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

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FOREWORD

Under the Ninth Malaysia Plan (2006-2010), the Department of Environment, initiated a study on the Criteria and Standards for Managing and Restoring Contaminated Land in Malaysia. As a result of the study, a contaminated land management framework which includes soil screening guidelines values and a series of guidelines were developed to enable proper assessment and management of contaminated site in Malaysia.

This guideline is the second in a series of guidelines on contaminated land management produced by the Department of Environment Malaysia. Contaminated Land Management and Control Guidelines No. 2: Assessing and Reporting Contaminated Sites provides a consistent and uniform approach to site investigation, assessment, risk assessment and reporting of all land properties classified as contaminated land. This guideline also covered the assessment approach, sampling design and techniques, quality assurance and quality control (QA/QC) protocols and report preparation as well as reviewing of such sites and to come out with the necessary actions to carry out remediation and rehabilitation measures when required.

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List of Abbreviations

^oC	Degree Celsius
APHA	American Public Health Association
BESA	Baseline Environmental Site Assessment
COPCs	Constituent-of-Potential Concerns
CSM	Conceptual Site Model
DNAPL	Dense Non-Aqueous Phase Liquid
DOE	Department of Environment
DQOs	Data Quality Objectives
ERP	Emergency Response Plan
ESA	Environmental Site assessment
FIDs	Flame Ionisation Detectors
HSE	Health, Safety and Environmental
JSA	Job Safety Analysis
LEL	Lower Explosive Limit
LNAPL	Light Non-Aqueous Phase Liquid
PIDs	Photo-Ionisation Detectors
PPE	Personal Protective Equipment
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control
SSL	Site Screening Levels
SSTLs	Site-Specific Target Levels
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds

1.0 Introduction

1.1 Purpose

The purpose of this guideline is to provide the approach in assessing and reporting contaminated sites. It provides a consistent and uniform approach to site investigation/assessment, risk assessment and reporting. 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. 3: Remediation of Contaminated Sites.

1.2 Scope and Application

This guideline shall be adopted for the assessment and reporting of all land properties classified in the "Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land".

This guideline defines procedures for the following site assessment activities, i.e.:-

- Initial Assessment (or Phase I ESA).

- Detailed Assessment (or Phase II ESA).

- Risk Assessment.

1.3 Definitions

Definitions applicable for this guideline are provided below:-

"Acceptance criteria" is the contaminant concentrations protective of human health and/or ecology based on a Tier 2 or Tier 3 risk assessment.

“Conceptual site model” means a working hypothesis presented in graphical or pictorial forms that is used to present identified potential nature and sources of contamination, their likely spatial distribution in soil (or other environmental media), routes of exposure (pathways), and the potential effects of the contaminants on the site and on adjacent sites and other receptors.

“Detailed assessment”, often referred to as a “Phase II environmental site assessment or Phase II ESA”, is an intrusive investigation and assessment of a property follows the completion of an initial assessment (also known as Phase I environmental site assessment or Phase I ESA) to identify and determine the presence, nature and extent of potential subsurface contamination.

“DNAPL” means chemicals that are more dense than water, insoluble or only slightly soluble in water that exist as a separate liquid phase in groundwater.

“Ecological risk assessment” means a process for organizing and analyzing data, information, assumptions and uncertainties to evaluate the likelihood that adverse effects to relevant ecological receptors or habitats may occur or are occurring as a result of exposure to chemical(s) of concern.

“Exposure pathway” means the course a chemical of concern takes from the source area(s) to a receptor or relevant ecological receptor and habitat.

“Exposure scenario” means the description of the circumstances, including site properties and chemical properties, or the potential circumstances under which a receptor or a relevant ecological receptor or habitat could be in contact with chemical(s) of concern.

“Hazard quotient” means the ratio of the level of exposure of a chemical of concern over a specified time period to a reference dose for that chemical of concern derived for a similar exposure period.

“Human receptor(s)” means the person(s) that are or may be affected by a subsurface contamination.

“Initial assessment” often referred to as “Phase I ESA” a non-intrusive investigative research conducted to obtain as much detailed site history and contamination information as possible without having to collect, sample and analyze environmental media. The initial assessment normally will be conducted to identify potential or existing environmental contamination liabilities associated with the property.

"LNAPL" means chemicals that are less dense than water, insoluble or only slightly soluble in water that exists as a separate liquid phase in environmental media.

"Point(s) of exposure" means the point(s) at which an individual or population may come in contact with a chemical(s) of concern originating from a site.

"Risk assessment" means an analysis of the potential for adverse effects on receptors and relevant ecological receptors and habitats caused by a chemical(s) of concern from a site.

"Tier 1 risk assessment" means a risk-based analysis utilizing non-site-specific corrective action goals for complete and potentially complete direct and indirect human exposure pathways and qualitative ecological screening evaluation for complete and potentially complete exposure pathways for relevant ecological receptors and habitats.

"Tier 2 risk assessment" means a risk-based analysis that involves an incremental refinement of the Tier 1 methodology to develop site-specific corrective action goals. The Tier 2 evaluation for human exposure pathways may include developing statistically representative concentrations of chemical(s) of concern for comparison to the Tier 1 corrective action goals, back-calculating Site-Specific Target Levels (SSTLs) by applying the direct exposure pathway corrective action goals established under a Tier 1 evaluation at site-specific determined point(s) of exposure, developing SSTLs for potential indirect exposure pathways at point(s) of exposure using site-specific conditions and the Tier 1 methodology, or developing SSTLs for complete or potentially complete exposure pathways using site-specific conditions for which no Risk-Based Screening Level (RBSL) were developed in Tier 1, or the evaluation may employ a combination of alternatives.

"Tier 3 risk assessment" means a risk-based analysis that involves a significant incremental effort over the Tier 2 evaluation to develop site-specific corrective action goals. The Tier 3 evaluation for human exposure pathways typically uses advanced exposure assessment, toxicity and risk assessment techniques (for example, probabilistic exposure assessment methods, use of bio-availability data, use of advanced fate and transport modelling) allowing maximum flexibility to develop SSTsL for potential direct and indirect exposure pathways at the point(s) of exposure based on site-specific conditions.

“Quality assurance/quality control” (QA/QC) means the use of standards and procedures to provide reasonable assurance that samples collected and data generated are reliable, reproducible and verifiable.

2.0 Overview of the Guidelines

"Risk-Based" approach is the overall guiding principle for the Contaminated Land Management Framework. The principles underlying a risk-based approach to site assessment and management are as follows:-

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

- Activities performed for site assessment should focus on collecting relevant information required to determine the likely health and environmental impacts associated with the site, and to make risk-based decisions regarding contaminated land management.

- 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.

The recommended contaminated land assessment procedure followed a tiered approach, as it was recognized that not all sites pose the same risk to human health and the environment, and resources should be focused on assessing and managing sites where a significant impact is likely. Three stages of assessment activities are as follows:-

Initial Assessment

An initial assessment (also known as Phase I Environmental Site Assessment (ESA)) is a systematic assessment process to identify any potential presence of subsurface environmental impacts based on a defined assessment protocol/procedure.

It typically involves a desk top study, interview and a site visit. The initial assessment will also used to obtain useful information for scoping of the detailed assessment.

