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Contaminated land management guidelines No 5

Site investigation and analysis of soils

Ministry for the Environment
Manatū Mō Te Taiao

New Zealand Government

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Abbreviations

ARO	Assessment of remedial options (report)
ASTM	American Society for Testing and Materials
BTEX	benzene, toluene, ethylbenzene and xylene
CLMG 1	Contaminated land management guidelines No 1 – Reporting on contaminated sites in New Zealand
CoC	contaminant (or contaminants) of concern
CSM	conceptual site model
DSI	detailed site investigation
EPA	Environmental Protection Authority (New Zealand)
FENZ	Fire and Emergency New Zealand
FID	flame ionisation detector
HAIL	the Hazardous Activities and Industries List
IQR	interquartile range
LIM	land information memorandum
MDL	method detection limit
NESCS	Resource Management (National Environmental Standard for assessing and managing contaminants in soil to protect human health) Regulations 2011
PFAS	per- and poly-fluoroalkyl substances
PID	photo-ionisation detector
PQL	practical quantitation limit
PSI	preliminary site investigation
QA/QC	quality assurance/quality control
RAP	Remedial action plan
RMA	Resource Management Act 1991
RPD	relative percent difference
SCS	soil contaminant standard
SGV	soil guideline value
SVI	site validation investigation
SVR	site validation report
SQEP	suitably qualified and experienced practitioner
TCLP	toxicity characteristic leaching procedure
UCL	upper confidence level
UoM	uncertainty of measurement
USEPA	United States Environmental Protection Agency
XRF	X-ray fluorescence, usually referring to field-portable XRF spectrum analysers

Glossary

Analyte	An element or chemical in a sample that is being quantified by an analytical method, whether in the field or in a laboratory.
Assessment of remedial options	(ARO) Investigation that identifies and assesses remedial technologies and strategies, either individually or in combination, to determine their viability and suitability for meeting the remediation objectives, and reduce the level of risk posed by contaminants at a site to acceptable levels. May form part of the remedial action plan (RAP).
Benchmarking	Collecting and analysing selected samples for the purpose of broadly assessing and characterising the levels of contamination or other environmental parameters at a site, or part of a site, without necessarily carrying out a risk assessment.
Chain of custody	The processes and procedures that must be followed to guarantee the identification and integrity of samples, from collection through reporting of test results. Chain of custody is usually required to ensure the legal evidential integrity of all samples and data will withstand scrutiny in a law court.
Contaminants of concern	Contaminants of concern are those contaminants that have been identified through research and/or investigation as potential or actual sources of risk to recptors or the contaminants of specific interest in targeted investigations.
Detailed site investigation (DSI)	A detailed site investigation (DSI) is a physical contaminated land investigation using intrusive and/or non-intrusive methods supported by field-screening methods and/or laboratory analysis, to collect data to fulfil specified investigation objectives based on a CSM or preliminary information. A DSI can provide statistically reliable data about the nature, distribution and concentration of the contamination, sufficient to complete a robust risk assessment. A DSI completed for the purposes of the NESCS means an investigation that complies with the definition of a detailed site investigation in Regulation 3 of the NESCS.
Detection limit	The lowest concentration that can be reliably measured by an analytical procedure. A detection limit is also known as limit of reporting (LoR), limit of blank (LoB), limit of detection (LoD), and limit of quantitation (LoQ).
Exposure area	A relatively geologically and chemically homogeneous area over which a receptor can expect a uniform level of exposure to identified contaminants when undertaking a particular activity. An exposure area that may form part of a larger heterogeneous site. Also referred to as a ‘decision unit’ or ‘averaging area’. See section 4.2.3.

Guideline value	In this document, 'guideline value' has been used when referring to the contaminant concentration limit against which analytical results are to be compared, that are appropriate for the receptor and/or land use. Guideline values for contaminants in soils protective of human health that are regulated by the NESCS are referred to as soil contaminant standards (SCS), which are mandatory when investigations under the NESCS are undertaken.
Field techniques	Field-based activities related to the collection of samples for field screening or laboratory analysis.
Hotspot	A localised area of elevated contaminant concentrations relative to the remainder of the site, generally as a result of a point-source discharge of a contaminant or contaminants.
LGOIMA	Local Government Official Information and Meetings Act
Practical quantitation limit	Refers to the lowest level of quantitation that can be reliably achieved during routine laboratory analysis of an analyte, using a particular method and/or equipment.
Physico-chemical	The properties of a substance relating to how it interacts in the environment. Examples of physico-chemical characteristics include solubility in environmental media, volatility, mobility, phase partitioning and diffusivity.
Quality assurance	Relates to the planned activities that are implemented so that quality requirements will be met.
Quality control	Relates to the observation techniques and activities used to demonstrate the quality requirements have been met.
Remedial action plan	A report that outlines the remedial and management works that have been selected to mitigate the risk posed by contaminants. Also known as a remediation action plan.
Regulatory agency	A regulatory agency is any agency (other than courts, tribunals and other independent appeal bodies) that has any of the following responsibilities for the whole or part of a regulatory system: monitoring; evaluation; performance reporting; policy advice; policy and operational design; legislative design; implementation; administration; information provision; standard-setting; licensing and approvals; or compliance and enforcement.[1] In the context of these guidelines, city councils, district councils, unitary authorities and regional councils, are the most common regulatory agencies.

