SWEDISH ENVIRONMENTAL PROTECTION AGENCY

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Compendium Remediation of Contaminated Sites in Sweden

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An overview of the process involved in the
remediation of contaminated sites in Sweden

Version 1

SWEDISH ENVIRONMENTAL
PROTECTION AGENCY

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Cover photo: Rebecka Karlsson, Swedish EPA.

Preface

This document provides a brief overview of the process involved in the remediation of contaminated sites in Sweden. It is aimed to be a complement to be used in the international cooperation of the Swedish Environmental Protection Agency to contribute to the exchange of ideas on how to improve the global environment.

It is not a guidance document and should not be used as such.

This document will be updated when necessary.

Stockholm 30 June 2021

Johanna Farelius
Deputy Head of Department
Sustainable Society Department

Abbreviations

BAT	Best Available Technology
DW	Dry Weight
EU	European Union
EQS	Environmental Quality Standards
ISO	International Organization for Standardization
SDGs	Sustainable Development Goals
SGI	Swedish Geotechnical Institute
SGU	Geological Survey of Sweden
SWaM	Swedish Agency for Marine and Water Management
Swedish EPA	Swedish Environmental Protection Agency
UCLM	Upper Confidence Limit of the Mean
UN	United Nations
US EPA	United States Environmental Protection Agency

Contents

Overview

The Swedish Environmental Protection Agency is involved in international cooperation with numerous countries and in various regional and multilateral forums. This document aims to describe the process involved in the remediation of contaminated sites in Sweden. It is intended to provide an overview of all steps involved in the process, from the identification of a contaminated site to choosing a suitable remediation method. It is aimed to be a complement to be used in the international cooperation of the Swedish Environmental Protection Agency to contribute to the exchange of ideas on how to improve the global environment.

The first part of this document offers an introduction to the Swedish system, including how Sweden is governed and a brief overview of the driving forces behind the environmental work connected to the remediation of contaminated sites in Sweden. It also describes the tools available to reach the goals set to ensure a safe environment for present and future generations. The second part of this document describes the process behind the remediation of contaminated sites. It is meant to explain what the process looks like in Sweden with respect to Swedish laws and working methods.

The guidance documents produced by the Swedish Environmental Protection Agency are meant to be applicable to any site or contamination and does therefore not include specific remediation methods. Each study site is unique and must be treated accordingly. The effectiveness of a remediation method is influenced by the properties of the contaminant, the size and characteristics of the contamination, as well as the local conditions at the site including factors such as geology, surface water and groundwater conditions and chemistry, land use and climate.

Levels of Government

There are three levels of government in Sweden. At the national level, there is the Swedish Parliament, which consists of 349 members who are elected every four years. Alongside the Parliament, there is the bureaucratic government, which constitutes of a prime minister and 22 ministers. The government is the driving force in the process of legislative change. There are also various governmental agencies of which one is the Swedish Environmental Protection Agency (Swedish EPA). Additional government agencies working closely with environmental issues are, for example, the Geological Survey of Sweden (SGU), the Swedish Geotechnical Institute (SGI), the Swedish Agency for Marine and Water Management (SwAM), the Swedish Chemicals Agency and the Swedish Food Agency.

The Swedish Constitution contains provisions defining the relationship between decision-making and executive power. The Swedish Parliament enacts laws, while the government issues regulations which expands upon and clarifies the laws issued by the parliament. Governmental agencies, like the Swedish EPA, can in turn issue instructions which provide further details relevant to interpreting the regulations issued by the government. All of these are legally binding.

At the regional level, there are 21 County Administrative Boards, a level of government immediately subordinate to the national government. At the local level there are 290 municipalities. The County Administrative Boards and the municipalities are the enforcement authorities for issues regarding environmental hazardous activities. The Defence Inspectorate for Medicine and Environmental Health is the enforcement authority for the Swedish Armed Forces' environmentally hazardous activities. There are no law-making powers at the regional or local level. The regional and local authorities must always exercise their powers in accordance with national legislation. Nor is there any hierarchical relation between the counties and the municipalities.

On entering the European Union (EU) in 1995, Sweden acquired a further level of government: the European level. As a member of the EU, Sweden has a direct influence on and is directly affected by EU decisions. Sweden is represented by the Swedish Government in the European Council of Ministers, which is the EU's principal decision-making body. More information about how Sweden is governed is available on the website of the Swedish Government: www.government.se.

The Swedish constitution includes four fundamental acts. One of these is the Instrument of Government that outlines the basic principles of Sweden’s form of government and how regulations are enacted. The Instrument of Government states that public institutions shall promote sustainable development leading to a good environment for present and future generations (Instrument of Government chapter 1, article 2).

Driving forces

This chapter will briefly describe the driving forces behind the environmental work connected to the remediation of contaminated sites in Sweden.

Swedish environmental law

This chapter describes the general structure of Swedish environmental law and how it connects to the remediation of contaminated sites. A more detailed description of Swedish environmental law can be found in the Swedish EPA report *Swedish Environmental Law - An introduction to the Swedish legal system for environmental protection* (Swedish EPA, 2017). The report is available on the Swedish EPA website.

Sweden has developed a three-instance system of special courts for matters pertaining to environmental law as well as matters of property registration, planning and building. This system consists of five Land and Environment Courts, the Land and Environment Court of Appeal and the Supreme Court.

It was not until 1969 that Sweden got its first Environmental Protection Act and it dramatically strengthened the role of the State in the protection of the environment. Amongst other things, it included a permit regime for environmentally hazardous activities and introduced provisions concerning environmental damages and compensation. Another new feature of the Environmental Protection Act compared to earlier legislation was provisions concerning the remediation of contaminated sites. Initially limited to cases where the contamination of one area could potentially lead to the contamination of other land or water areas, these provisions essentially stipulated that anyone who had polluted an area was also responsible for the remediation of that area. In 1989, these provisions were strengthened to assign responsibility for remediation of sites solely on the basis that a site was contaminated.

The Environmental Code is Sweden's most comprehensive piece of environmental legislation and entered into force on 1 January 1999. The Environmental Code (the Code) was based on 15 environmental acts, which were all reviewed and consolidated into one single act. As a result, the Code has a broad scope. Apart from material provisions, the Code also sets out the basic framework for implementing environmental protection through its provisions concerning procedure, supervision, sanctions, compensation and environmental damages. The purpose of the Code is to promote sustainable development. The Code applies to all persons and operators who undertake activities or measures which may have an impact on the fulfilment of the objectives of the Code. The Code consequently applies to all activities which could cause negative impacts on human health or the environment. Furthermore, government agencies, including the Swedish EPA, issue general guidelines providing assistance concerning the interpretation of the Code and underlying legislation.

Contaminated areas are often related to industrial sites contaminated by inadequate management of chemicals and/or waste, or from inadequate or non-existent treatment of wastewater. Contamination has been caused by both public enterprises and private companies. In many cases, contamination is caused by substances, operations or waste disposal methods that are not in accordance with current environmental legislation. Chapter 10 of the Environmental Code contains provisions concerning contaminated sites and the remediation thereof. There it is stated that the operator, who is currently operating or previously operated a site which is polluted, is considered liable for conducting investigations and if necessary, remediation, of the site. A property owner who at the time of acquisition (e.g. through purchase, gift or inheritance) knew about the contamination or reasonably should have known about it may also be deemed liable. The above is based on what is often called the "Polluter Pays Principle". However, if a polluting activity ceased before the introduction of the Environmental Protection Act in 1969, the polluter cannot be held liable. Where a responsible polluter cannot be identified or held responsible, public funding may be used to conduct investigations and remediation. This funding is administered by the Swedish EPA.

The general rules of consideration assign a responsibility for operators to minimize and control the environmental impact of their activities and has led to the establishment of a system of compliance based on self-monitoring by operators.

To supplement the Code, the Swedish Parliament adopted a system of national environmental objectives in 1999. The environmental quality objectives outline the intensions of the Parliament for the environmental work, while the Environmental Code is a policy instrument used to obtain these objectives. All provisions in the Environmental Code should be applied to ensure that the goals of the Code are met in the best possible way. If there is uncertainty about a decision, the environmental objectives should work as guidance and the final choice shall be the option that is most likely to promote sustainable development (Environmental Objectives Bill 2000/01:130 and Environmental Code Bill 1997/98:45).

Environmental quality objectives

The overall goal of Swedish environmental policy is "to hand over to the next generation a society in which the major environmental problems in Sweden have been solved, without increasing environmental or health problems outside Sweden's borders" (*The Generational Goal*).

In 1999 the Swedish Parliament adopted 15 national environmental quality objectives, and in 2005 a 16th objective was added (Figure 1). These objectives are not legally binding and are instead meant to be used as a guide in the decision-making process on environmental issues by outlining the intentions of the Swedish Parliament.

The environmental objectives Sweden has adopted are of three different types. One is the generational goal, which defines the overall direction of environmental efforts. The generational goal is intended to guide environmental action at every level of society. To facilitate those efforts, and to make the generational goal more tangible, there are also the 16 environmental quality objectives and several milestone targets. The milestone targets are designed to set out the changes in society that needs to occur in order to attain the generational goal and the environmental quality objectives.

Sweden's environmental objectives system is an established system that has involved systematic monitoring for many years. The environmental objectives are more precise in terms of the environmental quality required for a good environment than the goals in Agenda 2030[1]. This level of detail is needed in order to monitor environmental progress and, in doing so, to understand which measures to prioritise.

Sweden's environmental quality objectives and its outdoor recreation objectives form the basis for the work of the Swedish EPA. The environmental quality objectives address the environmental dimension in Agenda 2030 and the outdoor recreation objectives relate to the environmental, social and economic dimensions.

Figure 1. The 16 Swedish Environmental Quality Objectives (Illustrated by Tobias Flygare).

[1] In September 2015, the United Nations General Assembly adopted a resolution containing 17 Sustainable Development Goals (SDGs) for a better world: Transforming our world: the 2030 Agenda for Sustainable Development (United Nations General Assembly, 2015). The goals were specified in more detail in 169 targets and 231 global indicators. Sustainable development meets the needs of present generations without compromising the possibility of future generations to meet theirs. It is not possible to achieve lasting sustainability without addressing the three dimensions of sustainability: economic-, social- and environmental sustainability. No goal can be achieved at the expense of the others – and success is required in all areas for the SDGs to be reached.

The 16 environmental quality objectives describe the quality of the environment that Sweden wish to achieve. These objectives are:

1) Reduced climate impact
2) Clean air
3) Natural acidification only
4) A non-toxic environment
5) A protective ozone layer
6) A safe radiation environment
7) Zero eutrophication
8) Flourishing lakes and streams
9) Good-quality groundwater
10) A balanced marine environment, flourishing coastal areas and archipelagos
11) Thriving wetlands
12) Sustainable forests
13) A varied agricultural landscape
14) A magnificent mountain landscape
15) A good built environment
16) A rich diversity of plant and animal life

Detailed descriptions of each of the environmental quality objectives are presented in the report: *Sweden's Environmental Objectives – an introduction* (Swedish EPA, 2018). The report is available on the Swedish EPA website. More information can also be found at www.sverigesmiljomal.se.

The environmental quality objective most essential for the work concerning remediation of contaminated sites is objective No. 4, A non-toxic environment:

"*The occurrence of man-made or extracted substances in the environment must not represent a threat to human health or biological diversity. Concentrations of non-naturally occurring substances will be close to zero and their impacts on human health and on ecosystems will be negligible. Concentrations of naturally occurring substances will be close to background levels".*

For each objective, there is a number of 'specifications', which clarify the state of the environment that is to be attained. The specification most essential for the work concerning remediation of contaminated sites is: "Contaminated sites are remediated to such an extent that they do not represent a threat to human health or the environment".

Other environmental quality objectives connected to the work with remediation of contaminated sites are for example objective No. 8, 9, 10, 15 and 16.

Tools

To obtain the goals of the Environmental Code and the national environmental quality objectives, several tools have been developed. Among these are government grants to fund the investigation and remediation of contaminated sites where no liable party can be identified, and national guidance documents which state how the work connected to the remediation of contaminated sites should be carried out in Sweden.

The role of the Swedish EPA is to coordinate, prioritise, provide guidance and to follow-up on the remediation of contaminated sites at a national level. The Swedish EPA also administers governmental grants for the remediation of contaminated sites and evaluates their effects. Furthermore, the Swedish EPA is involved in international work concerning remediation of contaminated sites, both within the EU and globally.

Enforcement

The enforcement authorities (municipalities, County Administrative Boards and/or Defence Inspectorate for Medicine and Environmental Health) should make sure that contaminated sites are assessed by identifying who may be held responsible for the contamination and demand that they carry out the investigations and remediation of which the liable party is obliged to carry out according to the Environmental Code. This work is an important step towards reducing exposure to hazardous substances that can harm both human health and the environment.

The work performed by the enforcement authorities is governed by local and regional priorities for the contaminated sites of which each authority is responsible. When, for example, a municipality wants to establish a new zoning plan, the area must usually be investigated to see if there are contaminants present that can affect the land use at the site. Then the enforcement authority is involved in the consultation.

When there is a suspicion that a site might be contaminated, it should be reported to the enforcement authority. The authorities are to determine if there is someone who can be held liable to carry out investigations to confirm that the site truly is contaminated. If it is determined that a liable party exists, they are compelled by law to conduct investigations, and if needed, remediation according to the “Polluter Pays Principle”. The liable party can be any operator, either a private company or a company owned by the government.

If a contamination is detected, for example during excavation of trenches or during investigations performed prior to property sales, the operator is compelled by law, to promptly inform the enforcement authorities. The authorities then decide how to proceed and if actions are needed to prevent the contamination to cause detriment to human health or the environment.

If there is not enough knowledge about the site conditions and/or the contamination to do the assessment, the responsible operator is compelled to investigate the extent of the contamination, as well as what risks it may pose to human health and the environment. If the operator or other liable party do not fulfil their obligations, or if the results of the investigations, risk assessment or other parts of the remediation process have to be improved, the enforcement authorities can demand more extensive investigations, remediation and/or documentation.

When enough information has been gathered about the contaminated site to be able to choose a remedial alternative, the liable party apply for a permit to the enforcement authorities to perform the remediation, including preventive measures. If necessary, the authorities may demand additional preventive measures that should be applied during the remediation, such as actions to prevent transport of contaminants to nearby areas before the remediation can be carried out. During inspections of the ongoing remediation and during the review of the final reports from the remedial principal, additional demands can be made. The enforcement authorities also provide guidance on how the result of the remediation should be presented.

The general rules of consideration in the Environmental Code assign a responsibility for operators to minimize and control the environmental impact of their activities and has led to the establishment of a system of compliance based on self-monitoring by operators.

By the Ordinance of self-monitoring, the operator/ liable party must also systematically examine, identify and assess the environmental risks connected to the activity and take adequate corrective actions. This includes identifying situations that could lead to non-compliance. The operator is obliged to keep himself informed about the activity’s impact on the environment.

During remediation, the operator must control if the surrounding areas are negatively affected by the remediation activities and immediately take preventive measures if needed. When the remediation is finalized, the operator has to show the enforcement authorities that the remediation has been satisfactory by data from measurements of residual contamination and the reduction of risk.

Excavation and transport of contaminated soil to a landfill is a common remediation alternative, although other methods should be considered. In Sweden, we are striving towards using alternative methods. To ensure that any contaminated soil, if transported from a site, is handled in an environmentally safe way, the transporters must have a license to show they fulfil the obligations by law for safe transport of hazardous waste. The contaminated soil or waste must also be transported to a licenced facility for waste management. No hazardous waste should be dumped anywhere else as it can cause harm at the dump site and in the surrounding areas and cause another contaminated site. To ensure that waste and contaminated soil and water are transported to a suitable facility, the receipt of waste is documented by the facility and the liable party has to send the receipts to the enforcement authority if demanded, to prove that the waste has been handled correctly. The liable operator presents the result of the remediation in a report to the authority, who review the report and if the documentation is complete the authority can close the case.

Depending on the site-specific conditions and the characteristics of the contaminants, different remediation alternatives may be more suitable. If in situ or on-site remediation is considered to be the best option, there must be results from investigations to show that the techniques can be successfully applied at the site. This could, for instance, be the presence and effectiveness of suitable microbes for degradation of a specific organic contaminant, as well as the right oxygen conditions and a sufficiently permeable soil layer.

Where a polluter cannot be identified or held responsible, and the contaminated site pose a high, or very high risk, to human health or the environment, public funding may be used to conduct investigations and remediation.

Government grants

There is a government grant for remediation of contaminated sites that is managed by the Swedish EPA and that may be used to fund investigations, site studies and remediation of contaminated sites when no liable party can be found, so called "Orphan sites" (Government Bill 2008/09:217). How the grant should be applied is regulated in the Ordinance (SFS, 2004:100) "Government grants to fund remediation of contaminated sites". Ordinance (2004:100) include the Commissions regulation (EU) No. 651/2014 of 17 June 2014 declaring certain categories of aid compatible with the internal market in application of Articles 107 and 108 of the Treaty (text with EEA relevance).

In 2016, the Swedish government decided to introduce an additional governmental grant for the remediation of contaminated sites to be used as residential areas. The purpose of this grant is to promote the redevelopment of contaminated areas that are no longer in use, instead of using new areas for residential purposes. This helps the environment by reducing contaminants that can harm both human health and the environment, as well as keeping undeveloped, open land, intact to preserve their ecosystem services and to be used for recreational purposes.

