As the Swedish guidelines suggest exposure from the soil at depth more than 0.7 meters down in the soil the risk will not be eliminated until most soil is excavated. In this case the remediation goal, this is to avoid risks to human health and the river, will only be fulfilled when all soil is removed and replaced with clean soil.

According to Danish guidelines the landuse depth would for this site be only 0.25 cm or similar, and for protection of health only excavation of the upper soil layer would be needed. For the slide risk and contamination transport to the river the conclusions are not easy. But ensuring the risks for slide and elimination of the transport of substances to the river should be enough. Further the regulations for contamination of non-polluted areas would prohibit this large quantity of soil to be put on land-fill. The cost for cleaning of the excavated soil is very high and this will probably not be suggested as a good solution.

Alternative D- Partly excavation. Excavation of 0.25 meter of soil, actions to increase the degree of stability and measures to decrease erosion. This would fulfil the Danish criteria for the site and minimize the risks to humans and river.

6.2 Rimforsa trä, Östergötland

A main study is performed by Ohlsson, Y., et al at Sweco Viak for an old woodwork and saw house site in Kinda municipality in Östergötland. The investigations included two main areas, Hackel 9:1 and Hackel 9:5. In this analysis the focus will be on Hackel 9:1 which was used for dipping of wood, a saw and drying of impregnated wood from the woodwork located at Hackel 9:5. The site is situated close to a small harbour for private use and the total area for the land registry is 106 625 m^{2}, around half this area is located in waters.

The activities with woodwork and saw were established in 1946 and were run for 40 years with several different owners. From 1963-69 the woodwork started using impregnation with Bolidensalt K33 containing copper, chromium and arsenic. The wood was dipped after to avoid inter alia mould. Liquids for dipping did contain chlorophenols and often also dioxin.
The area is now partly fenced as an industrial site. It is partly used as a sports area with a soccer field, and harbour for private boats. Major parts of the area are covered with asphalt or grass. Near the site Kinda Channel is situated, which is flowing into surface water source for a municipality downstream. The surrounding is used for residential and agricultural and children are often playing in the investigated area. The landuse is expected to remain as today also in the future.

6.2.1 The initial survey

1. Initial survey phase

- Collection of data from historical sources, mapping and guidelines
- Acquisition of geological and hydrological data
- A site visit
- Assessment of collected data and hypothesis on possible contaminations

The area is well documented with known activities and owners, including used processes. This is similar to Danish collection of data and historical sources.

Topography, hydrology and geology is investigated and described in detail, precipitation and important water paths are identified to be the lake Järnlunden. Similar would have been performed in Denmark.

For this site the hypothesis on possible contaminations are copper, arsenic, chromium, dioxin and chlorophenols. The suspected hot-spots are located close to earlier activities and especially around buildings. Similar would be suspected with Danish methods.

6.2.2 The site investigation phase

2. Site investigation phase

- Investigations (preliminary and supplementary)
- Risk assessment
- Reports
- Outline project

Investigations are performed in three phases to localize and delimit the contaminations. Soil samples are taken and groundwater sampling is performed at five locations.

6.2.2.1 Investigation analysis

In Denmark the sampling would probably have been carried out in two steps, first overview and later planned from the existing knowledge about site use. The Danish process would have performed sir samples, especially for detection of chlorophenols. They would also focus on identification of hot-spots to surely localize the main sources of pollutants. The results could probably localise the hot-spot sources more precise.

The results from the soil sampling in Sweden with comparison with quality criteria are presented in Table 23.

Table 23 Detected levels and quality criteria, Bold indicate exceeding of SL and Bold and underlined exceeding of LSL. Yellow indicate exceeding of Danish criteria (Ohlson et al 2007).

	Arsenic (mg/kg TS)	**Copper** (mg/kg TS)	**Chromium** (mg/kg TS)	**Dioxin** (ng/kg TS)	**Chlorophenols** (mg/kg TS)
Mean	**<u>66</u>**	56	32	**<u>178</u>**	low
Median	**<u>49</u>**	30	16	**18**	
Max	**<u>257</u>**	**185**	**158**	**<u>1300</u>**	**<u>4.5</u>**
Min	6.4	10	4.3	0.76	low
SWE: SL	**15**	**100**	**120**	**10**	**0.5**
SWE: LSL	**<u>40</u>**	**<u>200</u>**	**<u>250</u>**	**<u>250</u>**	**<u>3</u>**
DK: Soil (soil/cut-off)	**20/20**	**500/1000**	**500/1000**	**N/A**	3/-
DK: Groundwater (µg/l)	**8**	**100**	**25**	**N/A**	0,1/ Evaporation: $2*10^{-5}$ mg/m3

The maximum levels of Arsenic, Copper and Chromium are all above the sensitive landuse criteria in Sweden, but only Arsenic is exceeding the Sensitive landuse criteria. The Danish soil quality criteria for Arsenic are exceeded. The samples for dioxin exceed the SL and LSL criteria in Sweden. There are no criteria available in Denmark as these substances are not prioritized anymore.

Chlorophenols is manly detected at depth 2.7 - 5.2 meters, 3.1 mg/kg TS for penta chlorophenols (most hazardous) and 4.5 mg/kg TS for other chlorophenols. Remain samples showed levels below the SL criteria and one groundwater sample shows 29 µg/l. This is very high and exceeding both Danish and Swedish criteria. Other samples had not detectable levels. Quality criteria for Chlorophenols are given above, including the evaporation criteria for Danish use. As no air samples are taken this cannot be compared but the existence of the criteria show that the substance occur in pore air, and detection is necessary according to Danish methods.

Groundwater samples show high levels of arsenic; 65 µg/l, which is considered high with both Swedish and Danish criteria. Dioxin in groundwater show 0.002-0.007µg/l, but this is uncertain due to muddy samples. No data available for Denmark for dioxin.

6.2.2.2 Risk assessment

The Swedish Risk assessment analyses the interesting parameters for all possible recipients. In Denmark the assessment is made separately for exposure of humans and groundwater. For the risk assessment information is needed about recipients, exposure, transport, toxicity etc. similar for both countries. Environmental protection is given in Sweden but not given in Denmark.

Transportation is suspected via dust or groundwater. Arsenic is bounded to particles and low leaching rate is assumed. Dioxin and chlorophenols are detected in very few locations, and not assumed to be transported to the lake.

Exposure to humans
The exposure analysis is made for today and future, 50-100 years. This is similar to Danish time span. The exposure analysis includes identification of exposure time, pathways and toxicity and acute toxicity.

Exposure is expected to humans and children visiting the site temporarily for sport activities and playground. Expected pathways are ingestion of soil, and also dust from non-covered areas. In the Swedish report evaporation is assumed to be very low for pentachlorophenol and dioxin, this might not be the case in Denmark.

Toxicity analysis of chlorophenols show that the knowledge level is pretty low in Sweden according cancer risks, and TDI for pentachlorophenol (the most toxic) is $3.0*10^{-3}$ mg/ (kg, day). The acute toxic effects are greatest for small children. Calculations are made with the assumption for children single intake of maximum 5g soil for a 10 kg child. Danish assumption is 10 g for a single intake.

The levels are not close to the acute toxic values for any of the analysed substances, see Table 24. In Denmark these levels for lethal dose would be a little lower due to the higher maximum intake, but in this case it would not influence the result.

Table 24 Acute toxic levels for most toxic substances.

Substance	Level (potential lethal dose) (mg/kg TS)	Level - other critical reasons (not lethal) (mg/kg TS)	Highest detected level (mg/kg TS)	Highest detected level in surface soil (mg/kg TS)
Arsenic	3 000	2 000	257	257
Dioxin	2	missing	0,0013	0,0013
Pentachlorophenol	58 000	missing	104	<0,1

In-depth classification has been made for the exposure analysis. A – 0-0.7 m; B – 0.7-2 m; C – > 2 m below surface. The exposure analysis is made from this classification, see Table 25:

Table 25 The results for the exposure analysis made for Hackel 9:1

Exposure pathway	***Hackel 9:1***		***Exposure time (days/year)***			***Expected exposure time for quality criteria - park area (days/year)***
			Class			
Via direct contact or wind erosion			*A*	*B*	*C*	
Direct intake of contaminated soil	***YES***	***Children:*** ***Adults:***	***80*** ***80***	***30*** ***30***	***10*** ***10***	***80*** ***80***
Skin contact	***YES***	***Children:*** ***Adults:***	***40*** ***40***	***15*** ***15***	***10*** ***10***	***40*** ***40***
Inhalation of dust	***YES***	***Children:*** ***Adults:***	***80*** ***80***	***30*** ***30***	***10*** ***10***	***80*** ***80***
Evaporation						
*Inhalation of fumes**	***YES***	***Children:*** ***Adults:***	***80*** ***80***	***80*** ***80***	***80*** ***80***	***80*** ***80***
Leaching						
*Ingestion of plants grown in the area***	***YES***		***365***	***365***	***365***	***YES = 0.0027 kg/d***
Ingestion of plants grown with contaminated ground of surface water	***NO***		***-***	***-***	***-***	***-***
Intake of groundwater	***NO***		***-***	***-***	***-***	***-***
*Skin contact with water by swimming in lake Järnlunden****	***YES***	***See model*** ***				***-***
*Ingestion of fish from Järnlunden*****	***YES***	***Children:*** ***Adults:***	***365*** ***365***	***365*** ***365***	***365*** ***365***	***See model ******

* Only stay outside
** According to the Swedish EPA model for park areas.
*** According to model for skin contact (not included here)
**** According to Norwegian model, Ingestion of fish is assumed to be 10% of the total intake.

In Denmark the Exposure of soil below 0.25 meter is not seen probable for normal uses. The Classes B and C would not be included. The area would be seen as a recreational area with 3-5 hours of exposure per day for adults and children, playgrounds are most likely for exposure. For ingestion of soil and skin contact a great likelihood of exposure is assumed and for inhalation of fumes and some likelihood of exposure is probable according to Appendix 5. The same duration of exposure is assumed for the countries (SE: 80/365 days = 0.22, DK: 3-5/24 h = 0.125 – 0.21). This would give similar results for exposure with Danish methods.

