    

Contaminated Land Management and Control Guidelines No. 3: Remediation of Contaminated Sites

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FOREWORD

This guideline is the third in a series of guidelines in contaminated land management produced by the Department of Environment Malaysia. Contaminated Land Management and Control Guidelines No. 3: Remediation of Contaminated Sites provides the important elements or steps in performing remediation at a contaminated site. It specifies the essential process of contaminated land remediation which covers remediation planning, implementation and closure of contaminated site.

This guideline set out the fundamental goals for remediation of contaminated sites which in summary, should be to select a socially, acceptable and cost effective and provides protection for public health and the environment as well as flexibility in the future use of land.

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List of Abbreviations

DOE	Department of Environment
HDPE	High Density Polyethylene
JSA	Job Safety Analysis
LNAPL	Light Non-Aqueous Phase Liquid
NAPL	Non-Aqueous Phase Liquid
PAHs.	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PID	Photo-Ionisation Detector
RAP	Remediation Action Plan
RI/FS	Remedial Investigation and Feasibility Study
SSL	Site Screening Levels
SSTLs	Site-Specific Target Levels
SVE	Soil Vapour Extraction
USEPA	United States Environmental Protection Agency

1.0 Introduction

1.1 Purpose

The purpose of this guideline is to provide detail guideline to conduct remediation for contaminated land in Malaysia. This guideline specifies essential processes of contaminated land remediation which covers remediation planning, implementation and closure. Other guidelines that would be applicable, complementing or supporting the application of the content of this guideline include:-

- Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land; and

- Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites.

1.2 Scope and Application

This guideline applies to remediation activities of all land properties as classified in the "Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land" that are concluded to pose unacceptable human health and ecological risk based on assessment findings in accordance with the "Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites".

Remediation processes would apply for the following scenarios:-

- Site(s) with soil and groundwater concentrations detected above the site screening levels (SSL) [refer "Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land"]; or

- Site(s) that pose unacceptable risk to human health based on the findings of a human health risk assessment performed in accordance with the "Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites".

For site(s) that pose other immediate physical threats/risks due to the physico-chemical nature of the released chemicals or sensitivity of the site setting, immediate emergency response action should be devised to contain the physical threats/risks. The polluter or responsible party is responsible for the emergency response, assessment and remediation as per the procedures specified under the Contaminated Land Management Framework. These situation(s) include but are not limited to the following:-

- Explosive conditions in underground utilities/structures caused by an accumulation of chemical vapour released from subsurface contamination.

- Chemical releases that may cause immediate impact to human health or the environment.

This guideline is not applicable and shall not be used as guidance for emergency response of any chemical release into the subsurface environment.

This guideline describes the following remediation activities, i.e.:-

- Remediation Action Plan;
- Remedial Investigation/Feasibility Study;
- Remediation Implementation; and
- Post Remediation Evaluation.

1.3 Definitions

Definitions applicable for this guideline are provided below:-

"Chemical release" means disposal, leakage and/or spillage of chemicals into the subsurface environment.

"Feasibility study" means a bench scale or pilot scale study carried out under a controlled manner to ascertain the effectiveness or design parameter of a specific remediation technology.

"Immediate physical threat/risk" means adverse physical consequence or hazardous environment caused due to the physico-chemical properties of the released chemical.

“Remedial investigation” means any data collection activities intended to address data gaps identified in a Remediation Action Plan.

“Remediation” means any action undertaken to eliminate, reduce, control or mitigate the risk resulting from contamination of the soil and/or groundwater media.

“Remediation actions” means any actions taken to reduce or mitigate human health and ecological risks posed by subsurface contamination. These actions include data collection for remedial planning, remedial design, remediation implementation and post remediation evaluation.

“Remediation Action Plan” means a written description of remediation action properly designed or planned as such to reduce or mitigate the human health and ecological risk posed by the subsurface contamination detected at a subject contaminated land property.

“Project closure” means the completion of remediation actions and the remediation actions have successfully met the pre-determined remediation goals.

“Post remedial evaluation” means specific evaluation activities carried out to verify the effectiveness of remediation activities and determine if remediation goals are met.

2.0 Overview of the Guidelines

A "Risk-Based" approach is the overall guiding principle for the Contaminated Land Management Framework. The principles underlying a risk-based approach to remediation activities are as follows:

- Decisions on contaminated land management should be based mainly on protection of human health or the environment.

- The resources available for site management are limited and therefore there is a need to appropriately allocate resources based on the risk to human health or the environment.

- Where the risk to human health or the environment is considered unacceptable, a range of risk mitigation strategies should be considered. The selection of site management options should be based on the ability of the proposed strategy to minimize the risk to human health and the environment, the certainty with which the strategy can be implemented and the cost of implementation.

- The immediacy of action at a site should reflect the magnitude of likely unacceptable impacts and the timeframe within which they may occur.

There are four stages of remediation activities, i.e.:-

<u>Stage 1: Remediation Action Plan (RAP)</u>

A remediation action plan is a tool or written document that details the necessary actions proposed for a contaminated land property. It will specify the objectives and target of remediation activities proposed and all proposed remediation actions.

Typically, a RAP would comprise of the following elements:-

- Review of site information.

- Discussion on remedial goals and targets.

- Proposed remediation strategy and actions.

- Selection of applicable remediation technologies.

Stage 2: Remedial Investigation, Feasibility Study and Remedial Design

This step aims to define the most appropriate remediation strategy and/or technologies appropriate for a contaminated land property. In general, this stage consists of the following elements:-

- Remedial investigation;
- Feasibility study; and
- Remedial design.

Stage 3: Remediation Implementation

Remedial implementation is the execution of finalized remedial design or technology onsite, in order to achieve the remedial goals defined in the RAP for a subject contaminated land property. The following elements will be incorporated in remediation implementation:-

- Compliance with applicable regulatory requirements;
- Work supervision;
- Site control; and
- Waste disposal.

Stage 4: Post Remediation Evaluation

Post remediation evaluation is intended to evaluate the effectiveness of the remediation work performed by confirming that the site complies with the remediation goals determined for the site.

Site investigation procedures and techniques specified in the "Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites" shall be used whenever applicable, during the post remediation activities.