[1] From, *'Government expectations for good regulatory practice'*, 2017, NZ Treasury, Wellington

Rinsate blank	A quality assurance sample collected for analysis after equipment decontamination, obtained by running deionised water through the sampling equipment and collecting the water. A rinsate blank is tested for any residual contamination, which provides an indication of the potential for cross-contamination between samples due to poor decontamination procedures. Also referred to as an equipment blank.
Sample matrix	The type of medium being sampled (for example, water, soil, sediment, air).
Sample holding time	The period of time that samples can be retained between the taking of the sample and the laboratory analysis for a specific material before the results are considered invalid. Sample holding times vary between analytes. Some types of analyses require preservatives to be added to the sample, and some require storage of samples at refrigerated temperatures.
Soil contaminant standard	Soil contaminant standards (SCS) are mandatory guideline values that relate to contaminants in soil, in the context of the NESCS.
Soil logging	A written record of information describing the soil encountered during the soil investigation. A sample log is also referred to as the stratigraphic log, strat log, geology log, bore log, test pit log or well log.
Sustainable remediation	Remediation governed by the International Standard ISO 18504, involving the elimination and/or control of unacceptable risks in a safe and timely manner whilst optimising the environmental, social and economic value of the work.
Targeted sampling	Sampling strategy that applies prior knowledge about the site and uses professional experience and judgement to select the suite of elements and substances to be analysed for, and sampling locations in areas where known, suspected or point source areas of contamination are believed to exist.
Territorial authority	A city council or a district council named in Part 2 of Schedule 2 of the Local Government Act, 2002.
Trip blank	A quality assurance sample, generally a sample container, often filled with distilled water, which travels unopened to the site with the empty sample containers and returns unopened to the laboratory with the samples. The purpose of a trip blank is to measure cross-contamination from other samples, field handling, storage and transport.
Volatiles	Chemicals that have a low boiling point that results in high vapour pressure at ordinary room temperature.

1 Introduction

1.1 Purpose

Contaminated land management guidelines No 5 – Site investigation and analysis of soils (CLMG 5, this guideline) is the fifth in a series of guidelines on contaminated site management produced by the Ministry for the Environment. It is designed to be used in conjunction with other documents in the series, and promotes a nationally consistent approach to the investigation and assessment of contaminated sites. While the document focuses mainly on soil investigations, many of the concepts are applicable to other environmental media encountered during contaminated land investigations.

This guideline describes good practice for the:

- design of contaminated site investigations
- sampling and analysis of soils and other environmental media on sites where contaminants are present or suspected to be present
- interpretation of data obtained.

This guideline is incorporated by reference into the *Resource Management (National environmental standard for assessing and managing contaminants in soil to protect human health) Regulations 2011* (referred to hereafter as the NESCS). Detailed site investigations (DSIs) conducted for NESCS purposes and submitted to territorial authorities must be undertaken in accordance with this guideline.

CLMG 5 also applies to contaminated land investigations that are completed for purposes other than to satisfy the requirements of the NESCS, particularly those that involve an assessment of risks to human health or the environment.

1.2 Use of these guidelines

The guidelines are mainly aimed at contaminated land practitioners and regulatory agencies that undertake and/or review contaminated site investigations, and in particular for NESCS purposes. Owners, occupiers and other stakeholders may also find the guideline useful for reviewing work undertaken, or for assessing tenders or proposals for work. While the guideline focuses on soil, many of the concepts are applicable to other media investigated during the assessment of contaminated land.

For practitioners, the guidelines provide good practice guidance on:

- establishing investigation objectives
- developing a conceptual site model (CSM)
- designing and carrying out fieldwork
- specifying laboratory analysis
- interpreting the data to fulfil the purpose of the investigation.