In Sweden new health based quality criteria are calculated, these are lower than LSL for Arsenic and Dioxin. In a Danish view the focus would be the risk for transportation of the substances from the soil to recipients and Jagg is used for calculations. The transportation is found low in this case, but the risk for effects from Arsenic is high. The acute toxic levels are not very high, but the detected levels for arsenic and chlorophenols are exceeding the guidelines pretty much. As the exposure is pretty extensive the risk cannot be neglected this far.

The results from the risk assessment in Sweden show that there is a risk from Arsenic due to ingestion or soil or plants. Dioxin may pose a risk as they are not digested quickly. Chlorophenols are not found hazardous as the high levels are detected lower in the soil. The major health risks considered are connected to the upper soil layers. Acute health risks are low. Both Arsenic and chlorophenols would be found hazardous with Danish methods and the main results would be similar as above. For dioxin the outcome is not certain as no Danish criteria are found. The focus on detection of hot-spots would delimit the sources more. Air sampling of chlorophenols would identify if there is a contribution to air at hazardous levels.

Drinking water protection

Groundwater from the site may be transported to surface water in the lake; the lake is no major drinking water source. As there is no expected drinking water use planned for the area this is not considered.

6.2.3 The remediation phase

3. The remediation phase

- Detailed plan of remediation incl. investigations
- Implementation of remediation action

Identification of possible remedial measures is performed. In Sweden it if found that a remedial action is necessary. The detected samples with high values are the base for this decision. The main aim for this action is to prevent exposure of humans and to delimit the transport of contaminations from the area. This can be made by several methods; bold measures are suggested in the report. Corresponding Costs are estimated and presented in Table 26:

A. **Excavation of contaminated soil.**
B. **Enclosing and sealing methods with cover of the soil would limit the exposure to humans and the transportation of substances from the site.**
C. **Restricted use of the area with fences etc.**
D. Destruction methods are possible to dioxins, but not arsenic. Not suggested
E. Thermal sorption that could eliminate both arsenic and dioxin can be performed in-situ. According to the main study this is not preferable as dioxins are low volatile. On site treatment is more efficient but demand larger amount of soil. Arsenic is not mentioned.

Table 26 Cost estimation of methods suggested for remediation (Main Study Rimforsa Trä, Sweco)

	Total cost estimated (SEK)		
A- Restricted use of area	530 000	-	650 000
B- Excavation			
Arsenic 0-0.5 m depth (900 m2)	210 000		
Dioxin Area1: 0-4m depth (800m2)	1 296 000		
Dioxin Area2: 0-1.5m depth (75 m2)	81 000		
B Total cost incl. all cost	4 000 000	-	5 700 000
C- Enclosing with cover	5 000 000	-	7 000 000

The site is preferable used for similar activities also in the future. Risk evaluation of the analysed alternatives conclude that Excavation is preferable as this action will not need further control, the levels remaining in the soil will not exceed the calculated site-specific criteria and the remediation goals are met. For the other alternatives control is needed and the levels are still higher than the criteria. Enclosing would allow use of the area but restrict changes in the use, the cost are also similar to excavation, which is found to be a better solution.

Mount of excavated soil are calculated for three main areas:

1. Arsenic with $800m^2$ area excavated at depth 0-0.3 m (100 m^2 0-0.5 m) → 300 m^3 excavated soil.
2. For dioxin contaminated soils the amount needed to excavate is estimated to 1 550 m^3 (the main part 0-1.5 m depth, remaining 0-4 m).

A Danish analysis would probably suggest similar actions for remediation. Reactive barrier and filter techniques may also be a possible measure. Arsenic is exceeding the cut-off criteria, indicating that remedial action is needed. Restricted use of the area is not preferable for this case as the area is daily used. Excavation would be possible, but only the upper soil layer would be found needed for remediation. For this kind of area, permanent covered with grass and plants, 0.25m would be enough. This would lower the cost as the amount of soil excavated decreases. The dioxin contaminations give the largest amount of soil and costs. Dioxin criteria are uncertain for Danish method, assuming similar restrictions to arsenic the amount of soil for excavation will be much lower than in the Swedish investigation.

6.2.4 Results and differences

This remediation project would have major similarities with Danish methods. The time perspective is 50-100 years and the main focus in this investigation is on human health, which would be the same as in Denmark. The investigations would have focused more on pore air detection, and the results for chlorophenols may have looked different with these detections.

As this site is not assumed to be important as a drinking water source the groundwater or surface water protection is not of major importance. The leakage of substances from the site to the groundwater is detected close to the river, where the major transport is assumed. In Denmark the assessment would have been performed downstream the groundwater’s flow. As a drinking water sources is not expected closely the assessment for groundwater would look similar in Denmark.

The exposure and exposure model to humans for this area look very similar in both countries. The assessment of exposure would look similar with the Danish model. The in-depth categories for the calculations of exposure in Sweden would not be necessary in Denmark as exposure at depth more than 0.25-1 meter is not expected possible. As these values are not determining the hazardous exposure in the assessment it would not be different without these.

The major difference in this comparison is the view of remedial action. In Sweden excavation is found to be the best option with excavation of most contaminated area with high levels of arsenic or dioxin. The excavation is for some areas down to 4 meters depth, where also the highest costs are found. In the Swedish investigation enclosing was found very expensive and therefore not preferable. Enclosing is normally performed with pavement of grass cover in Denmark, and could be a possible alternative. If excavation was chosen the amount of soil excavated would be lower, excavation to 0.25 m is assumed. The cost would be lower than presented above. There is still an uncertainty about dioxin as it has no Danish quality criteria and is not prioritized anymore. Either measure; excavation or enclosing, would due to Danish guidelines reduce the risk level, but contaminants would remain in the ground. This is not preferable according to Swedish criteria.

7 Discussion

The Swedish and Danish works on remediation of contaminated sites have developed differently. It is difficult to evaluate the effect of the different approaches in reality as effects on humans and ecosystems are mostly long-term effects and very difficult to identify. Instead the evaluation here has focused on identified differences within the process and statistics with a discussion about probable consequences.

In Sweden large quantities of soil are excavated with governmental allowance. The major reason for excavation is to ensure that no exposure to humans occurs and that the environment is protected. In the comparison of how humans are suspected to be exposed by substances a clear difference is found. In Denmark the topsoil is the only soil in contact with humans, whereas in Sweden contact with deeper soil cannot be excluded; exposure to soil at 1-3 m depth is expected. This would be very unlikely under normal conditions, which is in accordance with the Danish view. By suspecting that exposure is possible at all depths the focus is not on the realistic exposure but on very unlikely cases. The depth-wise division used in Denmark gives a clearer exposure assessment with more realistic risk estimations.

The Swedish goals for protection of the environment and the environmental objectives are good initiatives to eliminate the negative effects from society on the environment. In the context of contaminated soil the question is what we are actually protecting, and when, if and how the goals actually can be reached. There are several uncertainties concerning the actual environmental benefits from soil remediation. In Denmark the conclusion was that there are other ways more efficient to protect environment than with remediation of soil contamination.

The methods for assessment of the risks and effects on environment used in Sweden are still associated with a low certainty. More knowledge would be required as this is a very influential part of the remediation process. Today the high requirements on protection often limit what remedial measures that can be used and to ensure environmental protection total excavation is in many cases the only way. Total excavation means that all soil is removed and replaced with cleaner soil. But as all sources are limited the soil has to be taken somewhere. The question is how the environment is protected at the site, where the clean soil is taken, and where the contaminated soil is disposed? Is the environment more protected with this removal and refilling system? Or would the environmental load be similar by ensuring limited leakage and transport from the site? Excavations give emissions from transports and other risks; disturbance in the soil may harm the ecosystems. The amount of soil excavated in Sweden could be lowered if the demands from authorities were clearer and more focus was put on the assessed risk. This would mean lower costs and less emissions, and possibilities to remediate many more contaminated sites. A national Swedish system for reuse of excavated soil would also increase the efficiency and sustainability for excavation.

The cost for remediation is much higher in Sweden with 40 millions/project compared to 2 millions/project in Denmark. The number of ongoing projects in one year is many times higher in Denmark with 8400 compared to 580 in Sweden. Comparison of excavated soil shows that there is 100 times more soil excavated per project in

Sweden. These are big differences and show that the Danish process has come to other conclusions than the Swedish process regarding how to handle the contaminated sites. One of the major problems with remediation is the high costs and limited resources; there are many sites in need for investigations and remedial actions. If Sweden would adapt some of the methods and values from Denmark the most relevant projects in Sweden would be remediated more rapidly than today.

The types of soil dominating are differing between and within the countries. The Danish soils are in general more porous and permeable sandy soils whereas Swedish soils mostly consist of less permeable clays, glacial tills and filling materials. This should mean that contaminants in general move quicker in Denmark than in Sweden and that the contamination load on various recipients is lower in Sweden.

Assessment and evaluation of needed remediation does focus more on the benefits and actual needs in Denmark. In Sweden there are several values influencing the choice of method:

- The idea that the remediation should be a one-off for all future possible actions for 100-1000 years.
- The goals stated in the environmental objectives – soil should be clean.
- The authorities often set a requirement of how much contaminants that should be removed., e.g. 90%

Denmark has also ideas about one-off remediation but as the cost is high for remediation the benefit for now and the coming future of 50-100 years is found to be the most important. A more individual and flexible view and evaluation of needed measure would increase the efficiency in Sweden.

The investigations and prioritisation between substances are still old-fashion in Sweden seen with the Danish view. There is a trend for changes coming, but still the main focus is on metals in Sweden. Earlier it was similar in Denmark, but today hazardous volatile substances are prioritized as they are very hazardous to humans and these are hard to avoid. A higher priority to volatile substances in Sweden would be needed as these compounds probably occur also here. Improvements of investigation methods would be preferable to evaluate the occurrence of volatile substances.

The Danish work with remediation has had a more rapid development. One reason is the high demand of clean groundwater in Denmark which have posed a pressure on regulation and organisation of these questions. The limited amount of land in Denmark is another factor influencing the development. Sweden has lower acute pressure as there are large areas still not used and both clean soil and water is more abundant. This has made it easier in Sweden to use landfills compared to Denmark.