The process of contaminated land remediation is presented as follows:-

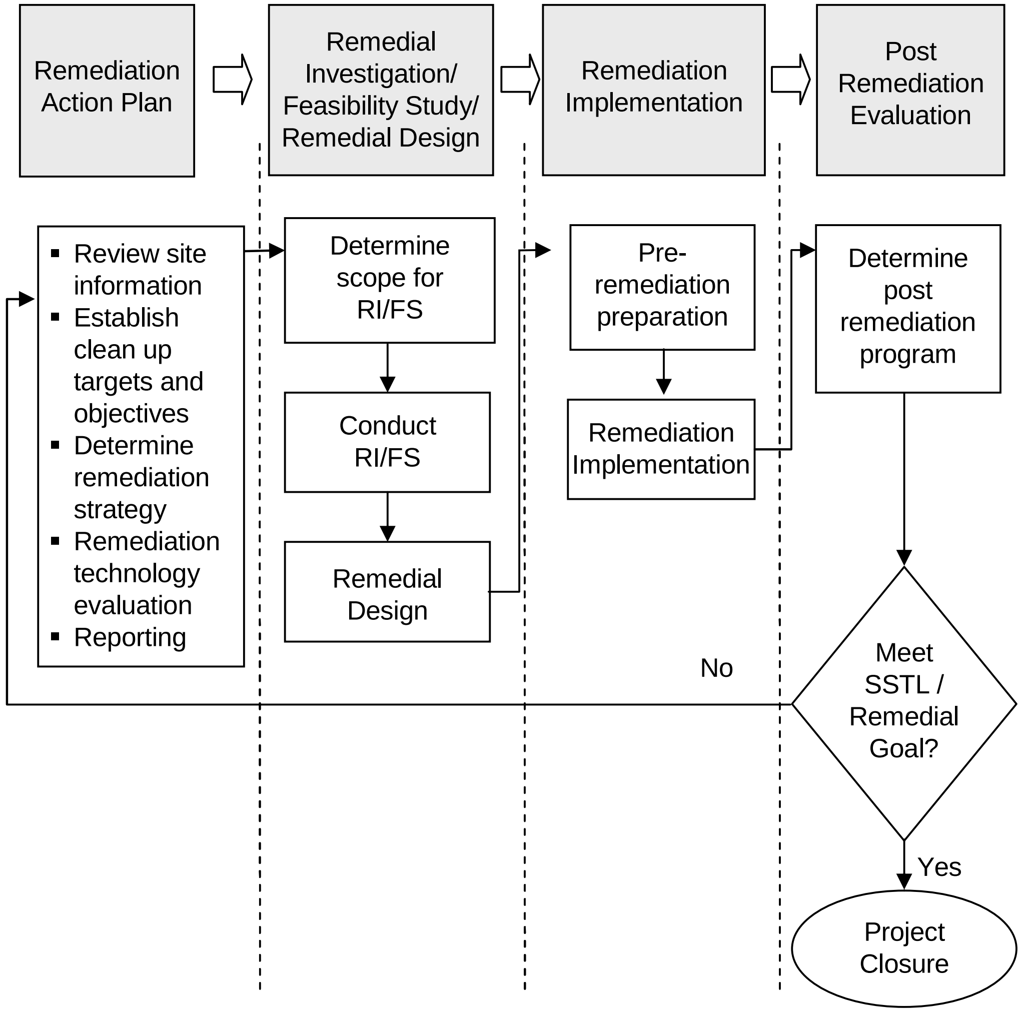

Figure 1: Remediation Process

3.0 Remediation Action Plan

A remediation action plan should be prepared before the implementation of any remediation actions. The RAP should be prepared by a qualified remediation specialist and/or remediation project manager, reviewed by a qualified contaminated land manager and submitted for approval by the Department of Environment.

3.1 Review of Site Information

A review of site information is necessary to understand the physical situation of the contaminated land property as well as the contaminant in question which will require remediation action. Upon completion of the site investigation and assessment phase, site specific subsurface contamination information, such as sources of contamination, sampling and testing results of soils, groundwater, surface water, sediments, or vegetation that determine the extent of contamination should be reviewed. This information will be closely examined to identify if there are any essential data gaps that would require further investigation, and to assist in the subsequent remediation planning.

3.2 Discussion of Remedial Goals

A site investigation and risk assessment performed for a contaminated site as described in the "Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites" will produce data and identify resources to assist in understanding the contaminant properties, distribution, geological and hydro geological regime of a contaminated site as well as assessing the risk to potential receptors. With the Site-Specific Target Levels (SSTLs) proposed from the risk assessment, further discussion on remedial goals by considering factors as given but not limited to those listed below, will be evaluated:

- The nature and degree of the contamination;
- The proximity of receptors and the potential pathways to them;
- The intended future use of the site;
- The site characteristics, including geology and soil type, depth to groundwater;

- Size of the contaminated area;
- Potential for off site migration;
- Costs of management or control; and
- Community concern considerations.

An economic cost benefit analysis of remedial objective options may be essential for more complicated scenarios of contaminated sites and should be performed in the remedial objective decision making process. Remedial objective options for a contaminated site may include:-

- Protecting potential receptor(s);
- Reducing or eliminating impacts to current receptor(s);
- Full clean up/removing all contamination;
- Partial clean up;
- Administrative management; and
- Combination of the above.

3.3 Remediation Strategy and Action

Based on the remediation goals, the appropriate remediation strategy and action should be proposed. In the event the risk is considered unacceptable, actions should be devised to reduce the subsurface contamination risk to an acceptable level both in the short and long term. In cases where there is no threat, or an acceptable threat, to human health or the environment, it may well be acceptable to devise a strategy whereby the contaminants are contained on site, or planning controls are used to limit the use of the contaminated land property. Remedial action options to achieve the remedial goal for a contaminated land property may include but not limited to:

- Containment of contaminant;
- Administrative controls including land use control and access restrictions;

- Active remediation;
- Soil remediation; and
- Groundwater remediation.

A remedial action may either be a single action or a combination of several actions. The decisions on which the selection of a remedial approach is based, is usually a balance between the remedial goals decided for the site, time available, capital and operating costs, long term liability and severity of the situation.

3.3.1 Containment of Contaminant

Containment at contaminated land property is used to minimize the vertical and horizontal migration of constituents of concern and can be used to isolate the contamination from potential receptors. Containment can be an effective and acceptable site management option but may require long-term monitoring. In theory, there is no limit to the contaminant concentrations which can be contained on a contaminated land property provided the integrity of the containment technology can be maintained until contaminant concentrations are reduced to acceptable levels. Containment options for soil can include vertical barriers, and asphalt or concrete capping. Containment options for groundwater can include maintaining hydraulic control at the site through groundwater extraction.

(a) Vertical Barriers

Vertical barriers, also referred to as cut-off walls, are used to prevent horizontal migration of contamination in either soil or groundwater. They are often used if a sensitive environment such as a stream, used for recreational purposes, is located downstream from a site. Vertical barriers are either comprised of a slurry wall, grout curtain or steel shoring and are most effective when an impermeable layer below the water table is available to key in to. A slurry wall consists of a trench down gradient or around the area of contamination that is filled with a soil (or cement) and bentonite slurry. To form a grout curtain, grout is injected into holes that are drilled in a regular pattern typically around the contamination. A cut-off wall can also be comprised of interlocking steel shoring that is vibrated into place.

Containment using vertical barriers is a moderate cost option if the impermeable layer is at a depth not considerably deep from the ground surface. This method may be used as an interim measure until land use of the site changes. This method however, does not eliminate contamination but simply manages the contamination by preventing it from migrating. In addition, future land use of the site is severely constrained as any containment system must be maintained intact.

(b) Capping

Capping at contaminated sites is typically used to isolate the contaminated soil from potential receptors and limit infiltration of rainfall. Limiting infiltration reduces the potential for downward migration of the contaminant in the soil to the groundwater. Capping also limits upwards migration of vapour. Cost-effective caps are typically comprised of concrete or asphalt. These caps are easily implemented but can be susceptible to weathering and cracking. Other capping materials can include clay and high density polyethylene (HDPE) liners. Capping can also trap vapours and direct them to areas such as basements. For this reason it may be necessary to consider putting in a venting system.

Capping is considered a low-cost option for isolating contaminants and limiting vertical migration of contaminants. Similar with vertical barriers, the contaminants are not destroyed but are simply managed. Furthermore, this method restricts future land use of the site.

(c) Hydraulic Control

Containment options for groundwater are designed to prevent further migration of the contaminated plume. Plume containment options typically consist of numerous extraction wells strategically placed either within the plume or near the leading edge. The number of wells and spacing between wells needed to maintain capture are a function of the hydrologic properties of the aquifer. Aquifer testing should be performed to obtain site-specific hydro geologic data prior to designing a well network. Hydraulic control is typically combined with an ex situ groundwater treatment option.

3.3.2 Administrative Control

Administrative control measures are used to limit human activities at or near a contaminated site to reduce the level of exposure to contaminants existing at a site. Administrative control measures include land use control and access restrictions. Reducing exposure to contaminants through the control of land use can be done by restricting future use of a site only for less sensitive uses e.g. redevelopment of a site for commercial use rather than residential use which therefore allows higher contaminant concentrations to remain on site. If significant contamination is allowed to remain on site, it must be demonstrated that the contamination will not cause an unacceptable risk to human health and the environment.

Access restrictions such as fencing and restrictions on groundwater use are used to minimize potential exposure to a contaminated media. Fencing is used to limit exposure to soil or surface water by sensitive populations such as children and animals. Restrictions on groundwater could be used if a contaminated plume is migrating off site and affecting off-site potable supply wells. Another option for restricting access to impacted groundwater is to provide an alternative water supply to groundwater users. Providing an alternative water supply could involve periodic delivery of bottled or tankered water to be stored on site or constructing a water supply line from an uncontaminated supply well.

3.3.3 Active Remediation

Active remediation involves reduction or removal of contaminants mass/concentrations from soil and/or groundwater. There are various active remediation technologies available. Each remediation technology has its advantages and disadvantages that need to be evaluated during the selection of the appropriate remediation method.