Detailed Assessment

A detailed assessment (also known as Phase II ESA) is a soil and groundwater investigation process that aims to determine if the subsurface environmental media is impacted.

A detailed assessment would normally be carried out after an initial assessment, should the findings of the initial assessment suggest that the land is potentially impacted by onsite or offsite activities.

Typical activities included in a detailed assessment are:-

- Soil boring;
- Groundwater well installation; and
- Soil and groundwater sampling.

Risk Assessment

Risk assessment is a process of estimating the potential impact of a contaminant on an ecosystem or human population under a specific set of conditions. The similar process can also use to determine the desired clean up target levels that are protective of human and environmental receptors.

Risk assessment can be performed in a tiered approach manner, i.e.:-

- Tier 1 risk assessment is a non site specific risk calculation or a comparison against the site screening levels [refer “Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land”].
- Tier 2 risk assessment is a site specific risk assessment based upon generally acceptable simple fate and transport models for the estimation of contaminant concentrations at the point of exposure.
- Tier 3 risk assessment is a more sophisticated site specific risk assessment that normally would utilize numerical or highly technical fate and transport or exposure modelling for the estimation of contaminant concentrations at the point of exposure.

Depending on the site complexities and project need, Tier 2 or Tier 3 risk assessment would be applied.

The process of assessment and reporting of contaminated land is presented as follows:-

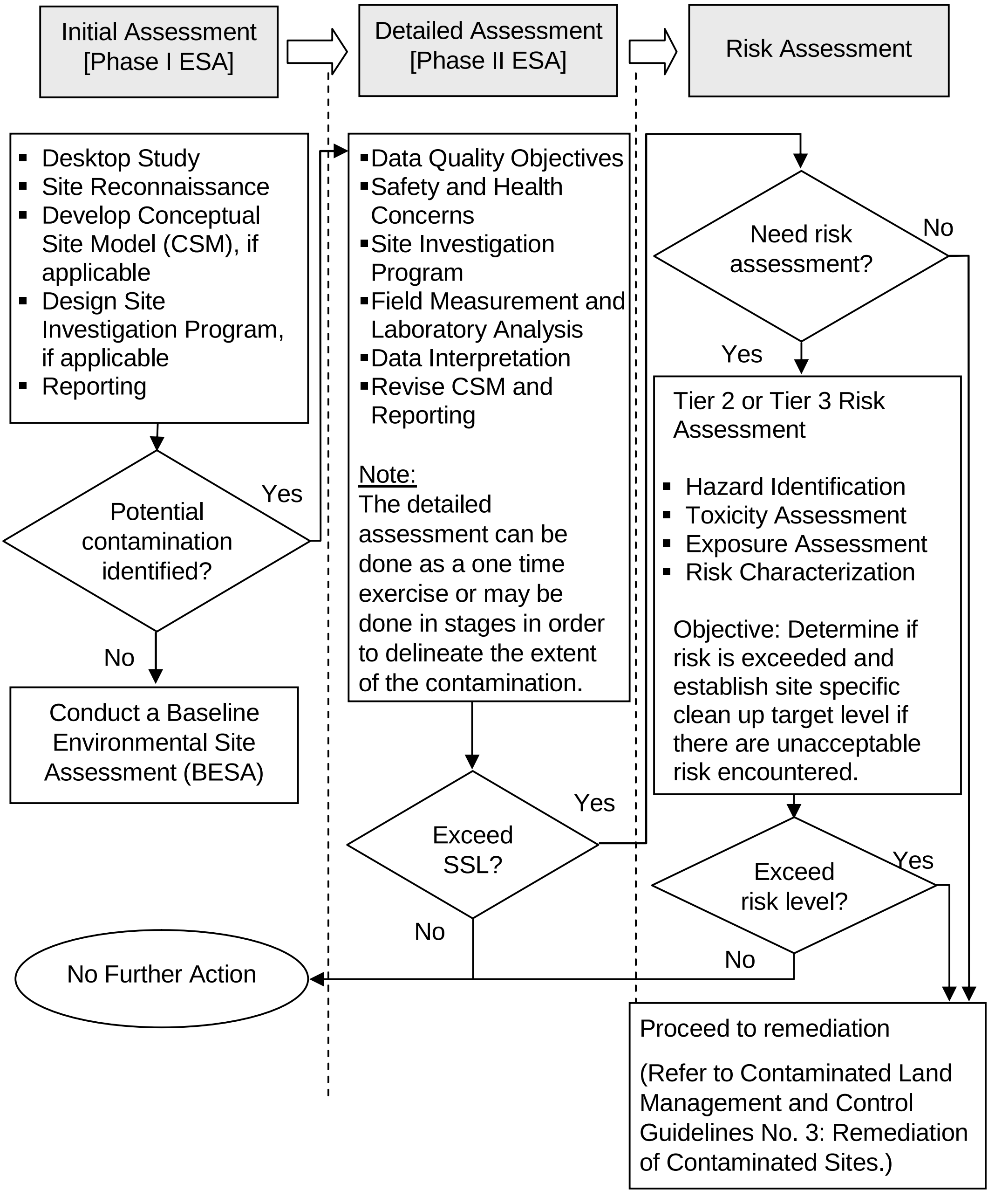

Figure 1: Site assessment and management process

Site(s) requiring initial assessment

Initial assessment should be performed for all land properties classified under Category 1 of Contaminated Land management framework. This would include but not limited to land properties which are:-

- Being transferred (to be done as part of the due diligence exercise);
- To be developed or redeveloped for different land use purposes; and
- Currently being used for polluting activities.

Site(s) requiring detailed assessment

Detailed assessment is required for those land properties identified with potential contamination based on the findings of the initial assessment. The sources of contamination may be originated onsite within the land properties or offsite from other outside sources of contamination at the neighbouring properties.

Site(s) requiring risk assessment

Land properties which are detected with subsurface contamination at concentrations higher than the Site Screening Levels (SSL) [refer "Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land"], or land properties that are intended to be cleaned up.

Need for remediation

Land properties identified with subsurface contamination above the acceptable risk levels will be required for clean up or remediation.

Conducting a baseline environmental site assessment (BESA)

For land properties which are not identified with any potential subsurface contamination during the initial assessment, it is recommended to conduct minimum baseline environmental site assessment to establish the background level of subsurface soil and groundwater quality for future reference, this is especially applicable for land properties that will be used for activities of polluting industries [as defined in "Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land"].

3.0 Initial Assessment

The initial site assessment comprises a desktop study, site reconnaissance, development of a conceptual site model (CSM), design of the detailed investigation and a report summarizing the results of the assessment.

3.1 Desktop Study

Background information to be collected during the desktop study should include the following:-

- The chronological history of previous uses, industries supported, and activities or processes carried out on the site.
- The nature of the probable/possible contamination (petroleum products, petrochemicals, solvents etc.) including chemicals used/stored and, hazardous wastes generated/disposed on site.
- Identification of equipment and areas where the likelihood of contamination resulting from historical or current work practices is high, including accidental spillage or leaks.
- History of previous releases and waste disposal practices.
- Location, age and construction material of above-ground and underground chemical or fuel storage tanks on the site. If integrity testing of storage tanks has been undertaken, the results of such tests should be reviewed.
- Locations and construction details of underground utilities.
- Present zoning of the site and details of the zone categories of properties surrounding the site.
- Likely future use of the site.
- Contour or topographic maps.
- Information in order to establish whether adjacent properties are, or have been, potential sources of contamination.