The centralised organisation in Denmark with five responsible authorities (earlier Amter) for most remediation issues has increased the knowledge and efficiency in this process. The local responsible authorities in Sweden have a hard work with organising and evaluating remediation projects. In the remediation process the authorities have an important role with legal responsibility, and lack of knowledge and experience make this process slow and uncertain. It is harder to share knowledge between 290 municipalities than 5 regions. A more centralised organisation in Sweden would help the work with remediation and contaminated sites. The number of employees for organisation of the guidelines and financial allowance is also very limited in Sweden, only half as many as in Denmark. This is another important factor for efficient and good organisation within the field, which could be improved.

This project was preformed with literature studies as the base for the comparison. Consultants and other professionals have given complementary information about practical applications in the remediation process. As the comparison is mainly on theoretical basis the reality may look different. The conclusion is still that there are main differences between the two countries in the view in how to achieve sufficient protection to humans and ecosystems from contaminated sites. The references are mainly produced by the Danish and Swedish EPA as they are responsible for these guidelines. This project has focused on the main guidelines and there was little possibility to learn how all guidelines are used in practice. This indicates that some of the conclusions may have been different if a more complete picture of all published material and practical use were available.

An overview comparison of the most important differences is given in Table 27.

Table 27 Comparison of the most important differences between the Swedish and Danish Remediation processes

Sweden	**Denmark**
Focus on environmental protection	Focus on groundwater protection
All soil depths should be given the same protection	In-depth division and landuse depth important
Local registers from mapping and industry data	Extensive national registers for mapping, industry and historical data
The 290 local and 21 regional authorities are responsible permission authorities	The 5 regional authorities are responsible permission authorities
Long term view - Action should include all future demands	Action should include demands for now and life-time of buildings
Excavation of all contaminations preferable	No transport of contaminated soil to clean areas
Around 1000 employees	Around 2000 employees
Cost per project: 40 million SEK	Cost per project: 2 million SEK
Soil excavated per project: 8000 ton	Soil excavated per project: 80 ton

8 Conclusions

The comparison of the remediation processes in Sweden and Denmark shows that the main elements and methods are similar but there are also some major differences in the values, methods and models. The main differences are concluded below.

There is a major difference in the focus for protection and risks in the two countries. Both countries are giving protection to human health and drinking water sources. In Sweden protection of the environment with ecological systems is extensive. Environmental objectives are developed to create a non-toxic and sustainable environment. In Denmark the protection of environment is weaker, and groundwater is mainly protected as drinking water source.

The protection of the environment in Sweden is determining many of the quality criteria and remediation projects in Sweden. In Denmark this protection was early eliminated from the remediation process as other protection values were found more important, and not possible to secure if also extensive protection of the environment was included. The money was found more appropriate for urgent and more efficient actions, e.g. eutrophication caused by the pig industry is giving more harm and should be in prior. This kind of comparison of risks is not possible in Sweden due to the EPA guidelines. Partly as a consequence of the view of environmental protection the landuse at different soil depths is differently developed in the two countries. In Sweden no soil-depth division should be made and protection is given to the ecosystem regardless of the depth. Exposure to humans is assumed possible also at lower depths. In Denmark the landuse depth is stated to ensure no exposure to humans is possible. A small depth to the contamination is seen as enough protection if the contamination is covered with grass, geo-textile etc.

The development of the quality criteria in Denmark differ from the Swedish criteria. Four individual criteria for soil, cut-off for soil, groundwater and evaporation give a more flexible way of assessing the risk. Another difference is the way the Danish levels of contamination are compared to the criteria. The detected values are not always most relevant, instead the substances available for exposure is calculated for comparison with the criteria. Digestion and sorption is considered and the landuse depth is assessed for the expected landuse. Chosen remedial measure should meet the remediation goals but a discussion about costs and benefits is also influencing the choice as remediation should give benefits to society to be efficient.

In Sweden, the quality criteria are used more as absolute limits. For complex cases new site-specific criteria are established for comparison with the detected levels. This method is good as the site-specific conditions are considered. When choosing the appropriate remedial measure the focus is at risk, remediation goals, and at the objective for non-toxic environment. For many projects this means that a total remediation is the only alternative as the remediation goals and environmental objective are not met otherwise. Digestion and transformation is normally not considered and all contaminants are seen available for transport and exposure.

The prioritizing of hazardous substances is different in the two countries, especially regarding volatile compounds. Denmark is more focused on evaporation and volatile compounds as these are a main threat to human health in indoor and outdoor air. In Sweden the focus is mostly on heavy metals and organic compounds like DDT, PCB and dioxins. Earlier, heavy metals were also the main focus in Denmark, but as the resources are limited the Danish EPA decided to focus more on the health effects. Many of the hazardous volatile substances found in petroleum derivates and oil are the most detected contaminants in both countries. However, until now detection of the volatile compounds is much more developed in Denmark, where pore-air sampling is a primary investigation. In Sweden air samples may be taken later in the investigation phase. As these substances have severe negative effects on humans it would be reasonable to investigate these more also in Sweden.

The impression is that the Danish process is more flexible for assessment of the single projects. Both processes are pretty conservative in the assessment of risks to ensure that the certainty is high enough. In the end of the process the Swedish structure is more conservative and the choice of measure should always ensure a long-term solution. The Danish process focuses more on the individual features and solutions to choose the most efficient solution for now and the future. Total remediation is often not preferable in Denmark as the costs are very high and large volumes of soil have to be removed and refilled. Consequently, it is acceptable in Denmark to leave contaminated soil at the site.

The conclusion of this review is that the remediation process is more clearly described in the Danish model. The four main elements are easily understandable and the structure with elements and steps is easily followed. The Swedish process is not easily overviewed in the first sight, with many elements and no clear order. An advantage is the detailed and clear description of the Risk Assessment in Sweden. The risk assessment for soil and landuse is more generally described in the Swedish process whereas risk assessment for evaporation and groundwater is more developed in Denmark. The focus on volatile substances is much stronger in Denmark.

Background information and data is more structured and well-documented in Denmark. There are large national databases for several kinds of historical, geological and other records. Many of the records are also available for public interest. The good organisation and structure on the information is a good help for investigations and risk assessment. In Sweden these registers are more locally organised, and with varying quality.

The development of the work with the remediation process has in Denmark been more focused and more rapid. Legislation and guidelines was much earlier developed, and the number of employees is two times larger in Denmark compared o Sweden (2000 compared to 1000). The number of employees at the EPA in Denmark for contaminated soil is 13-14 compared to 7 at Swedish EPA or totally 7 including employees at SGU. The structure of the organisation at national and regional level has been very important for the development in Denmark, both with collaboration and technical and practical development. The responsibility is more centralised in Denmark than in Sweden; five regions in Denmark, compared to the shared responsibility between the 21 regions and 290 municipalities in Sweden. The legislation and organisation to gather and develop knowledge is also an important difference. The interest organisations in Denmark to share knowledge and experience are partly based on stakeholders from the regions. Especially the review work performed by Depotrådet is very important for the Danish development, and would be needed also in Sweden.

The number and size of the remediation projects are differing very much between the two countries. In 2005 there were 8 400 remediation projects in Denmark compared to 580 projects in Sweden. The cost for remediation is much higher in Sweden with 40 million/project compared to 2 million/project in Denmark (in SEK). The quantity of excavated soil is 100 times higher per project in Sweden compared to Denmark, 8 000 tonnes compared to 80 tonnes, see Table 28. The proportion of remediation projects using excavation is only slightly higher in Sweden, which means that the main difference is the amount of soil removed at the remediation. This big difference probably depends on the depth division for Danish excavations and definitions of landuse depth. A large proportion of the soil is directly put on landfills in Sweden as remediation of the soil is very expensive. The question is if the Swedish country is becoming cleaner by all this excavation, or if the soil is just moved to avoid exposure to humans and the ecosystems investigated?

Table 28 Comparison of figures on cost and sites in Denmark and Sweden

	Identified sites	**Prioritized sites**	**Cost per remediation** (SEK)	**Ongoing projects**	**Cost for remain-ing remediation** (billion SEK)	**Tonnes of excavated soil per project**
Sweden	80 000	17 500	40	580	45	8 000
Denmark	55 000	14 000	0.85-2.0	8 400	20	80

The case studies also indicate that the main difference in the outcome would be the amount of soil excavated from the site. Investigations would probably also be differently carried out with more focus on evaporation.

The development in use of remedial measures is more rapid in Denmark than in Sweden. The use show that there are major differences but the focus and view of remediation in Denmark allow more methods to be used as total remediation is normally not demanded.

In Denmark there is a national system for classification and reuse of contaminated excavated soil. This makes it possible to recycle the soil for purposes where the soil does not need to be total clean. No similar system is developed in Sweden and reuse is only possible within projects or between partners.

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Appendix

Appendix 1 Remedial measures

1. Remediation of soil contamination

Excavation

Excavation is the most common method for remediation of soil contamination. By removing the contamination and soil under controlled conditions until the sides and bottom is sufficiently clean and refilling with new material, the soil is cleaned. The level deciding when it is clean enough is determined by the acceptance criteria for the specific substance. This is documented with soil samples taken from bottom and the sides of the excavation pit.
The advantages with this method are that is quick, can be used for all kinds of contamination and is well documented. Theses factors explain why it is still the most widely used method. Disadvantages for excavation are that it results in environmental effects and big quantity of contaminated soil. After the excavation it is possible to clean the soil on site or at larger cleaning facilities. (Danish EPA 2002)

Soil vapour extraction or Vacuum extraction

It is primarily a physical extraction (stripping) method for highly-volatile xenobiotic organic substances. Can be used for different volatile of half volatile hydrocarbons. It is most used in looser soil types and contaminations in the unsaturated zone. Highly volatile substances are sucked out from the soil using ventilation screens installed in the unsaturated zone subjected to a vacuum using a ventilator. The method is illustrated in Figure 40. For heavy contaminated soil the extracted air is cleaned with carbon filter to comply with the air-quality criteria for the specific substances. Depending on the soil type, contamination and stop criteria the time required for this method is varying, typical from five month to several years. The method is well tested in the US. (Danish EPA 2002, Helldén 2006)

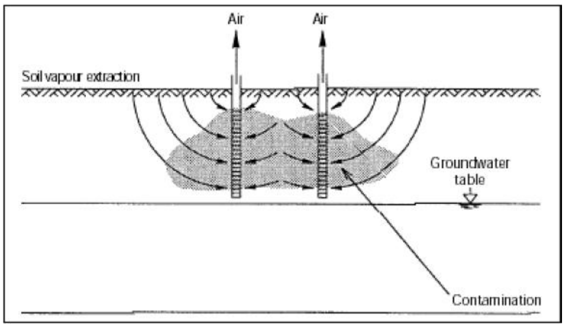

Figure 40 Soil vapour extraction (Danish EPA 2002)

Bioventilation

Bioventilation is in operation in several countries, for example in Denmark and the US. It has most potential for lighter anaerobic degradable organic contaminants such as mineral-oil products and solvents but not chlorinated solvents in permeable soil types. The method normally uses air or oxygen in for aerobic microbial degradation of xenobiotic organic substances in the unsaturated zone. Air is blown in using a ventilator and decomposition of the contamination is stimulated. This method is good for contaminations located under or close to buildings. It is beneficial as a supplement to or in combination with other methods such as groundwater pumping and soil vapour extraction. Illustration of the method is given in Figure 41 (Danish EPA 2002).