Remediation method selection for a particular site depends on many factors, e.g. type of contamination, location of contamination, distribution of contamination, soil type, geology and hydrogeology, time available for clean-up, acceptable residual contamination, land use, working environment during remedial measures, costs of the methods, and documentation of the methods application. Furthermore, the environmental effects should be assessed so that the best environment is achieved for the resources invested.

3.3.4 Soil Remediation

(a) Excavation

Excavation is by far the most common remedial method in the case of soil contamination. The contamination is removed, usually by an excavator, under controlled conditions, until the sides and bottom of the excavation are sufficiently clean. This is determined by the cleanup criteria for the specific contamination, which must be met at the completion of excavation work. The criteria for excavation must be documented using analyzes of soil samples taken from the sides and bottom of the excavation. In order to ensure that the requirements are complied with, the excavation must be supervised by qualified remediation project manager or qualified remediation specialist.

The advantage of excavation is that it is quick and well documented. Furthermore, excavation is applicable for all types of soil and contamination. The disadvantages of the method are the resulting environmental effects. Pre-treatment of excavated soil prior to disposal may be required.

(b) Soil Vapour Extraction (SVE)

SVE is used to extract volatile and some semi-volatile organic compounds from unsaturated soils. This process is accomplished by reducing the pressure in the soil vapour space and mechanically drawing large volumes of air through the pores in the soil, which volatilizes and strips the volatile and semi-volatile compounds from the soil matrix into the air stream. In this process, volatile organic vapours are removed from the soil through horizontal or vertical wells installed in the impacted area. The wells are perforated above the water table and a vacuum is applied to the wellhead to draw the vapours to the surface where they are discharged. Depending on the type and concentration of contamination, it is often necessary to clean the extracted air, usually using carbon filters.

SVE can also be used to volatilize free product from the water table. A vacuum is often applied to an existing groundwater monitoring well by connecting the well to a vacuum pump or blower. A moisture separator, also referred to as a knock-out drum, is installed before the blower to collect moisture that may damage the pump.

There are many factors that influence the effectiveness of SVE systems, including vapour pressure and solubility of the contaminants present, soil moisture, and temperature, air permeability of the soil, porosity, and stratigraphy. SVE is most effective with homogeneous, highly permeable soils contaminated with organic compounds that are highly volatile. In order to design a SVE system properly, air-permeability tests should always be performed. The location of the contamination can be decisive in choosing this method, as this method is well suited to contamination which lies close to, or under, buildings. The time required to remediate can vary depending on the soil conditions and the type of contamination (typically from five months to several years).

The advantages of this method are that the system is generally easily installed and can be used for remediation of volatile compounds in accessible locations e.g. under buildings and roads. In addition, this method can be used to remediate free product in existing monitoring wells and requires low maintenance. The disadvantages of this method are that it requires mid to high permeability soils to work and transfers the contaminants from subsurface to the atmosphere which then may require treatment of the extracted vapour.

(c) Bioventilation

Bioventilation is the aerobic microbial degradation of xenobiotic organic substances in the unsaturated zone, for example through the addition of atmospheric air or oxygen. A number of bioventilation screens are installed in the unsaturated zone. Air is blown in using a ventilator, and decomposition of the contamination is stimulated. Usually, a number of passive 'air-emission screens are located at appropriate distances depending on the characteristics of the contamination. Bioventilation stimulates biodegradation by blowing in air, unlike soil vapour extraction where contamination components are sucked out of the soil. This method is known best suited to remediation of lighter, aerobically degradable organic contaminants (mineral-oil products and solvents, but not chlorinated solvents) in permeable soil types. The method is also most suitable for substances with a low to moderate vapour pressure. Otherwise, there is a risk that the substance will be stripped before it is degraded. Air permeability tests and bioactivity tests should be performed when designing the equipment, with a view to ascertaining the air flow and the degradation potential of the site.

A bioventilation system can be easily installed and is a low-cost option that is effective for petrol, diesel and crude oils. Furthermore, this method can be performed for contaminants beneath buildings, roads and other surface features without disturbance. The disadvantage of this method is the relatively longer timeframe required for remediation to take place.

(d) Forced Leaching

Contaminants are forced to leach by artificially increasing the infiltration of water through the contaminated area, possibly by recirculation extracted groundwater. It may be beneficial to add nutrients, bacteria, and oxidants to the water to stimulate degradation, or detergents may be added to increase bio-accessibility (detergent leaching).

The leach water is infiltrated, either via leach fields, via sprinklers, or directly into the saturated zone. The leach water will usually be treated water abstracted from the contaminated zone, or uncontaminated water abstracted nearby for the purpose of hydraulic control.

This method works best in combination with other methods, normally remedial pumping. In this case, the abstracted water can be used for leaching after treatment, and hydraulic control is ensured. The method appears to be appropriate for remediation of soluble and bio-degradable contaminants in relatively homogenous, sandy deposits with well-defined hydraulic conditions.

The drawback of this method is that there can be operational problems due to clogging of screens, precipitation of iron and biological growth. In addition, substances which are added to the infiltration water can give pollution problems, e.g. bacteria, detergents, etc.

(e) Bioremediation

In bioremediation, optimal conditions for degrading contamination are created in the soil. This can be done by adding appropriate micro-organisms (inoculation technique) or by improving living conditions for naturally occurring bacteria (stimulation technique), for example by adding oxygen or detergents (increases biological availability by increasing solubility).

In principle, most organic substances can be degraded by micro-organisms, except substances such as Polychlorinated Biphenyls (PCB), chlorinated dioxins, heavy metals, and high-molecular Polycyclic Aromatic Hydrocarbon (PAHs). Certain conditions regarding the physical-chemical relationships in the soil matrix must also be fulfilled. These include oxygen content, inorganic nutrient content (e.g. ammonium and phosphate), availability and toxicity of the xenobiotic substances, temperature, and pH. Additionally, water content and soil type are also significant (soil with a high clay content is not appropriate). This method requires a long duration of the remediation process to take place.

(f) Land Farming

Land farming is a biological treatment process that reduces the toxicity of organic constituents in soil by enhancing the natural microbial degradation process. For land farming, soil is excavated and place in 0.3 to 0.5 meter lifts on an engineered pad. The soil is periodically sprayed with a nutrient/water mixture, and tilled. Samples are taken to establish the success of the method until the concentrations of contaminants reach the desired clean-up level. Leachate from the spraying process and storm water run-off are collected in a sump and reapplied over the soil lifts.

Land farming is typically an inexpensive option for remediating soils with petrol, diesel and waste oil, but requires a large area of land. Petrol is easily degraded and takes less time to achieve clean-up levels than diesel and waste oil. Typical clean-up times are three months to one year.

This method is a low-level technology and is relatively inexpensive depending on design of the engineered pad. This method has also proven effective on a wide range of petroleum hydrocarbons. The disadvantages of this method are that it requires a large land area and may require the management of odour released from the biological treatment.

3.3.5 Groundwater Remediation

(a) Pump and Treat

Pumping from deep aquifers is typically performed from screened wells. In order to bring contamination under hydraulic control, a pumping strategy must be prepared. A pumping strategy includes the following:

- Location of pump wells.
- Number of pump wells.

- Pump yield.
- Pump levels.

Depending on the situation, a number of different methods are available to fulfill the pumping strategy. These include ordinary pump-and-treat from screened wells, separation pumping, skimming, injection, recirculation, or possibly a combination of methods.

In cases where contamination consists of a light non-aqueous phase liquid (LNAPL) on the groundwater, it is typical to remove the LNAPL by skimming before alternative remedial methods are started. If a LNAPL e.g. petrol and oil is present, extensive drawdown of the groundwater table should be avoided as this will cause the contamination to smear the exposed soil where it cannot be removed using simple methods. Using several wells with a smaller drawdown, possibly with the aid of vacuum to remove air and water simultaneously, can be the optimal solution in these cases.

In cases where there is groundwater contamination near the ground surface, it is often advantageous to utilize drains connected to a collection sump from which groundwater is pumped. This solution is particularly relevant in connection with excavation, as the method usually requires extensive excavation. Drilling horizontal drains can be a solution in some cases. Suction-probe equipment may be appropriate for short-duration pumping in sand aquifers near the surface (max. 5 to 7 meter delivery head). Bio slurping is a relatively new method, which in principle is a further development of the suction-probe technique. By using a vacuum, both liquid and air are removed at the same time through an adjustable suction pipe which can be located in conventional wells. The well opening must be sealed to maintain a vacuum.