- The results of any previous investigations of the site or surrounding land.

- Locations of surface water bodies (streams, rivers, estuaries, wetlands), particularly where these may be adversely affected by contaminated groundwater or surface drainage from the site. Surface water bodies should be evaluated to determine environmental values, beneficial uses, sensitivity to change, and physical, chemical and biological characteristics.

- Characteristic and locations of human receptors within at minimum 500 meter radius from the site, particularly receptors who reside at down gradient locations of the site.

- Hydro geological information which should include:-

  - The extent and use of aquifers in the area;

  - Estimated depth to groundwater;

  - Probable direction of groundwater flow and gradient;

  - Soils and soil properties (soil type, grain size, total organic carbon, porosity and hydraulic conductivity);

  - Location of any springs;

  - Sources of local municipal water supply, and the location of registered private or industrial wells or bores; and

  - Tidal and tidal influence information.

3.2 Site Reconnaissance

A visual inspection of the site supplements the information gained from the desktop study and should include:

- Location of buildings and hard-standing;

- Location of overhead power cables and canopies;

- Location of underground utilities;

- Availability of water and electricity supplies;

- Surrounding land uses;
- Proximity and type of potential exposure pathways;
- Anecdotal site history information;
- Age and condition of chemical piping and chemical storage tanks;
- Site topography and surface run-off patterns/collection;
- Site ground surface covering;
- Signs of surface straining;
- Condition of nearby vegetation; and
- Signs of off-site migration of products.

3.3 Development of an Initial Conceptual Site Model

The objective of a conceptual site model (CSM) is to detail the nature and extent of contamination, the potential migration pathways and to identify potential receptors to the extent possible based on information gathered from the desk study and site visit.

A CSM is a system diagram identifying contaminant *sources*, routes of exposure (*pathways*), and what *receptors* are affected by contaminants moving along those pathways. Exposure pathways and receptors should be identified for both current and future uses of the site (where appropriate). The model will be based on a review of all available data gathered during the various investigation phases, and should be used to design the detailed site investigation taking into account identified data gaps and uncertainties.

3.4 Design of a Detailed Assessment Plan

Once the CSM has been prepared, a detailed investigation program can be designed to confirm (or refine) the CSM and fill the data gaps. It is typically most cost effective to perform a detailed assessment program in stages. The overall aim of the first stage is to determine whether contaminants are present at or moving from, the site at concentrations that constitute an unacceptable adverse environmental or health risk as cost effectively and quickly as possible. The subsequent stages will depend on data gap and project need.

The detailed assessment plan should list the types of sampling to be performed, the number of samples to be collected, the proposed location of each sample, and the laboratory analyses to be performed and be prepared by a registered environmental site assessor or a registered contaminated land manager.

3.5 Reporting

The initial assessment report should contain the following information:-

- **Executive Summary.** This section should provide information on the objectives of the assessment, scope of work, summary of findings, conclusions and recommendations.

- **Introduction.** This section should detail the purpose of the initial site assessment and provide an outline of the report.

- **Background.** This section should describe the site in detail and provide site information such as location, historical land uses and current activities.

- **Findings.** This section should detail the findings of the desktop study and include information such as description of the surrounding environment, site geology and hydrogeology and observations on site conditions.

- **Conceptual site model.** This section should detail the nature and extent of potential contamination, the potential migration pathways and identify potential receptors.

- **Recommendations.** This section should include recommendations for the type of sampling needed to further define the nature and extent of contamination.

- **Appendices.** Information should include a map of the site location, site layout plan, surrounding land use and photographs.

An initial assessment report should be prepared and reviewed by qualified environmental site assessor and/or qualified contaminated land manager.

4.0 Detailed Assessment

Detailed assessment involves primarily the installation of soil boreholes, groundwater monitoring wells, soil and groundwater sampling and analysis and data evaluation.

The following should be considered when planning a detailed assessment:-

- **Objectives of the site investigation including data quality objectives**: A clear objective of why the data is being collected and what it will be used for will help focus the investigation. The data quality objectives should list how the data will be used, the type of data needed (i.e. screening or definitive), the detection limits required, QA/QC sampling and how data quality will be assessed.

- **The number, type, and locations of the samples to be collected**: The rationale behind the sampling strategy should be well defined as should the types of analyses required for each sample.

- **The most appropriate (and cost-effective) field sampling procedures for each of the targeted environmental media**: Decontamination of equipment between sampling should be considered as should protocols such as identification, preservation, handling, packaging, and shipping requirements.

- **Identification of safety, health and environmental issues**: Safety and health hazards and environmental concerns at a site should be evaluated before the field investigation so that appropriate control measures can be developed to minimize their impact.

4.1 Establish Data Quality Objectives

The purpose of data quality objectives (DQOs) is to guide decisions and processes for collecting, analyzing and evaluating data that will satisfy the overall program objectives.

The development of DQOs should specify the following:

- Sample locations and frequency;

- Sample collection procedures;

- Sample handling procedures;
- Measurement of constituents; and
- Analytical methods used to measure the constituents.

4.1.1 Data Categories

There are two data categories, each with specific QA/QC elements to ensure data will be of known quality. The categories include screening data and definitive data.

Definitive data generated can be used in risk assessment and site characterization while screening data are typically used for real-time health and safety monitoring or organic vapour concentrations and measurement of water quality parameters during purging and sampling activities.

4.1.2 Site Screening Levels and Detection Limit Requirements

Site Screening Levels (SSLs) provided in the "Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land", specifies a concentration above which the soil and groundwater quality of a subject property is considered to be a concern. The sampling and analysis methods used must be accurate at the site screening levels. The analytical technique chosen should have a detection limit equivalent or less than the site screening levels.

4.2 Sampling Strategy

The components of a sampling strategy should include number, type and locations of the samples to be collected for the environmental media of concern as well as the types of analyses required for each sample.

4.2.1 Soil Sampling

The rationale for choosing the sampling method, location, number of samples, type of sample, and analyses for adequately characterizing the unsaturated zone is discussed in this section.

(a) Sampling Methods

In general, there are three different site sampling methods, i.e., systematic grid, random and judgmental sampling.

Random sampling is most suitable during Baseline Environmental Site Assessment (BESA) for lands which are not previously used for any industrial activities or lands which are not identified with any onsite or offsite sources of contamination. Judgmental sampling is most appropriate when site information such as the presence of onsite or offsite sources of contamination is known or is suspected to be limited to a specific area. Systematic grid sampling is applicable during delineation assessment where quantification of subsurface contamination is required.

Sampling methods may to a great extent depend on the type of contaminants suspected to be present onsite and, the behaviour of the suspected contaminants in the subsurface environment.