If the good practice requirements set out in these guidelines are not met, the reasons for doing so should be documented in the site investigation report. The implications of not meeting these guidelines should be clearly stated to enable a regulatory agency to exercise its discretion in assessing the adequacy of the investigation and the appropriateness of the conclusions.

The practitioner undertaking this work should be appropriately trained and have relevant experience in the type of investigation being conducted, or should be working under the direction of such a person. A certified environmental practitioner with site contamination specialisation (CEnvP (SC)) is considered to be a suitably qualified and experienced practitioner (SQEP), provided that their qualifications and experience are relevant to the specific work being undertaken. If the investigation is being carried out to meet a regulatory requirement of the NESCS, the investigation must be done by a SQEP, who must also certify the report.

The overall content of these guidelines should help regulatory agencies and other stakeholders using or assessing contaminated land reports to:

- understand the site investigation objectives
- assess whether the investigation objectives have been achieved
- understand any uncertainties around sampling, analysis and data interpretation
- determine whether the site investigation has been undertaken in line with the nationally consistent approach set out in the guideline.

For sites that have regulatory requirements, the regulatory agency, usually a district or regional council, should be satisfied that:

- the investigation undertaken is adequate and meets the stated objectives
- conclusions and any recommendations for further investigation, remediation or management are complete and appropriate
- the investigation has been undertaken by a suitably qualified and experienced practitioner (SQEP).

If the regulatory agency is uncertain about any of these aspects, they could seek further advice from a SQEP, or commission an external peer review.

CLMG 5 is not intended to provide practitioners and stakeholders with definitive instructions on contaminated land management. Other documents exist that provide more specific details on the many aspects of site investigations, including New Zealand guidelines on the investigation, assessment and monitoring of land potentially contaminated by gasworks residues, petroleum hydrocarbons and timber treatment chemicals, as well as sites contaminated with PFAS and chemicals used in sheep dips. New Zealand and overseas documents used in the preparation of these guidelines are listed in **the references**, and sources of additional information are provided throughout the document.

1.3 Scope

This guideline provides guidance on how to design and carry out an investigation of land where contaminants are present, or are suspected to be present. It does not include guidance on generating a remedial action plan (RAP) or completing remedial work. Guidance on generating a RAP is provided in *Contaminated land management guidelines No 1 – Reporting on contaminated sites in New Zealand* (Ministry for the Environment, 2021) (referred to hereafter as CLMG 1).

Contaminated site investigations for NESCS purposes may be carried out over a number of stages, with each stage designed to achieve specific objectives. This staged approach is shown in figure 1. Investigations for purposes other than NESCS requirements generally follow the same process.