If it is concluded that there is no existing liable party to pay for the investigations and remediation of a contaminated site, or if there is limited liability, government grants may be used. In such cases, the municipality applies for funding for the remediation of a site within its region to the County Administrative Board. The County Administrative Board prioritise among all the applications within its county and then makes an application for funding to the Swedish EPA. This chain is illustrated in Figure 2.

The Swedish EPA can approve funding on a 10-year basis, which makes it possible to make long-term plans and make sure that there is funding for remediation projects that proceed over several years.

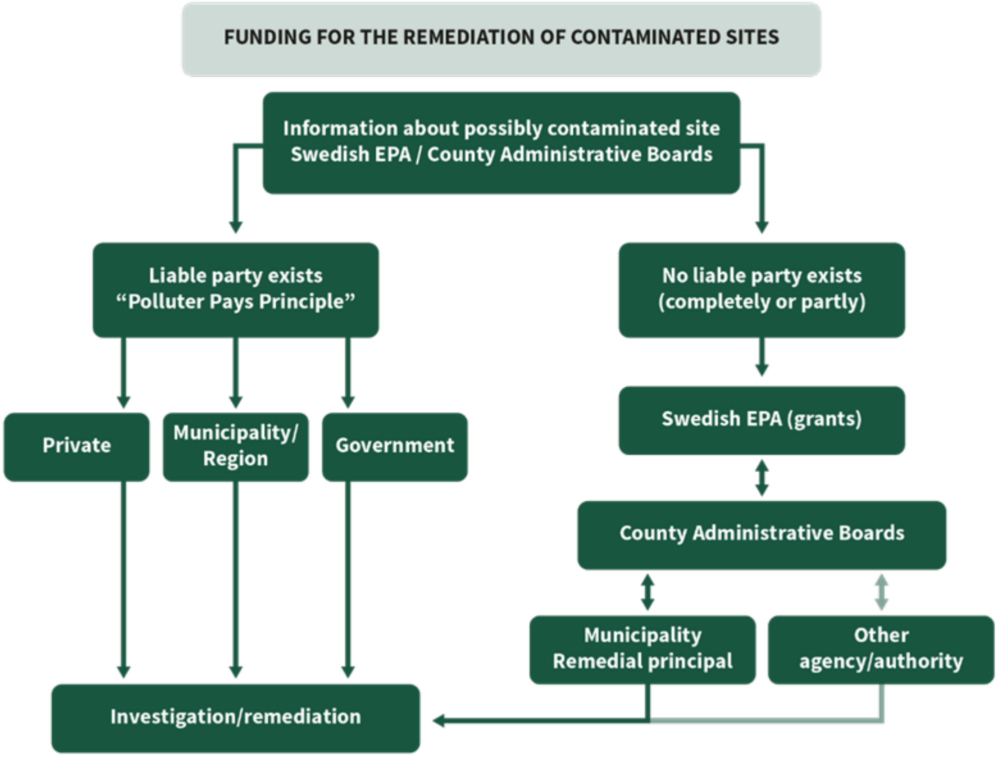

Figure 2. A schematic illustration of who may be held liable to fund the investigation and remediation of a contaminated site in Sweden.

Stakeholders involved

The Swedish EPA has been working with remediation of contaminated sites for several decades together with the County Administrative Boards and local municipalities. But there are many other organizations contributing in the work on remediation of contaminated sites – including the Geological Survey of Sweden (SGU), the Swedish Geotechnical Institute (SGI) and the Swedish Agency for Marine and Water Management (SwAM), as well as higher education institutes and private operators (Figure 3). The Swedish Geotechnical Society and "the Clean Soil Network" (*Nätverket Renare Mark*) are non-profit networks of organizations including consultants, researchers, government authorities, and remedial contractors who coordinate the exchange of information and experiences in meetings, conferences, and courses.

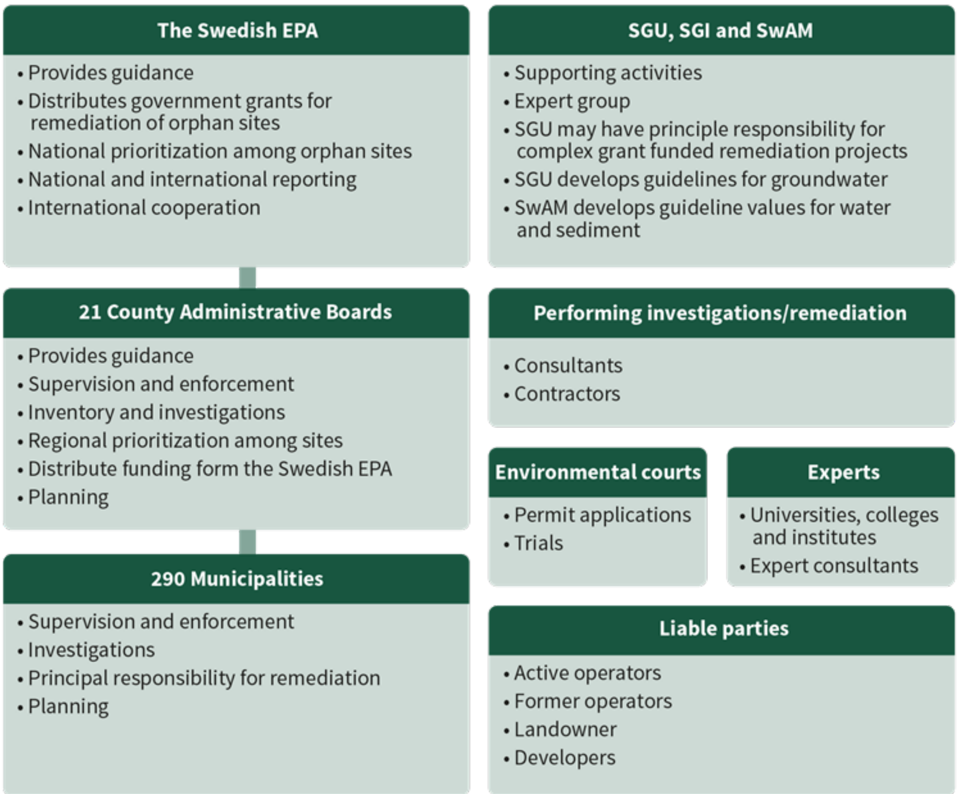

Figure 3. Stakeholders and their different roles in the remediation process.

International networks

The Swedish EPA is involved in several international networks to discuss matters concerning remediation of contaminated sites and to exchange knowledge and experience in meetings and conferences. Two important platforms for this exchange are NORDROCS and COMMON FORUM.

The Swedish non-profit organization "the Clean Soil Network" (*Nätverket Renare Mark*), and corresponding organizations in the other Nordic countries, organize an international conference called Nordic Meeting on Remediation of Contaminated Sites (NORDROCS) to share knowledge and discuss issues connected to the remediation of contaminated sites. The main objective for NORDROCS is “Crossing Borders” with the goal to share and discuss the way contaminated land is managed within the Nordic countries. More information about NORDROCS is available on their website: www.nordrocs.org.

The COMMON FORUM on Contaminated Land was initiated in 1994 and is a network for policy makers, regulators and technical advisors with expertise in the field of contaminated sites from Environment Authorities of the member states of the European Union, as well as countries within the European Free Trade Association. COMMON FORUM is a platform for the exchange of knowledge and experience, for initiating and following-up on international projects among member states and is an important way of sharing information about recent development in the field of contaminated land within the European countries. More information about COMMON FORUM is available on their website: www.commonforum.eu.

Guidance documents

The Swedish EPA has produced several reports providing guidance on how to work with contaminated sites in Sweden, from conducting inventories of possibly contaminated sites, to choosing a suitable remediation method to remediate a specific site. The Swedish EPA report: *Methods for inventories of contaminated sites. Environmental quality criteria, Guidance for data collection* (Swedish EPA, 2002) provides guidance on the method that should be applied while conducting an inventory of contaminated sites in Sweden.

The Swedish EPA, in collaboration with other experts, has produced three main guidance reports that described all necessary steps involved in the remediation of contaminated sites in Sweden. The guidance in the reports are applied by all stakeholders involved in the process, including the consultants and contractors who perform the investigations and remediation, as well as the enforcement authorities. The first report "Choosing a remediation method. A guide from formulating remediation goals to quantifiable remedial objectives" (Swedish EPA, 2009a) provides a general overview of all steps involved in the remediation process, while the second report "Risk assessment of contaminated sites. A guide from simplified to detailed risk assessment" (Swedish EPA, 2009b) provides a more detailed description of how to conduct a risk assessment. The third report "Guideline values for contaminated sites. Model description and guidance" (Swedish EPA, 2009c) provides guidance on how to derive site-specific guideline values using a model for calculation of acceptable levels of contaminants, depending on land use and specific site-conditions. The contents of these three reports are summarized in the second part of this document: The Remediation Process.

The Swedish EPA has also developed a guidance report to describe how the Environmental Code is to be applied in the remediation of contaminated sites and to gather established practice within the field (Swedish EPA, 2012). The purpose of the report is to clarify who may be held responsible to conduct investigations and remediation of a contaminated site. It also creates better basis for the enforcement authorities to demand the remediation of which the liable party is obliged to undertake.

The knowledge-based programme Sustainable Remediation (*Hållbar Sanering*) was initiated to increase the knowledge on remediation of contaminated sites and was a part of the Swedish EPA's work towards achieving the environmental quality objective "a non-toxic environment". During the programme period from 2003 to 2009, about 50 projects were carried out within the following five main areas: Site investigations, Risk assessment, Risk evaluation, Risk communication and Remedial measures. The results of these projects were presented in a series of reports and each report contains a short summary in English. In order to provide an overview of the accumulated knowledge gathered by the programme, the most important results from the five areas have been identified and summarized in a single report, which is also available in English. The reports are available for download on the Swedish EPA website: www.naturvardsverket.se/publikationer.

The government Ordinance (SFS 2004:100) “Government grants to fund remediation of contaminated sites” states that the Swedish EPA should produce a national plan for the remediation of contaminated sites, which should include a plan for how to prioritise among the applications to receive funding. The “National Plan for prioritising applications for government grants for the remediation of contaminated sites” (Swedish EPA, 2020) contains priority basis and selection criteria for the grant applications from the Country Administrative Boards. It is a tool to make sure that the government grant is used where it is most needed/effective to ensure the health of both humans and the environment. The national priority aims to promote:

- Prevention of acute and serious risks
- Remediation prompted by regulatory control
- Innovation of remediation techniques, methods and work procedures
- Completing ongoing remediation projects
- Regards to climate related risks
- Effective management of grants
- Reduced total contaminant load of recipients
- Remediation to turn contaminated sites into residential areas

In addition to the National Plan, the Swedish EPA also produce a manual to ensure the quality of the remediation projects that have received government funding, “Kvalitetsmanualen” (Swedish EPA, 2021). This manual is an extension of Ordinance 2004:100 and works as a guide for the County Administrative Boards on how to write their applications for funding. The manual, as well as the national plan, are continuously updated to ensure that they are up to date with changes in the legislation.

The Remediation Process

Remediation is needed when a land or water area, a building or a facility is contaminated to such an extent that it entails unacceptable risks to human health, the environment or natural resources. Remedial actions are intended to reduce such risks to acceptable levels. Remediation may also be required for other reasons, e.g. in connection with redevelopment. Since selection of suitable and cost-effective remediation methods lies at the core of a remediation project, it is important that the remedial alternative selection process is well-founded and transparent.

This part of the report will summarize the content of the three main guidance reports concerning remediation of contaminated sites in Sweden (Swedish EPA 2009a, 2009b and 2009c), and will also include some additional information from other reports published by the Swedish EPA to provide an overview of how contaminated sites are managed in Sweden. All reports are listed in the reference list at the end of the report.

Remediation of contaminated sites often involves complex projects that have to be assessed in steps. Each step increases the knowledge about the site and which remedial alternative that is the most suitable for the conditions at the specific site. The process entails the following steps: formulation of remediation goals, investigations and studies, risk assessment, evaluation of remedial alternatives, selection of a remedial alternative, and formulation of quantifiable remedial objectives (Figure 4). During the process, the number of possible remedial alternatives is reduced step-by-step using a range of criteria (remedial alternative evaluation and selection criteria).

The Swedish EPA's principles for site remediation should work as a guide through the entire remediation process.

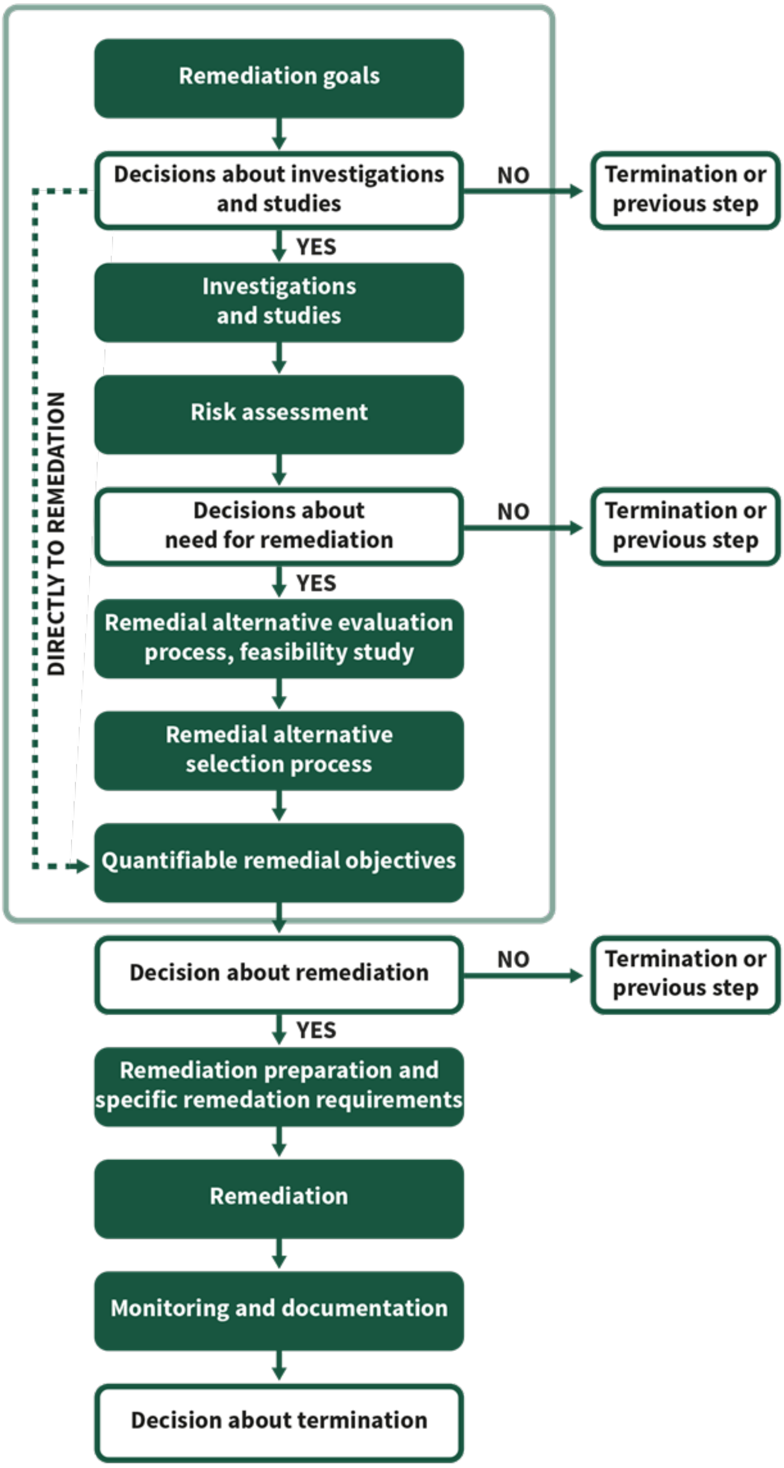

Figure 4. A schematic illustration of the remediation process in Sweden.

The Swedish Environmental Protection Agency's principles for site remediation

The overall purpose of remediation of contaminated sites is the long-term reduction of risk of damage or inconvenience to people's health, the environment or natural resources, and a reduction of metals and non-naturally occurring substances in the environment. Site remediation in Sweden is based on the Environmental Code and the environmental quality objectives issued by the Swedish Parliament.

The Swedish EPA has formulated important principles for site remediation in Sweden. The principles have been formulated from a long-term sustainability perspective in order to protect human health, the environment, and natural resources, now and in the future. The principles are reflected in the investigation methodology prescribed by the Swedish EPA and in the generic guideline values for contaminated land. The most important principles are listed below.

Assessment of risks to human health or the environment from contaminated sites should be carried out from both a short-term and long-term perspective.

It is important to examine what can happen from a long-term perspective, for example with regards to lingering contamination, where the long-term performance of protective/control measures, and future changes to land use must be considered.

Groundwater and surface water are natural resources which are almost always worthy of protection.

The environmental quality objectives state that future generations shall have access to groundwater and surface water which provides safe and sustainable drinking water and contributes to a good living environment for plants and animals in lakes and streams. Lakes and streams shall be ecologically sustainable and their diverse living environments shall be preserved.