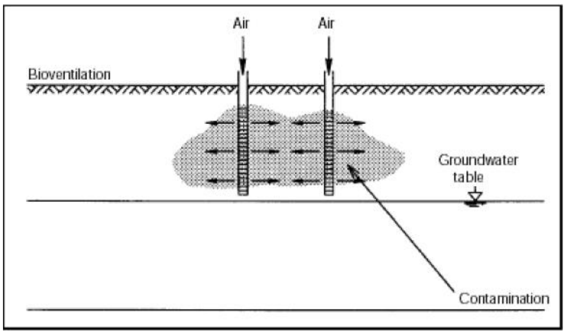

Figure 41 Bioventialtion (Danish EPA 2002)

Forced leaching

This method is used for soluble and biodegradable contaminations in relatively homogenous, sandy deposits under well-defined hydraulic conditions. The contaminants are forced to leach by artificial increasing the infiltration of water through the contaminated area, see Figure 42. Recirculation of water and sometimes adding of nutrients, bacteria, and oxidants is usual to stimulate the process. Detergents can be used to increase the bioaccessibility. In combination with other methods like remedial pumping the method have best efficiency. Total remediation seems impossible for this method, and some operational problems have been observed (Danish EPA 2002).

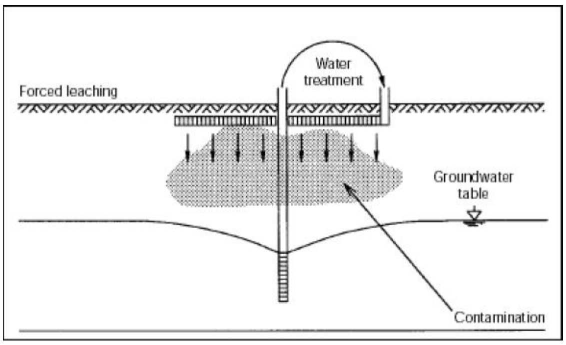

Figure 42 Forced leaching (Danish EPA 2002)

Soil washing
The contaminant is washed out from the medium by sorting the small fractions from the bigger fraction. The method can be used in permanent treatment facilities or in-situ. Water is the regular washing agent, which is cleaned and reused in the treatment facility. The main usage is cleaning of metal contaminated soils and sediments from mining and metal industry. Internationally the method is used mainly for cleaning of metalsa and PAH, but it can also be used for extraction of organic compounds (PAH, PCB and alifat/Mono aromats etc (Swedish EPA 2007).

Immobilisation
By keeping the contamination in place in the soil an area can be used for a specific purpose without moving the contamination. Constructional methods are often used for immobilisation in Denmark, e.g. asphalt or paving. With the cover a downward movement can be ensured, and contact with the surface can be avoided. To ensure that the contaminant stay in place membranes or low permeable materials can be used. Also vertical barriers can be used to avoid vertical spreading for complex cases, for example membranes, sheet piling or vertical barriers of bentonite/concrete. These techniques are well-tested as they and used especially abroad. The method is illustrated in Figure 43.

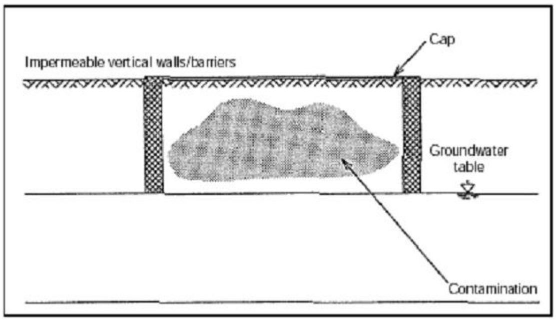

Figure 43 Sealing of contamination (Danish EPA 2002)

Sealing is a method but crucial as it is hard to guarantee impermeable materials. The ground water can have movement in horizontal direction and may be affected by the contamination in the water bearing layers. It is therefore important to consider volatile substances, and be aware of that other methods are needed in combination with sealing to avoid leaching of volatile substances. Emplacement of membranes should be supplemented with systems for collecting and draining precipitation (Danish EPA 2002)

Bioremediation
This method acts so that optimal conditions for degradation or contaminations in the soil by adding micro-organisms or by improving living conditions for naturally-occurring bacteria (by adding of oxygen or detergents). It can be used for most organic substances, except PCB, Chlorinated dioxins, heavy metals and high-molecular PAHs. The physical-chemical conditions are important for this technique; many factors have to be checked out. This far test on this method has given heterogeneous and high-concentration residues, and the long duration for this method is a problem. The biological in-situ model is not yet in use commercially in Denmark (Danish EPA 2002).

Thermal sorption
Thermal heating of the contaminations in a constructed, often rotating, oven. Mainly used for organic compounds like VOC, semi-VOC, PCB, Pesticides, Dioxines/furaner and Volatile Metals (Arsenic and mercury). Heating of the media at temperatures of 100-800°C evaporate many substances, and at even higher temperatures 800-1000°C hydrocarbons are then destroyed. The substances can then be cached in a filter or destructed in an afterburner. This method can be called a concentration or a destruction method.

2. Other in-situ methods of soil remediation

Electro kinetic soil remediation is a technique where heavy metal contaminants are forces out from the soil using an electric field (electro migration). It can be used for organic substances using electro-osmosis. This method is still not for commercial use, but pilot project show the big potential for heavy metals.

Stream stripping is used for removal of volatile components using two counter-rotation drill bits. Steam and compressed air are pumped down through the bits, and onto the soil. As the method it very energy consuming, require flat ground (not more than 1% slope) and the upper layer on the soil is removed, it is seen as not potential in Denmark. Infiltration of active substances to degrade toxic substances is another method, still not tested in Denmark (Danish EPA 2002).

3. Remediation for groundwater contamination

Several methods are available or under development. The most common remedial methods known today are (Danish EPA 2002):

- Pump-and-treat from screened wells.
- Separation pumping from specific levels.
- Pumping with multiple pumps in several phases.
- Skimming LNAPL contamination from screened wells.
- Pumping from drainage systems.
- Pumping from suction-probe equipment (including 'bioslurping').
- In-situ methods including
    - Air sparging
    - Adding oxidising agents
    - Reactive barrier and filter techniques

Pump and treat

Pumping is used to bring contaminations under hydraulic control. Pumping is typically performed from deep aquifers from screened wells, see Figure 44. A strategy is needed to prepare a measure, including the following steps;

- Location of pump wells
- Number of pump wells
- Pump yield
- Pump levels

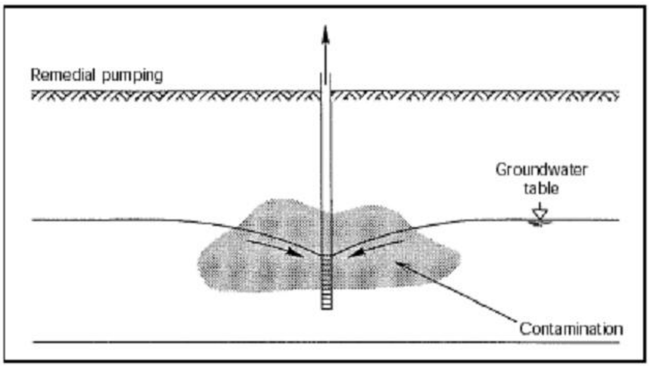

Figure 44 Pump and treat method (Danish EPA 2002)

Reactive barrier and filter techniques

Filter techniques can be used in the ground to absorb water borne or dissolved substances in the ground or surface water. By using filters with a matrix, a sorbent and a filter for particle separation the substance can be absorbed by physical, electrostatic or chemical adsorption or chemical substitution. A reactive barrier is a filter put downstream the groundwater in the saturated zone for adsorption of the contaminations, see Figure 45. The method can be used for treatment of metals, PAH, dioxin and PCB relatively efficient. For PCB and dioxins a particle filter is enough to catch the insoluble compounds (Helldén 2006)

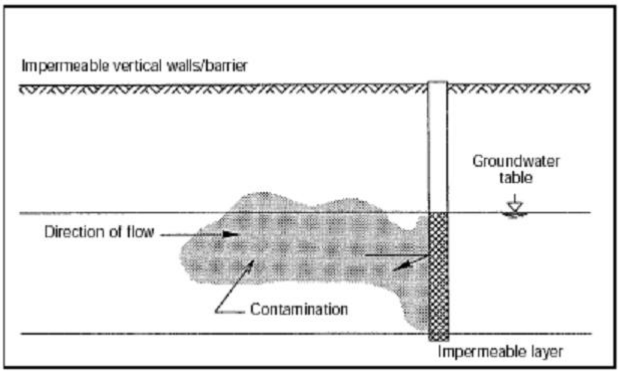

Figure 45 Impermeable barriers (Danish EPA 2002)

Air sparging
Air sparging is an in-situ remediation technology used for remediation of volatile or half-volatile organic substances in the groundwater zone. It is especially useful for lighter gasoline constituents like BTEX (benzene, ethylbenzene, toluene, and xylene). Air of high pressure (or nitrogen /oxygen) is blown into the saturated zone under the groundwater level. Through air channels the air with contaminations will raise, see Figure 46. The method was introduced in the US 1980 and mainly used there. Despite the age there are very few cases documented with successful results. The method has to be combined with vacuum extraction to collect the volatile substances that are evaporated from the saturated zone (Swedish EPA 2007, Danish EPA 2002)

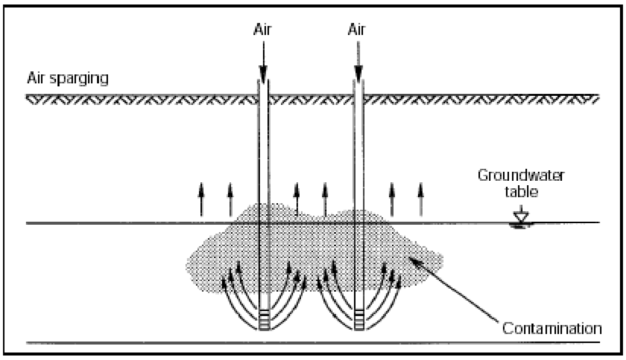

Figure 46 Air sparging method (Danish EPA 2009)

4. Remediation of sediment

Dredging of sediment
This is a special case of excavation for sediment under water. There are normally several differences accept that it is under water: the sediment are often loose, have high level of water and high level of organic substances. This can cause spreading and clouding of the contamination, and to deal with this specific methods have been developed; e.g. such-dredging and freeze-dredging.