There are various methods which can be used to optimize pumping strategies. The strategy is usually set on the basis of the location of water abstraction wells and their capture zones. The overall groundwater flow direction is normally determined through measuring the potentiometric surface. Through pump tests, the hydraulic parameters of the aquifer, transmissivity, specific yield, and leakage can be determined. Furthermore, the vertical variations in the reservoir can be determined by geophysical logging. By performing conductivity and temperature logging, variations in ion distribution and temperature can be determined, and flow logs determine variations in inflow. In addition, there are a number of logs which provide various geological information on the formation (gamma, electricity, resistivity, and conductivity logs).

With other hydro geological data and knowledge of the extent and nature of the contamination, these data can be used to determine the optimal pumping strategy. Groundwater flow and contaminant transport models can be used where conditions require information on alternative strategies. There are examples of several types of numerical models which have different applications. Both two and three-dimensional models are available. Today, three-dimensional models are usually used, which can perform both stationary and dynamic simulations of the scenarios desired.

Pump types and technical equipment to control pumping depend on the situation. There are numerous types of pumps. Submersible pumps are often used in deeper aquifers, while vacuum pumps and centrifugal pumps are suitable for aquifers close to the surface (up to a depth of about 7 meter). There are various technical accessories to ensure hydraulic control by maintaining the required groundwater potentials, e.g. level controls, pressure transducers, timers, or electrodes.

Following construction, a running-in phase (implementation) for the remedial installation begins. This phase is aimed at optimizing operation. Instructions for running-in the technical equipment are prepared (includes recording electricity consumption, checking pumps, documenting pump yield, documentation of water treatment, etc.). In addition, instructions for contamination removal are prepared (includes recording pump performance, recording water/air quantities, taking water table measurements, analysis programme, and results).

(b) In-situ Remediation Methods for Contaminated Groundwater

<u>Air Sparging</u>

Air sparging is a method which utilizes physical removal and microbial degradation of contamination in the groundwater by blowing, for example, atmospheric air below the groundwater table. Air is blown below the groundwater table so that volatile components are stripped and transferred from the water phase to the unsaturated zone, where they must be removed using other techniques. Furthermore, microbial decomposition in the groundwater zone is stimulated because of the added oxygen.

The geology of a site is a decisive factor in the effectiveness of air sparging in that a reasonable amount of homogeneity in the media is required. In order to determine whether a site is appropriate for this method, and to design the system, a well-designed pilot test should be conducted in the form of air-sparging/tracer tests in the reservoir where the system is to be installed.

A related method, developed from air sparging, is biosparging. In this method, the primary objective is to stimulate the biological process. Here, the oxidizing agent is added in pulses under lower pressures.

This method generally is inexpensive and environmentally friendly and typically remediates groundwater quicker than conventional pump-and-treat systems. The disadvantage is that the air flow may channel along preferential paths leading to incomplete remediation. Furthermore, layers of fine-grained sediments may form barriers to upward airflow, diverting the flow laterally which can spread contamination.

In Situ Bioremediation

In situ bioremediation is based on stimulating the natural breakdown of contaminants within the subsurface by enhancing environmental conditions. Groundwater is extracted and treated in a surface mounted bioreactor. The effluent from the reactor, rich in micro organisms, nutrients and oxygen, is then reinjected into the aquifer up gradient of the extraction point. The treated groundwater can also be recirculated through the soil and allowed to percolate to groundwater to promote in situ biodegradation within the soil in addition to the groundwater.

The advantages of this method are that it allows for soil and groundwater treatment with one technology as well as typically remediates groundwater quicker than conventional pump-and-treat systems. The disadvantages are that this method requires close monitoring, is not suitable for low permeability soils and requires thorough knowledge of geology and hydrogeology.

Monitored Natural Attenuation

Natural attenuation, also referred to as intrinsic bio attenuation, relies on the natural processes of biological degradation, volatilization, adsorption, and dispersion, which naturally occur at a site, to reduce the level of contamination in the soil and groundwater. In the absence of human intervention, many contaminant plumes will develop until they reach a quasi-steady-state. At steady-state, the contaminant plume is no longer growing and may shrink somewhat over time. Major processes controlling the size of the steady-state plume include:

- Release of dissolved contaminants from the source area.
- Down gradient transport of the contaminants and mixing with uncontaminated groundwater.
- Volatilization.
- Abiotic and biologically mediated transformation of the contaminants of concern.

The choice for monitored natural attenuation may be adopted as the single remedial action for a contaminated site, or for residual contamination removal after completion of a remedial treatment performed at the site.

Periodic monitoring is required to assess the continued effectiveness of natural attenuation. The monitoring program developed for each site should specify the location, frequency, and type of samples and measurements required to evaluate if attenuation is performing as expected, and is capable of meeting the remedial objective. The monitoring duration and frequency should be site-specific according to the plume status, hydro geological characteristics of the site including water level fluctuations, rate of contaminant transport, and the distance of the contamination plume to a receptor. The frequency of monitoring may be reduced over time depending on the progress rate of the remediation. A contingency plan should be developed in the event natural attenuation is no longer effective for the site due to changes in conditions. The contingency plan may include implementing engineering controls for containment of contaminant, active remediation e.g. soil or groundwater cleanup actions or measures to enhance natural attenuation processes, such as stimulating microbial activity.

3.4 Preparation of a Remediation Action Plan

The remedial objective and remediation approach should be documented in the Remediation Action Plan (RAP). The RAP provides a summary of the contamination, site conditions including risk to potential receptors and a proposal by the responsible party on the remedial action as well as site management to be implemented at the site. The RAP should be developed to outline clearly the following important elements:

- Set remedial objectives or site management goals that ensure the site and any relevant additional land contaminated by site activities will be suitable for its current or proposed land use and will pose no unacceptable risk to human health or the environment, either on-site or off-site.

- Remedial action and work plan to achieve an acceptable level of risk for the current or proposed site's land use in the short as well as long term.

- Criteria to assess effectiveness of remediation.

- Health and safety considerations as well as environmental safeguards required in completing the proposed remedial actions tasks.

- Approvals, permits or licenses required by regulatory authorities to undertake the remediation.

A RAP should contain the following sections:

- **Executive summary.** This section should discuss the remediation goals, proposed remediation strategy and actions, selected remediation technologies.

- **Introduction.** This section should provide background information on site conditions and contamination and the responsible party.

- **Review of previous site investigation and assessment.** This section should summarize the findings of previous site investigation(s) and assessment(s).

- **Proposed remediation strategy.** This section should provide the discussion on remediation targets, site specific target levels (SSTLs), and should also present the proposed remediation strategy and the corresponding actions. Rationales of the proposed remediation strategy and actions should be provided.

- **Detailed discussion on remediation actions.** Detailed discussion should be provided on each proposed remediation action with emphasis on design and operation of the proposed remediation actions or technologies and additional information requirements. This section should also identify any special approval that has to be obtained from the Department of Environment or any other applicable government departments.

- **Site management plan.** Description of health and safety considerations and necessary actions to be taken with regards to the disposal of waste generated and any other adverse environmental impacts that potentially result from the remedial tasks performed. A health and safety plan should be included in this section.

- **Implementation program.** This section should set out an implementation schedule with the appropriate actions and milestones for the completion of various activities.

- **Post remediation evaluation.** Discuses the cleanup criteria used to assess the effectiveness of the remediation activities and methods for evaluation. The cleanup criteria set for the site will be in accordance with the remediation method adopted and the environmental media involved e.g. soil or groundwater.

Under situations at which appropriate remediation technologies are to be determined based on additional data required, the site management plan, implementation program and post remediation evaluation can be provided in the subsequent RAP revision.

Any subsequent changes to the RAP due to any changes in site conditions or additional information obtained should be documented accordingly. Such changes, if any, shall be reported and a copy of the revised RAP shall be submitted to the Department of Environment for approval.