The transport of contaminants from a contaminated site should neither result in an increase in the background levels, nor emissions which pose a long-term risk of reducing the quality of surface water and groundwater resources.

Even if adjacent groundwater and surface water is not considered an important receptor, they are interlinked with other bodies of water and can contribute to diffuse pollution. The basic principle is thus to protect the environment as a whole and people's health in particular.

Sediment and aquatic environments shall be protected so that no disruptions arise in the aquatic ecosystem, and so that especially protection-worthy and valuable species are protected.

Good water quality in lakes, streams, and coastal environments is crucial to the aquatic and marine biological life. Once contaminants have entered a watercourse, they can spread far, rapidly, and affect ecosystems within a large geographical area. One national objective for the environmental work is also for fish in Swedish seas, lakes, and streams to be fit for human consumption in terms of their content of anthropogenic substances.

The soil environment shall be protected so that the ecosystem's functions can be maintained to the extent needed for the intended land use.

The level of soil protection should correspond to a level where the soil can fulfil the functions expected within the intended land use. Long-term thinking is the main reason for always considering the preservation of a certain ground function.

The goal shall be to have equal protection levels within an area which has the same overall land use, such as a residential area.

With the same long-term sustainability approach, divisions with different requirements (different quantifiable remedial objectives) at different depths or in a plane shall be avoided where possible from a technical and financial standpoint. The risk of potentially remaining contamination can be hard to assess from a long-term perspective. The land use in a subarea can change the transport conditions, for example via groundwater, and contaminants may be moved around during earthworks. In practice, it is difficult to handle various restrictions for small volumes or surfaces. This means that information regarding potentially remaining contaminants at the site needs to be preserved to avoid incorrect handling in the future.

The exposure from a contaminated site should not constitute the full exposure which a person can tolerate.

People are exposed to contaminants in numerous ways, via air, food, water, consumer products, pharmaceuticals and in their work environment. Contaminated sites are thus one of many sources of exposure to contaminants. Based on this, the Swedish Environmental Protection Agency does not believe that exposure from a contaminated site should constitute the full tolerable daily intake.

Inventory

The first step in the remediation process is to identify areas that could be contaminated. A contaminated site is, according to the Swedish EPA definition, a well-defined area for which the level of contamination from one or more point-sources significantly exceeds the relevant background level (natural or due to large-scale diffuse pollution). A contaminated site can consist of a landfill or an area of contaminated soil, groundwater, surface water or sediment, as well as buildings and facilities. The pollution of land and water by industrial activities has occurred over a period of several hundred years, resulting in a large number of landfills and other contaminated sites.

During the inventory, information about the history of the site and previous operations as well as influencing environmental factors are compiled. This information should constitute the documentation required to perform a risk classification of the site, to plan a general investigation and for an assessment of the issue of liability.

Environmental quality criteria are used to assess individual contaminated sites, which can range in size from a petrol station to a large industrial complex or part of a groundwater system that has been polluted by a point source. The criteria have been developed primarily for the investigation of contaminants that have been in the ground for a long period of time, but they may also be applied to more recent, acute problems.

The purpose of the criteria is to permit a comprehensive assessment of the risks associated with specific contaminated sites, even in cases for which available data are limited. The results are intended to provide a basis for the setting of priorities and for decisions concerning additional investigations, remediation, the declaration of a hazardous site, or other measures. The area is assigned to one of four risk classes as a result of the assessment, indicating the level of risk to human health and the environment:

Class 1: Very high risk
Class 2: High risk
Class 3: Moderate risk
Class 4: Low risk

Many different aspects within the context of the following four general issues are considered in the classification:

- **A hazard assessment**: Which contaminants are present and how dangerous are they?
- **The contamination level**: What is the level of each contaminant in each media they occur? What is the total amount of each pollutant? What is the total volume of contaminated material?
- **The migration potential**: How rapidly does the pollutant spread through various media?

- **Sensitivity/protection level of people, plants and/or animals**: How sensitive are the exposed groups, present and future? What are the potential risks, present and future?

Only a small portion of the information required for risk classification is derived from environmental monitoring programmes or site investigations and surveys. Most of the data is generated by literature-, archive- and map studies. The information gained from the inventory is used to determine which contaminants to expect at the site and thus to analyse for, and in which medium the contaminants can be expected to occur and thereby sample them.

A method has been developed for the assessment of risks on a uniform basis and with a reasonable degree of reliability. By applying a uniform method, sites can be compared in order to set priorities for further investigation and remediation, and to make decisions about hazardous and suspected hazardous sites. This method is described in detail in the Swedish EPA report: *Methods for inventories of contaminated sites. Environmental quality criteria, Guidance for data collection* (Swedish EPA, 2002), which is available on the Swedish EPA website. The report is a complete guide for all the steps involved in conducting inventories of contaminated sites. The guidance report describes the environmental quality criteria used to assess individual contaminated sites and explains how to collect the necessary data, plan and carry out the required sampling and analysis. The report also contains information on quality assurance and safety issues.

National inventory of potentially contaminated sites

In order to identify contaminated sites in Sweden the County Administrative Boards have, with the support of the Swedish EPA, carried out an extensive inventory of sites which previously had, or currently have operations that can cause contamination of soil, sediment, surface water and groundwater. Examples of such activities are chemical industries, dry cleaners, mines or sawmills. The inventory was conducted between 1999 and 2015 and resulted in the identification of approximately 85 000 potentially contaminated sites in Sweden, of which around 26 000 are classified according to potential risk. About 1 200 of these sites are classified as risk class 1 and could constitute a "Very high risk to human health and the environment", and around 8 000 sites are classified as risk class 2, "High risk to human health and the environment". Sites in class 1 and 2 are prioritised to receive funding from the Swedish EPA to be investigated and, if needed, remediated.

However, identifying a site as risk class 1 during the inventory does not necessarily mean that it is contaminated to such an extent that it poses a very high risk to human health and the environment. Site investigations and studies have to be conducted to verify if the site is actually contaminated.

A database has been created to manage site-specific soil contamination data. This database contains data on potentially contaminated sites, sites that have been declared contaminated, sites that have already been remediated and sites that have been declared clean. For the database to fulfil its purpose it is important that new information and results from the different steps of the remediation process are added to the database.

Today, approximately 128 of the most severely contaminated sites in Sweden have been remediated with funding from the Swedish EPA.

Remediation goals

Remediation goals should be formulated early in the remediation process, as the risk assessment is performed based on these goals. Depending on how these goals are formulated, some remediation methods can be excluded or deemed more appropriate, which should be considered when performing the remedial alternative evaluation process and remedial alternative selection process.

The remediation goals states what should be obtained by the remediation. Primarily, they state what use and function the site should have after it has been remediated, as well as what level of contamination can be considered an acceptable risk within the site or the surrounding areas. The remediation goals also take the current land use into consideration.

The formulation of the remediation goals is dependent on the type of contaminated site they represent. For example, the remediation goals will most likely be quite different for an abandoned mining site, which will primarily affect the surrounding environment, compared to the remediation goals formulated for an abandoned industrial site to be used for residential purposes, in which the risk of harming the health of future residents is the primary concern.

Several aspects have to be considered when formulating the remediation goals:

- The principles for site remediation formulated by the Swedish EPA
- The policies and stand points of the practitioners
- The economical basis for the project
- Specific site conditions
- Legal basis
- The environmental quality objectives

It is also important to think long-term. The remediation goals should be formulated in such a way that no additional measures are required to maintain the goals after the remediation has been completed. The goals should also encourage recycling and re-use, and materials and energy should be used as efficiently as possible. The remediation goals may be expressed in different ways, either as risk reduction, a reduction of contaminant concentration or volume, reduced transportation of contaminants to the surrounding environment, reduced exposure, protection of natural resources or as protection of the current land use, or other interests.

The remediation goals should be formulated in such a way that they can easily be translated into quantifiable remedial objectives. If this is not the case, the remediation goals should be reformulated. Specific remediation requirements are formulated to define in detail what is needed in order to obtain the quantifiable remedial objectives.

The relationship between the environmental quality objectives, the remediation goals, the quantifiable remedial objectives and the specific remediation requirements are illustrated in Table 1.

Table 1. An example of how the environmental quality objectives, remediation goals, quantifiable remedial objectives and specific remediation requirements may be formulated for a hypothetical remediation scenario.

Environmental Quality Objectives	**Remediation Goals**	**Quantifiable Remedial Objectives**	**Specific Remediation Requirements**
The site should be suitable for its intended land use and constitute a good living environment.	The site should be in such a condition that it can be used for residential purposes. Potential risks for the residents posed by the contamination should be at a low risk level.	The Mercury concentration within the site should not exceed the site-specific guideline value of 1 mg/kg dw.	4000 m^3 of soil should be removed and sent to an approved facility for waste management.

Investigations and studies

When planning the investigations at a contaminated site, it is important to consider possible risk and potential need for remedial actions, including potential receptors that may be affected by the contamination, to make sure that the investigations can deliver the necessary information required for the rest of the process. The investigations provide supporting documentation that is processed and evaluated in the risk assessment, remedial alternative evaluation process and remedial alternative selection process, as well as in the formulation of quantifiable remedial objectives. A good supporting documentation is of great importance in the process of choosing a remedial action.

The documentation must include information regarding:

- The history of the site (such as e.g. previous industrial operations and substances that have been used in the processes)
- Soil conditions
- Sequence of strata
- Presence of surface waters
- Groundwater level and flow direction
- Sediments
- Buildings and facilities
- Presence of contaminants (their concentrations, amounts and spatial distribution) in different media
- Results of reference investigations to determine background levels
- Certain forecasts regarding possible future changes within an area, from both a short-term and long-term perspective, for example in terms of expected changes

in precipitation patterns or water levels caused by climate change, can also be of interest.

All of this information is compiled in a conceptual model that is used as a guide through the remediation process. The conceptual model can then be used to identify knowledge gaps and to identify risk objects, and thereby be used to develop a plan for how to proceed with further investigations. The conceptual model should be updated regularly during the remediation process as new knowledge is gained in the different steps.

In larger or more complex projects, there is often cause for relatively extensive sampling and monitoring to be conducted. This reduces the level of uncertainty and improves the basis for the risk assessment as well as the remedial alternative evaluation and selection processes. The cost of sampling and monitoring is often lower during the investigation phase than during the implementation phase. A reduced risk of encountering surprises in the implementation phase also justifies thorough sampling and monitoring during the investigation phase. However, the extent of the sampling and monitoring should be determined based on the need for supporting documentation for each individual study site.

In smaller and simpler projects, or in projects that can be treated as "typical" projects based on previous experience (such as the remediation of several petrol station sites), the extent of the investigations can often be limited. It may be sufficient to state the type of contaminant, its estimated amount and distribution, as well as the physical attributes of the area (such as the geological, hydrogeological and environmental conditions), as well as the main risk objects and values to be protected. In such limited projects, the risk assessment, as well as the remedial alternative evaluation and selection processes are also usually less extensive.

Investigations of areas that include refuse dumps or landfills with mixed waste, or areas affected by complex contamination mixtures will usually require significantly more data. When the documentation is limited or when there is a lack of information, more cautious assessments must be made.

In general, repeated sampling and monitoring over a longer period will often contribute to better grounds for the risk assessment compared to just taking a few individual samples at one point in time. This especially applies to media with naturally occurring variations over time, such as surface waters, groundwaters, biota and to some extent sediments. Variations can be due to seasonal variations in temperature, precipitation, evaporation, surface run-off etc. If there is limited knowledge of the variations that occur in the media, a conservative interpretation of the monitoring data should be considered to incorporate possible changes over time. Soil also has naturally occurring variations, but these are primarily spatial variations (if degradation is disregarded as this is usually a relatively slow process).

It is also important to investigate the right substances as well as additional parameters necessary to interpret the results, e.g. pH, oxygen conditions, organic carbon content etc. In addition, it is important that the samples are handled in a correct way so that the results are representative of the contamination situation.

The investigations should be made in several steps, from limited to detailed investigations. The accuracy in sampling and analyses of relevant media and relevant substances will thus increase successively.

Basis for investigation

The following sections of this chapter is mainly based on the Swedish EPA report 5888 “Sampling strategies for contaminated soil” (Norrman et al., 2009a) and provides a brief overview of important things to consider when carrying out investigations on a contaminated site. Examples of what an Environmental Investigation Report may include is presented in Appendix 2 and is based on the guidance report 6688 “Guidance on Status Reports” (Swedish EPA, 2015).

DESK-TOP STUDY

The first thing to do when investigating a potentially contaminated site is to perform a desk-top study. All relevant available information is compiled to create an initial conceptual model for the site.

This includes looking into the operational history of the site using information from archives, photographs, maps and from interviews with for example staff and/or people who live in the area. It may also include results from earlier investigations at the site.

Questions that needs to be answered and information to include in the desk-top study:

- What substances are related to the operations performed at the site and therefore can be expected? This includes both historical and present operations (such information can be found using archives, maps, or performing interviews).
- Is there a potential risk for pollution of the soil, groundwater, surface water, sediment and/or buildings? Have there been any accidents that potentially could have caused contamination? Have there been waste disposal at the site? (Archives, maps, interviews).
- What are the characteristics of the substances? How toxic are they? How mobile are they? Will they produce degradation products? Do they have bioaccumulation potential? Are they sensitive to changes in pH or redox potential, etc.?
- Properties of the site and potential transport pathways (geological and hydrogeological maps and site inspections).
- In what media can the substances be expected? Which transportation pathways exists?
- What are the values to be protected at the site and in the surrounding area that could be affected? Humans, water resources, agricultural land, endangered species etc.?

SITE PROPERTIES AND TRANSPORT

Contaminants can move with soil, air, groundwater, or surface water and establishing these transportation pathways is important to understand the risks involved. Perhaps there is a nearby building where vapours from a contaminant spill might migrate, or a nearby river or lake – or a groundwater drinking water well – that can be affected.

To understand the transport properties, it is important to know:

- Soil type and its permeability
- Soil layers with difference in permeability, e.g. presence of impermeable layers
- Depth to and gradient of the groundwater table
- Location of saturated/unsaturated zones
- Presence of any underground structures, such as trenches or gravel around pipes and cables, as they can act as a transportation pathway.

What media to sample in order to best provide the information needed should be carefully evaluated before proposing an investigation strategy. Sampling of several different media (soil, groundwater, sediment, surface water, indoor air, buildings, fish, vegetables etc.) is almost always required in order to finally assess the risks and need for remediation. The samples are evaluated in combination with information regarding the site's history, physical conditions, etc.

Different substances will have different physical properties. This means that they will show essentially different characteristics in the soil and entail different exposure risks. For example, metals and dense heavy organic substances such as dioxins can adsorb to soil particles. Light liquids that have a lower density than water, such as diesel or petrol, can move as free phase on top of the water surface. Dense liquids that have a higher density than water can sink through the soil profile until they hit a sealing stratum or unfractured bedrock. A typical example of a dense liquid is trichlorethylene. Water-soluble substances can be certain types of pesticides or chemicals, such as sulphuric acid, salts, etc. As different substances move in different ways through the soil profile, this must be taken into consideration when planning a sampling strategy.

There are some parameters that are usually measured as they can influence the mobility of certain compounds. Parameters such as pH, oxygen conditions and organic carbon content can influence the solubility of a compound and will indicate if the contaminant will be found in the water phase or attached to particles. It can also affect the chemical form of the compound which influence e.g. its toxicity. These parameters also affect which remedial alternatives that may be suitable.

Sampling strategy

Based on the desktop study, assessments about the site properties can be made – such as the sources and transport of contaminants, what type of contaminants that could be present at the site, potential areas of spills etc. This information should be included in the design of the investigation. As the investigations proceed, new knowledge will be gained, and future investigations and the conceptual model should be revised accordingly. Based on what type of contaminant/-s that is/are, or might be present, the site may be divided into smaller subareas (characteristic areas) or subvolumes with different sampling strategies. How to delineate the subareas is determined based on both the activity that caused the contamination and the kind of substances expected at the site. The sampling strategy should, if relevant at the site, be adjusted to the properties of the smaller subareas. The best option is if the delineation allows each subarea/subvolume to be more or less statistically homogeneous, meaning that the average, variance, etc. do not vary too much within the area/volume.

When designing a sampling strategy, the following six general steps can be included:

- Define the aim of the sampling
- Decide how prior knowledge about the site is to be handled
- Define spatial and temporal delineation (subareas etc.)
- Determine the sampling scale and type of samples
- Select one of the following three sampling approaches:
  - probability-based
  - assessment-based, or
  - search-based approach
- Determine the number of samples and their placement based on the selected approach.

The various steps are reported in the order deemed to be the most logical. However, the methodology must not be considered as a simple chain of steps to gradually work through from beginning to end and then be finished. On the contrary, an iterative working method is recommended, where you go back one or several times to possibly revise the assumptions and estimations that have been made.

In remediation projects, the assessment-based approach is most suitable in the early stages of the project, where the aim is to confirm or disprove that there is a contamination in the investigation area. Here, prior knowledge will be of great importance. However, a downside is that it is difficult to assess the uncertainty in the investigation, as the sampling is largely subjective. Another downside is that the prior knowledge may be incorrect (for example due to flaws in the historical inventory), which can lead to incorrect conclusions being made based on the sample results.