Appendix 2 Comparison of quality criteria in Denmark and Sweden

(Danish EPA 2008, Swedish EPA 2008)

Denmark				Sweden			Comparison of criteria	
Soil quality criteria	Cut-off criteria	Ground water criteria	Substance	Sensitive Landuse	Less sensitive landuse	Ground water criteria	Soil Water	~2 times / >~10 times ~2 times / >~10 times
[mg/kg]	*[mg/kg]*	*[µg/ liter]*		*[mg/kg]*	*[mg/kg]*	*[µg/ liter]*	Limiting Reason	
20	20	8	**Arsenic, inorganic**	10	25	10	Backgr.	In Soil
100	-	-	**Barium, inorganic**	200	300		E-Tox	E-Tox
1,5	-	1	**Benzene**	0.012	0.04	10	GW	GW
40	400	1	**Lead, inorganic**	50	400	5	In Soil	E-Tox
0,5	5	0,5	**Cadmium**	0.5	15	5	In Plants	Surf W
3	-	0,1	**Chlorophenols** (sum af mono- ,di- , tri- og tetra-phenoler)	0.5	3		GW	GW
20	-	1	**Chromium (VI)**	2	10		E-Tox	E-Tox
500	1000	25	**Chromium (III + VI)** SWE: (share of CR VI <1%)	80	150		E-Tox	E-Tox,GW
500	-	50	**Cyanides,** inorganice SE: total	30	120		E-Tox	E-Tox
10			**Cyanides,** DK: oxygen volatile SE: free	0.4	1.5			
0,02	-	0,01	**1,2-dibromethan**	0.0015	0.025	1	Health DW	GW
1	-	1	**1,2-dichlorethan**	0.2	0.06	30	GW	GW

Denmark				Sweden			Comparison of criteria	
Soil quality criteria	Cut-off criteria	Ground water criteria	Substance	Sensitive Landuse	Less sensitive landuse	Ground water criteria	Soil: ~2 times / >~10 times; Water: ~2 times / >~10 times	
[mg/kg]	*[mg/kg]*	*[µg/ liter]*		*[mg/kg]*	*[mg/kg]*	*[µg/ liter]*	Limiting Reason	
8		1	**Dichloromethane**	0.08	0.25		GW	GW
500	1000[i]	100	**Copper**	80	200	4000	E-Tox	E-Tox
1	3	0,1	**Mercury, inorganic**	0.25	2.5		Health/gas	Health/gas
-	-	5[d]	**Methyl-*tert*-butyl ether, MTBE**	0.2	0.6	50	E-Tox GW	GW
5	-	20	**Molybdenum, inorganic**	40	100		GW	SW
30	30	10	**Nickel**	40	120		GW	E-tox
70	-	0,5	**Phenols (total)**	1.5	5		GW	GW
4 [g]	40 [g]	0,1[h]	**Kulbrinter, PAH** SWE: low molecule weight	3	15	10	E-Tox	E-tox
0,3	3	0,01	**Benzo(*a*)pyren** SWE:medium molec. weight	3	20	0.2	Health/gas	Health/gas
0,3	3		**Dibenz(*a,h*)anthracen** SWE:high molecule weight	1	10		In. Plants	E-tox
5	-	1	**Tetrachloroethylene**	0.4	1.2		GW	GW
-	-	5	**Toluene**	10	40	60	E-tox	GW
2000	-	1	**1,1,1-trichlorethan**	5	30		E-tox	E-tox

Denmark				Sweden			Comparison of criteria	
Soil quality criteria	Cut-off criteria	Ground water criteria	Substance	Sensitive Landuse	Less sensitive landuse	Ground water criteria	Soil Water	~2 times / >~10 times ~2 times / >~10 times
[mg/kg]	*[mg/kg]*	*[µg/ liter]*		*[mg/kg]*	*[mg/kg]*	*[µg/ liter]*	Limiting Reason	
5	-	1	**Trichloroethylen**	0.2	0.6		GW	GW
-	-	5	**Xylener (*o*-,*m*-,*p*-xylen + ethylbenzen)**	10	50	20	E-tox	E-tox
500	1000	100	**Zink**	250	500	700	E-tox	E-Tox

E-tox – Ecotoxicicological/ecosystem limitation
GW – Groundwater limitation
In soil – Inhalation of soil
In. Plants – Ingestion of plants

Totally 28 substances are compared

12 substances have 10 times lower quality criteria in Sweden (Marked with red).
7 substances are ~2 times lower in Sweden.

2 substances have ~10 times lower value in Denmark
2 substances with ~2 times lower criteria in Denmark.

Appendix 3 Swedish Quality Criteria

(Swedish EPA 2008)

Table for Swedish quality criteria for contaminated sites			
Substance	**Sensitive Landuse**	**Less sensitive Lu**	**Comment**
Antimony	12	30	
Arsenic	10	25	
Barium	200	300	
Bly	50	400	
Cadmium	0,5	15	
Cobalt	15	35	
Copper	80	200	
Chromium total	80	150	The share of Cr (VI) is below 1% of the total chromium
Chromium (VI)	2	10	Rem 2
Mercury	0,25	2,5	
Molybdenum	40	100	
Nickel	40	120	
Vanadium	100	200	
Zinc	250	500	
Total cyanide	30	120	
Accessible Cyanide	0,4	1,5	Rem 2
Phenol + cresol	1,5	5	Rem 2
Sum of chlorophenols (mono - penta)	0,5	3	Rem 2
Sum mono- and dichlorobenzene	5	15	Rem 1,2
Trichlorobenzene	1	10	
Sum tetra- and pentachlorobenzene	0,5	2	
Hexachlorobenzene	0,035	2	
Dichloromethane	0,08	0,25	Rem 1,2
Dibromochloromethane	0,5	2	Rem 1,2
Bromodiechloromethane	0,06	1	Rem 1,2
Trichloromethan	0,4	1,2	Rem 1,2
Tetrachlormethan	0,08	0,35	Rem 1,2
1,2-dichloroethane	0,02	0,06	Rem 1,2
1,2-dibromoethanen	0,0015	0,025	Rem 1,2
1,1,1-trihloroethane	5	30	Rem 1,2
Trihloroethylene	0,2	0,6	Rem 1,2

Table for Swedish quality criteria for contaminated sites			
Substance	**Sensitive Landuse**	**Less sensitive Lu**	**Comment**
Tetrahloroethylene	0,4	1,2	Rem 1,2
Dinitrotoluen (2,4)	0,05	0,5	Rem 2
PCB-7	0,008	0,2	PCB-7 is assumed to 20% of total PCB
Dioxin (TCDD-ekv WHO-TEQ)	0,00002	0,0002	Including also dioxin like PCB
PAH L	3	15	PAH with low molecule weight
PAH M	3	20	PAH with medium molecule weight
PAH H	1	10	PAH with high molecule weight
Benzene	0,012	0,04	Rem 1,2
Toluene	10	40	Rem 1,2
Ethylbenzene	10	50	Rem 1,2
Xylene	10	50	Rem 1,2
Aliphatic hydrocarbons >C5-C8	12	80	Rem 1,2
Aliphatic hydrocarbons >C8-C10	20	120	Rem 1
Aliphatic hydrocarbons >C10-C12	100	500	Rem 1
Aliphatic hydrocarbons >C12-C16	100	500	
Aliphatic hydrocarbons >C5-C16 Total	100	500	Total Aliphatic hydrocarbon fractions
Aliphatic hydrocarbons >C16-C35	100	1000	
Aromatic hydrocarbons >C8-C10	10	50	
Aromatic hydrocarbons >C10-C16	3	15	
Aromatic hydrocarbons >C16-C35	10	30	
MTBE	0,2	0,6	Rem 1,2

Remark 1 – Substances that will preferable occur in the pore air. Complementing analysis of soil air and indoor air is recommended

Remark 2 – Substances that will preferable occur in the soil or groundwater. Complementary analysis of soil and ground water is recommended.

Totally there are Swedish quality criteria available for 52 substances.

Appendix 4 Establishing Quality criteria in Sweden

Exposure

The Toxicological Reference value (TRV) used for calculations of the quality criteria is the toxicological reference value in [mg/kg body weight, day] i.e. the TDI value for non-genotoxic substances or the risk based tolerable daily intake for genotoxic substances.

The principles for calculation of the exposure to humans are calculated with the formula below. The level of contamination in the soil [C] giving exposure on humans that is possible harmful:

$$C = \frac{TRV}{EXP * CD * DF}$$ (C=concentration of contaminant in the soil)

TRV The weight based Toxicological Reference Value (TRV) for the contaminant; intake of the contaminant in [mg/kg].
EXP The average daily exposure from the contact medium (soil, air, water, and plants), weight based. For example intake of soil per kg body weight per day.
CD The Contaminants distribution between soil and contact medium.
DF The dilution that takes place in the contact medium before the contaminant reaches the human.
(Swedish EPA 2007)

For the different pathways and contaminants expressions are given to calculate the distribution and exposure. Exposure from the pathways is added up giving the integrated human health value. This is made as the inverse of the sum of the inverted reference soil concentrations. For sensitive landuse all pathways are included:

$$C_{SLU} = \frac{1}{\frac{1}{C_{InhD}} + \frac{1}{C_{InhS}} + \frac{1}{C_{DUp}} + \frac{1}{C_{InS}} + \frac{1}{C_{InP}} + \frac{1}{C_{InDW}} + \frac{1}{C_{InDW}} + \frac{1}{C_{InF}}}$$

For calculation of TDI the intake from the specific contaminated site is set to 50 % of the total intake. Substances phased out, for example lead, cadmium and mercury are only 20% of the tolerable intake is assumed to come from the site, for persistent organic compound, dioxins and PCB corresponding figure is 10 %. This is compensated for in the end of the calculation. When calculating the quality criteria parameters presented in Table 29 are used.