4.0 Remedial Investigation, Feasibility Study and Remedial Design

The remedial investigation and feasibility study (RI/FS) and remedial design process outlined in this guideline provides a general reference for the methodology for characterizing the nature and extent of risks posed by contaminated sites and for evaluating potential remedial options. This approach should be viewed as a dynamic, flexible process that can and should be tailored to specific circumstances of individual sites. It is not a rigid step-by-step approach that must be conducted identically at every site.

In general, this section discusses the following steps:-

- Scoping for RI/FS.
- Implementation of RI/FS.
- Remedial design.

All work performed under RI/FS should be reviewed by a qualified remediation specialist or a contaminated land manager, unless otherwise specified.

4.1 Scoping for RI/FS

Scoping is the initial planning phase of the RI/FS process. Scoping activities typically begin with review of the RAP prepared for the contaminated land property. Based on the data need and remediation actions or remediation technologies identified, the scope for relevant pilot studies deemed to be necessary for the subsequent remedial design will be defined.

Activities to be performed during the scoping for RI/FS include but are not limited to the following:-

- Propose remedial investigation activities to address data needs identified in the RAP;
- Identify suitable treat ability studies and define the scope of the treat ability studies; and
- Identify the optimal sequence of site actions and investigative activities.

The identification of data needs is the most important part of the scoping process. Data needs are identified by evaluating the existing data and determining what additional data are necessary to characterize the site, develop a better conceptual understanding of the site, narrow down the range of remedial alternatives that have been identified, and support enforcement activities.

Scoping and implementation of RI/FS is viewed as the intermediate process between the RAP and remedial design. The scoping is highly dependent upon the remediation strategy and actions identified during the RAP and the finding of the RI/FS is expected to facilitate the subsequent remedial design.

4.2 Implementation of RI/FS

The implementation of the RI/FS may include additional environmental media sampling, laboratory bench scale or pilot scale treat ability studies, calculation of remedial design parameters etc. Normally, the RI/FS scope would involve, to a great extent, field activities almost similar to those of a detailed site assessment. The sampling and investigation activities conducted during the RI/FS should be performed in accordance with the procedures specified in the "Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites". In the event if field pilot testing is performed, remediation field management elements as specified in **Section 5** should be followed.

4.3 Remedial Design

Based on the finding of the RI/FS, a remedial design shall be performed by a qualified remediation specialist and reviewed by a qualified contaminated land manager. The design should include process design and all necessary equipment specifications in a design document to be submitted to the Department of Environment. The design document should demonstrate the calculation on the contaminants final concentrations to be achieved and estimation on the remediation period required based on the applicable design practices. The design should also take into consideration meeting all required regulatory requirements, such as air emission requirements, noise and vibration limits, discharge quality requirements, equipment safety requirements, field work safety requirements and other requirements to comply with legal requirements and prevent nuisance impacts to the surrounding neighbouring facilities.

5.0 Remediation Implementation

5.1 Compliance with Applicable Regulatory Requirements

It is important to understand the regulatory requirements that may be applicable to the contaminated site and the remedial work to be performed. The responsible party must identify all laws and regulations applicable and/or relevant to every task performed for the remediation and may seek assistance with this effort from the government agencies. As a guide, **Table 1** provides a listing of regulations and summary of the requirements which may be applicable to tasks associated with remediation works.

Table 1: Environmental, health and safety regulations potentially applicable to remediation of contaminated sites

Regulation	Summary of Requirements	Authority Involved
Environmental Quality (Scheduled Waste) Regulations 2005	Sets forth the requirements regarding the generation, storage and disposal of scheduled wastes. The following are classified as scheduled waste: ▪ Contaminated soil, debris or matter resulting from cleaning-up of a spill of chemical, mineral oil or scheduled wastes (SW 408).	Department of Environment
Environmental Quality (Clean Air) Regulations 1978	Stipulates permissible limits of concentrations of air impurities.	Department of Environment
Environmental Quality (Control of Pollution From Solid Waste Transfer Station and Landfill) Regulations 2009	Sets forth the acceptable conditions/discharge standards for leachate onto/into any soil or into any inland waters.	Department of Environment

Regulation	Summary of Requirements	Authority Involved
Environmental Quality (Industrial Effluent) Regulations 2009	Sets forth the acceptable conditions/discharge standards for Industrial effluent or mixed effluent into any inland waters.	Department of Environment
Environmental Quality (Sewage) Regulations 2009	Sets forth the acceptable conditions/discharge standards for sewage into any inland waters.	Department of Environment
Planning Guidelines for Environmental Noise Limits and Control 2004	Specifies noise limits for facilities temporarily engaged in construction, maintenance or demolition work including the operation of power generators, excavators, dozers and loaders, powered hand held concrete breakers and picks, compressors, tower cranes, welding generators, cooling towers and piling operations.	Department of Environment
Guidelines for Public Safety and Health at Construction Sites 1994	Provides requirements for construction sites pertaining to warning signs, enclosure of construction sites, transportation of materials, restriction on worksite access, disconnection of utilities, guarding of mechanical equipments and temporary accommodation of construction workers.	Department of Occupational Safety and Health
Factories and Machinery Act 1967	Specifies requirements for notification to the Chief Inspector of Factories and Machinery for any building operation or work of engineering construction.	Department of Occupational Safety and Health

Regulation	Summary of Requirements	Authority Involved
Factories and Machinery (Building Operations and Works of Engineering Construction) (Safety) Regulations 1986	Sets forth safety requirements for all building operations and works of engineering construction undertaken for trade or business, industrial or commercial undertaking, or on behalf of the Government or other public authority. This Regulation stipulates safety requirements for excavation works including stability of excavation and provision of guardrails, watchman, warning signs and adequate illumination at excavation sites. This regulation also includes a wide range of other requirements concerning amongst others personal protective equipments, scaffolds, passageways and work platforms, precautions on traffic, vehicles at construction site, and electric circuits at construction area, material handling and disposal of construction debris.	Department of Occupational Safety and Health
Guidelines on Trenching for Construction Safety 2000	Provides guidelines for safety and health consideration for works involving trenches.	Department of Occupational Safety and Health
Occupational Safety and Health Act 1994	Establishes provisions for securing the safety, health and welfare of persons at work, and for protecting others against risks to an employee's safety or health in connection with their activities at work.	Department of Occupational Safety and Health

The responsible party has the overall responsibility in ensuring that the remediation activities carried out at the contaminated land property comply to all applicable regulatory requirement related to subsurface remediation.

5.2 Health and Safety Considerations

5.2.1 Site Safety Planning

Prior to the start of a remediation work, a health and safety plan should be prepared. The health and safety plan should include an extensive assessment of the hazards, the safety precautions or measures to eliminate or reduce the risks associated with the hazards, personnel and equipment decontamination procedures, emergency response procedures and key individuals assigned to the project and their responsibilities for conducting work activities in a safe manner.

The emergency response procedure should include information on emergency actions such as emergency contact numbers, who should be informed of an emergency occurrence and escape routes. In the event an emergency occurs, all associated works should be stopped and work should only recommence once the situation or condition has been evaluated to be safe. The cause of the accident should be investigated and corrected to prevent future similar accidents.

In addition to a health and safety plan, a job safety analysis (JSA) should be prepared which will be specific to job tasks performed. The JSA should take into consideration all hazards associated with each task and for each task, appropriate hazard control and precaution measures should be identified. The JSA should be regularly updated and communicated to all staff involved in the work. Staff should be briefed before the start of work on the hazards associated with their job scope and precaution methods that should be undertaken to eliminate or reduce the risks in relation to the hazard. In addition, the JSA should also be regularly updated and new hazards identified should be properly documented and communicated to all staff.

In addition, where air-borne chemicals could be a hazard to personnel, appropriate controls should be implemented and documented in the health and safety plan. Staff should position themselves upwind of potential hazardous sources so as to minimize the risk of exposure to airborne sources. If volatile organic compounds may be encountered during the site work then a portable photo-ionisation detector (PID) may be required at site to monitor for the chemicals. Action (warning) and higher stop work levels should be established.

There must also be adequate supervision of control or preventive measures identified in the health and safety plan to ensure that the measures are applied correctly and adequately. Additionally, all staff involved in the remediation field work should have appropriate training in the use of any field equipment which may be required.