A probability-based approach is a suitable approach to apply in later project stages, for example, when comparing the results with different guideline values, risk assessments, volume calculations or other questions that arise during the investigations or in preparation for remediation.

A probability-based sampling strategy, such as systematic random sampling, is applied when representative statistics are needed for an area or subarea (characteristic area). The data can be used to derive a representative concentration for that site or part of the site. The three most common probability-based sampling patterns are random sampling, systematic random sampling, or systematic sampling (Figure 5).

Depending on the choice of methodology, the results are treated accordingly with statistical methods. If the location of pollution of any media is known, the sampling could be directed to these sites, but sampling should in addition be performed randomly.

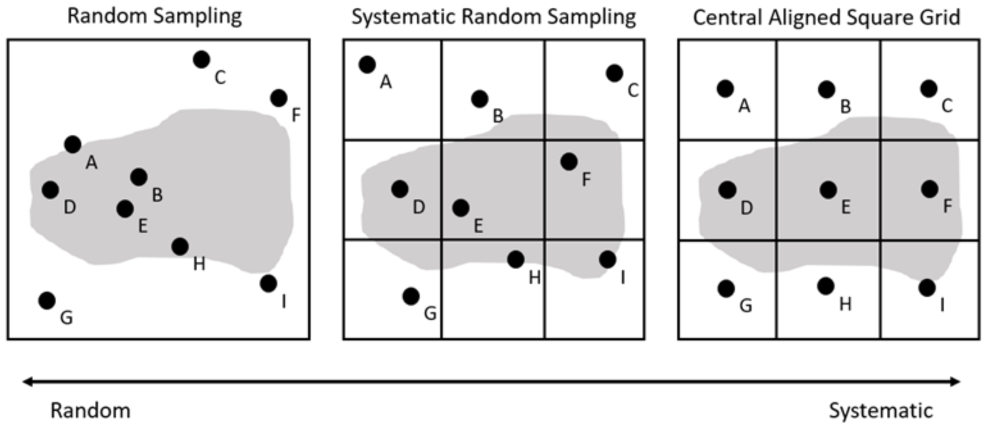

Figure 5. The three most common probability-based sampling patterns are random sampling, systematic random sampling, or systematic sampling. The figure is based on Gilbert (1987) and Engelke & Norman (2009).

A search-based approach is most suitable when the site or hotspots must be localised and prior knowledge is limited, for example, when searching for buried barrels or smaller areas of very high concentrations of contaminants.

One important purpose of the sampling is to determine the extent of the contamination, not only horizontally but also vertically. Samples should therefore also be taken at different depths.

When choosing the sampling approach, the transport characteristics of the various substances must be considered. A probability-based sampling in a large soil volume is not very meaningful if, for example, the contamination is only expected to occur at the bottom of this volume or in the area around the groundwater surface. In that case, a two-dimensional assessment-based approach may be more relevant, as the sampling is performed where the contamination is expected to occur.

Sampling plan

The sampling plan should include what substances to analyse for, and in what media. This will be based on knowledge about the properties of the contaminants and their likely presence in soil, soil gas, groundwater, as a free phase, and whether they are likely to be encountered near the source or to have been transported further away. Once this is established, the sampling technique is selected, and the systematic of the sampling – as well as number of samples, volume of sample to be collected and, when relevant, preservation of the samples (as sometimes for example groundwater samples need to be stabilised with acid for certain compounds). These issues can be discussed with the laboratory.

Without documentation, the sampling risks losing its value, as the background of when, where, how, and why the samples were taken is missing. If this documentation is not available, it will also be difficult to determine how representative the samples are and whether any data can be reused for other purposes in the later stages of a remediation project.

The following information should be documented in a sampling plan:

- What substances to analyse for
- Sampling approach
- Sampling technique
- Number of samples
- Sampling vessel and volume
- Sample preservation
- Analytical technique
- A plan for protective measures for environment and health of field workers at the site and for people living at the site or visiting the site.

SAMPLING TECHNIQUES – SOIL

The sampling of soil can be conducted by drilling boreholes, excavating test pits or manual sampling (using a hand auger/shovel). Drilling techniques have the benefit of being potentially less damaging, and it enables deep sampling so sampling from different strata can be carried out. It also has the advantage that groundwater monitoring wells can be installed in the bore hole. However, it is usually more expensive. Excavation is often cheaper and easier, and it gives a good visual overview of the soil profile. However, pay attention when sampling volatile contaminants as they can be disturbed during excavation and depart from the soil in vapor phase before the samples are analysed. They can also change character. The analyses may therefore show a lower concentration of the volatile contaminants in the soil than what is actually the case. Sometimes it might be relevant to measure pH in soil during sampling.

FIELD MEASUREMENTS

There are a couple of instruments that can be used directly in the field to determine whether a soil is contaminated or not, or to choose which samples to analyse in the laboratory. Results from field measurements should always be compared with analyses from a laboratory to ensure that the correlation is good enough. For instance, if XRF (X-ray fluorescence) is used in the field for detection of metals in the soil, a tenth of the samples should be analysed at the laboratory to ensure that there is enough correlation. A PID (Photo Ionization Detector) can be used in the field for detection of e.g. petrol and other volatile contaminants. The use of field instruments is often cost and time effective when applicable.

SAMPLING TECHNIQUES – GROUNDWATER

The choice of sampling technique, such as pumps or bailers, depends on what contaminants the samples are to be analysed for. In addition, some parameters have to be measured in the field and not in the laboratory as they are affected by e.g. temperature changes – those are for example pH, dissolved oxygen concentration, redox conditions, electrical conductivity, and turbidity. These parameters can indicate the presence and extent of a contamination and are used to determine the possibility of e.g. biodegradation.

LABORATORY ANALYZES

The laboratory chosen to perform the analyses should, when available, use applicable international standards for analyses of contaminated soil, sediment, or water. The analyses should also have correct detection limits, that is, concentrations can be measured at as low levels as necessary for comparison with guideline values. It is important that the samples are handled correctly from the moment the samples are collected in the field, during transport to the laboratory, during any storage as well as during analyses. This is to ensure that the conditions in the sample do not change before the samples have been analysed. Improper handling may affect the concentration of contaminants in the sample compared to the concentrations at the contaminated site. This is especially important for water samples and substances that may be degraded by e.g. an increased temperature. Cooling of soil samples is important if there are volatile substances in the sample as they can otherwise easily evaporate from the soil.

Standards, Soil quality – Sampling ISO 18400

There are a couple of international standards available for purchase[2] that can be used for guidance during the investigation:

Part 100: Guidance on the selection of sampling standards
Part 101: Framework for the preparation and application of a sampling plan
Part 102: Selection and application of sampling techniques
Part 103: Safety
Part 104: Strategies
Part 105: Packaging, transport, storage and preservation of samples
Part 106: Quality control and quality assurance
Part 107: Recording and reporting
Part 201: Physical pretreatment in the field
Part 202: Preliminary investigations
Part 203: Investigation of potentially contaminated sites
Part 204: Guidance on sampling of soil gas
Part 205: Guidance on the procedure for investigation of natural, near-natural and cultivated sites
Part 206: Collection, handling and storage of soil under aerobic conditions for the assessment of microbiological processes, biomass and diversity in the laboratory

Evaluation and risk assessment

It is important to select a representative concentration for each characteristic part of the site. This should be the concentration that best represents the contamination situation and should be calculated for a subarea (characteristic area) that is fairly statistically homogeneous in terms of its contamination (meaning that the average, variance, etc. do not vary too much within the area/volume). The representative

[2] Available on the International Organization for Standardization (ISO) website: www.iso.org

concentrations are then compared with relevant values, e.g. the generic guideline values, to assess the risk posed by the contamination.

There are different ways to select representative concentrations for a contaminated site to compare with e.g. guideline values. The simplest form is to use the max, mean, median or percentile. These alternatives are often used when there are relatively few samples or if it is a less complex contamination situation. If the contaminant content at the 90th percentile is used, for instance, it means that 90 percent of all samples have a lower contaminant content. Representative concentrations need to be assessed for different characteristic areas where there have been several different sources of contamination or due to the spatial distribution, as they are considered to represent different populations.

The Upper Confidence Limit of the Mean (UCLM) at a one-sided confidence of 95 % (UCLM95) is commonly used to evaluate that a representative concentration has been captured. In practice, this means that you only accept that there is a 5 % probability that the true mean is larger than UCLM95, i.e. to use UCLM95 is a way to define a confidence interval for the mean for the representative concentration. The UCLM95 is common to use when a probability-based sampling approach has been used.

An example would be to use UCLM95 and define the representative concentration to be 900 mg/kg. This would be the same as saying “there is a 95 % probability that the true mean concentration in this area is lower than 900 mg/kg”, which is the same thing as saying “the probability that the true mean concentration in the area exceeds 900 mg/kg is 5 %” (Norrman et al., 2009b).

The UCLM, median and other statistics can, for example, be calculated using a statistical program from the United States Environmental Protection Agency (US EPA). The program can be downloaded for free at: https://www.epa.gov/land-research/proucl-software.

Risk assessment

Contaminated sites can pose a risk to human health and the environment if exposure to toxic substances occurs within the contaminated site or in the surrounding area. A risk assessment evaluates which risks a contaminated site constitutes, today and in the future, and to what extent the contamination has to be reduced to, to not expose humans or the environment to unacceptable risks.

The Swedish EPA methodology for risk assessment, like most international methodologies for risk assessment, consists of four main elements:

- A problem description including a conceptual model
- Exposure analysis
- Effect assessment
- Risk characterization

Following this methodology generates a structured risk assessment and can be used regardless if it is soil, sediment, water or even a building that is to be assessed. The method can be used to assess health risks as well as environmental risks regardless of the extent of the risk assessment. However, the individual steps should be adapted to incorporate all steps needed depending on the extent of the project.

The first step of a risk assessment, regardless of the scope and level of ambition of the assessment is to establish a problem formulation, including a conceptual model that describes how contaminants can spread form the site and affect human health, the environment and natural resources. This problem formulation is also used to identify data gaps and the need for additional investigations and studies to be conducted.

A complete problem formulation consists of the following elements:

- Establishing the scope and spatial extent.
- A description of the sources and properties of the contaminants.
- A description of transport and exposure routes and pathways.
- A description of the risk objects.
- A description of possible future scenarios.
- A conceptual model.
- Identification of knowledge gaps that form the basis for supplementary studies and investigations.

Figure 6 shows an example of a conceptual model of what a contamination situation may look like and the information that is required to perform a risk assessment and to evaluate suitable remedial alternatives.

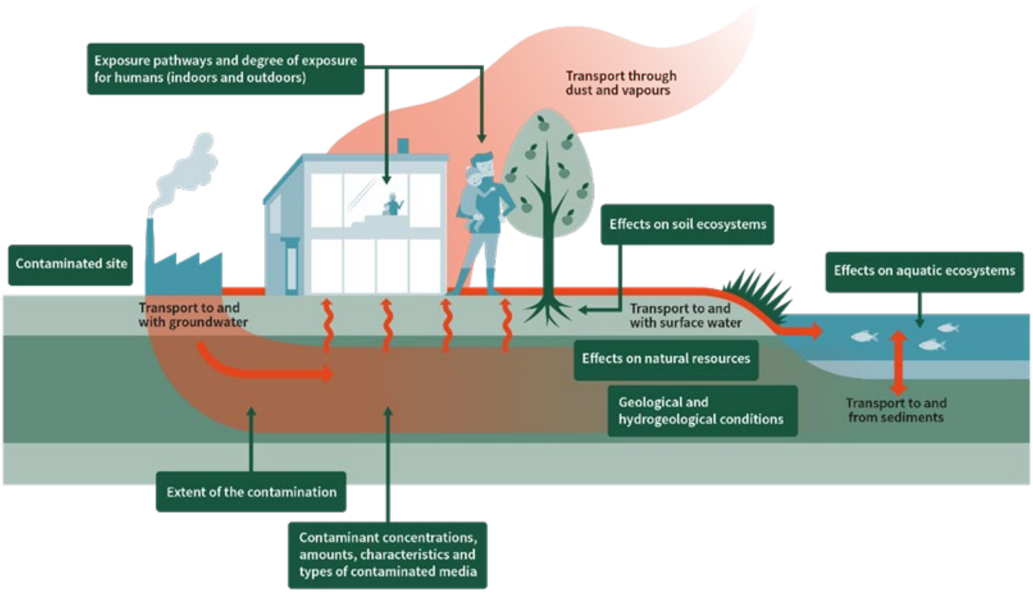

Figure 6. The picture includes examples of necessary information required to make a risk assessment and to evaluate suitable remedial alternatives.

The risk assessment also includes an analysis of the degree of contamination, contaminant transport and exposure (exposure analysis), an effect analysis and a summary risk characterization. A step-by-step procedure makes it possible to adapt the scope and direction of the assessment in order to reach a reasonable degree of confidence and level of expectation in both a simplified and a detailed risk assessment. Prior to each new step, it is important to evaluate whether continued investigations and research are motivated.

Simplified or detailed risk assessment

Whether a simplified or detailed risk assessment should be performed is decided on a case-by-case basis. Usually, a simplified risk assessment is carried out first. If necessary, it can then be followed by a detailed risk assessment. A simplified risk assessment results in a general evaluation of the risks and provides an indication if the site needs to be remediated or if further investigations are required.

In a simplified (screening level) risk assessment, the existence of a risk is assessed by comparing measured concentrations in the contaminated media with risk-based criteria, for example guideline values or environmental quality standards. Regarding the soil, it should first be determined if the Swedish EPA generic guideline values for contaminated soil are applicable. If necessary, it is also possible to calculate site-specific guideline values for soil using a model developed by the Swedish EPA in collaboration with a group of experts. The contaminant load on surrounding areas emanating from the contaminated site should also be assessed.

It may be necessary to perform a detailed risk assessment when the contamination situation is extensive or complicated, or when several different types of media are contaminated. There might also be a need for a detailed risk assessment if there are no relevant risk-based concentration criteria, if the conditions for using generic guideline values are not fulfilled, or if uncertainties concerning the risks are too high. A detailed risk assessment has a greater focus on quantification of the risk, through the use of measurements, modelling or other calculations, than does a simplified risk assessment. There is often a need to investigate casual relationships by use of several independent methods across all or part of the source pathway-receptor chain. The combined results from studying casual relationships and multiple lines of evidence can lead to a more certain risk characterization. A detailed risk assessment can for example include studies of contaminant transport via groundwater, sediment or air, calculations of the actual dose to which humans are exposed and biological studies and ecotoxicological tests.

Guideline values

Guideline values are one of several tools used in risk assessments. Guideline values, in the context of the remediation of contaminated sites, indicate the contaminant levels which do not pose unacceptable risks to human health, the environment or natural resources. However, contaminant concentrations which exceed guideline values do not necessarily give rise to negative effects. The Swedish generic guideline values are not legally binding values.

The Swedish EPA in collaboration with other experts, has developed a model to derive guideline values for contaminated land. The model for calculating guideline values is available in the form of an Excel file. The generic guideline values are adapted for commonly occurring conditions at a number of contaminated sites in Sweden. To determine if the generic guideline values can be used at a site, the conditions within the contaminated area must be considered. If it is determined that the generic guideline values are not applicable, site-specific guideline values have to be derived, taking the particular conditions at the site into consideration. In simplified risk assessments, measured contaminant concentrations at the site are compared with generic or site-specific guideline values.

The model to derive guideline values can also be used for the calculation or the control of site-specific guideline values. The parameters and data included in the model should be used for guidance when site-specific guideline values are calculated. The latest version of the program is available for downloading from the Swedish EPA website.

If changes are made to the model compartments or the input data, it is important to make sure that the guideline values are still applicable as the model is based on assumptions and is only valid for certain conditions. It is also important to carefully document all changes and motivate why they were made.

An important part of the derivation of guideline values is the expected land use at the site. Land use determines the likely activities on the site and therefore determines which groups of people will be exposed to the contaminants, and to what extent exposure will occur. Land use also affects the degree to which protection of the soil environment is required on the site. The Swedish generic guideline values have been derived for two different types of land use, sensitive land use (e.g. a residential area, agricultural land or a school) and less sensitive land use (e.g. office space, a shopping centre, an industrial area or a parking lot).

Table 2 shows a few of the generic guideline values that have been derived for contaminated soil in Sweden. The values reflects the toxicity of the substances, as well as their likelihood to be transported from the soil to other media where exposure of humans and other organisms can occur, for example transport to groundwater, surface water, indoor and outdoor air, plants and animals.

Table 2. A few of the generic guideline values for contaminated soil in Sweden.