Table 29 ***Parameters used for calculation of quality criteria (Swedish EPA 2007)***

Parameter	Value	Meaning
Degree of organic coal in the ground	2%	Sorption of organic substances in the soil
pH in the ground	5-7	Metals' transport and availability
Dilution of ground/pore water SL LSL	1/15 1/55	Transport to drinking water well and to surface water recipient
Dilution of surface/pore water	1/4000	Transport to surface water recipient
Dust level in outdoor air	70 µg/m3	Inhalation of dust
Dilution in indoor air/pore air	1/5000	Inhalation of fumes

Assumptions for intake via soil, dust and water

Estimations are made about intake and exposure to humans by soil; direct intake by ingestion and through skin, inhalation of dust and intake through water. The calculations are made in separate for the four different pathways. Below the two first are described in detail.

There are some general assumptions for the calculations used in Sweden:

General assumptions for long time exposure:

Body weight (BW)	Weight Child: 15 kg Weight adult: 70kg	
Total lifetime:	80 years	(6 years as a child)

Exposure from direct intake of soil

To calculate the exposure to humans by direct intake via soil, intake in three ways are considered; intake by soil direct in the mouth, fingers with soil on or dust that get stuck in the mouth and throat. The calculations are based on the daily mean intake by long term exposure. The number of times or days in the area is considered, not the number of hours or single times for exposure. The Direct intake of soil [mg/kg] is calculated with the formula:

$$C_{is} = \frac{TRV}{R_{is} \times f_{bio-or}} \times 10^6$$

TRV – toxicological reference value [mg/kg body weight, day], TDI for non genotoxic substances

$\mathbf{R_{is}}$ – The daily mean value for intake of soil [mg soil/kg body weight]

f_{bio-or} – Relative bioavailability factor by intake of soil, dimensionless

The soil intake, $\boldsymbol{R_{is}}$ *[mg soil/kg body weight]* is calculated by:

$$R_{is} = \frac{DI \times t_{is}}{365 \times BW}$$

DI – Daily intake

t_{is} – Number of days/times for exposure per year

BW – Body weight

Data assumptions used for calculations of direct intake of soil are given in Table 30.

Table 30 Assumptions in data for calculation of intake of soil (Swedish EPA 1997)

Assumptions for exposure direct intake	Children		Adults	
	SL	*LSL*	*SL*	*LSL*
Daily intake of soil [mg/day]	1200	80	50	20
Days of exposure per year	365	60	365	200
Number of years of exposure	6	6	74	59
Weight based daily exposure [mg soil/(kg,day]	8	0.88	0.71	0.16

Exposure via skin contact

Exposure via uptake of contaminants via contact with skin give different exposure depending on: The exposed area of skin, the amount of soil stuck on the skin, the uptake of contaminant through skin and number of days/times of exposure. The model used is called CSOIL, also used in the Netherlands and USA. Assumptions for exposure to skin in Sweden are given in Table 31.The single way concentration in the soil for exposure via skin contact, C_{du} *[mg/kg]* is given by:

$$C_{du} = \frac{TRV}{f_{du} \times R_{du} \times f_{bio-du}} \times 10^6$$

TRV – toxicological reference value [mg/kg body weight, day], TDI for non genotoxic substances
f_{du} – The substance specific relative absorption factor
R_{du} – The daily mean value for skin exposure of soil [mg soil/kg body weight]
f_{bio-du} – Relative bioavailability factor by uptake by skin, dimensionless
For the given scenarios $f_{bio-du}=1$

The skin exposure R_{du}[mg soil/kg body weight, day] is given by:

$$R_{du} = \frac{SE \times A \times t_{du}}{365 \times BW}$$

SE – Surface exposure
A – Exposed surface [m^2]
t_{du} – Number of days/times, for exposure per year
BW – Body weight

Table 31 General parameters for exposure via skin R_{du}:

Assumptions for exposure skin	Children		Adults	
	SL	***LSL***	***SL***	***LSL***
Surface exposure [mg/m^2]	2000	2000	2000	2000
Exposed area of skin [m^2]	0.5	0.2	0.5	0.3
Daily skin exposure [mg]	1000	400	1000	600
Number of days for exposure	120	60	120	90
Number of years of exposure	6	6	74	59
Weight based daily exposure	22	4.4	4.7	2.1

Similar calculations and assumptions are made for inhalation of dust, fumes, intake of ground water and intake of plants (Swedish EPA 1997).

Appendix 5 Exposure patterns for various landuses in Denmark

(Danish EPA 2002)

Land use	Sensitivity	User group	Site characteristic s	Daily duration of exposure	Ways of exposure		
					Inh.	SkC.	Ing.
Roads, etc	Non-sensitive	Healthy adults	Paved	Minutes	(+)	-	-
Industrial	Non-sensitive	Healthy adults	Buildings Car parks Grass	8 hours Minutes Minutes	++ (+) (+)	- - (+)	- - -
Office	Non-sensitive/ Sensitive	Healthy adults	Buildings Car parks Grass	8 hours Minutes Minutes	++ (+) (+)	- - (+)	- - -
Shops: foodstuffs other	Non-sensitive/ Sensitive	Healthy adults, children, pregnant women, elderly, the sick	Buildings	Employee/-customer 8 hours, 1 hour 8 hours, 1 hour	++ ++	- -	(+) -
Blocks of flats	Sensitive	Healthy adults, children, pregnant women, elderly, the sick	Buildings Car parks Grass Playgrounds	24 hours Minutes-hours 4-12 hours 4-12 hours	+++ (+) (+)	- - + +++	- - + +++
Private houses	Highly sensitive	Healthy adults, children, pregnant women, elderly, the sick	Buildings Gardens (grass) Flower beds Crops	24 hours 4-12 hours 4-12 hours 3/4 of the year	+++ (+) (+)	- + +	- + ++ ++
Allotment gardens	Sensitive	Healthy adults, children, pregnant women, elderly, the sick	Buildings Gardens (grass) Flower beds Crops	4-8 hours 1/4 of the year	+++ (+) (+)	- + +	- + ++ ++
Recreational areas	Sensitive	Healthy adults, children, pregnant women, elderly, the sick	Grass Playgrounds Flower beds Paths	3-5 hours 3-5 hours Minutes/hours Minutes	(+) + (+) (+)	+ +++ ++ (+)	+ +++ ++ -
Schools	Sensitive	Healthy adults, children of school age, pregnant women	Buildings Paved Grass	4-8 hours 2 hours 1 hour	++ - (+)	- - ++	- - (+)
Kindergartens	Highly sensitive	Healthy adults, children, pregnant women	Buildings Playgrounds Paved Car parks	8 hours 8 hours 8 hours Minutes	++ + - -	- +++ - -	- +++ - -
Nursing homes	Sensitive	Elderly, sick, healthy adults, pregnant women	Buildings Grass Fenced-in	24 hours 0-3 hours	+++ (+) -	- (+) -	- - -

- : no likelihood of exposure
(+) : slight likelihood of exposure
\+ : some likelihood of exposure
++ : greater likelihood of exposure
+++: great likelihood of exposure

Inh. Inhalation
SkC. Skin contact
Ing. Ingestion

Appendix 6A Danish Quality criteria for soil, groundwater and evaporation

(Danish EPA 2008)

Substance	CAS-nr	Soil quality criteria [mg/kg]	Cut-off criteria [mg/kg]	Ground water quality criteria [μg/ liter]	Evaporation quality criteria [mg/m^3]
Acetone	67-64-1	-	-	10	0,4
Acrylonitril	107-02-8	0,1	-	0,1	0,00004
Aldine	309-00-2	-	-	0,03	-
Alkyl benzene, aromatic kulbrinter	1330-20-7	-	-	1[a]	0,03[b]
Arsenic, inorganic	-	20	20	8	-
Barium, inorganic #	-	100	-	-	-
Benzene	71-43-2	1,5	-	1	0,00013
Benzotriazol (+ tolyltriazol)	95-14-7	30	-	-	-
Lead, inorganic	-	40	400	1	-
Boron	-	-	-	300	-
Butylacetat (n-, iso-)	123-86-4 110-19-0	-	-	10	0,1
Cadmium	-	0,5	5	0,5	-
Captafol	2425-06-1	10	-	0,1	-
Chloroform	67-66-3	50	-	-	0,02
Volatile organic Chloro compuonds[1] Sum of volatile organic compounds r	-	-	-	1 3	-
Chlorphenoler (sum of mono- ,di-, tri- and tetra phenoler)	-	3	-	0,1	2×10^{-5}
Chromium (VI) Chromium (III + VI)	-	20 500	- 1000	1 25	-
Cyanides, inorganic Cyanides, syreflygtige	- -	500 10	-	50	 0,06
DDT + DDE	50-29-3 72-55-9	0,5	-	0,1	-
1,2-dibromethan	106-93-4	0,02	-	0,01	2×10^{-6}
1,2-dichlorethan	107-06-2	1	-	1	1×10^{-4}
1,1-dichlorethen	75-35-4	5	-	1	0,01
1,2-dichlorethen (*cis* + *trans* isomere)	156-59-2 156-60-5	85	-	1	0,4
Dichlormethan	75-09-2	8		1	0,0006
1,2-dichlorpropan	78-87-5	5	-	1	0,0005
Dieldrin	60-57-1	-	-	0,03	-
Diethylether	60-29-7	-	-	10	1
Di-(2-ethylhexyl)phthalat,	117-81-7	25	-	1	0,005[2]

[1] With volatile organic chloro compunds inclues: di- og trichlormethan, dichlorethener, 1,2-dichlorethan, trichlorethen, trichlorethaner, tetrachlorethen og tetrachlorethaner. Grundvandskriteriet gælder for det enkelte stof.