In addition, all health and safety legislative requirements which are applicable to the work performed should be reviewed and complied with.

5.2.2 Underground Utilities

The location of underground services should be carried out prior to excavation or drilling works at a site. Underground utilities may include power, gas, product, telecommunication, water, sewer and storm water. The procedure for determining the location of underground utilities includes:

- Gathering information such as contacting client project engineer, site operators and local utility owners to obtain as built plans and their knowledge of the site.

- Identifying potential underground hazards prior to commencing excavation or drilling work. A site walk over to check for signs of excavation work and visual signs of services against plans which includes boundary junction boxes, water meters, water taps, location of toilets, electricity meter or cable entry points, gas pipes and meters, fuel dispenser, vent lines, tank cover slabs and manhole covers.

- Identifying potential underground hazards during excavation. Note should be taken of excavated material, looking for trench backfill material, plastic marker tape and any other indication that services may be existing in the vicinity. Operations should be immediately stopped if there are any concerns during the excavation or drilling.

- Employing the services of a detection specialist, where appropriate, to mark the location of services on the ground.

- Hand excavation in the proposed excavation and well installation locations if insufficient data is available to accurately determine the location of the utility lines.

5.3 Supervision

Remedial measures for contaminated soil or groundwater should take place under environmental and specialist supervision. The objective of supervision is primarily to ensure that remedial measures are implemented as described in the remediation action plan, and that remedial solutions operate in the best possible manner. Therefore, environmental supervision should be conducted with regard to the environmental effect of the remedial measures and should examine the services provided by the contractor. The following tasks are usually performed as part of supervision:

- Ensure compliance with criteria set for assessing remediation effectiveness (e.g. field measurements and analyzes);
- Ensure compliance with the site management plan i.e. health and safety as well as environmental requirements identified for the site in relation to the remedial tasks performed; and
- Document work completed.

5.4 Site Works Control

The following controls of the site works are necessary:

- Dust generation must be kept to a minimum. Dampening the ground may be necessary;
- Surplus spoil from the site activities that is considered to be contaminated are required to be collected, labelled, stored and disposed as scheduled waste so that the waste does not present a hazard;
- All vehicles and equipment used on site may be required to be cleaned prior to departure so that no dust or chemical residues are transported off-site; and
- Noise levels should be monitored. Activities known to generate high noise levels should be restricted to specific times.

5.5 Decontamination

Practicing proper decontamination of equipment including both remediation and sampling equipment will minimize the potential for cross contamination of samples or introduction of contamination from equipment to sampling locations or any other uncontaminated areas. For sampling, it is recommended that dedicated sampling equipment is used onsite. However, where non-dedicated sampling equipment is used, the equipment should be decontaminated appropriately prior to use.

5.6 Disposal of Waste

Special precautions should be taken to prevent contaminated media from contaminating uncontaminated areas. As such, contaminated soil or water produced from the remediation works, prior to offsite disposal should be stored in a proper designated location where the contaminant is not likely to escape into the environment. If contaminated waste is to be treated onsite, proper monitoring of treatment should be conducted to ensure treatment is effective and will not pose any risk to human health or the environment from its release or discharge.

5.7 Quality Control/Quality Assurance

It is essential to have a quality assurance system in place in order to ensure optimal control of remedial projects with regard to quality, time, and costs. Quality assurance may include planning of controls, the actual controls and documentation of controls. A quality assurance plan should be developed and at the minimum should contain the sub-activities to be controlled, and the persons responsible to perform such controls. Quality assurance will also usually include document management and control, and project inspection.

For field sampling, to ensure that all field and laboratory data collected for soil and groundwater samples provide reliable information, a quality control procedure should be followed. The procedures are provided in the "Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites". The procedure includes providing duplicate samples, trip and equipment blanks as well as requirements for sample preservation and analysis at an accredited laboratory.

6.0 Post Remediation Evaluation

6.1 Evaluation and Adjustment

Upon completion of remedial actions, the next step is to evaluate the effectiveness of the remediation work performed by confirming that the site complies with the cleanup criteria set in the remedial action plan. This is done through an evaluation and adjustment phase followed by final validation which is designed to evaluate and document the effect of completed remedial measures.

The application of the remedial action plan should be assessed both in terms of the management and remedial goals established, and how remediation was undertaken. This will vary according to:

- The degree of contamination originally present and the remediation goals set for the site.
- The type and extent of remedial processes that have been carried out.
- The current or proposed land use.

Evaluation is performed through conducting sampling and analysis of relevant parameters and comparing resulting data with the cleanup criteria set based on the remedial goals decided for the site. The evaluation process may also include a statistical evaluation to make decisions regarding whether a site has met the cleanup criteria in spite of uncertainty.

Prior to execution of the evaluation and adjustment phase, procedures for evaluating measured parameters should be prepared. These should include operating parameters and values with a view to adjusting the remediation and criteria for final validation to validate that the remedial objectives stated in the remedial action plan have been achieved. Procedures should also describe the frequency and form of reports, in which evaluation and adjustment measures should progress to ensure that the required environmental effect is achieved.

The evaluation and adjustment phase depends on the type of remedial measures. With excavation, the evaluation phase is short term and takes place more or less simultaneously with the remediation phase. With in-situ remediation of soil, air or groundwater, the evaluation and adjustment phase can be longer term. The evaluation and adjustment phase is followed by validation of compliance at the conclusion of the remediation.

The final validation must confirm statistically that the remediate site complies with the clean-up criteria set for the site in the remedial action plan. A number of computer tools can also assist with sample planning and the assessment of statistics related to sampling.

6.1.1 Evaluating Excavation

Excavation removes soil contamination either partly or completely. Evaluations are carried out simultaneously with the excavation in order to ensure that the soil is sorted into contaminated soil and clean soil. Evaluation should also ensure that residual contamination is in compliance with the excavation criteria (e.g. that the contamination level in the sides and bottom of the excavation are sufficiently low). Procedure for managing the contaminated soil should be clearly stated in the RAP. In order to ensure that requirements are complied with, excavation must take place under the supervision of a qualified remediation specialist or remediation project manager.

There are three types of evaluations for excavation:

- Evaluation of the excavated soil.
- Evaluation and documentation of residual contamination after excavation.
- Evaluation of remediate soil.

(a) Evaluating Excavated Soil

In order to optimize remediation of contamination, a clear excavation strategy should be agreed upon. The excavation strategy primarily depends on the results of contamination mapping in the investigation phase, in particular the homogeneity of the contamination. A strategy for sampling must always be established, outlining where samples are to be collected from, how often they are to be taken, and how samples are to be taken for field measurements and laboratory analyzes. Furthermore, attention should be directed to how the excavation is to be physically carried out. This is important with regard to geotechnical considerations, and is also often important with regard to evaluating the excavation. For example, it may be appropriate to describe how large an area should be removed at each level, the depth of soil removal at each level, the maximal extent of the excavation, what size the bucket the excavator should have, etc.

The method and cost of soil treatment depends on the type of contamination and its concentration. It is therefore necessary to document the contamination in the excavated soil by taking soil samples for analysis. The number of samples which should be taken for laboratory analysis depends on several factors, including:

- How homogeneously the contamination is distributed.
- The type of contamination (can the contamination be detected using simple methods, for example field measurements or visually).
- Whether the contamination is to be divided into several classes of contamination for different methods of disposal.
- How the soil is to be disposed of (soil for reuse or land filling may require more analyzes than soil for treatment).
- The total amount of contamination (small amounts require relatively more analyzes than large amounts).
- How many investigations have been carried out before excavation started (for example, has the contamination been well-defined).

In the remedial design and investigation phase, a plan for the collection of samples is established. The plan may include the number of samples and the systematic pattern of distribution to be used in the area in question and divided into each layer of soil to be removed. In addition, the plan can describe collection of samples from an interim soil storage location, receiver facilities, or directly from the excavator bucket.

When taking samples with volatile substances, especially in interim soil storage location, it is necessary to be aware of losses of contaminants.

Therefore, appropriate sample containers (diffusion-proof), sampling methods (not surface samples) and handling should be used.