The advantages and disadvantages of site sampling approaches are presented as follows:-

Table 1: Advantages and disadvantages of site sampling approaches

Method	Advantages	Disadvantages
Systematic Grid (5 – 30 m)	Statistically reliable site coverage.	Grid may cover low risk areas of site. Costly. May under - represent high risk areas.
Random	Less expensive alternative. Reduces the number of sample points and limits the choice of sampling locations to random selection.	All areas of the site have an equal probability of sampling. Does not target, therefore may miss high risk areas.
Judgmental (also known as selective)	Focuses on critical areas in a cost effective manner. Scale of investigation can be scoped/refined on the basis of field screening results.	Requires well-developed CSM.

Source: *Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand, 1999*

(b) Sampling Locations

Sampling locations will depend on the CSM and the scope of the detailed assessment plan. Typically, sampling locations will be placed at the area suspected with subsurface contamination or at down gradient locations to the suspected contaminated area. It is also recommended to consider placing of sampling locations at both up gradient and down gradient of the site to determine the background level of contaminants concentrations and the boundary concentrations for comparison purposes.

Further sampling as deemed necessary should be conducted to delineate or determine the lateral extent of contaminants from a known source or addressing any data gaps affecting subsequent management decision.

(c) Number of Soil Sampling Points

The number of sampling points is chosen to adequately characterize the vertical and lateral extents of contamination and should concentrate on areas highlighted by the desktop study and site reconnaissance as likely to contain contamination. The actual number of sampling points will depend on the following factors:-

- Size of the site;
- Extent of suspected release;
- Sampling;
- Degree of confidence required;
- Costs;
- Future land use;
- Availability of suitable equipment; and
- Time-scale.

(d) Sampling Depth

Sampling depths should be properly evaluated depending on the potential contaminants suspected at the sampling locations. Aqueous density of contaminants would affect the contaminants behaviour in the subsurface environment.

For site(s) suspected to be impacted by Light Non Aqueous Phase Liquid (LNAPL), the soil boring depth should be at least 3m below the static groundwater level. For site(s) suspected to be impacted by Dense Non Aqueous Phase Liquid (DNAPL), the soil boring depth is recommended to reach the impermeable soil layer of the aquifer.

Care should be exercised to ensure that DNAPL contaminant does not cross contaminate the deeper aquifer. In the event when both LNAPL and DNAPL are suspected to be present onsite, depending on the geological formation of the site, separate groundwater monitoring well systems with different well design may be required. Depth of boring and sampling should be determined by the Registered Environmental Site Assessor or Registered Contaminated Land Manager.

(e) Types of Samples

Either discrete or composite soil samples can be obtained. Compositing is a technique where soil is collected from several locations, mixed together, and then sampled. Depending on the data quality objectives, discrete soil samples are more preferred in most cases, because transferring samples between containers or during compositing compromises the integrity of the samples.

4.2.2 Groundwater Sampling

Groundwater monitoring systems are installed to determine the concentrations of contaminants in groundwater and to collect hydro geological data around and down gradient from the potential contaminant source. The rationale for choosing the location and number of groundwater monitoring wells and recommended analyses for groundwater are discussed in this section.

(a) Sampling Location

The number and location of groundwater monitoring wells will depend on the CSM and the scope of the detailed assessment plan. The placing of wells and well design should be performed under the supervision of a registered Environmental Site Assessor or Registered Contaminated Land Manager. Consideration must be given to:-

- Potential or known sources (e.g. Tanks, piping, etc.);
- Confidence in CSM (e.g. Flow direction);
- Potential upstream sources (necessitating background monitoring);
- Anticipated spread of contamination; and
- Bore separation to determine hydraulic gradient.

Well locations and completion depths should be selected to ensure that all probable contaminant flow paths are monitored. The placing of the wells will depend on the CSM and the findings of initial assessment.

(b) Number of Groundwater Sampling Points

The minimum number of sampling points required for a detailed assessment is shown in Table 2.

Table 2: Minimum number of sampling points

Area of Site (m^2)	Minimum Number of Sampling Points
≤ 300	3
≤ 500	5
≤ 1,000	6
≤ 2,000	7
≤ 3,000	9
≤ 4,000	11
≤ 5,000	13
≤ 6,000	15
≤ 7,000	17
≤ 8,000	19
≤ 9,000	20
≤ 10,000	21
≤ 15,000	25
≤ 20,000	30
≤ 25,000	35
≤ 30,000	40
≤ 35,000	45
≤ 40,000	50
≤ 45,000	52
≤ 50,000	55
> 50,000	Case-by-case basis

A minimum of three spatially-distributed wells are necessary to determine flow direction and hydraulic gradient. The actual appropriate number of wells shall not be less than the minimum number of sampling points stated in Table 2.

For land size exceeding 50,000 m^2, it is the responsibility of the polluter or land owner to propose the number of sampling points (no lesser than 55 sampling points) and each sampling point should be justified.

4.3 Field Investigation Techniques

This section describes the most common field investigation techniques used to characterize a potentially impacted site. These techniques include soil vapour screening, soil vapour sampling, test pits, boreholes, and groundwater monitoring wells.

4.3.1 Soil Vapour Screening

Soil vapour screening (also commonly known as soil gas screening) can be a useful screening tool in determining the spread of volatile organic compounds (VOCs) resulting from spills or leaks. They are generally undertaken as a preliminary screening tool to identify potential hot spots of soil contamination to assist in the design of a detailed assessment plan. Soil vapour survey results provide a relative measure of contamination at a site.

The sampling technologies typically used to measure organic vapours are:-

- Portable Photo-Ionization Detectors (PIDs) and Flame Ionisation Detectors (FIDs);
- Portable gas chromatograph; and
- Gas detection tubes.

Instruments should be calibrated prior to use.

4.3.2 Soil Vapour Sampling

Soil vapour sampling is normally performed as part of the soil vapour assessment, and this is particularly applicable for site(s) with complete soil vapour indoor inhalation exposure pathway. Factor affecting soil vapour migration such as subsurface stratigraphy, biodegradation, groundwater table fluctuation, soil moisture and groundwater recharge, building ventilation system and presence of other preferential pathways should be considered. Soil vapour sampling is preferably to be conducted at the sub-slab at the point of exposure; alternatively soil vapour sampling can also be performed at the exterior or near slab locations assisted with data extrapolation. Exterior and near slab soil vapour samples should be collected at a minimum depth of five feet below the ground surface to avoid any potential vapour leakages or "short circuiting".

(a) Soil Vapour Well Installation

Soil vapour well can be installed by using hand auger, or any dry-drilling methods. Soil vapour well diameters are normally smaller compare to typical groundwater monitoring wells. Depending on project need, nested soil vapour wells or multi-stage soil vapour wells can be constructed for soil vapour collection.

Annulus space immediately surrounding the soil vapour probes will be backfilled with sand media with a vertical length of approximately 0.2 meter. Above each sand media filled annulus, a layer of hydrated bentonite will be placed to prevent leaking that interfere the soil vapour results. Typically, the surface seal (the seal above the last sampling interval) will be approximately 3 feet in thickness. During the installation of soil vapour wells, care should be exercised to prevent soil vapour leakages.

(b) Leak Test

Leak test will be conducted by using oxygen upon completion of the soil vapour well installation. Oxygen content will be tested by using portable oxygen meter. Elevated oxygen measurements may indicate significant short-circuiting. In addition, aboveground sampling equipment will also be carefully checked for leaks.