Substance	Sensitive land use (mg/kg)	Less sensitive land use (mg/kg)
As	10	25
Pb	50	400
Cd	0.8	12
Cr (total)	80	150
Trichloroethene	0.2	0.6
Dioxin	0.00002	0.0002
PAH-H	1	10
Benzene	0.012	0.04
Aliphatics >C5-C8	25	150
Aromatics >C5-C8	25	150
MtBE	0.2	0.6
As	10	25

The generic guideline values are intended to protect people living on or visiting the site. The assessment of health risks takes into account exposure caused by direct contact with the contaminated soil, as well as indirect exposure, which can occur by the transport of contaminants to air, groundwater, and plants. The model takes six different exposure pathways into account: ingestion of soil, direct skin contact, inhalation of dust particles, inhalation of vapours, ingestion of vegetables, fruits and mushrooms, and ingestion of drinking water (Figure 7). Exposure is estimated based on feasible conservative assumptions and may be higher than the average exposure. The cause for this is to make sure that people who, due to behaviour or other circumstances, are likely to experience a higher exposure than the average person are protected. To calculate site specific guideline values, all the relevant exposure pathways for the intended land use are evaluated. This is a way to define the activities that may occur within the intended land use, without any negative health effects occurring. The exposure should be estimated based on the group that may be subjects to the highest risk of exposure to the contamination.

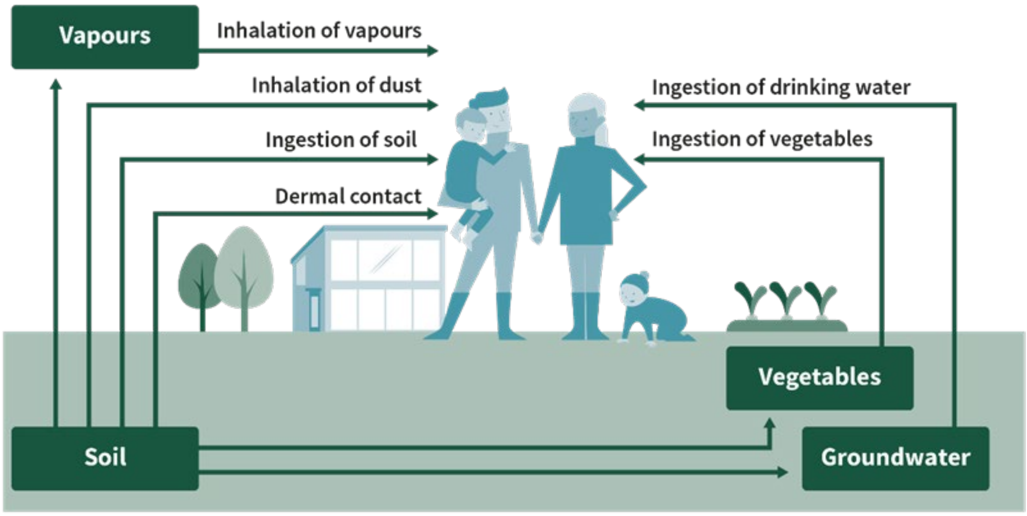

Figure 7. Transport and exposure routes and pathways considered during the derivation of the Swedish generic guideline values.

The guideline values also take into account the protection of the soil environment on the site. Guideline values for the protection of the soil environment states the concentration level at which the ecosystem can provide its services for the intended land use. The guideline values are based on ecological quality criteria produced by agencies in several different countries. Two methods are used to establish such criteria. The first method is based on a statistical distribution of the effect on different species and ecological processes based on ecotoxicological tests. In the second method, the lowest value available for ecotoxicological data is divided with a safety factor. The latter is used when ecotoxicological data is limited.

Guideline values for effects on the soil environment have been developed for two levels of land use, sensitive land use and less sensitive land use. These guideline values are based on the protection of the soil environment corresponding to a protection of 75 percent of the soil living species for sensitive land use, and 50 percent of soil living species for less sensitive land use. However, a protection of 75 percent of the species does not automatically mean that 25 percent of the species are affected.

The method to develop guideline values for protection of the soil environment is based on an evaluation of toxicological data from a selection of species. It is therefore difficult to adapt to site-specific conditions. Furthermore, the available data for numerous substances is limited, which makes it difficult to estimate safety margins for levels where negative effects occur.

The demands for protection of the land/soil properties can, to some extent, be made site specific through higher or lower demands compared to the Swedish EPA generic guideline values for sensitive and less sensitive land use. However, it is not appropriate to, for example, define different protection levels for the soil environment at different depths. The soils importance for the total ecological function decline with depth with respect to the soil type, hydrological conditions and the type of ecosystem. However, it is the entire soil profile that constitute the ecosystem. Furthermore, the soil ecosystem is not separated horizontally by the occurrence of different land use but interact over different subareas. Groundwater and surface water are also protected against effects which occur as a result of the transport of contaminants.

The final guideline value is the lowest of the values derived to protect human health, the soil environment, groundwater and surface water. In addition, a number of adjustments of the guideline values are made in order to avoid acute toxic effects and the occurrence of free-phase organic contaminants in soil. Finally, the guideline values are checked to ensure that they are not lower than the background levels which occur naturally, or as a result of large-scale diffuse pollution.

More detailed information in English about how the generic guideline values were derived is available in the report *Development of generic guideline values. Model and data used for generic guideline values for contaminated soils in Sweden* (Swedish EPA, 1997). However, it should be kept in mind that the generic guideline values and the model used to derive them has been revised twice since the publication of the 1997 report, both in 2009[3] and 2016[4].

Uncertainties and documentation

There are uncertainties throughout the risk assessment process, from problem formulation to risk characterization. These uncertainties should be described and assessed in both simplified and detailed risk assessments. The purpose is to understand and put forward the uncertainties and to describe how they have been handled. Since the amount of data available for a simplified risk assessment is often limited, data collection and interpretation should be carefully considered. Comparisons with guideline values should be made using representative concentrations (based on measured concentrations in relevant media). Uncertainties due to the limited amount of data can be dealt with by using conservative assumptions and choices, so that risks are not underestimated. In a detailed risk assessment, uncertainties must often be addressed more specifically in order to clarify the robustness of the risk assessment and the margin of safety that exists. This can be achieved through use of qualitative evaluations, presentation of alternative approaches or with the help of quantitative calculations.

It is important to properly document all the different steps of the risk assessment process, regardless of their scope and extent. The methods and data, supporting documentation, parameters used for calculations, assessments and assumptions that have been made and other relevant information should all be presented and motives for their selection should be clearly stated. This helps to make the risk assessment process transparent and makes it possible even for those who are not directly involved in the work to follow and understand how the risk assessment has been carried out.

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[3] Swedish EPA report 5976 (2009c)

[4] http://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Fororenade-omraden/Riktvarden-for-fororenad-mark/Berakningsverktyg-och-nya-riktvarden/

Remedial alternative evaluation process

A remedial alternative evaluation is carried out to identify and analyse potential remedial alternatives using remedial alternative evaluation criteria. Remedial alternatives can focus on source reduction or reduction of transport and exposure. An initial analysis is used to filter out alternatives that do not meet the remediation goals or interested parties' preconditions, are not technically feasible, or do not provide acceptable results (Figure 8). During the subsequent detailed analysis, the remaining alternatives are studied with respect to costs, potential risks during and after implementation of the remedial alternatives and possible disturbances that may occur. The remedial alternative evaluation process results in a selection of remedial alternatives that will move on to the next step in the remediation process: The remedial alternative selection process.

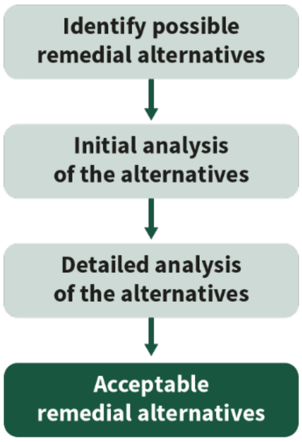

Figure 8. A schematic illustration of the remedial alternative evaluation process.

A remedial alternative may consist of several remediation methods, which in turn may include several different remediation techniques. The distinction between these three categories are illustrated in Figure 9.

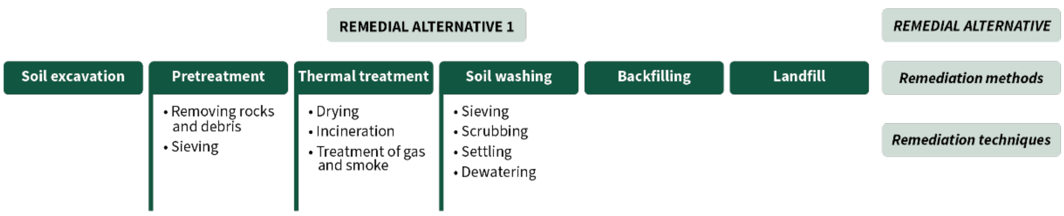

Figure 9. An example showing how a remedial alternative may consist of several remediation methods, which in turn may include several different remediation techniques.

The Swedish EPA's principles for site remediation should work as a guide during the entire remediation alternative evaluation process.

Aspects to consider

A few aspects to consider while sorting out possible remedial alternatives are:

- The remedial alternative should reduce the risks to human health and the environment to the extent which is technically feasible and economically reasonable.
- The remediation should only have to be carried out once.
- Any potential damage that may occur during the implementation of the remedial alternative should be less severe compared to the total damage caused by the contaminated site.
- The remedial alternative should not require any maintenance or supporting actions to take place after the remediation has been completed. Some long-term monitoring may however be necessary.
- The Best Available Technology (BAT) should be used, unless it entails unreasonable costs.
- Energy-efficient technology should be promoted when possible.
- Remediation should be carried out in such a way that the planned future land use is not restricted.
- The remediation should be conducted in such a way that the site will not become re-contaminated due to spread of contaminants from areas where remediation has not yet been carried out.
- Remediation should, when possible, be carried out before the spread of contaminants results in a need for more extensive remediation measures and before any acute situations occur.
- If contaminant residues are left in the ground, further treatment or implementation of protective and control measures should not be made impossible, e.g. by erecting new buildings on the contaminated site, without properly investigating the consequences.
- If solid phase contaminants are left behind, protective measures should be implemented that reduce the risks to such an extent that it has the same corresponding protective effects as if the material had been taken care of at a landfill.

Some of these aspects are considered already while formulating the remediation goals. Contamination situations which constitute acute risks, e.g. that a drinking water resource is affected, should always be prioritised to be evaluated. Remediation measures aimed to reduce acute risks and prevent severe contamination should also be prioritised.

As discussed in previous steps of the remediation process, the site conditions for each individual site heavily influence the choice of remediation method. Therefore, while identifying possible remedial alternatives, all factors influencing the effectiveness of a remediation method should be considered. This includes factors such as the properties of the contaminant, hydrological and hydrogeological conditions, geotechnical conditions etc. The occurrence of buildings, facilities, trees, proximity to nearby recipients, as well as already on-going activities within the area are examples of additional factors that influence the choice of remedial alternatives. By thorough investigations of the technical conditions for different combinations of remediation methods, contaminants, and contaminated media it is possible to filter out some of the remediation methods already during the initial evaluation.

As development of new and the improvement of already existing remediation methods are constantly taking place, a list of remediation methods quickly becomes outdated. Therefore, no specific remediation methods will be recommended in this document. A thorough investigation of existing remediation methods should be conducted in each new remediation project.

General approach

Different types of projects have to be assessed in different ways to find the most suitable remediation alternatives. The Swedish EPA promotes source reduction over reducing transport of, and exposure to, contaminants. The Swedish EPA also promotes methods that destroys the contaminants (only possible for organic compounds), rather than encapsulation methods or transporting excavated material to a landfill. However, the most important thing is to eliminate or reduce the risks to acceptable levels and the most suitable method to accomplish this must be evaluated for each individual site.

There are also administrative restrictions, which are primarily restrictions regarding land use and extraction of groundwater at the site. Such restrictions are aimed at preventing damage or negative effects on human health and the environment, and to prevent/advert actions that may increase the transport of, and exposure to, the contamination.

It should be considered whether or not administrative restrictions may be required at the contaminated site. The Swedish EPA does not consider administrative restrictions to be remediation methods within the meaning of the law. Administrative restrictions should therefore not be accepted as more than temporary protective measures if they are not combined with other, more concrete remediation methods. To just implement administrative restrictions as a permanent solution, without implementing any other remedial efforts, is a last resort and should only be applied in exceptional cases.

On the other hand, the Swedish EPA recommend implementing administrative restrictions, such as putting up fences, warning signs and similar precautions if the site may pose acute risks to human health. Administrative restrictions may also be used to inform future developers of the contamination situation, even if the risk assessment concludes that risk reduction is not needed at present.

Protective and control measures applied to stop the transport of and exposure to contaminants, such as for example encapsulation methods, may be used when there are contaminant residues left in the ground that exceeds the relevant guideline values. Such measures should be supplemented by monitoring and administrative restrictions to ensure that future activities, such as excavations, do not counteract the effects of the protective measures taken.

When the selected remedial alternative includes protective measures or administrative restrictions, the financial resources needed to maintain them have to be included in the budget.

Prioritising among remedial alternatives

When prioritising among remedial alternatives, the toxicity and properties of the contaminants (such as their persistence or if they are bioaccumulative), as well as the total contaminant load and additional risks connected to the implementation of each remedial alternative, have to be considered. Some remedial alternatives may induce an increased risk of exposure to, and transport of, the contaminants during the implementation of the remedial alternative. Transporting excavated soil to a landfill or treatment facility may also result in extensive emissions if the volume is large or if the soil is transported over long distances. If the excavated soil could contain residues of invasive species this will also influence how the soil can be handled and which remedial alternatives that can be applied[5]. Even the energy consumption for different treatment options have to be considered.

Furthermore, the longevity of the remedial alternatives has to be taken into account. The remediation should last, at least for as long as the time period considered in the risk assessment. In addition, possible future changes within the area should be considered, as they may affect the effectiveness of the treatment.

Initial analysis

A few questions to use while performing the initial evaluation of the remedial alternatives are:

- **Will the remedial alternative fulfil the remediation goals?**

  Remedial alternatives that do not contribute to attainment of the remediation goals are filtered out.

- **Will the remedial alternative follow the set conditions?**

  Acceptable remedial alternatives should not go against conditions set by the remedial principal or other stakeholders (e.g. intended future land use, timeframe, permits etc.) or other interests such as cultural interests (e.g. preservation of historical buildings) or inconvenience to the general public (will the remedial alternative give rise to loud noises, strong smells, traffic disturbances or other disturbances?).

- **Is the remedial alternative technically feasible?**

  Acceptable remedial alternatives should be technically feasible and factors such as access to the site and equipment, existing buildings and facilities, geotechnical

[5] Soil containing residues of invasive species are regulated according to the EU Regulation No 1143/2014 of the European Parliament and of the Council of 22 October 2014, on the prevention and management of the introduction and spread of invasive alien species.

aspects, as well as hydrological and climatological factors (e.g. risk for flooding and erosion) must be considered.

- **Will the remedial alternative provide the desired results?**

  Acceptable remedial alternatives should effectively reach the desired results (e.g. reduced contaminant concentration, reduced contaminant transport, reduced exposure, reduced volume of contaminated soil etc.)

Detailed analysis

During the first part of the detailed analysis, each remedial alternative is assessed in more detail with respect to their technical feasibility. Then the analysis is continued by looking more specifically at:

- **Costs**

  The costs are identified and summarized for each of the remaining remedial alternatives during the remedial alternative evaluation process. However, evaluation of the costs is performed during the following remedial alternative selection process. Costs may involve project design, permit applications, procurement of contractors, installing wells, treatment of contaminated wastewater etc. Potential additional costs, such as for rewiring or constructing temporary roads during the remediation, implementing administrative restrictions etc. must also be accounted for.

- **Risks during and after implementation**

  To be able to judge whether or not a remedial alternative will attain the remediation goals, a risk assessment is re-applied during the remedial alternative evaluation process to evaluate possible “scenarios” that are the result of the different remedial alternatives, both during and after their implementation.

- **Disturbances**

  The remedial alternatives should result in as little disturbances as possible.

Summarizing the evaluated remedial alternatives

The remedial alternative evaluation process should result in a selection of suitable remedial alternatives to be assessed in the next step of the remediation process: the remedial alternative selection process.

Before moving on to the next step, all remedial alternatives and remediation methods investigated during the remedial alternative evaluation process should be accounted for and documented. Remediation goals and evaluated remedial alternatives, as well as their consequences, should be summarized to clearly state which alternatives that have been considered and how the assessment was made that resulted in the remaining remedial alternatives. Even discarded alternatives and corresponding evaluation should be stated and documented to make the entire process transparent.

The remedial alternatives that will go on to the remedial alternative selection process can be listed according to their level of expectation to achieve the remediation goals.

For each of the remedial alternatives the following should be stated:

- Which remediation methods and remediation techniques that are to be applied.
- Expected effects and consequences with respect to human health and the environment, natural resources, economical aspects, as well as other interests.
- Which safety measures that should be applied.

Techniques and methods that are under development may involve large uncertainties, and therefore these uncertainties should also be carefully described.

Remedial alternative selection process

The remedial alternative selection process consists of finding a suitable balance between the costs of various remedial alternatives and their environmental consequences and technical risks, as well as the advantages and disadvantages of each alternative. This is done using a set of remedial alternative selection criteria which reflect the attainment of the set goals, technical and financial aspects and collective or individual concerns. Uncertainties and timing as well as psychological factors, recreational and esthetical values are also considered. At the conclusion of the selection process, a best alternative should have materialized.

The remedial alternative selection process is performed in every remediation project, regardless of its size, complexity, remedial principal, how it is financed etc. The selection process should be conducted in close collaboration between the remedial principal, enforcement authority and other involved parties, and in some cases even the general public.