If excavated soil containing organic contamination is to be delivered to soil treatment facilities, the number of required samples primarily depends on the need to sort the soil into different categories with a view to achieving financial advantages. Therefore, the number depends on the specific case (amount, homogeneity, type of contamination, price differences between categories).

Assigning soil directly to a landfill requires greater certainty and therefore a larger number of samples than soil assigned to a treatment facility. The number of samples and methods of analysis depend on the specific case (amount, homogeneity, type of contamination, final landfill), and the environmental authorities' requirements for documentation.

Requirements for the selection of analysis parameters and methods are the same as in the investigation phase and depend on the type of contamination. These are described in the "Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites". Analyzes must be carried out at an accredited laboratory.

(b) Documentation of Residual Contamination

Excavation is stopped temporarily when it is estimated by an inspection that adequate contamination has been excavated to have reached compliance with the previously set cleanup criteria. Compliance with the cleanup criteria should be documented by collecting an appropriate number of samples for chemical analysis from the sides and bottom of the excavation. These samples may be supplemented by field measurements. The number of samples should be determined in the RAP and any subsequent changes to the RAP should be documented accordingly. The focus should be on the most critical areas. If remediation is carried out due to risks involving outdoor areas and indoor air, most of the samples should be taken from the uppermost metres, while for risks involving the groundwater, there should be more documentation from the bottom of the excavation. The density of samples also depends on the nature of the contamination.

Under the description of cleanup criteria set in the RAP, a minimum number of analyzes must be stated, as well as the number of analyzes per area unit. As a rule, samples should always be collected from all sides and the bottom of the excavation. In cases where there are visual indications in the open excavation that the contamination distribution is inhomogeneous, for example through the distribution of geological layers and/or soil colour, more samples should be taken for residual contamination.

To document completion of the project, a report is prepared which documents that agreements have been complied with, including excavation, handling, and analysis procedures, and concentration levels in both excavated soil and remaining soil. A risk assessment should be carried out to determine the consequences of allowing residual contamination to remain.

6.1.2 Evaluation of In-situ Remediation of Soil Contamination

The following is a description of the concepts of evaluating the operation and final compliance of in-situ remediation of soil contamination. Evaluation takes place at regular intervals during operation with a view to ascertain the progress of remediation and whether the technical equipment is working optimally. The final compliance takes place when an evaluation of operation shows that it is likely that the cleanup criteria have been reached.

(a) Evaluation of the Operating Period

The following describes possible evaluations for in-situ remediation methods used for soil contamination, including active methods such as soil vapour extraction and bioventilation, and passive methods such as immobilization methods.

During the operating period, the contamination should be monitored so that changes in the contamination can be documented. In soil vapour extraction, operation should initially be followed closely (samples should be collected at least one week after the start), and subsequently with increasing time intervals, for example after 1, 3, 6, 9, and 12 months. Further evaluation of operation after this period can be set according to the results of the first year's operation. This will typically be about two to four times each year.

During the operating period, measurements will primarily be of the contaminants in the discharged air. Furthermore, the air flow and the air pressure should be monitored. As completion of the remediation approaches, monitor wells for soil gas/groundwater may be included in the evaluation. In addition to measuring contaminants, it is possible to measure for oxygen, carbon dioxide, and temperature in the discharged air.

In bioventilation, evaluation of the operating period is best carried out by measuring oxygen and carbon dioxide consumption using bio-activity tests. By comparing with earlier measurements, an indication of changes in activity is obtained. In bio-activity tests, a specific quantity of oxygen is injected into the contaminated layer. Changes in the oxygen and carbon dioxide content are subsequently measured in the nearby monitoring wells. As a minimum, this should be carried out twice a year.

In addition, contaminants in the soil gas should be analyzed for in existing monitor wells at the end of the operating period. Monitoring groundwater/soil can also be advantageous with regard to checking whether the water/soil is cleaner. Air measurements will typically be performed if the cleanup criteria consist of air concentrations. The same applies to water/soil. In monitoring groundwater, the redox conditions should be checked in order to determine the degradation potential.

In forced leaching, evaluation of the operating period is best performed by analyzing water samples from the inlet and outlet of the water-treatment device. Analysis should be carried out an appropriate number of times at increasing time intervals. This should be done about once a week in the first month and subsequently about once a month, extending to a minimum of once every six months.

In addition, samples from monitoring wells should be analyzed at appropriate intervals during the operating period for content of contaminants in the groundwater aquifer.

In immobilization methods (fixing/capping methods) the clean side of the cut-off system should initially be monitored twice a year, falling to once a year. For volatile contamination, it is normal to carry out soil gas measurements, while for water soluble substances; the groundwater aquifer should be monitored down gradient of the cut-off system. For extra security and to achieve optimal monitoring, it may be relevant to construct double walls, with monitor wells placed between the walls.

(b) Final Compliance

Cleanup criteria for final compliance should be set before commencement of remedial measures and should be documented in the RAP. The following parameters should be included in the decision process:

- Sample medium for final compliance (air/soil/water, possible combination).
- Procedures for evaluating final compliance.
- Strategy of sampling to determine the lasting effect of remediation.
- Measurement and analysis parameters and procedures.
- Permissible variation in results.

Contamination may be in the water, soil, and/or air phase. Therefore, it is possible to determine changes in the contamination in a single medium, or in a combination of several media. For example, if the indoor air is threatened, a soil gas criterion could be set. If remediation takes place due to risks for outdoor areas, a soil criterion may be appropriate, and a groundwater criterion could be set if drinking water is threatened. It is often necessary to establish new wells/boreholes between existing wells/boreholes. The normal procedure for evaluating final compliance is to obtain a concentration in the media (soil, water, air) which relates to the limit values for individual substances. In a few cases, the obtained ratios between individual contaminants have been used. In these methods, substances which are quickly removed are compared with substances which are difficult to degrade. This method can only be used in remediation where the substances which degrade rapidly are the most critical, usually for indoor air concerns.

Finally, cleanup criteria for final compliance may be interpreted pragmatically in relation to the rate of remediation. When the remediation process is sufficiently slow, remedial measures can be stopped temporarily. A subsequent risk assessment forms the basis for deciding whether remedial measures should be stopped permanently, or whether it is necessary to continue using another technique. Several remediations have followed this process in practice. There is a difference between the effect during operation and the lasting effect for many in-situ remedial methods. In some cases, contaminants will reappear/flow back after equipment is shut off, causing the remediation to fail to comply with original cleanup criteria for final compliance (rebound effect). The final compliance evaluation should therefore establish a sampling strategy which will document the lasting effect (that the remediation is satisfactory). Thus, before commencing remedial measures, decisions should be made on which sample medium will provide the best evidence of the lasting effect, the number of samples required for sound decision-making (when it absolutely certain that the remediation effect is lasting), the length of time between sampling, and whether individual samples or mixed samples (soil) should be taken. Typically, there should be assessments of how long it will take before contamination is transported into the water phase and further into compliance wells.

When the evaluations during the operating period reveal adequately low concentrations in air discharge (where this is the only requirement for operation), samples must be collected from the sample medium selected for the final compliance. Samples must be collected from places other than the air discharge for ventilation methods. As a minimum, two consecutive analysis of the air discharge should show no measurable contamination. The samples should be collected with about a two month interval, where the pump has been stopped for a period. Following this, samples of soil/water/air can be collected from new wells in order to check for compliance with the cleanup criteria for final compliance.

In forced leaching, the quality criteria for compliance are fixed concentrations either in soil or in groundwater. However, in practice, these pre-set criteria have not been used. For in-situ remediation completed up to now, risk assessment of residual contamination has provided the basis for stopping remediation. For most passive in-situ methods, e.g. immobilization, there is no distinction between final compliance and evaluating the operating period. Monitoring corresponding to evaluating the operating period is continued (although as time goes by, longer intervals between monitoring rounds are used).

Decisions must be made on which contaminants are to be quantified through analysis. These may be individual substances or mixtures of substances. It is important to define the evaluation procedures to be used, including methods of analysis. If a specific correlation is to be demonstrated, it may also be relevant to use field measurements as part of the cleanup criteria for final compliance.