[2] See air quality crtiera for DEHP.

Substance	CAS-nr	**Soil quality criteria** **[mg/kg]**	**Cut-off criteria** **[mg/kg]**	**Ground water quality criteria** **[μg/ liter]**	**Evaporation quality criteria** **[mg/m^{3}]**
DEHP					
Fluoride, inorganic	-	20	-	-	-
Formaldehyde	50-00-0	75	-	-	0,001
Furfural [3]	98-01-1	4	-	-	0,002
Heptachlor/ heptachlorepoxid	1024-57-3	-	-	0,03	-
Isopropanol	67-63-0	-	-	10	1
Copper	-	500	1000^{i}	100	
Kulbrinter fra olie – og/eller benzinprodukter: [j] C_6-C_{10} kulbrinter >C_{10}-C_{15} kulbrinter >C_{15}-C_{20} kulbrinter >C_{20}-C_{40} kulbrinter Sum af kulbrinter, C_6-C_{40}		 25^{k} 40^{k} 55^{k} $150^{k, l}$ $150^{k, l, m}$	 - - - -	 9	 0,1
Mercury, inorganic	-	1	3	0,1	-
Lindan	58-89-9	0,6	-	0,1	-
Lithium, inorganic	-	500	-	-	-
Methyl-*tert*-butyl ether, MTBE	1634-04-4	-	-	5^{d}	0,03
Methyl-*iso*-amylketon	110-12-3	-	-	-	0,005
Methyl-*iso*-butylketon	108-10-1	-	-	10	0,2
Molybdenum, inorganic	-	5	-	20	-
Naphthalen	91-20-3	-	-	1	0,04
Nickel	-	30	30	10	-
Nitrobenzene	98-95-3	5	-	-	0,0002
Nitrochlorbenze #	100-00-5 121-73-3	5	-	-	0,0005
Nitrophenoler: Mononitrophenoler Dinitrophenoler Trinitrophenoler	25550-58-7	 125 10 30	 - - -	 $0,5^{c}$ $0,5^{c}$ $0,5^{c}$	 0,005 0,005 0,005
Nonylphenol	84852-15-3	25	-	20^{e}	0,02
Nonylphenolethoxylat	-	65	-	-	0,05[4]
Paraquat	4685-14-7	5	-	0,1	-
Parathion	56-38-2	0,1	-	0,1	-
Pentachlorphenol	87-86-5	0,15	-	$0,01^{f}$	1×10^{-6}
Pesticides, total - individuelle	-	-	-	0,5 0,1	-
Phenols (total) Phenol Creosol Xylenoler	- 108-95-2 1319-77-3 -	70 - - -	- - - -	0,5 - - -	- 0,02 0,003 0,002
Phthalates (no DEHP)	-	250	-	1	-
Polyaromatic	-				

[3] Soil quality criteria for Furan was earlier wrong published as 40 mg/kg.

[4] See the air quality crtiera for Nonylphenolethoxylat.

Substance	CAS-nr	**Soil quality criteria [mg/kg]**	**Cut-off criteria [mg/kg]**	**Ground water quality criteria [µg/ liter]**	**Evaporation quality criteria [mg/m³]**
Kulbrinter, PAH Benzo(*a*)pyren Dibenz(*a,h*)anthracen Fluoranthen	50-32-8 53-70-3 206-44-0	4 [g] 0,3 0,3	40 [g] 3 3	0,1[h] 0,01 0,1	-
Selenium, inorganic #	-	20	-	-	-
Styrene	100-42-5	40	-	1	0,2
Silver, inorganic	-	50	-	-	-
Tinsides, inionic (LAS, AOS, AS)	-	1500	-	100	-
Tetrachlorethylen	127-18-4	5	-	1	0,006
Tetraethylbly + Tetramethyllead	78-00-2, 75-74-1	4	-	-	0,0003
Tetrachloromethan	56-23-5	5	-	1	0,005
Thallium, inorganic	-	1	-	-	-
Tin	-	500	-	-	-
Toluene	108-88-3	-	-	5	0,4
Tolyltriazol (+ benzyltriazol)	29385-43-1	30	-	-	-
Tributyltin, (sum af TBT), målt som Sn/kg #	-	1	-	-	-
1,1,1-trichlorethan	71-55-6	2000 [5]	-	1	0,5
Trichloroethylene	79-01-6	5	-	1	0,001
Tricresylphosphater, total *o*-TCP	-	350 15	- -	- -	- -
Vinyl chloride	75-01-4	0,4	-	0,2	4×10^{-5}
Xylener (*o-,m-,p*-xylen + ethylbenzen)	1330-20-7	-	-	5	0,1
Zink	-	500	1000	100	-

a. sum of 1-methyl-3-ethylbenzen, 1,2,4-trimethylbenzen, 1,3,5-trimethylbenzen
b. sum of C_9-C_{10} aromatiske kulbrinter
c. general phenol limit for drinking water
d. content under indhold under 2 µg/l bør tilstræbes
e. sum of octyl- og nonylphenol
f. correspond to the analytic-chemical detection limit for the substance
g. soil: sum of benzo(*a*)pyren, benzo(*b+j+k*)fluoranthen, dibenzo(*a,h*)anthracen, fluoranthen, and indeno(*1,2,3-cd*)pyren
h. water: sum of benzo(*b+k*)fluoranthen, indeno(*1,2,3-cd*)pyren and benzo(*ghi*)perylen
i. Earlier wrong published
j. Kriteriet gælder forureninger med alle olie – og/eller benzinprodukter, herunder bl.a. fra benzin/fyringsolie/dieselolie/gasolie/terpentin/petroleum. Foruden kriterier for sum og fraktioner af kulbrinter skal kriterier for enkeltkomponenter og sum heraf, der kan forekomme i olie- og/eller benzinprodukter overholdes: benzen, toluen, xylener, alkylbenzener, 1,2-dibrom- og 1,2-dichlorethan, MTBE, tetraethyl- og tetramethylbly, samt PAH

[5] New value is 2000 mg/kg, limiting factor is children's exposure to soil.

Appendix 6B Danish Ecotoxicological Quality Criteria

(Danish EPA 2005)

Økotoksikologiske Jordkvalitetskriterier (JKK)	
Stof	JKK (mg/kg)
Aluminium	ingen toksiske effekter hvis pH>5
Anioniske detergenter	5
Arsen	2
Benzo(*a*)pyren	0,05
Bly	50
Cyanid	utilstrækkeligt datagrundlag
Kadmium	0,3
Klorerede fenoler (sum, undtaget PCP)	0,01
Kobber	30
Krom (III)	50
Krom (VI)	2
Kviksølv (uorganisk)	0,1
Mineralsk terpentin	utilstrækkeligt datagrundlag
Nikkel	10
Pentachlorophenol (PCP)	0,005
Polyaromatiske hydrocarboner (PAH'er)	0,5
Zink	100

(In English; Bly-lead, Kviksølv-mercury)

Appendix 7 Danish Remediation Prevention techniques

(Danish EPA 2002)

Method	Contamination type			Soil type	Docu-menta-tion e)	Other condi-tions
	Org./ Inorg. a)	Volatility b)	Degrada -bility c)	Perme-ability d)		
Soil contamination						
Excavation with off-site treatment	+/(-)	All	+	All	++	f)
Excavation with landfilling	+/+	All	All	All	++	g)
Excavation and on-site treatment	+/-	+	(+)h)	(+)h)	+	i)
Soil vapour extraction	+/-	++	-	+	++	
Bioventing	+/-	+	++j)	+	+k)	
Forced leaching	+/+l)	-	-	++	+	m)
Immobilisation	+/+	(+)n)	All o)	All	+	
Steam stripping	+/-	+	All	+	(+)p)	q)
Groundwater contamination						
Remedial pumping, draining	+/+l)	All	All	+	++r)	s)
Bio-slurping (including suction probes)	+/+t)	All	All	+	+	
In-situ remedial methods for groundwater contamination						
Air sparging	+/-	+u)	-v)	+	+	x)
Adding oxidising agents (ORC)	+/-	All	+	+	(+)y)	
Vertical cut-off barriers	+/+	(+)n)	All	All	+	
Reactive permeable barriers	+/+	All	+z)	+	(+)y)	æ)
Natural attenuation	+/-	All	+ø)	All	(+)y)	å)

a) +/- = Organic contamination
-/+ = Inorganic contamination
+/+ = Both types

b) ++ = Very volatile
+ = Volatile
- = Non-volatile

c) ++ = Very degradable
+ = Degradable
- = Non-degradable

d) ++ = Very permeable
+ = Permeable
- = Very low permeable

e) ++ = very well documented
   + = tested in Denmark
   - = effect not documented
f) Contamination position is vital
g) High environmental impact
h) Depending on method of cleansing
i) Makes great demands on surroundings etc.
j) Aerobically easily degradable substances
k) A number of plants in active use
l) Demands substance water-solubility
m) May cause problems of plant clogging
n) Depending on method, but usually chosen for high-boiling contamination
o) This method is usually selected for contamination which is difficult to degrade
p) Not used in DK
q) Requires level ground and that no rocks are found above a soil depth of
r) approximately 0.3 m. Energy-intensive
s) Good for hydraulic contamination control, but may be difficult to obtain with low acceptance levels
t) Attention must be given to problems in connection with substances with a density greater than that of water
u) Particularly useful for NAPL oil contamination
v) Stripping of contamination must be possible
w) Contamination must be degradable with bio-sparging
x) Contamination must be removed from the unsaturated zone, possibly by means of soil vapor extraction
y) Effects proven in the USA
z) Not necessarily aerobically degradable contamination
æ) Used in combination with ‘Funnel & Gate'
ø) Contamination must be proven to degrade
å) This method demands extensive monitoring

Appendix 8 Establishing quality criteria in Denmark

Exposure

Exposure pathways considered in the tolerable daily intake calculations are:

- Ingestion of soil
- Eating crops grown on contaminated soil
- Skin contact with soil
- Inhalation of fumes from soil
- Intake of drinking water that is contaminated

Through experience the intake of soil through skin or mouth by children is the limiting factor for establishing the TDI-values. Estimates for the intakes that are used in the calculations:

Intake of soil per day	**Exposure through skin per day**	**Inhalation of air per day**	**Water intake per day**
Child: 0.2 g (Maximum single intake 10 g)	Child: 1 g	Child: 10 m^3	Child: 1 litre
Adult: 0.025g	Adult: 0.1 g	Adult: 20 m^3	Adult: 2 litres

Hazard assessment and calculation of TDI

TDI is used to describe the chemical substances’ hazardous features, and establish a dose-response or dose-effect relationship for the substances. The critical effect is the effect that is determining the heath assessment. This no-effect level is used to calculate the TDI values. In Figure 47 a picture show the dose- response relation.