Basis for the selection process

The risk assessment identifies potential risks to human health, the environment and natural resources at the site, in the surrounding area and during remediation. The remedial alternative evaluation process assesses the remedial alternatives mainly with respect to which effects that can be achieved, how and to what cost. The remedial alternative selection process adds to this by looking at cost effectiveness, technical feasibility, if future monitoring and restrictions are needed, the affected stakeholder's satisfaction with the result, contribution to sustainable development etc. Additional aspects such as if the alternative is profitable may also be assessed in the remedial alternative selection process.

The information needed for the remedial alternative selection process comes from the risk assessment and the remedial alternative evaluation process and may include:

- The remediation goals
- Preconditions and interests of the people involved
  - If the remedial alternative requires a permit.
  - Existing obstacles or opportunities.
  - Need for administrative restrictions or future restrictions of land use.
  - How other interests, public and private, are affected.

- Technical feasibility
  - The remediation methods applicability, availability, reliability, longevity, and controllability.
  - The amount of energy, natural resources and transport needed for each alternative.
  - Quality assurance and control.
  - National and international experience of the remediation methods included in each remedial alternative.
- Attainment of the remediation goals
  - The extent of remediation needed to attain the remediation goals using each remedial alternative and what level of contamination that will be left after remediation.
- Costs
  - Costs and timeframe for the implementation of each remedial alternative.
  - How costs and the timeframe may be calculated, as well as any potential economic risks.
- Risk assessment during and after remediation
  - Risks connected to any contaminant residues left at the site.
  - The land use applicable after treatment, i.e. will any future restrictions of the land use be necessary?
  - Potential risks to human health, the environment and natural resources that may occur during the implementation of the remedial alternative.
  - Negative effects on the environment caused by the remedial alternative.
- Disturbances
  - If the remedial alternative obstructs future remediation (if contaminant residues are left behind).
  - If an increased risk to human health, the environment or natural resources may occur at another location as a consequence of the remedial alternative.

Remedial alternative selection criteria

The remedial alternative selection criteria are used to evaluate the different remedial alternatives to find a suitable balance between the costs of various alternatives and their environmental consequences and technical risks. The selection criteria should be well defined and independent of each other. Choosing a set of selection criteria is, in itself an evaluation of which issues that are considered more important, as the choice reflects a prioritisation among them. It is therefore important that everyone involved in the project are in agreement of which criteria to choose, as well as how they should be applied. The criteria are also used while communicating the results to the authorities and to the general public.

As every remediation project is unique, there is no meaning in providing a set list of selection criteria in this document. Instead, some examples of common selection criteria that may be used are presented. Such criteria may include: Attainment of the remediation goals, technical aspects (including the availability, applicability and longevity of the remediation technique), costs during and after implementation, as well as esthetical and phycological values.

Evaluation of the remedial alternatives

Some of the selection criteria are quantifiable, for example to which extent the concentration of contaminants has been reduced, or the cost per volume remediated material. Such criteria can be used directly to compare different remedial alternatives. Other criteria are qualitative and may have to be described in some other way to be able to compare whether or not the criteria will be met by the remedial alternative, for example using words such as "Yes…maybe…no" or a points system such as "5…3…1".

The remedial alternative selection criteria can then, for example, be summarized and evaluated in a table. Some of the selection criteria may be considered more important than others and, in such cases, the different criteria could also be given different weight. An example showing both a non-weighted and a weighted result is illustrated in table 3, where a points system has been applied to evaluate which of the remedial alternatives (1 through 8) is more suitable. A high score means the remedial alternative is good and a low score indicates that the remedial alternative does not provide the desired outcome.

Table 3. An example of a summarized evaluation of the remedial alternative selection criteria using a points system, where 5 = best and 1 = worst.

Remedial alternative		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Selection criteria:	Weight:								
Total environmental impact	2	4	3	4	5	1	2	2	1
Local environmental impact	2	3	4	3	4	4	2	2	2
Timeframe for implementation	2	4	5	3	2	3	3	3	5
Acceptance	1	4	5	4	4	3	2	2	1
Fulfilment of remediation goals	2	4	4	3	3	4	4	3	2
Risks during implementation	1	4	4	3	2	3	3	2	2
Costs	3	2	1	3	4	3	3	3	5
Average score		3.6	3.7	3.3	3.4	3.0	2.7	2.4	2.6
Weighted average score		3.4	3.4	3.2	3.5	3.0	2.8	2.5	2.9

The average score in table 3 indicates that remedial alternative No. 2 and 1 are the best alternatives. The weighted average score, however, indicates that remedial alternative No. 4 is the most suitable alternative. In the second scenario, the costs for remediation has been given a higher weight, and the relatively low costs for remedial alternative No. 4 then gives it the highest score.

However, when summarizing the different alternatives this way it is important to note that positive features of some criteria (like for example a low total cost) rarely completely compensate for the negative features of other criteria (such as total environmental impact or high risks during the implementation of the remedial alternative). One way of incorporating this into the evaluation is to promote alternatives that show a relatively low variance in their score. This would then promote remedial alternative No. 1 in table 3, rather than alternative No. 2 or 4.

A sustainable remedial alternative has to be sustainable from an economical-, social- and environmental point of view. A remedial alternative that receives an extremely low score in one category should therefore not be chosen. In table 3, remedial alternative No. 2 is considered extremely expensive (with a score of 1), while alternative No. 5 has a high negative impact on the environment. Therefore, both of these remedial alternatives are unsuitable as they cannot be considered sustainable from either an economical or an environmental point of view.

Proposing a suitable remedial alternative

In the end of the remedial alternative selection process, a "best" remedial alternative should have materialized. If there are still some uncertainties regarding which remedial alternative to choose, the process is repeated.

The selection process may show that there are technical, economical or other limitations which means the remediation goals will not be reached by the proposed remedial alternatives. Then it may be necessary to go back to the remedial alternative evaluation process to find other remedial alternatives that fulfil the remediation goals, increase the funding for the project or even go back and re-formulate the remediation goals. If the remediation goals are altered, the entire remediation process must be repeated.

When a "best" remedial alternative has been chosen, the remedial alternative selection process is ended. Then the remediation goals may be translated into quantifiable remedial objectives. It is also important to properly document how the evaluation in the selection process was performed and clearly state how the assessment of different aspects was made.

The remedial alternative selection process described in this document is an example of how to select a suitable remedial alternative, but other methods such as a Life Cycle Analysis, Cost-Benefit Analysis, Cost-Effectiveness Analysis, Multi-Criteria Analysis, Multi-Attribute Techniques, Analytical Hierarchy Process or other methods may also be applied in a more detailed selection process.

Quantifiable remedial objectives

Remediation goals are implemented in the form of quantifiable remedial objectives that clarifies what has to be achieved in order to attain the goals. There should be at least one, and usually several, objectives for each remedial alternative, and the remedial objectives should be clearly related to the remediation goals.

The quantifiable remedial objectives should consider both short-term and long-term effects. Remediation to prevent acute situations should, for example, show immediate effect, which should be reflected in the quantifiable remedial objectives. The objectives have to be formulated to fit the remediation methods and techniques that are to be used at the specific site. For certain remedial alternatives, quantifiable remedial objectives may be required already during the implementation phase, for example if there is a risk of contaminating nearby water courses. Such objectives may also be connected to conditions in a permit, or to maintain safe working conditions during the implementation of a remedial alternative.

The quantifiable remedial objectives must be followed up after remediation has been completed, so that attainment of the remediation goals can be confirmed. This requires sufficient knowledge of what the situation was like before remediation was initiated to be able to validate the effectiveness of the remediation method. It is also important to know how to measure and quantify the attainment of the objectives.

If it is not possible to formulate remedial objectives that are quantifiable, the remediation goals have to be re-formulated.

Formulating quantifiable remedial objectives

When formulating quantifiable remedial objectives, the same method is applied as when formulating the remediation goals.

Quantifiable remedial objectives can be formulated in different ways depending on what is to be achieved. This may include risk reduction by reducing the source, transport, and/or exposure, protection of natural resources or protecting land use and other interests. Table 4 provides a few examples of how quantifiable remedial objectives may be formulated and what type of risk reduction it implies.

Table 4. Examples of how different types of quantifiable remedial objectives can be formulated.

Remediation goal	Quantifiable Remedial Objective	Type of goal
Good living environment for residents in the area.	The total contaminant concentration within the site should be reduced by X kg.	Reduced contaminant concentration.
Good quality surface water in nearby water courses.	The contribution of arsenic from the site to the recipient must not exceed X kg arsenic/year.	Reduced transport.
Promote biodiversity.	By excavating the uppermost 1 m of soil and replace it with clean soil, exposure should be reduced to almost zero.	Reduced exposure.

It is often better to state a quantifiable remedial objective in absolute terms, such as a reduced transport by a certain amount per year, compared to as a percentage decrease. Determining a reduction as a percentage requires a substantial amount of data to be gathered, both before and after remediation.

Remediation preparation and specific remediation requirements

Prior to the start of the remediation, specific remediation requirements are developed in the form of performance requirements, functional requirements and characteristic requirements. These are intended to guide the remedial contractor's efforts, thereby assuring attainment of the remediation goals and quantifiable remedial objectives. Specific remediation requirements should be as detailed as possible and pertain to all remedial activities and all affected media and material types. Furthermore, it must be possible to estimate the cost of the requirements.

Specific remediation requirements

Formulating specific remediation requirements is a key part of the remediation preparation. It is important that the remedial principal summarizes the results from the investigations and provides the contractor sufficient guidance regarding how the quantifiable remedial objectives are to be applied. Table 5 shows an example of how quantifiable remedial objectives can be translated into specific remediation requirements.

The specific remediation requirements are used during the procurement and the follow-up inspection after remediation has been completed, as well as during the environmental inspection. The specific remediation requirements are used to guide the contractor through the remediation to ensure that the remediation goals and quantifiable remedial objectives are met by the chosen remedial alternative. The specific remediation requirements should also consider how potential unanticipated events should be handled. The specific remediation requirements should be as detailed as possible and include all remediation actions as well as what different kinds of media that are to be remediated or processed.

Table 5. An example of how the quantifiable remedial objectives can be translated into specific remediation requirements.

Quantifiable Remedial Objectives	Specific Remediation Requirements
The Mercury concentration on the site should not exceed the site-specific guideline value of 1 mg/kg dw.	4000 m^3 of soil should be removed and sent to an approved facility for waste management.

Appendix 3 provide a few examples of things to consider when formulating specific remediation requirements for certain types of activities.

Procurement

Investigations and remediation of contaminated sites are often complex projects that should be carried out in steps. This may require several different procurements. It is therefore recommended to systematically identify and evaluate anticipated actions. If the need for consulting services is recurring, procurement of the services as a framework agreement can simplify and streamline the overall procurement work.

It is important to continuously evaluate the state of knowledge of the project and what is required to assess potential risks and need for action. Regardless of where you are in the remediation process, the remedial principal must define the purpose of the work to be procured and how this will contribute to the overall strategy for the project. The purpose of what is to be procured differs depending on whether one procures sampling and investigation, or a remediation action and preparation. The purpose may also depend on where you are in the investigation or remediation phase.

To define the purpose of the work to be procured, it is helpful to use a conceptual model to identify what issues to address in the project. Once the purpose and the directives of the work to be procured has been defined, a tender document is drawn up. The tender document is based on the knowledge available at the time of the procurement.

Tender documents

The tender documentation is the client's (the remedial principal's) documentation for the supplier's (the consultant's or contractor's) tender. This documentation should describe what is to be procured and what qualification criteria are placed on the supplier. The tender documents must also describe how the tenders will be evaluated, as well as other conditions that may apply. For the sake of clarity, the qualification criteria should be stated together in a separate section in the tender documents. In Sweden, all suppliers must be given equal opportunity and the procurement process must be transparent and published openly.

It is important to formulate the tender documents so that it is complete and clear from the beginning. As a general rule, the documents may not be altered during the procurement process. If the qualification criteria need to be significantly changed, the procurement process must normally be performed again from the beginning.

A tender document consists of:

- Qualification criteria
- Technical specifications
- Administrative regulations
- Award criteria
- Commercial terms
- Special contract terms

The tender documents can be divided into administrative regulations, a technical description, a price list and a template for evaluation. It must also report on the conditions, scope, execution and approval requirements for the work. A price list in a consultant tender contains information such as hourly fees, costs for different analyses, establishment of sampling equipment, installation cost per groundwater well, etc. Among other things, a price list facilitates later regulation of the amount of work during the project, for example if more sampling is required, or if fewer groundwater wells are needed than initially thought.

Many remediation contracts include an environmental inspection during ongoing remediation work. This is for instance to ensure control and treatment of contaminated groundwater before releasing it to a recipient and to classify soil or other material that are to be directed to different waste management facilities. Normally, this environmental control has a major impact on the remediation workflow, for example in the form of waiting for analysis results. How the follow-up for the assessment of the result of the remediation will be performed also has to be described in the tender document. Finally, a contract needs to be signed between the client (the remedial principal) and the supplier (consultant or contactor) on what the assignment will cover, when it should be completed, how it should be reported and what the costs will be, etc.

The remediation work ends with a final inspection, i.e. to see if the contractor has fulfilled their obligations or if there are any shortcomings. In this context, it is essential that the client's (the remedial principal's) or contractor's environmental inspection has ensured that the contractor has complied with the specific remediation requirements.

Remediation – implementing the chosen remedial alternative

When a contractor has been procured, the remediation can begin. As every remediation project is unique, it is difficult to describe this part of the process with much detail. However, some important aspects to consider during the implementation phase of a remedial alternative will be presented.

Safety issues

When conducting investigations and remediation of contaminated sites, it is essential to take precautions against the special risks associated with contaminated soil, gas, water and waste material. All personnel must be informed of the risks that their work may entail, and a clear chain of responsibility must be established before any work is initiated. An emergency plan should also be in place in case of an accident. Particular emphasis should be placed on preventing personal injuries, as well as accidents involving the spread of contaminants in the environment.

The type and use of safety equipment must be adapted to the circumstances at the site, and always allow a sizeable margin against anticipated risks. The minimum requirements consist of a telephone, overalls, rain gear, helmet, gloves, work boots, rubber boots, and a spray bottle with clean water. Other items that are usually on hand are face protecting visor, safety glasses, hearing protection, chemical-resistant overall and particle-filter mask.

There is always a risk of fire when working with flammable substances. To mitigate fire or explosive hazards, extra caution should be exercised when working with, for example, methane gas, petrol, diesel and other oils, paraffin, solvents, and powerful oxidants in combination with organic substances. Wherever there is the slightest risk of remaining explosives, no drilling should be attempted without the approval of qualified experts.

Some substances can be transformed and become toxic when exposed to air. In excavation shafts and confined spaces, vapours and gas can also displace air. This can cause oxygen levels to drop to dangerously low levels.

Pockets of gas or groundwater can be kept under high pressure by impermeable geological layers. Such conditions may be difficult to detect and must always be kept in mind when drilling through such layers. If there is a risk of contaminated water discharges, precautions must be taken in advance so that the borehole can be sealed after drilling to prevent contaminated groundwater from rising to the surface.

In old industrial areas, and wherever old building materials are used as backfill, there is a risk of concealed hollows in the ground that can result in poor stability, cave-ins, etc.

Furthermore, all sites must be checked for possible buried cables, even where none are suspected. It is also important to keep an eye on above ground wires and cables. The precise location of water and sewage pipes must also be established, especially if they are still in use.

When excavating and transporting contaminated soil, there is a risk of contaminant transport through dusting. If this is considered to be a potential risk to human health and/or the environment, covered trucks, in which the contaminated soil is contained, should be used for transportation. If possible, the excavation shafts should also be watered during excavation to reduce the amount of dusting. To avoid transport of contaminated soil to surrounding areas by for example truck tires, certain cleaning stations may be set up where the trucks are cleaned before leaving the site.

When performing alternative remediation actions to excavation, either on-site or in situ, the effects of the remediation action must be closely monitored and evaluated, perhaps over a longer period of time.

More detailed information about safety during investigations and remediation can be found in, for example, the ISO standard ISO 18400-103:2017 Soil quality - Sampling - Part 103: Safety.

Remediation alternatives

As development of new and the improvement of already existing remediation methods are constantly taking place, a thorough investigation of existing remediation methods should be conducted in each new remediation project. This section will show a few examples of available and commonly used remediation methods and some key aspects to consider for each method.

EXCAVATION OF CONTAMINATED SOIL

To be able to carry out treatment ex situ, the contaminated soil has to be excavated. To clarify the conditions for excavation, basic information about the geotechnical conditions is required. The level of detail has to be sufficient to be able to foresee difficulties that will affect the cost of the excavation. This means that one has to have a good knowledge of the origin and composition of the contaminated matrix. The contaminated matrix often consists of, for example, soil material for filling of varying composition, and sometimes includes larger elements of demolition- and industrial waste. This can lead to requirements for sorting of different fractions during excavation, even if an actual treatment on the site is not planned.