(c) Equilibration Time

After the installation of soil vapour wells, the wells will be allowed for achieving its equilibrium with the partitioning between different media, as drilling activities will disturb the existing equilibrium maintained within the subsurface environment. As such, all the soil vapour wells will be allowed for equilibration time of 5 days.

(d) Sample Probe Purging

The construction details of each sampling probe within the soil vapour wells will be recorded. Based on the length and internal diameter of the sampling probes, a dead volume should be calculated. Dead volume is the air volume occupied within the sampling tube and other sampling instrument. A minimum of five dead volumes will be purged prior to soil vapour sampling. The purged gas should be measured for its soil vapour concentration by using a Photo-Ionization Detector (PID).

(e) Other In situ Measurement

Other in situ measurements whichever deemed necessary, such as oxygen (O_2), carbon dioxide (CO_2), methane (CH_4), lower explosive limit (LEL), groundwater level etc., should be measured as part of the soil vapour assessment program.

4.3.3 Test Pits

Test pits are holes excavated using a mechanical digger such as a backhoe or excavator for the purpose of obtaining soil samples. Test pits are used for near-surface soil sampling to enable site contamination to be characterized.

4.3.4 Boreholes

Boreholes are used for soil sampling where test pit excavations cannot be made and where monitoring wells may also be installed. Various drilling methods are available for drilling boreholes and collecting samples. The choice of drilling method is typically made based on depth of bore, type of geology likely to be encountered, and number of samples to be collected during drilling. To prevent cross contamination, dry drilling is the preferred drilling method for detailed assessment.

(a) Soil Classification

Logging of soils should follow a consistent methodology and format to reduce the subjective nature and widely varying content of descriptions. Logs of the soil encountered should be prepared on standard borehole log sheets.

(b) Equipment Decontamination

Specific quality control measures for machine drilling are as follows:-

- The drilling rig to be used should be in sound working order and free of oil leaks and cleaned prior to arriving at the site.

- A cleaning pad should be established on the site where the drilling rig and other large equipment can be cleaned without risk of contamination to sampling locations.

- All drilling equipment should be cleaned between boreholes.

4.3.5 Groundwater Monitoring Wells

Groundwater monitoring wells should be constructed of inert material; typically polyvinyl chloride (PVC). Conventional solvent glues should not be used because they could introduce chemicals into the water and would affect interpretation of sampling results. Instead, mechanical screw fittings should be used on all casing and screen joints. If necessary, screen and casing should be adequately cleaned to remove trace contaminants.

Screen lengths and slot size should be determined on site, under the supervision of a qualified geologist or hydro geologist, after drilling has established the location of the water-bearing zone. Slot sizes should be selected based on the geology at the site. The slots should be small enough to prevent subsurface material from entering the well yet large enough to not impede groundwater or product flow.

In general, a nominal slot width of 0.5 millimetres with two rows of slots per screen length and average spacing of 5 millimetres and between slots is adequate. The slots should be machined and the machined cuttings removed before the screen is employed. A minimum of 0.5 meter of unslotted casing with a well end cap should be provided below each screen, to act as a sump for collection of any fines that may pass through the screens.

Well screen should be properly positioned to ensure collection of representative groundwater sample and well screen positioning will depend on the behaviour of the suspected contaminants. For contaminant with liquid density lighter than water, the top of the screen should be placed between 1.0 and 1.5 meters above the water table as logged during drilling or at the discretion of the field engineer/geologist where the depth to groundwater is less than 3.0 meters. There should be at least 1.5 meters of standing water in the well at all times. For contaminant with liquid density heavier than water, at least 2.0 meters of well screen without straddling the groundwater table should be provided.

Following screen and casing installation, graded sand should be placed around the screen and to a height of approximately 200 millimetres above the uppermost screen slots. Sand filter material should be pre-washed and screened to eliminate foreign material. A clean pipe must be used for deep holes to ensure correct placement of the sand.

A layer of filter cloth or fine sand should be installed between the filter pack and the bentonite seal to prevent vertical bentonite intrusion into the gravel pack. The bentonite seal should be placed directly above the filter pack and should extend for a minimum thickness of 300 millimetres or as dictated by soil conditions. Final levels of both screen filter packs and bentonite seals should be verified by direct measurement using a slim line probe lowered down the annular space between borehole wall and casing.

Holes should be backfilled or grouted above the bentonite seals to approximately 250 millimetres below ground level. The final completion at the surface should comprise a concrete collar seal and protective covers to provide security of the well and prevent accidental damage. The wells should be equipped with lockable covers.

Where the site is accessible to vehicular traffic, the installation should be fitted flush with the ground surface using a cover for protection.

(a) Well Development and Aquifer Testing

Well development is necessary after drilling and installation to remove sediment disturbed by the drilling rig. A number of well development methods are available:-

- Surging with bailer or surge block;
- Compressed air pumping with gentle surging;
- Bailing;
- Pumping; and
- Combinations of the above.

Adequate development must be verified on the basis of stabilization of basic water chemistry parameters including electrical conductivity, pH, temperature, and turbidity. Records of development must be maintained.

On completion of development pumping, the groundwater recovery should be monitored with the rate of water level rise recorded against time. The pumping time and recovery data can be used to estimate hydraulics conductivity.

After the well has been developed, aquifer testing can be performed to evaluate aquifer parameters such as hydraulic conductivity and flow velocity. The general principal of aquifer testing is to remove water from a well and monitor and record the rate of water level decrease or rise with time in that well and nearby wells.

4.4 Sampling Methodology and Protocols

This section discusses specific procedures for collecting samples. Sample handling, identification, preservation, packaging and shipping are also discussed.

Sampling involves a number of common elements regardless of whether soil or water is being collected. The main steps in a sampling event are as follows:-

- The sampling area is isolated to minimize potential for cross-contamination;
- Sampling equipment arrives at the site clean and wrapped;
- Samples are collected in a manner which minimizes risks of cross-contamination;
- Samples are placed in containers and labelled;
- Samples are placed in cool storage;
- Quality assurance samples are collected; and
- Samples are transferred with documentation to the laboratory.

4.4.1 Sample Collection

The area around the sampling location may be subject to surface contamination or cross-contamination from dust liberated during the investigation. It is necessary to establish an area on which sampling equipment and containers can be placed without risk of contamination. This is generally achieved by placing a clean plastic sheet on the ground, a table or the tailgate of a vehicle.

In addition to keeping an area clean for sample handling, the following sample collection procedures should be observed:-

- All sampling equipment should be cleaned prior to obtaining each sample;
- Field personnel should wear clean PVC/latex gloves whilst handling sampling equipment and whilst taking samples;
- A clean pair of gloves should be used for each sample;
- Care should be taken when sampling to avoid any opportunity for excess aeration of the sample;
- Sampling equipment must be operated in a manner which avoids stirring up sediment;
- During groundwater sampling the temperature, pH, turbidity, and electrical conductivity of each sample should be recorded;
- Each sample container should be labelled for identification purposes. Sampling details and other pertinent data should be recorded;
- All samples should be kept under 4ºC in iced chilly bins. Samples should be dispatched to the laboratory for analysis on the day of sampling; and
- Chain-of-custody documentation should be completed for each sample.