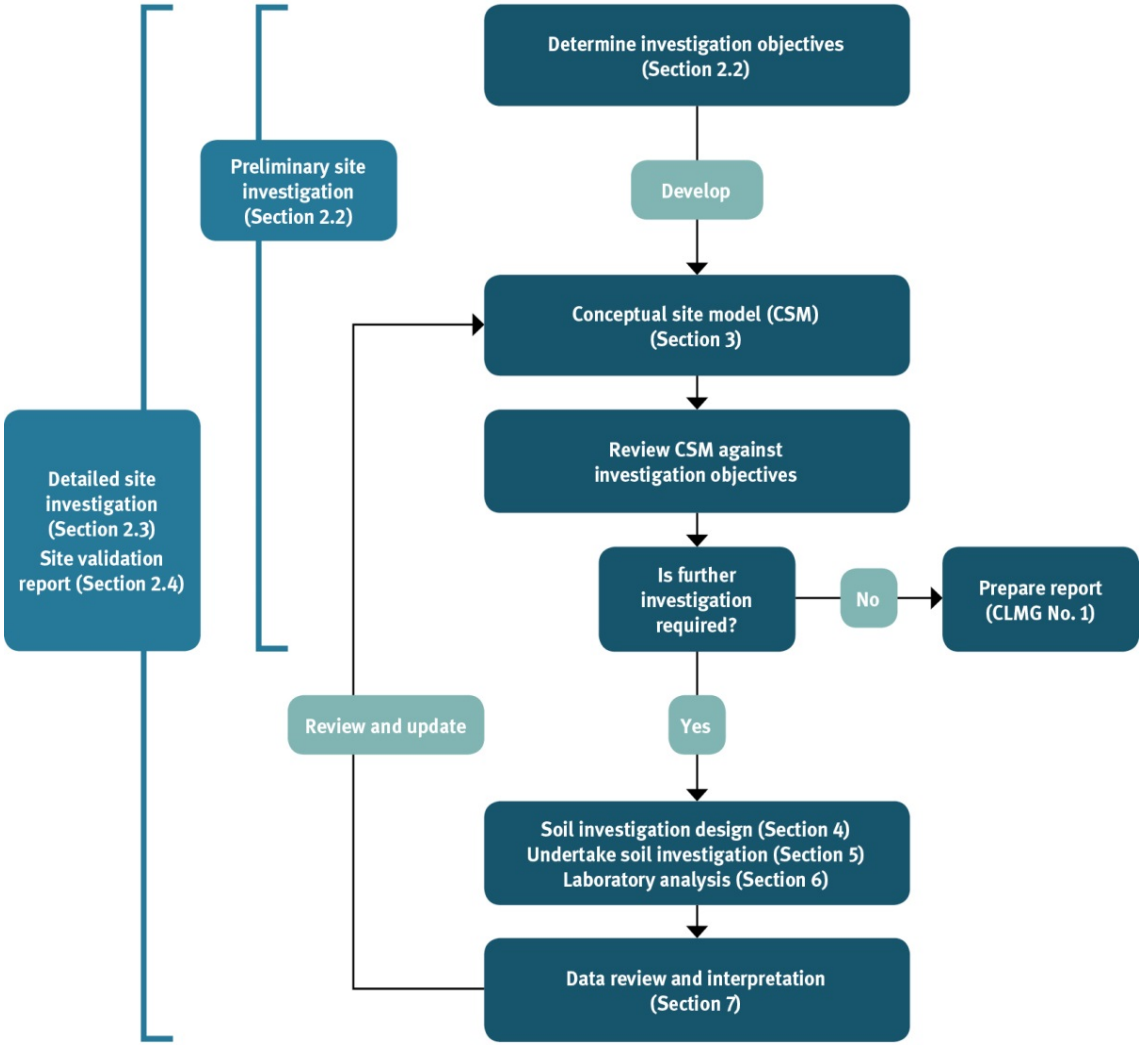
The first step in any investigation is to set clear and appropriate investigation objectives (refer section 2.1), that focus on the reasons for undertaking the site investigation, taking into

account the originator's requirements, the historical, current and future land use/uses, and any relevant regulations.

Once the objectives are established, preliminary information should be gathered to develop a conceptual site model (CSM) (refer section 3) that describes the environmental setting of the site, and identifies any actual and potential links between the potential contaminant sources and receptors (human and/or environmental). It is this model that guides the subsequent decisions on whether further investigations and/or remedial actions are required.

If it is decided soil sampling is required to meet the objectives of the investigation, a site investigation design (refer section 4) should be developed before undertaking the site investigation (refer section 5) and any laboratory analysis (refer section 6). Depending on the findings of the sampling work, further supplementary detailed investigations may be required. Data and information obtained at each investigation phase should be reviewed (refer section 7), and the CSM updated to assess whether the information is sufficient to fulfil the investigation objectives.

Figure 1: Recommended approach to site investigation for NESCS purposes



This phased approach is consistent with international guidance, such as that contained in Australia's National Environmental Protection (Assessment of Site Contamination) Measure (NEPC, 2013) and the British Code of Practice for the Investigation of Contaminated Land (BS 10175:2013). It is also broadly consistent with the planning approach contained in the USEPA seven-step, data quality objective process (USEPA, 2006b).

Although these guidelines were originally concerned solely with the investigation and analysis of soil, the same general principles apply to the design of investigations of other media such as air, groundwater, sediments, or surface waters, which are affected by contaminants. The collection and analysis of samples from these media may also be integral to a detailed site investigation. The general principles in these guidelines can be applied to all sampling media. However, it is recommended that where more detailed guidance relevant to a specific medium or sampling methodology exists, this should also be consulted.

Clear reporting of the findings is a key aspect of any site investigation. Guidelines and a checklist for reporting are contained in CLMG 1. Preliminary and detailed site investigations conducted under the NESCS and submitted to a territorial local authority must be reported on in accordance with CLMG 1. However, the reporting guidelines in CLMG 1 could be applied to all contaminated site investigations.

1.4 Workplace health and safety

Activities on contaminated sites present multiple health and safety challenges, including physical works, such as excavation, and chemical hazards presented by the contaminants present at a site. These guidelines are not intended to address health and safety requirements, although these are a critical component of any site investigation.

For regulatory advice on workplace health and safety when working on potentially contaminated land, contact WorkSafe New Zealand or visit its website www.worksafe.govt.nz.