The location of the groundwater table in relation to the contaminated soil is of great importance. If the contaminated soil consists of permeable material, the inflow of water that needs to be taken care of can become large. A lowering of the groundwater table for excavation below the groundwater level can also mean that clean soil becomes contaminated. Under certain soil conditions, a lowering of the groundwater table can lead to a risk of erosion, subsidence, and landslides. Sheet piling or other relief work is then needed to prevent this from happening. Even if a lowering of the groundwater table is not carried out, the excavation alone can pose risks with respect to the stability of the soil. In addition, the conditions at the site may be such that the stability is unsatisfactory, even before any actions are carried out. This is especially true on slopes, in areas where embarkments have been established on clay soil, and next to or in a water area. Such risks and the need for preventive measures to mitigate risks must be clarified in the remedial alternative evaluation process.

It is also essential to clarify if there are obstacles to excavation in the area, such as buildings or underground installations and pipes. Pipe trenches may also present a risk of spreading contaminants during excavation. In addition, the density of the soil layers as well as the presence of large rocks and similar obstacles should be investigated.

Additional factors that should be described during the remedial alternative evaluation process are the risk of inconvenience during the excavation as a result of odours and vapours that may arise from the excavation shaft. Some substances can be transformed and become toxic when exposed to air. In excavation shafts and confined spaces, vapours and gas can displace air. This may pose a fire or explosion hazard, or cause oxygen levels to drop to dangerously low levels. In such cases, the health of personnel working in or near the shafts must be of the highest concern and protective measures must be applied to mitigate the risks.

There is often a need to store contaminated soil before it can be treated. In such cases, temporary protective measures are needed to prevent contamination of underlying soil and surrounding areas. This can be done, for example, by covering the soil, place it on an impermeable substrate and collecting leachate. It may also be appropriate to erect barriers or dig ditches to divert and collect clean stormwater and/or groundwater so it will not get in contact with the contaminated soil. This prevents the water from being contaminated as it otherwise must be collected and treated.

PRE-TREATMENT

Treatment of contaminated material (e.g. soil) usually involves some kind of pre-treatment to adapt the material to a particular remediation technique. There may also be a need for additional treatment after the principal treatment has been carried out. Some typical such techniques are:

- Sieving
- Removing oversized material
- Crushing
- Dewatering

Sieving means removing unwanted material and sorting the soil into different fractions based on their particle size. A reason for sieving the contaminated soil is because the contaminants often are attached to the finer fractions of the soil matrix, while the larger particles usually are less contaminated. Another reason can be that a certain size fraction is unsuitable for the chosen remediation technique. The smallest fraction that can be separated by sieving is usually 15 mm.

Large rocks and debris (larger than 100 mm) are often not remediated. Partly because of their size as they may be difficult to handle, but also because they often (but not always) have a relatively low degree of contamination. Large natural rocks may therefore be appropriate to reuse, for example for backfilling an excavation shaft. However, demolition debris, trash, concrete and other non-naturally occurring material are not suitable to reuse and should be sorted out.

Crushing is used to break apart soil aggregates and to crush large rocks and pieces of concrete into smaller sized fractions.

Dewatering is needed to be able to treat contaminated sediments, as well as further treatment of soil after soil washing. There are several different dewatering methods available. The main techniques that are used are passive and mechanical dewatering, as well as active evaporation. Passive dewatering relies on non-aided evaporation and draining, while mechanical dewatering may use a centrifuge, or a mechanical press to separate the water from the soil or sediment. Inorganic substances, polymers or heat may be added to speed up the dewatering process.

BACKFILLING AND REUSE OF SOIL OR OTHER MATERIAL

Backfilling is the process of replacing or reusing the excavated soil that has been removed during the remediation. Backfill can consist of the same soil that was excavated (treated or untreated), or of soil and rocks from somewhere else. If soil is brought in from somewhere else, it is important to make sure that the new soil does not contain other contaminants (such as heavy metals, organic hazardous substances or residues of invasive species e.g. roots or seeds). To determine whether excavated soil (treated or untreated) can be reused at another location, the background levels at the location should be used as a guide. There may also be additional requirements that have to be fulfilled, such as what type of soil it is, its permeability, shear strength etc.

TREATMENT OF CONTAMINATED WATER ON-SITE

There are a number of situations where large quantities of potentially contaminated water have to be collected and remediated, e.g. during dredging of sediments and subsequent sediment dewatering, when groundwater or stormwater is collecting in excavation shafts, or when the groundwater table has to be lowered to facilitate excavation. It may also be required, e.g. in case of spills that may affect a nearby river or a groundwater aquifer. In such cases, establishing a water treatment facility may be required. The treatment method should be adapted to the type of contaminants present as well as the water quality, as factors such as high concentrations of e.g. dissolved organic carbon may influence the effectiveness of a certain type of treatment method.

DESTRUCTION OF CONTAMINANTS IN SITU

In situ remediation is performed directly on the site, without excavating the soil. It primarily includes different methods to stimulate biological or chemical degradation. This occurs through optimization of the conditions at the site, adding reagents or adding microorganisms. Degradation of contaminants can even be done using soil fungi and plants. Destruction of contaminants in situ also includes methods that include separation and concentration techniques as a first step, e.g. displacing volatile contaminants as a gas.

For this type of methods to work, the contamination must consist of substances that can be remediated using these techniques. It is also important to investigate the geochemical conditions in the contaminated matrix, such as oxygen conditions, redox potential, fraction of organic carbon, access to nutrients, if there are ongoing degradation processes and if there are other substances present that can disturb the process e.g. through using up the added oxidation reagent. In addition, the risks connected to each method must be evaluated, e.g. the risk of making the contaminants more mobile. Sometimes bench scale experiments or limited pilot scale trials may be required to be able to evaluate if the method will be successful at the site.

The structural and physical features of the soil, such as particle size, hydraulic conductivity and variations in the distribution of the contaminants within the contaminated matrix is crucial information, as these conditions can affect the effectiveness of the treatment method as well as the time required to perform the remediation.

ENCAPSULATION OF CONTAMINANTS IN SITU

Barriers may be installed to stop the transport of, and exposure to, contaminants from the site. Barriers may be physical, hydraulic, geological or biogeochemical, and are used to immobilise the contaminants. Some examples of barriers are installing vertical and horizontal impermeable barriers to encapsulate the contaminated site, or to use reactive barriers that treat the contaminants as water flows through the barrier. An example of a situation when this type of barrier can be used is when the contaminants are difficult to access and are located deep within the saturated zone of the soil, under the groundwater table.

In connection to installing barriers, it is often necessary to dig ditches or apply other constructions that prevents or minimize the inflow of water to the contaminated area.

Documentation

It is important that the entire remediation process is well documented, from the formulation of remediation goals, through investigations and studies, risk assessment, the evaluation and selection of remedial alternatives, to the implementation of the chosen remedial alternative and monitoring after remediation has been completed. The documentation should cover all technical and scientific as well as financial aspects of the remediation project. Uncertainties also have to be assessed and documented throughout the entire remediation process.

Therefore, a structured documentation should be initiated early in the process. Everyone involved in the project, as well as other interested parties, must be able to follow and understand the entire process, from start to finish, even if they were not directly involved in the work.

The documentation is also used to verify that the remediation goals have been achieved.

Evaluation

It is important to evaluate the remediation with regards to several different aspects, including both technical and scientific aspects, as well as the financial aspects of the project. This includes looking into how well the first conceptual model corresponded to the true contamination situation, how effective the chosen remediation alternative turned out to be, how well the contractors have met the specific remediation requirements, total costs for the project, and so on.

Additional aspects to follow-up and evaluate are the decisions that were made during the project, the implementation of administrative restrictions as well as if how information was communicated to all involved stakeholders during the project was satisfactory and well received.

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Appendix 1.

Terminology

Based on Appendix 1, Swedish EPA report 5978 (Swedish EPA, 2009a).

Concept	Explanation
Acceptable residual concentrations	The concentrations of various substances that may remain on a site when remediation measures are completed.
Acceptable residual mass	The amount (mass) of a substance that may remain on a site when remediation measures are completed.
Acute toxicity	Negative effect of a substance on a human or other organism arising from occasional and short-term exposure.
Administrative restrictions	Temporary or permanent rules and restrictions, e.g. for type of land use and groundwater extraction, with the aim of preventing harm or inconvenience to human health or the environment. The purpose may also be to prevent actions that may obstruct future remediation measures, or that can increase transport of or exposure to contaminants.
Affected area	The area affected or, in the long term, may be affected by the pollution from a contaminated area.
Anthropogenic contribution	The proportion of the occurrence of a substance which has been caused by human activity.
Background concentration	The sum om natural background concentration and diffuse anthropogenic contribution.
Background exposure / Exposure from other sources	The exposure of a person or organism from sources other than polluted areas, for example via food or inhalation.
Barrier	A physical or hydraulic structure intended to prevent the transport of or exposure to contaminants.
Baseline alternative	No action is taken.
Causality	Describes the causal relationship between the occurrence of pollution and negative environmental and health effects as links in a chain, for example, the presence of pollution hat, through dissemination, causes uptake and negative effect in a receptor.
Chronic toxicity	Negative effect of a substance on a human or other organism as a result of prolonged or repeated exposure.

Continuation of Appendix 1: Terminology.

Concept	**Explanation**
Cleanup	Remedial action that completely or partially remove or destroy contamination at a contaminated site.
Computer program for calculation of guideline values	An Excel-based program which is used for calculation of general or site-specific guideline values according to the methodology developed by the Swedish Environmental Protection Agency.
Concentration methods	Treatment methods aimed at concentrating the pollutants into a smaller volume which can then be disposed of by landfilling, containment or destruction. Examples of concentration methods are vacuum extraction, soil washing and thermal desorption.
Conceptual model	A simplified illustration or description of the area concerned; how it looks physically and how it is believed to work in terms of sources of pollution, protective objects, pollution spread, exposure, etc.
Contaminant	A substance derived from human activity and present in soil, rock, sediment, water or building material at a level that exceeds the background value.
Contaminant hazard	A measure of how hazardous to health and the environment the substances that occur in a polluted area are, based on their inherent properties (without regard to exposure).
Contaminant load	The amount of contamination (in total or per unit of time) that is transported towards a water receptor (groundwater or surface water) from a contaminated area.
Contaminated site	A relatively well delimited area (land or water area, buildings and facilities) where one or more contaminant substances are present.
Degree of contamination	The degree of contamination in a polluted. Includes contaminant concentration, amount and volume.
Dense, non-aqueous phase liquid	Liquid that is heavier than water and which is mostly immiscible with water. DNAPL therefore often occurs in free phase. See also LNAPL.
Destruction methods	Treatment methods aimed at destroying pollutants. Destruction methods are thus exclusively applicable to organic substances. Examples of destruction methods are combustion and various chemical and biological degradation methods.

Continuation of Appendix 1: Terminology.

Concept	Explanation
Detailed risk assessment	A risk assessment of a contaminated area where guideline values are not applicable because the generic conditions of the site mean that are the basis of the generic values are not met, or the uncertainties surrounding the risks are great. Methods other than the Swedish Environmental Protection Agency's model for land may need to be used for the risk assessment, or parts of it.
Deterministic risk assessment	In a deterministic risk assessment, specific values are used to describe variability and safety factors to describe uncertainty. The result is reported as a distinct value for the risk being investigated.
Diffuse pollution contribution	The part of the occurrence of a contaminant that cannot be attributed to point sources.
Diffuse pollution discharge	Emissions of pollutants where the distribution of the emitted pollutants cannot be well delimited. Emissions can come from either point sources or diffuse sources.
Diffuse pollution source	A pollution source which cannot be well defined.
Disturbances	Impact during the implementation of a remediation measure, usually temporary, which normally does not entail increased risks to health, the environment or natural resources if adequate safety measures are followed. Typical disruptions are emissions, increased traffic, noise, dust and odour, as well as restrictions on ongoing operations, shutdowns, relocations, etc.
Effect assessment / toxicity assessment / dose-response assessment	Part of the risk assessment. Describes at what concentrations or doses adverse effects occur.
Encapsulation methods	Construction of barriers enclosing a remediation site to prevent or substantially reduce the supply of water or oxygen to the contaminated material in order to prevent further transport and exposure of the contaminants.
Enforcement	Enforcement according to the Environmental Code is divided into operational supervision and guidance. Operational supervision is where a supervisory authority monitors compliance with the law and provides information and advice directly to the party conducting an activity or taking an action (business operator). Supervision guidance means that a supervisory authority provides support and advice to the operational supervisory authorities and coordinates, monitors and evaluates operational supervision.

Continuation of Appendix 1: Terminology.

Concept	Explanation
Enforcement agency	A community body that has the power to exercise supervision over a regulated subject area. Examples of operational supervisory authorities according to the Environmental Code are municipalities (municipal committees), county administrative boards and certain central authorities. The Swedish Environmental Protection Agency is one of the central authorities that has supervisory responsibility for supervision under the Environmental Code.
Environmental quality standard (EQS)	Specifies the level of pollution or disturbance that, after a certain point in time, may not or should not be exceeded, or should be aimed at reaching. An environmental quality standard may cover a specific geographical area or the entire country. The government sets the levels for the EQS. Environmental quality standards are legally binding.
Environmental risk area	A severely contaminated area for which the county administrative board, according to Chapter 10. of the Environmental Code, has decided on restrictions on land use or other precautionary measures.
Ex situ treatment	Treatment of soil or water from a remediation site after the material has been moved from its original position by excavation, dredging, pumping or similar. Ex situ treatment can be done on site or elsewhere.
Exposure assessment	Part of the risk assessment. Describes human, plant and animal exposure to pollutants based on measured levels in various contact media.
Fate and transport conditions	Current distribution of pollutants and conditions for further transport in the environment.
Fill, filling material	Material supplied by human activity, and that can consist of stone, gravel, construction waste, soil, excavation, shavings, slag, etc.
Fixation methods	Treatment methods aimed at reducing bioavailability and preventing continued transport of pollutants, usually using chemical or biological additives.
Free phase	The presence of a substance that has largely retained its own physical character in a soil or water area, regardless of the medium in which it is found, such as oil on the groundwater surface. See also DNAPL and LNAPL.

Continuation of Appendix 1: Terminology.

Concept	**Explanation**
Generic guideline value	A guideline value, recommended by the Swedish Environmental Protection Agency, that applies to the entire country. The value applies to many but not all contaminated sites. Is not legally binding. Indicates a level below which the risk of adverse effects on human health the environment or natural resources is normally acceptable in the context of contaminated land.
Guideline value	In the context of remediation, the contaminant content in a medium below which the risk of adverse effects on people, the environment or natural resources is normally acceptable. The guideline values are not legally binding. See also Limit value.
Guideline value for environmental effects	The level of pollution in a medium above which there is a risk of adverse effects on the environment.
Guideline value for health effects	The level of contamination in a medium above which there is a risk of undesirable effects on humans.
Immobilization	Chemical, physical, or biological processes that change the chemical bonds of pollutant substances in a way that reduces their mobility.
Immobilization methods	Treatment methods aimed at reducing bioavailability and preventing continued spread of pollutants. Examples of immobilization methods are stabilization, solidification, immobilization, and containment.
In situ treatment	Treatment of contaminated media directly in place in soil in order to reduce the amount of pollution.
Individual interests	Interests related to individuals, companies, or organizations.
Intrinsic value	An assessment of how important it is to protect species or ecosystems that are exposed to pollution. The protection value is mainly based on the presence of valuable nature.
Land area	A delineated land area that, to a varying extent, displays variations in soil, mountains, groundwater, groundwater, pore air, terrestrial organisms, or terrestrial plants.
Land disposal, land filling	Long-term storage of waste (e.g. contaminated soil) as a means of final disposing.
Land use	The purpose for which a land or water area is utilized or will be utilized.
Land use restrictions	Limitations in the permitted use of land or water areas to prevent adverse effects caused by pollution in an area. Implemented normally with the help of administrative measures.

Continuation of Appendix 1: Terminology.

Concept	Explanation
Less sensitive land use	Land use where pollution levels limit land use and where the protection of health and the environment in the area is less extensive than for sensitive land use. Groundwater is protected at a certain distance from the site. The site can be used for offices, trade, industry, traffic facilities and similar. This land use is predefined as a given scenario in the Swedish Environmental Protection Agency's model for contaminated land.
Level of ambition	The scope, focus and degree of detail in a site investigation.
Level of expectation	The remediation target that can be achieved using a specific method.
Liability study	Investigation aimed at identifying who is legally responsible for investigation and remediation of a specific site.
Light, non-aqueous phase liquid	Liquid that is lighter than water and which is mostly immiscible with water. Therefore, LNAPL often occurs in free phase. See also DNAPL.
Limit value	A concentration limit (for example, an environmental quality standard or drinking water standard) which, if exceeded, may lead to legal, economic or other tangible consequences. See also guideline value.
Line of evidence	Results of studies that "prove" or substantiate parts or the entire causal chain between the occurrence of pollution and adverse effects. If results from several independent approaches strengthen causal relationships, risk characterization becomes more reliable.
Medium	Soil, air, groundwater, sediment and surface water as well as construction materials.
Method for inventories of contaminated sites	The Swedish Environmental Protection Agency's methodology for inventory of contaminated areas. The methodology is used for risk classification.
Model compartments	The Swedish Environmental Protection Agency's model for calculating guideline values for contaminated land is built on several model compartments. These are sub models that describe methods, including calculation of contaminant transport and exposure. They are expressed mathematically by means of equations and are based on a conceptual model that states under which conditions the mathematical model is valid.