(a) Soil Sampling Procedures

During sampling, subsurface conditions encountered at every borehole, test pit or auger hole should be logged on field log sheets. Depths should be referred to the ground surface. Unusual or unexpected subsurface conditions such as the presence of staining or odours should be recorded on the log sheets or in the field log book where relevant. Recorded data for the drilling component should adhere to standard borehole logging.

The borehole/test pit numbering system adopted should conform with that specified in the sampling plan. Every soil sample should be collected, labelled and documented.

(b) Groundwater Sampling Procedures

The following measurements should be taken prior to sample collection:-

- Standing water level; and
- Total depth of the well.

Water levels should be measured from the lip of the standpipe or well cover every time groundwater samples are collected. The reference point should be noted and surveyed to a relative datum.

Wells should be purged prior to sampling. If purging is to take place, then two types of purging methods are typically used: micro-purging and macro-purging. In macro-purging, at least three bore volumes of water are removed from the monitoring well. Purging the well removes any stagnant water or water which is not representative of the aquifer. For micro-purging, a low-flow pump is placed at the sampling depth and water is drawn from the well at a specific location.

For each purging method, temperature, electrical conductivity, pH, and turbidity should be monitored. Purging should continue until these parameters stabilize. Records of temperature, electrical conductivity, pH, and turbidity measurements should be maintained. The well should be allowed to recharge to at least 80% before collecting a sample.

Samples should be collected after macro-purging with a suitable sampling device (e.g. a stainless steel or teflon bailer, dedicated disposable bailer, or a low-flow pump). The low-flow pump is typically used to collect the water sample using the micro-purge method.

Additional requirements are as follows:-

- A low pump rate should be used for purging to reduce mobilization of sediment;
- The bailer or pump should be lowered gently to avoid disturbance of any sediment that may still be in the bore and to avoid damage to the bailer or the rope;
- Samples should be recovered from the slotted section of the standpipe;
- Care should be taken when sampling to avoid aerating the sample;

- The sample should be transferred directly from the sample device to the sample containers; and
- As the bailer or pump is removed from the well, care should be taken to place the rope or pump leads on a plastic sheet or other means of keeping them clean.

(c) Sample Identification

Each sample should either be individually labelled at the time of collection using waterproof ink or pre-labelled by laboratory personnel. If pre-labelled, pre-preserved sample bottles are provided by the laboratory for specific analyses, other pertinent information should be added to the label at the time of collection. Self-adhesive labels should be securely affixed to the sample container.

Each sample label should include the following information:-

- Site name;
- Sample ID code or number;
- Name of sample collector;
- Date and time of collection (this starts the holding time clock);
- Depth of sample;
- Preservatives used (or absence of any preservatives); and
- Analyses requested.

(d) Sampling Packaging and Preservation

Laboratory analytical methods guidelines should be consulted for information regarding sample volumes, size and type of sample containers, preservatives, and holding times required. In most cases, preservation includes refrigeration of the sample (4ºC) from the time of sampling to laboratory analyses.

Preservatives should be prepared in the laboratory using reagent grade chemicals and distilled water and stored in tightly sealed containers, away from sources of contamination. If sample containers are not pre-preserved in the laboratory, aqueous preservatives can be taken to the field in small dropper bottles to facilitate field preservation procedures.

(e) Shipping

Samples should be properly labelled, recorded on the chain-of-custody form and shipped to the laboratory as soon as possible. Care should be taken to preserve the integrity of the samples in transport by keeping them cool (4ºC).

Samples should be packaged in a proper shipping container to avoid leakage, breakage or contamination.

All samples should be accompanied by a chain-of-custody record. The following information should be included in a chain-of-custody record as a minimum:

- Sample identification numbers which can be referenced to specific sampling points and times;
- Name or number of the sample collector;
- Sample collector's signature;
- Date and time of collection;
- Location of site;
- Sample type;
- Analyses requested;
- Signatures of persons involved in the chain of custody (sampler, transporter, laboratory personnel who accept the sample); and
- Dates of sample possession (when relinquished, when accepted).

(f) Field Documentation

A field log book should be maintained by field personnel. The log book should be used to record general progress, any deviation from the sampling and analysis plan, changed conditions, any health and safety incidents, and any other notable observations. Other notable observations might include the presence of staining or odour or significant PID readings.

All sampling areas should be located with reference to the site plan and by measuring distances from permanent features identified on the site plan. All sampling areas should be referenced by a location number. A record of all sampling locations should be kept and recorded on a base map.

A record of samples collected should be kept by the field supervisor. This record should incorporate at least the following information:

- Job number;
- Sampling location number;
- Sample number;
- Sample depth; and
- Date.

(g) Field Quality Assurance/Quality Control (QA/QC)

Field QC samples include field duplicate samples, equipment rinsate blank samples, and field blank samples. Field QC samples assess sample collection techniques and monitor possible cross-contamination between samples and/or equipment.

The various types of field QC samples are as follows:-

- **Field duplicate samples.** Field duplicate samples are collected from a single sample location in conjunction with field samples and submitted to the laboratory without indication of the association between the two samples (i.e. a 'blind' sample). The field duplicate sample analyses assess the consistency of the sampling technique and the precision of the analytical laboratory. One field duplicate sample is typically collected for every 10-20 field samples.

- **Equipment rinsate blank samples.** Equipment rinsate blank samples are collected after a sampling device has been decontaminated to assess potential cross-contamination between samples as a result of poor decontamination procedures. One sample per day is typically collected.

- **Field blank samples.** Field blank samples are bottles of deionised water prepared in the field and included in each sample cooler containing VOC samples. Field blank samples are used to evaluate sample representativeness by identifying any volatile compounds that may have been introduced into the field samples during sample collection, transportation or storage at the laboratory. One sample per day is typically collected.

- **Trip blank samples.** Trip blank samples are bottles of deionised water prepared in the laboratory and included in each sample cooler throughout the whole journey of the cooler box from the laboratory to the field and back to the laboratory from the field. Trip blank samples are used to evaluate potential cross contamination during sample storage in the cooler box and during sample transfer and shipment. One sample per cooler box is typically provided.

4.5 Laboratory Analysis

The types of analyses to be performed on soil and groundwater samples collected at impacted sites are based on the objectives of the assessment and should be performed in accordance with recognized methods such as United States Environmental Protection Agency (USEPA) Test Methods and American Public Health Association Standard (APHA) Methods.

4.5.1 Laboratory Quality Assurance/Quality Control (QA/QC)

Samples should be sent to accredited laboratories for analysis. Procedures and checks should be in place to ensure accurate testing and reporting of analyses. As a minimum, every batch of analyses should include:-

- Calibrating standards;

- A laboratory 'blank'; and

- Replicates, at an appropriate frequency (usually 1:10 or 1:20) − this is a test of both sample homogeneity and laboratory precision.

4.6 Refinement of Conceptual Site Model (CSM)

As part of the detailed assessment, the initial CSM developed during the initial assessment shall be refined based on additional information collected during detailed assessment.

It should be noted that CSM is a living document which shall be used throughout the entire contaminated land management cycle. It may evolve, refine or revise based on additional or updated site specific information collected.