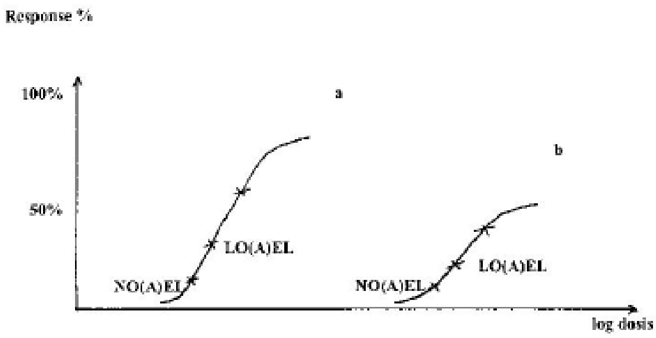

Figure 47 The dose response relationship and referring NOEL and LOEL values (Danish EPA 2006)

To assess the effects on humans health based quality criteria are established for several chemical substances considering soil and water exposure. For these substances the toxic features are analysed. An assessment to find out at what exposure levels negative effects will take place are carried out. Both acute toxic effect and quality values, i.e. smell or taste on water, are considered. The no-effect level (NOEL), sometimes this is written as the No adverse effect level (NOAEL), is used to estimate the most critical effect. If this is not available a lowest effect level LOEL, is used. From this the tolerable daily intake, TDI, is calculated. Uncertainty factors, UF, are also included in this calculation to secure that the values are not too high for anyone; i.e. that all groups of people are included (old people, children, sensitive people etc.), and uncertainties from the calculations are compensated for. TDI is calculated by the formula:

$$TDI = \frac{NO(A)EL \text{ or } LO(A)EL}{UF_1 + UF_2 + UF_3} \quad [mg/kg]$$ (TDI is normally given in mg/kg)

UF_1= used when the no-effect level is calculated from animal tests to compensate humans higher sensitive to certain sub-stances. Usually set to 10.
UF_2= used to compensate for individual variation, and to sensitive individuals, children and seniors. Usually set to 10.
UF_3= Consider uncertainties for the establishment of the no-effect level. Normally 1-10

If the uncertainty factor UF is exceeding 10 000 when multiplying the three parts, the TDI value should not be used. If there are no NOAEL values available mathematical models are used to calculate the TDI value. (Danish EPA Guideline No. 5 2006)

Analogously with the TDI a Tolerable concentration (TC) can be calculated. The TC-value tell the concentration in the soil (mg/kg), drinking water (mg/l) and air (mg/m^3 air) (Danish EPA 1990).

Calculation of quality criteria

Different quality criteria are used for soil, ground water and fumes. In these calculations it is assumed that 100 % of the intake comes from the exposure of the contaminant from the site/source. If it is known that there are other exposure pathways also exist, a percentage of the TDI contributing from the soil or water will be used.

Soil quality criteria

Calculations of TDI values are using the TDI-value and the soil exposure. The formula gives the criteria:

$$QC_{Soil} = \frac{TDI \times V \times f}{E_I (or E_S)}$$

TDI – Tolerable daily intake of drinking water (mg /kg body weight/day)
f – Percentage of TDI that is allocated for the intake of soil
V – Body weight, Child 1-3 years old; 13 kg
E_I – The daily exposure from ingestion of soil, standard values that are used:
1) 0.0002 kg/day is the 95% per tile where the whole TDI or major part of this is used for calculation of the quality criteria.
2) 0.0001 kg/day is the median value used when TDI is based on the risk ration of 10^{-6} or if the contaminated soil is contributing to a smaller part of TDI
E_S – Daily exposure through skin. Standard value: 0.001 kg/day for children

The soil quality criteria can also be expressed as the acute toxicity criteria:

$$QC_{Soil} = \frac{TD \times V}{E_I (or E_S)}$$

TD – Tolerable single dose
V – body weight, child 1-3 years old: 13 kg
E_I (or E_S) – maximum single intake of soil 0.010 kg ingestion or through contact with skin

In the calculations data about the bio accessibility, i.e. the uptake in intestinal canal should be included as far as possible, as some substances have very strong binging to particles and will have reduced bio accessibility.

Except the heath aspects the quality criteria also respect bad smell and external appearance. For soil there are no guidelines for these subjective valuations, but for smell the air quality criteria have guidelines. (Danish EPA Guideline No. 5 2006)

Drinking water quality criteria
The quality criteria for drinking water give advice for how high levels of contaminants can leach out to the ground water. The drinking water criteria can, in combination with other references, be used for establish ground water quality criteria. These criteria are not depending on the soil quality criteria. The drinking water criteria are calculated by:

$$QC_{drinkingwater} = \frac{TDI \times f}{E_{Drinkingwater}}$$

TDI – Tolerable daily intake of drinking water (mg /kg body weight/day)
f – part of TDI that is allocated to drinking water
$E_{drinking\ water}$ – Daily exposure of drinking water

1) 0.08 litre /(kg body weight,day) for children 1-10 years old (the 95:th percentile) Used for acute toxicity or when the main part of the TDI is used for calculation of the drinking water criteria
2) 0.03 litre /(kg body weight,day) for children 1-10 years old (the median value) Used for calculation of a life time risk of 10^{-6} or if a smaller part if TDI is used for calculation of the drinking water criteria

Body weight Adult – 70 kg
Daily drinking water intake – 2 litre/ day

The smell, taste and visual impression of the water is also important for the quality of the drinking water. Even if the water is not hazardous, it should also not create a negative association from substances. In several cases the smell, taste and visual impression will be the restriction for the level of substances acceptable in the water. There is also smell and taste criteria given in literature and some new values are developed from new better methods.

(Danish EPA 1995; 2006))

Air quality criteria

The evaporation from a contaminated ground should not give so high values that the quality criteria for air are exceed.

$$QC_{air} = \frac{TDI \times f}{E_{air}}$$

TDI – Tolerable daily intake of drinking water (mg /kg body weight/day)
f – part of TDI that is allocated to drinking water
E_{air} – The daily exposure of air, standard values for daily inhalation: for children 1-5 years old; 0.5 m^3/kg body weight/day

For most effects the total dose is the important, not the concentration in the air. If the exposure is only parts of the time, this is compensated for in the calculation. For example 6 hours a day, five days a week, will be corrected with a factor 6/24 for a whole day and 5/7 with continuous exposure for a week.

Some substances have a very piquant smell that is taken into consideration in the air quality criteria. When this is needed, the air quality criterion is put to 1/3 of the 50 % smell-criteria. The smell-criterion is defined as the concentration in the air where 50% of a panel of people can register the smell. 1-5 % of the population will under optimal circumstances feel the smell with the chosen level. (Danish EPA Guideline No. 5 2006)

Appendix 9 Danish prioritized hazardous substances

- Acryl amid
- Certain Alkenes and cyclic alkenes
- Alkylphenoler and alkylphenolethoxylater
- Alkylsulfonsyrephenylester
- Benzenamin, n-phenyl-, styreneret
- 1,4-Benzendiamin, N, N-mixed phenyl og totyl derivater
- Biphenyl
- Bisphenol-A
- 2,2'-Bisphenol F diglycidylether
- Lead and leadcompounds
- Boron compounds (several)
- Certain Brominated flame retardants (several)
- Butanonoxim
- Cadmium and cadmiumcompounds
- Visse chlorerede solvents (certain)
- Chlorparaffiner (kort-, mellem- og langkædede)
- Visse chromatforbindelser
- Cobalt(II)sulfat
- Creosotforbindelser med kræftfremkaldende "urenheder"
- Cyclohexan-1,2-dicarboxylsyreanhydrid (uspec.)
- Dibenzyl(methyl)benzen
- 3,4-Dichloroanilin
- Diethanolamin
- N,N-Dimethylformamid
- Ethanthiol
- Fluorerede drivhusgasser (HFC'er, PFC'er, Svovlhexafluorid)
- Formaldehyd
- Formamid
- Glutaral
- Glycidyl neodecanoat
- Visse glykolethere
- Hexahydro-4-methylphthalsyreanhydrid
- Hydrocarboner, C4, 1,3-butadien-fri, polymd., Triisobutylen fraktion, hydrogeneret
- Hydroxybenzener -hydroquinon og resorcinol
- Hydroxylammoniumsulfat
- Visse isocyanater - MDI og TDI
- Kobber og kobberforbindelser
- Kviksølv og kviksølvforbindelser
- 4,4'-Methylendianilin
- Mercaptobenzothiazol (MBT)
- Molybdentrioxid
- MTBE
- Natrium- og calciumhypochlorit
- Visse nikkelforbindelser
- 4-Nitrotoluen
- Octadecyl-3-(3,5-di-tertbutyl-4-hydroxyphenyl)propionat
- Octamethylcyclotetrasiloxan
- Certain oil products
- Certain organic tin compounds Visse organiske tinforbindelser
- Overfladeaktive stoffer, der ikke nedbrydes fuldstændigt under anaerobe forhold
- Visse parfumestoffer
- Pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl) propionat)
- PFOS forbindelser
- Phenol, 2,6-bis(1,1-dimethylethyl)-4-methyl-
- Phenylglycidylether
- Visse phthalater
- Phthalsyreanhydrid, Methyltetrahydro- (unspec.)
- Visse pigmenter og farvestoffer
- Propylenoxid
- Styren
- Terphenyl (unspec.)
- Thiram
- Certain Tar-products
- Triglycidylisocyanurat
- Triphenylphosphit
- Tris(2-chlorethyl)phosphat
- Tris(2,4-di-tert-butylphenyl)phoshit
- Zink