Continuation of Appendix 1: Terminology.

Concept	**Explanation**
Model for guideline values	The word benchmark model is used to denote the methodology for calculating guideline values, both the theoretical description and the calculation program. The benchmark model is made up of a number of smaller models, see Model compartments.
Multi-criteria analysis (MCA)	A tool for comparing remedial alternatives through a structured weighing of economic, technical, social, cultural and ecological factors.
Natural concentration	The content of a substance that would exist without anthropogenic influence, often expressed as pre-industrial level.
Need for remediation	The need for remediation measures on a remediation object. The need for remediation may be justified by risks to health, the environment or natural resources.
Non-natural substance	A substance that is not naturally found in the ecosystem, i.e. has been created by human activity, or whose presence in nature largely depends on human influence.
Off-site treatment	Treatment of excavated or dredged soil and water from a remediation site, off site following transport.
On-site treatment	Treatment of excavated soil or water on site, without transport off site. Treatment can be carried out in situ or ex situ.
Operator	Anyone who conducts or has conducted an activity or has taken a measure that has contributed to pollution or serious environmental damage and is thus legally responsible for remedying the damage.
Point discharge	Emissions from a source that occur at a well-defined location. The emission can either contribute to a contaminated site or result in diffuse pollution.
Point source	A source of pollution where the source can be relatively well defined.
Pollution	Environmental damage that may result in harm or inconvenience to human health or the environment through pollution of a soil or water area, groundwater, a building or a plant. The definition applies to legislation after August 1, 2007.
Predefined scenario	A scenario that is predefined in the Swedish Environmental Protection Agency's model and calculation program.

Continuation of Appendix 1: Terminology.

Concept	Explanation
Probabilistic risk assessment	A risk assessment using probabilistic approaches where probability distributions describe variability and uncertainty in one or more of the input variables. The result is reported as a probability distribution for the risk being investigated. Also called probability-based risk assessment.
Problem formulation	The initial step of the risk assessment. Known or suspected contaminants, transport and exposure routes as well as receptors are reported in a conceptual model. Any knowledge gaps and need for supplementary investigations and investigations are identified.
Public interests	Interests that affect the general public and society at large, and that should be taken into account when planning and locating buildings, as well as carrying out risk assessment prior to remediation measures.
Qualitative data	Data that cannot be specified using a numerical value, i.e. is not quantitative, but can still be described using other properties.
Quantifiable remedial objectives	Development of the overall remedial objectives into quantifiable targets. Provides a basis for formulating action requirements.
Quantitative data	Data that can be specified by numerical value, for example as a quantity, a flow or a volume.
Recipient	A surface water area or groundwater reservoir that receives pollutants from a contaminated site.
Remedial action	A measure aimed at eliminating or reducing current and future impact on human health, the environment or natural resources from pollution in soil, groundwater, sediment, landfills, buildings and facilities.
Remedial alternative	One or more remedial methods that together can be used to meet overall remediation goals. Examples of such methods may be quenching, harping, and sieving, thermal treatment, and backfilling. Often, several similar action alternatives with varying scope or expectation levels are evaluated.
Remedial alternative evaluation criteria	Criteria used in the remedial alternative assessment to identify suitable remediation options. May refer to fulfilment of overall action objectives and stakeholders' basic conditions, technical feasibility, results achieved, costs, risks during and after implementation, disruptions, etc.

Continuation of Appendix 1: Terminology.

Concept	Explanation
Remedial alternative evaluation process, feasibility study	An investigation that illustrates appropriate remediation options for a remediation object and the respective consequences of the alternatives in the form of risk reduction, costs and other relevant aspects. Provides a basis for the remedial alternative selection process.
Remedial alternative selection criteria	Criteria used in risk assessment to select remedial options. May refer to goal achievement, technology, and economics as well as general and individual interests and others.
Remedial alternative selection process	A comparison of appropriate remedial options for an individual remediation object where desirable risk reduction is set against technical and economic opportunities as well as general and individual interests. Provides the basis for the final choice of method.
Remedial contractor	The company that undertakes to carry out and implement the physical remediation measures that have been decided.
Remedial design	Detailed planning and specification of implementation of remediation, and of the requirements of the contractor.
Remedial designer	The person or company that plans a remediation.
Remedial principal	The party responsible for carrying out site investigation or remediation. May be the same person as the Responsible party.
Remediation	Investigation, remediation, and other measures to remedy pollution or serious environmental damage. The definition applies to the legislation from 1 August 2007.
Remediation	See Remedial action
Remediation goals	The overall purpose or objectives of a remediation. Provides a basis for risk assessment, feasibility study and remedial alternative evaluation study.
Remediation method	Application of one or more remediation techniques to solve a specific technical problem, such as a thermal treatment plant. Such a plant often utilizes a variety of remediation techniques for management of soil, drying, combustion, flue gas management, etc.
Remediation objectives	See Remediation goals
Remediation site	A site which is contaminated, and which may or may not have undergone remediation.
Remediation technology	A specific way of solving a general technical problem, such as destruction of an organic pollutant by combustion. There are usually several competing technologies that can solve the same problem.

Continuation of Appendix 1: Terminology.

Concept	**Explanation**
Representative concentration/value	The concentration value that best represents the risk situation in contact and dissemination media without underestimating the risk. The choice of representative content is object specific and a statistical measure should be chosen.
Residual concentrations	The levels of various substances that remain on a remediated site when remediation measures are completed.
Responsible for remediation of contamination	Anyone who has caused or contributed to the occurrence of contamination or serious environmental damage or who is legally responsible for investigations and remedial actions (for contamination events that took place 1 August 2007). See also Responsible party.
Responsible party	The party, which is legally responsible for, to a reasonable extent, carry out remediation of a contaminated site (where contamination originated in activities that took place before 1 August 2007). Both operator and site owner can be held responsible for site remediation. See also Responsible for remediation of contamination.
Restoration	Remediation actions where the purpose is to restore a contaminated site (usually a water body) to good ecological status, as close to the area’s original (natural) condition as possible, with reasonable efforts.
Risk	The likelihood and consequences of the adverse effects on health, the environment or natural resources that a contaminated site may cause.
Risk assessment	The process used to identify and quantitatively or qualitatively address risks to human health, the environment or natural resources that a contaminated area may cause. Provides the basis for action assessment and risk assessment.
Risk characterization	Part of the risk assessment. The results of the exposure analysis are evaluated against risk-based criteria developed in the effect assessment.
Risk classification	A comprehensive form of risk assessment made in connection with inventory according to the MIFO methodology. A potentially contaminated site is classified according to risk on a scale from 1-4. Risk classification is an aid that is intended to form the basis for priorities and decisions about potential further investigations.
Risk objects	Recipients such as humans, animals, plants, natural resources, areas or ecosystems that should be protected against harmful effects.
Risk reduction	The reduction in the transport or exposure to contamination that is required for the risks to reach an acceptable level with regard to human health, the environment and natural resources.

Continuation of Appendix 1: Terminology.

Concept	**Explanation**
Scenario	A scenario is a complete set of input data (contaminated area, land use, geology, exposure conditions and similar) in the Swedish Environmental Protection Agency's for calculation of generic or site-specific guideline values calculate benchmark values for a specific or general case.
Sector specific guideline value	A recommended guideline value that only applies to certain types of well-described objects where contamination originates from a specific type of activity, such as petrol stations. Applies to many but not all items of the same type.
Sensitive land use	Land use where pollution levels do not normally limit land use and where groundwater and surface water adjacent to the area are protected. The land can be used for housing, agriculture, schools and similar. It is predefined as a given scenario in the Swedish Environmental Protection Agency's model for contaminated land.
Sensitivity	An assessment of how susceptible exposed people are to pollution. Evaluated at group level.
Separation methods	See Concentration methods
Serious environmental damage	Environmental damage that has its origin in spill or similar, occurring after 1 August 2007 and which is so serious that the ensuing soil contamination poses a significant risk to human health, with significant negative effect on aquatic environment quality, or significantly harms or impedes preservation of an animal or plant species or the habitat of such species.
Simplified risk assessment	A risk assessment of a contaminated site where the conditions allow the use of general and site-specific guideline and limit values. The Swedish Environmental Protection Agency's model for land can be used.
Single exposure pathway concentration	Calculated for individual exposure routes in the Swedish Environmental Protection Agency's Excel-based program for calculation of guideline values model for soil. For individual exposure pathways, the concentration in soil that results in an exposure that does not exceed the acceptable levels set by the Swedish Environmental Protection Agency, assuming that exposure occurs only through this exposure pathway, is calculated. One-way concentrations for the different exposure routes are weighted together to an unadjusted integrated health guideline value.
Site	A remediation site.
Site-specific guideline value	A guideline value specifically developed created for a specific object and its conditions.

Continuation of Appendix 1: Terminology.

Concept	**Explanation**
Solidification methods	Treatment methods that convert soil or sediment into a single body, limiting water flow so that leaching of pollutants is reduced.
Specific remediation requirements	A clarification in quantifiable terms that are decided prior to remediation to ensure that the remediation targets are met.
Stabilization methods	Treatment methods that convert pollutants in soil or sediment to a less leachable state, making them less mobile.
Transport conditions	See Fate and transport conditions
Upper confidence limit of the mean	Upper confidence limit for the average content. Specifies an upper limit for how high the "true" average content can reasonably be, given some certainty. The desired level of certainty is indicated as a degree of confidence.
Water area	A delimited area that is completely covered by water and which to a varying extent contains surface water, sediment, plant and zooplankton, bottom-living organisms, free-swimming (pelagic) organisms or bottom-living plants.

Appendix 2.

Examples of what an environmental investigation report may include

A SUMMARY

BACKGROUND

- History of the site – describe the activities that has occurred at the site, both previous (historic) and current (present) activities. This may include several different activities, or only one depending on the specific case.
- A description of the current use of the site at the time of the investigation, for example if it is an industrial area, a commercial area, or if the site is unaffected by human activity.
- An identification of relevant hazardous substances that are currently being used or produced by the operator according to the permit and that could cause a contamination.
- An identification of potential sources for historic contamination.
- A description of the site conditions, including topography, soil type, hydrogeology, transport pathways as well as the presence of contaminants in soil, groundwater, surface water, sediments and/or buildings resulting from previous activities.
- A description of the area, which may include a model.
- A literature review and summary of previous reports, including a reference list.

ENVIRONMENTAL INVESTIGATION
Sampling

- Describe the basis for the sampling strategy.
- A justification of the outline of the investigation, with the purpose of establishing the degree of contamination as well as the volume contaminated media.
- Details about the sampling strategy for groundwater and surface water.
- A justification of the number of samples, the spacing of the sampling points as well as spatial distribution and sampling pattern.
- A description of the limitations regarding the location of sampling points and investigations.
- A description of which methods that are used for the sampling, such as drilling boreholes, excavating sampling pits etc.
- Details about the sampling, such as sampling locations, depths, frequency etc.

- The method used for collection, storage and transport of the samples to a laboratory.
- A description of the level of precision chosen for sampling and analysis.
- A description of the critical steps of the process, both from a quality and an environmental point of view, as well as how these steps have been handled.

Analysis

- A motivation for the choice of parameters to analyse for.
- A description of the methods used for analysis (including their limit of quantification and measurement error), citing relevant accredited analyses (quality-assurance of standardized methods) or describing other validating methods used to ensure the reliability of the results.
- Account for the parameters that have been analysed for each individual sample.

RESULTS

- A description of the site conditions e.g. geological and hydrogeological conditions.
- Include an illustration showing the soil layers and groundwater levels within the area.
- Results from chemical analyses and sampling summarized in tables.
- A description of the extent of the contamination, describing the type of contaminants, their characteristics, spatial distribution, as well as concentrations and volume of contaminated material (e.g. soil).
- Include a map over the contamination situation in a standardized coordinate system. Account for the concentrations of individual contaminants as well as relevant values for comparison (in Sweden, the generic guideline values are used for comparison and risk assessment).
- An evaluation of the results.
- A description of how the results have been evaluated, e.g. by statistical analysis or by other methods.

APPENDIX

- A list of references for the background.
- Relevant documentation concerning the activities at the site (showing their extent as well as important parts of the operation or facility), aerial photographs, photo documentation of all sampling sites, buildings, facilities etc.
- Distribution of cables and pipes in the ground.
- A sampling strategy plan including coordinates for all sample locations.
- Field protocols describing the field work and observations, bore holes, pits, groundwater pipes and wells, or other installed equipment for sampling as well as which samples that have been sent for analysis.

- Relevant quality assurance. This may include accreditation of staff, calibrating instruments, using certified laboratories etc.
- Analysis reports, including relevant analysis standards and stating the limit of quantifications as well as measurement errors.

Appendix 3.

Examples of specific remediation requirements

This section will provide a few examples of how to formulate specific remediation requirements for certain types of activities.

CLASSIFICATION OF CONTAMINANTS

A basic set of specific remediation requirements should, among other things, describe which media that are to be remediated (classification of contaminants) and how the contaminated material should be handled. Quantifiable remedial objectives are often formulated as acceptable levels of contaminant residues, i.e. the maximum level of contaminants that may occur in the relevant medium after remediation. Based on the acceptable residual content that may be left after remediation, specific remediation requirements are then set up for which materials at the site that should be remediated. The acceptable residual content may need to be defined as specific remediation requirements for a certain scale, subarea, depth interval or volume, depending on the governing factors. Examples of governing factors are transport conditions, the location of risk objects (which can be outside of the remediation site) etc. It should also be specified with what certainty the classification should be made. The specific remediation requirements should specify how sampling should be performed, sampling density and frequency, how the samples should be analysed, what parameters to analyse for, method of analyses, quantification limits, measurement uncertainties, response time as well as how the data should be processed to verify that the specific remediation requirements have been met.

SECONDARY EFFECTS

In connection to the remediation of a contaminated site, secondary effects can arise, for example in the form of emissions by odour, dust, evaporation, run-off or transport of contaminants by other means. Specific remediation requirements should be formulated for e.g. handling volatile substances (regulating the size of open shafts, staging surfaces and storage areas) as well as emissions from machinery. In addition to this, requirements should be formulated to hold the contractor responsible to ensure safe working conditions, that guideline values concerning health of working personnel are not exceeded and that applicable noise standards are met.

HANDLING REPLACEMENT MATERIAL

In remediation projects, large volumes of material are usually needed for backfilling, covering etc. Therefore, in addition to the requirements for the materials that are being remediated, additional specific remediation requirements should be imposed on material brought to the project, such as treated soil that are to be reused, or purchased replacement material. The requirements should cover both acceptable levels of contaminants as well as technical quality and be adapted to the remediation goals that exists for the site and that are to be attained after remediation.

CONTROLLED NATURAL DEGRADATION

In some cases, for example if the contaminants do not pose an immediate threat to human health or the environment and the land use is not expected to change within the near future, it may be possible to allow nature to take care of the situation by natural biodegradation of e.g. lighter organic substances. This assumes that the spread of contaminants to unaffected areas has stopped, as a result of the ongoing natural degradation. Natural biodegradation should be evaluated and monitored to determine whether or not the risk reduction that can be achieved is sufficient to make this an appropriate remedial alternative. The specific remediation requirements should primarily prove that natural degradation is ongoing, control the speed of the degradation, as well as verify that no transport of contaminants from the site occurs.

HOW TO TAKE CARE OF OTHER CONTAMINATED MEDIA

As it is common for remediation actions to generate water- and air pollution (either directly by treating contaminated water or air or as a result of remediating solid waste such as soil), demands regarding how these media should be collected, treated and eventually released back into the environment are required.

BARRIERS, TREATMENT FACILITIES AND PROTECTIVE MEASURES

The specific remediation requirements should be adapted to the chosen remediation method as well as the specific conditions at the site. For a barrier, the specific remediation requirements may address the permeability, material and size of the barrier. For encapsulation methods, the specific remediation requirements may address the permeability of the material used for encapsulation, groundwater levels in the area, or the thickness and quality of overlying material. Requirements for temporary protective measures may be required to prevent the spread of contaminants to or from the site during the remediation. This may involve the use of e.g. sheet piles or hydraulic barriers.

ADMINISTRATIVE RESTRICTIONS

Specific remediation requirements concerning administrative restrictions at the site can for example refer to restrictions regarding e.g. the design of fences, putting up signs, a ban on excavation, restricted access to the area, use of certain fuels and chemicals, as well as waste management.

CONTROL DURING AND AFTER REMEDIATION

It is important to make sure that the results of the remediation are satisfactory. In addition to the regular requirements regarding the quality of the analysis (sample distribution/density, accuracy and measurement frequency etc.) additional requirements such as who performs the measurements (the contractor through self-ordinance or the client through a controller), statistical processing of data, interpretation, which measures should be taken in the event of a deviation from the plan, as well as how to report the results should be stated.

Requirements for environmental control are designed in a similar way as for the performance control, but are supplemented with conditions for, among other things, the length of the measurement period.

INFORMATION AND COMMUNICATION

Good communication is important and specific remediation requirements should therefore be formulated to be used as a base when developing a plan for how and when information should be communicated to involved stakeholders and the general public during the different stages of the remediation process. It should include a time plan for when information will be communicated, as well as in what format, e.g. through meetings, brochures, videos, exhibitions, demonstrations and/or site visits.