The CSM shall present suspected or identified sources of subsurface contamination, transport mechanism, exposure pathway and suspected or identified human or ecological receptors. Potentially complete or complete exposure pathways shall be highlighted in the CSM.

4.7 Health, Safety and Environmental (HSE) Considerations

Prior to the start of fieldwork, a HSE plan should be developed. The plan should include but not limited to the following:-

- **Health and safety measures:** Safe work practices and control measures used to eliminate or minimize potential hazards should be described so that the work is carried out in a safe manner.

- **Job safety analysis (JSA):** A site specific JSA should be developed detailing each task associated with the scope of work and the safe work method.

- **Pollution control measures:** Control measures to eliminate or minimize air, water, soil and noise pollution should be described in order to prevent pollution of the environment. This would include method for disposal of drill cuttings. If the soil is obviously stained then it should be sent to a licensed prescribed premise. If the soil is relatively clean it can be backfilled. Provision must be made for disposal of development and purged water from installed wells. In general, if the water is relatively clean it can be discharged to the drain. If contaminants are present, the water must be collected and properly disposed in accordance with local regulations. All scheduled waste should be managed in accordance with the regulations.

- **Personal Protective Equipment (PPE):** A list of the hazards and appropriate PPE to be used should be provided.

- **Emergency Response Plan (ERP):** The ERP should identify potential emergencies that may occur and planned actions for dealing with them. The plan should include a list of emergency contact numbers, the location of the nearest emergency services such as hospitals and the fire department, evacuation routes and assembly points.

The HSE plan should be made available on-site and discussed with the field team, including drilling contractors, prior to commencement of field work.

4.8 Reporting

The contamination assessment report should contain the following sections:-

- **Executive summary.** This section should discuss the purpose of the investigation, summarize the findings of the investigation and risk assessment, and present the conclusion and recommendations.

- **Introduction.** This section should describe the site in detail. The site description should include a detailed history of the site including the location of any known or suspected chemical storage or use, or any other activities which may have posed a risk to human health or the environment.

- **Background.** This section should include information such as historical land uses, geology and hydrogeology, climatology, and a list of chemicals used on site. The hydrogeology section should include a discussion of the proximity of surface waters and other sensitive receptors.

- **Field investigation.** This section should describe the sampling performed at the site including how the samples were collected, the location and number of samples collected, and the analyses performed.

- **Field and analytical results.** This section should summarize the information obtained during the field investigation including site-specific geology, hydrogeology and analytical results. The discussion of the site geology and hydrogeology should include physical characteristics of the soil (variation with depth) and groundwater (depth, flow rate, flow direction). Figures showing sample locations with analytical results are especially helpful.

- **Conceptual site model.** This section should detail the nature and extent of potential contamination, the potential migration pathways and should identify potential receptors. The CSM in the contamination assessment report should be an updated version of the one presented in the initial assessment report.

- **Risk analysis.** An evaluation of the potential risks to human health and the environment should be presented in this section. Typically, a Tier 1 assessment would be performed. A Tier 1 assessment involves comparing site concentration data with SSLs.

- **Conclusion and recommendation.** The next course of action and options for mitigating the adverse risks to human health and the environment should be discussed.

- **Appendices.** The following information should be included in appendices:

    - Boring logs;

    - Well detail diagrams; and

    - Laboratory reports.

A detailed assessment report should be prepared and reviewed by qualified environmental site assessor and/or qualified contaminated land manager.

A copy of the report shall be submitted to the DOE.

5.0 Risk Assessment

The overall aim of the site assessment and management process is to manage and minimize the risk to human health and the environment, through the cost-effective implementation of risk mitigation strategies. Risk assessment allows the most significant risks to be identified and addressed, and the more significant pathways to be identified, facilitating effective targeting of risk mitigation strategies.

A risk-based approach to the design and implementation of site management strategies arises out of an understanding of exposure pathway analysis. For a risk to human health to occur, a complete exposure pathway must exist between the source of contamination and the receptor.

Where an exposure pathway is incomplete then there is no risk. An exposure pathway consists of a:-

- Source;
- Transport mechanism;
- Point of exposure; and
- Exposure route.

The development of an accurate CSM of the site is an important step in identifying complete exposure pathways.

The acceptable risk levels as a result of subsurface contamination are defined as follows:-

Carcinogenic risk:	1 in 10,000 to 1 in 1,000,000 (expressed in probability)
Non-carcinogenic risk:	Hazard Quotient (HQ) = 1 (unit less)

Detailed information for conducting a risk assessment study can be found in the following documents:-

- American Society for Testing and Materials (ASTM) E 1739-95 “Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites” or its latest edition.

- American Society for Testing and Materials (ASTM) E 2081-00 “Standard Guide For Risk-Based Corrective Action at Chemical Release Sites” or its latest edition.

- Risk Assessment Guidance for Superfund (RAGS): Volume 1 - Human Health Evaluation Manual (Part A) (U.S. EPA, 1989a) or its latest edition.

A risk assessment in which the clean up goal is to be established should take into consideration site specific scenarios in a conservative manner. CSM which represents the site exposure scenarios shall be used as an important tool for the scoping of risk assessment. Each complete exposure pathway identified in the CSM shall be assessed in the risk assessment.

5.1 Tier 1 Risk Assessment

To assist in quickly identifying those sites that may pose a significant risk to human health and the environment, SSLs were adopted for a number of generic scenarios, based on conservative assumptions. Where contaminant concentrations at a given site do not exceed the generic acceptance criteria, it may be concluded with a high degree of confidence, that the site does not pose a significant risk to human health or the environment.

The Tier 1 assessment is based on comparison of measured contaminant concentrations in soil and groundwater from the site with the SSLs adopted or a set of Tier 1 screening values developed. If the measured contaminant concentrations are less than the SSLs or Tier 1 screening values then the site may be suitable for the nominated use.

The SSLs adopted in the “Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land” document are based only on consideration of human health risk. Where the potential exists for a significant ecological impact to occur, a site-specific evaluation of ecological impact or ecological risk should be undertaken.

In order to develop widely applicable criteria, many conservative assumptions have been incorporated. Therefore, if the SSLs are exceeded this does not necessarily imply the actual risk posed by the site is unacceptable. Instead, it indicates that further investigation and site-specific evaluation of acceptance criteria may be warranted.

When chemical concentrations at a site do not exceed the SSLs, no further action is required. When chemical concentrations at a site exceed SSLs, progress to Tier 2 risk assessment to determine Tier 2 RBSLs which are more appropriate for site conditions, and then compare site conditions with these RBSLs.

5.2 Tier 2 Risk Assessment

If the Tier 1 risk assessment indicates that there is potential for a significant risk to human health and the environment, then a Tier 2 risk assessment may be initiated. Usually a Tier 2 risk assessment would be initiated where the likely savings from use of site-specific criteria outweigh the cost of the Tier 2 risk assessment.

As part of a Tier 2 risk assessment, the basis for the generic SSLs used in the Tier 1 risk assessment may be reviewed in order to determine their applicability at a given site. Where consideration of site-specific factors suggests the assumptions used to derive generic SSLs are appropriate, it is expected that Tier 2 acceptance criteria would be similar to the SSLs, although the point at which they are applied in the CLM processes may differ.