6.1.3 Evaluating Groundwater Remediation

As there are many methods or principles for the remediation of groundwater contamination and most of those methods or principles are academically discussed and technical manuals are available, technical references or evaluation methods established for different groundwater remediation techniques shall be used to the extent possible. For the purpose of demonstrating the process of evaluating groundwater remediation, the following subsections present the groundwater remediation evaluation process with focus on the pump and treat and in-situ groundwater remediation methods only.

(a) Evaluating Pump and Treat

When pumping is started, it is necessary to check whether the contamination is under hydraulic control. A monitoring programme is usually established when the plant is constructed, and this is revised once the installation has been run in. The monitoring programme lays down where the potentiometric surface should be measured and where measurements of pump yield are to be made, as well as how often the yield is to be measured.

Wells for monitoring hydraulic control are usually located within and near the borders of the capture zone of the well. Therefore, observations on both sides of the groundwater divide should document that the contamination plume is on the right side of the divide. Evaluation of whether contamination has been remediate as planned includes sampling and analyzes of contaminants in the pumping well and monitor wells. Wells for monitoring remediation should be located within the contamination plume, at the source of contamination, and possibly in minor upper aquifers above the contamination plume, down gradient of the source.

The monitoring programmes establish where samples are to be collected, and how often water samples are to be collected, as well as which analysis are to be conducted. In pump-and-treat, there is often a difference between the remediation effects during operation and the lasting effects. When the pump is turned off, contaminants will often be released/flow back, so that remediation does not comply with the cleanup criteria for final compliance as expected (rebound effect). For example, contaminating substances can be released into groundwater when the groundwater table rises after pumping is slowed down. It is therefore very important that the lasting effect is measured after pumping has been stopped.

There should be estimates of when it will be possible to ascertain any rebound effects in wells. If the lasting effect is deemed to have been met, but control measurements after a period of three months or so indicate that cleanup criteria for final compliance have been exceeded, pumping must be recommenced. This procedure should be repeated until the cleanup criteria for final compliance have been achieved.

The desired remediation level is established on the basis of the risk assessment conducted in the investigation phase. The cleanup criteria for final compliance should contain requirements that values below the remediation level are achieved for several consecutive monitoring rounds. In addition, samples should be analyzed from several monitor wells as well as from the pump well. Cleanup criteria for final compliance may be varied according to the location of the well from which the sample was collected.

When discharging contaminated groundwater, evaluations should be made to ensure that the treatment processes are running satisfactorily. For example, in filter technology, all filters must be regularly backwashed, cleaned, or replaced. The effect of the filter is reduced over time as the filter material slowly loses its ability to adsorb and/or absorb components, or it becomes clogged. Therefore, a certain amount of monitoring and evaluation of operation must be expected in connection with backwashing, cleaning, and replacement of filters.

The extent of monitoring water treatment is very method specific, and should therefore be described in the monitoring programme. For example, separators must be emptied at appropriate intervals. For water treatment with activated carbon, the system usually comprises two filters in series. The treatment effect of the system is best measured between the filters so that the filters can regularly be replaced one at a time, and contaminants never break through the final filter.

(b) Evaluating In-situ Remedial Methods

Evaluation of the remediation effect of air sparging, as with pump-and-treat, is primarily done through monitoring the groundwater. This implies analysis of groundwater samples from monitor wells located centrally and on the periphery of the contaminated area. The frequency of sampling can, for example, is after 1, 2, 3, 6, 12, 18, and 24 months. It should be noted that air sparging can cause significant spreading of contamination by transport in the sparged air in the saturated zone, probably as a result of low-permeability horizontal zones. The existence of such low-permeable zones should be examined in the design phase. If these zones are present, monitoring should also be carried out further away from the sparge area, in regard to possible indoor air problems as well as to groundwater. At the same time, it is also important to regularly measure the potentiometric surface of the groundwater in order to monitor mounding of the water table.

Concurrently with air sparging, it is normal to remove stripped contaminants from the unsaturated zone using soil vapour extraction. Measurements of these air emissions should be included in the monitoring programme. For air sparging, the pragmatic view will generally apply with regard to cleanup criteria for final compliance.

Remedial measures can be stopped when concentrations of contaminants are low and there are no notable changes in the contamination pattern (even after taking possible rebound effects into account). In addition, a specific risk analysis should conclude that remedial measures can be stopped. Sparging may be replaced by monitoring or pump-and-treat if the risk analysis deems this necessary.

Reactive permeable barriers allow the passage of groundwater, while degrading or removing contamination from the groundwater. Compliance is evaluated in the groundwater zone and should include samples collected before inflow, in the barrier itself, and after the barrier. Furthermore, contamination should be monitored up gradient and down gradient, as well as before and after any cut-off walls in order to examine effectiveness. To ensure the required flow direction, and in order to enable commencement of possible measures against mounding problems, the groundwater table should also be monitored.

Impermeable barriers should primarily be monitored down gradient of the contamination. As an extra measure to achieve optimal evaluation, it may be relevant to establish double barriers with monitoring between the barriers. With methods where oxidizing agents are added to the groundwater zone, effectiveness should be evaluated down gradient and in pump wells where the purpose is to produce an ‘oxygen barrier’. In addition to contaminants, monitoring should identify when the oxidizing agent should be replaced or recharged.

6.2 Validation Reporting

After completion of the evaluation and adjustment phase, a site validation report detailing the application of the remedial action plan, any variances from the proposed plan and the results of validation is required. The report should give details of the programme and enough information to let the reviewer replicate the assessment. The site validation report must assess the results of the post-remediation testing against the clean-up criteria stated in the remedial action plan. Where targets have not been achieved, the reasons for this must be stated and additional site work proposed to achieve the specified remedial action plan objectives should be listed. If any contingency plans were detailed in earlier reports, they should have been implemented before the site validation report is submitted.

The site validation report should also include, where possible, information confirming that all the requirements of the local government agencies have been met. In particular, documentary evidence should be included to show that any disposal of contaminated material off-site (scheduled waste) has been done or will be done in accordance with the remedial action plan, and with the requirements of the disposal site and the relevant local authority.

Validation report shall be prepared by qualified remediation specialist or remediation project manager and approved by contaminated land manager prior to submitting to Department of Environment for final approval.

6.3 Ongoing Monitoring and Management Plan

The requirements for an ongoing monitoring and management plan for the site should be assessed where:

- Full clean-up is not possible or preferable;
- Monitored natural attenuation is selected as the preferred remedial option; and
- On-site containment of contamination is proposed.

Where remedial goals are achieved in accordance with the remedial action plan, as confirmed by the site validation report, there may still be a requirement to provide an ongoing monitoring and management plan. A monitoring program should detail the proposed monitoring strategy, what will be monitored, the location and frequency of monitoring, and the reporting requirements (format, content and frequency). It should also state the proposed period for reviewing the monitoring and management plan.

The ongoing monitoring and management of a site should be properly documented and reported. The report should provide details on the activities performed, results obtained and confirmation that the risks are being managed in accordance with the remedial objectives decided for the site.

6.4 Execution of Site Restoration

Investigating and remediating a site might alter site conditions and the site may have to be restored to its pre-remediation conditions. This section familiarizes the person conducting a remediation with some aspects of restoration. The extent of restoration depends on site-specific conditions and the remedial action chosen. Considerations for restoration may include:

- **Backfilling**: Usually, backfilling should occur after the cleanup objectives have been met. Backfill should, to the extent practicable, have physical properties similar to the material which was removed.

- **Impermeable Layers**: In areas where impermeable geologic layers are encountered and breached, backfill of similar hydraulic characteristics should be placed.

- **Vegetation and Grading**: Restoration of the vegetative soil layer should be performed to the extent practicable. This includes applying seed and mulch in prepared areas at recommended rates. Trees and other vegetation which were removed should be restored to the extent possible with nursery grown trees of the same species. The site should be graded to reflect pre-existing conditions using information gathered during the preconstruction topographic survey.

6.5 Project Closure Reporting

Upon completion of post remediation evaluation, it is the responsibility of the polluter or responsible party to ensure that a project closure report is prepared by qualified remediation specialists and reviewed by a qualified contaminated land manager. The project closure report shall be submitted to the Department of Environment for approval.

The project closure report shall contain the site remediation objectives and targets, scope of remediation activities, and findings of post remediation evaluation.

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