Following the development of Tier 2 RBSLs and the assessment of contamination, a risk-based site management plan may be developed.

As with the Tier 1 process, part of the Tier 2 decision-making process is the need to evaluate the results of the Tier 2 risk assessment and the cost-benefit relationship associated with implementation of the site management plan in relation to proceeding to the Tier 3 risk assessment.

5.3 Tier 3 Risk Assessment

A Tier 3 risk assessment may be initiated where:-

- A Tier 2 risk assessment indicates that a significant risk to human health and the environment may exist; and

- The cost of remediation or other risk management strategies warrants further detailed consideration.

A Tier 3 risk assessment involves detailed, site-specific consideration of the relevant exposure pathways, and may entail additional sampling and analysis of environmental media. Tier 3 risk assessment would normally involved more sophisticated fate and transport numerical modelling processes to determine the exposure concentration of the Constituent-of-Potential Concerns (COPCs) at the point of exposure.

A Tier 3 risk assessment is generally regarded as more site specific and would be less conservative as compared to Tier 1 and 2 risk assessment, as such it will normally provide a less conservative SSTLs which can significantly reduce potential remediation costs or any costs of compliance.

5.4 Development of Site-Specific Target Levels (SSTLs)

The objective of this section is not to provide detailed or definitive guidance regarding the conduct of Tier 2 and 3 risk assessments, but rather to provide a general indication of the issues that may require consideration and the level of detail required as part of Tier 2 and 3 risk assessments. The complexity of the Tier 2 and 3 risk assessments mean that the scope of work should be determined by appropriately qualified and experienced risk assessment specialist on a site by site basis.

5.4.1 Developing Tier 2 SSTLs

A Tier 2 risk assessment is initiated where:-

- The measured contaminant concentrations exceed the Tier 1 acceptance criteria (or the Tier 1 acceptance criteria are regarded as inappropriate); and
- The likely savings in remediation costs resulting from this less conservative acceptance criteria compensates for the additional cost associated with a Tier 2 risk assessment.

Based on the results of the Tier 1 risk assessment, site conditions and receptor locations, a critical review of the completeness and relevance of exposure pathways should be conducted. The identification of relevant and complete exposure pathways is a critical element of any Tier 2 risk assessment.

The development of Tier 2 SSTLs can be based largely on screening level fate and transport models with incorporation of site-specific data to reduce the level of conservatism inherent in the criteria development. Alternatively, simple two-dimensional fate and transport modules may be used to refine risk estimates and site-specific acceptance criteria.

Examples of site-specific information that can be included in the derivation of Tier 2 criteria include:-

- The depth to contamination;

- Soil type and properties (e.g. moisture content, porosity, density, organic carbon content), including variability in soil properties through the soil profile;

- Local climatic conditions (e.g. temperature and wind speed);

- Building construction details and ventilation rates;

- Quantity of home-grown fruit and vegetables likely to be consumed (based on site use and physical constraints);

- Current and potential site use and activity patterns (e.g. duration of indoor and outdoor exposure, distance from the contamination to the receptor);

- Nature and diversity of ecosystems, including the occurrence of specific species which have been identified as sensitive and likely to control the derivation of ecologically-based acceptance criteria; and

- Physical setting of the site and the relevance of beneficial uses considered in the derivation of the SSLs.

Prior to collecting additional information, the review of exposure pathways should be completed such that the information gathering can be focused toward addressing the exposure pathways identified as relevant and complete.

It is anticipated that the documentation associated with a Tier 2 risk assessment may include:-

- An overview of the setting of the site and the site-specific considerations;

- Justification for the adoption of site-specific values for parameters of relevance to the derivation of Tier 2 SSTLs;

- Details of the calculation of SSTLs; and

- An assessment of the uncertainty associated with the adopted SSTLs and the likely impact of use of default values for some parameters where site-specific data is not available.

5.4.2 Developing Tier 3 SSTLs

SSTLs developed in the context of a Tier 3 investigation incorporate a high degree of site-specific information, and state-of-the-art-risk assessment. The development of Tier 3 acceptance criteria may involve considerable expenditure and therefore the benefit gained from reduced conservatism is only able to be realized on a relatively small number of complex sites. The decision to proceed with Tier 3 risk assessment requires judging whether the remediation savings likely to result from less conservative criteria outweigh the cost associated with the Tier 3 risk assessment.

The Tier 3 risk assessment and the development of Tier 3 SSTLs may involve:-

- Detailed consideration of the distribution and spatial variability of the contamination;
- Incorporation of site-specific exposure assumptions, as per the Tier 2 investigations detailed site measurements and investigations to refine exposure parameters (e.g. activity patterns for site users), parameters of importance in fate and transport modelling or calibrated/validated fate and transport predictions;
- A detailed review of the toxicology of each chemical of concern in order to confirm or refine the dose response factors, including consideration of site-specific factors that may influence the absorption and distribution of contaminants within the body (e.g. form of contaminant);
- Detailed fate and transport modelling, particularly in relation to groundwater contamination, in order to improve predictions of contaminant concentrations at the point of exposure; and
- Quantitative uncertainty and sensitivity analysis, incorporating techniques such as probabilistic risk assessment.

5.5 Reporting

A Tier 1 risk assessment should be reported as part of the Detailed Assessment report, and Tier 2 and 3 risk assessments shall be prepared as a stand alone report.

A Tier 2 or Tier 3 risk assessment report should contain the following sections:

- **Executive summary.** This section should discuss the purpose of the assessment, summarize the findings of the risk assessment, and present the conclusion and recommendations.

- **Introduction.** This section should describe the site in detail with emphasis on complete exposure scenarios and site specific conditions that would be essential for the risk assessment, such as current and future land use, surrounding land use, identified sensitive receptors, brief discussion on chronology of site contamination and investigation.

- **Discussion on Conceptual Site Model.** This section should discuss on the updated CSM with emphasis on complete exposure pathways, transport mechanisms and exposure pathways.

- **Hazard identification.** This section should discuss the data screening, COPCs, and determination of representative concentrations.

- **Toxicity assessment.** This section should summarize the relevant pathway specific toxicity information for the COPCs.

- **Exposure assessment.** This section should detail the exposure scenarios, receptor information, exposure assumptions, concentrations at point of exposure and other relevant exposure information.

- **Risk characterization.** Discuss on acceptable carcinogenic and non carcinogenic risks, discussion on the carcinogenic and non carcinogenic risks of the COPCs. Discussion on SSTLs in the event if the COPCs pose risk above the acceptable risk.

- **Conclusion and recommendation.** Highlight the critical exposure pathways with unacceptable risk and provide the SSTLs for these COPCs.

- **Appendices.** The following information should be included in appendices:

    - Summary of complete exposure pathways;

    - Data screening for COPCs;

    - Summary of toxicity information;

- Summary of exposure information;
- Calculation of exposure concentration;
- Summary of risk characterization; and
- Summary of SSTLs.

A Tier 1 risk assessment can be performed by a registered environmental site assessor and/or risk assessment specialist. A Tier 2 or Tier 3 risk assessment shall be prepared and reviewed by a registered risk assessment specialist.

A copy of the report shall be submitted to the Department of Environment.

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