Specific health and safety documentation required to address all health and safety risks presented by a site, including contaminant-specific risks and their management, falls outside the scope of these guidelines.

1.5 Document structure

Section 2 provides an overview of the scope of a preliminary site investigation, a detailed site investigation, and site validation reports.

Section 3 contains information about conceptual site models.

Section 4 provides guidance on the design of site investigations, including the sampling and analysis plan.

Section 5 provides guidance on implementing the field sampling component of the investigation, including quality assurance and control.

Section 6 contains information on laboratory analysis, including quality assurance and control.

Section 7 provides guidance on interpreting the data gathered during the site investigation, particularly the comparison of analytical results with guideline values.

2 Site investigations

Site investigations should provide robust and reliable data or information that improves the quality of the conceptual site model (CSM), to enable sound, risk-based decision-making. A CSM describes the source-pathway-receptor linkages at a site, and is central to site investigations (refer to section 3).

These guidelines address the following three types of site investigations:

- preliminary site investigations (refer to section 2.2)
- detailed site investigations (refer to section 2.3)
- site validation investigations (refer to section 2.4).

These investigation types are required for activities regulated under the NESCS,[2] but are also appropriate for a range of non-regulatory purposes and situations.

The investigation types and common alternative names are summarised in table 1 (below).

Table 1: Main investigation types and common alternative names

Preliminary site investigation (PSI)	
Alternative names	Preliminary site study; phase 1 background information study; phase 1 contaminated site audit; phase 1 environmental site assessment (ESA).
Purpose	To provide information about the nature and historical use of a site to inform development of the CSM. The findings of a PSI determine whether subsequent site investigation is needed. Under the NESCS, a PSI may be: a. used to establish whether the NESCS applies to a site by showing whether, or how likely it is, that the site has had Hazardous Activity and Industry List (HAIL) activities undertaken on it (R6(3)), or b. required to establish whether subdividing land or changing the use of the piece of land can be carried out, pursuant to the NESCS, as a permitted activity (R8(4)).
Detailed site investigation (DSI)	
Alternative names	Stage 2; phase 2 field investigation; phase 2 environmental site assessment (ESA); environmental benchmarking.
Purpose	To collect field data to identify the nature and concentration of the contamination present on a site and delineate its extent to meet the investigation objectives. This typically involves collecting samples of various media (eg, soil, groundwater, vapour) for laboratory analysis and characterisation of the site contamination conditions. The results of a DSI are used to update and reduce uncertainty in the CSM. A DSI may be undertaken in stages to provide supplementary information where previous investigations either did not provide enough data or identified the need for more information to fulfil the investigation objectives. Under the NESCS, a DSI may be: a. used to establish whether the NESCS applies to a site by showing that any contaminants in or on a site are at, or below, background concentrations (R5(9)) b. required to support applications for resource consent where the activity to be undertaken is not a permitted activity (regulations 9, 10 and 11).

[2] Refer to the NES for current regulated activities

Site validation investigation (SVI)	
Purpose	To establish the site conditions at the conclusion of remedial actions taken at a site and determine whether the remediation objectives outlined in the RAP have been achieved. The site validation report (SVR) is produced at the completion of the SVI and may also communicate the site's compliance with relevant district and/or regional rules or conditions in any applicable consents. Under the NESCS, a regulator has discretion over the adequacy of the SVR, where applicable, for restricted discretionary activities and discretionary activities (R10(3)(d)).

2.1 Investigation purposes and objectives

2.1.1 Site investigation purpose

The purpose of a site investigation is the primary reason for undertaking the investigation, and should be clearly understood from the outset of the investigation. An investigation may have more than one purpose. Clearly stating and understanding the purpose of the investigation will make determining the investigation objectives easier.

Site investigations undertaken for regulatory purposes include:

- determining if a site is a 'piece of land' under the NESCS
- determining if the risk posed by contaminants is unacceptable
- determining whether remedial objectives have been achieved
- determining compliance with conditions of a resource consent
- assessing actual or likely environmental effects of site contamination
- complying with regional council regulatory responsibilities under the Resource Management Act 1991 (RMA).

Site investigations may be necessary to achieve certain non-regulatory purposes, such as:

- for pre-purchase and pre-lease due diligence
- for property valuations
- for site audits and site benchmarking investigations
- to determine appropriate options for disposal of contaminated soil or media
- to identify and/or quantify potential liabilities
- to benchmark site conditions
- to inform an assessment of remedial options
- to enable the appropriate development and/or use of a site.

The NESCS identifies the types of site investigations that may be undertaken to comply with the regulatory requirements of the NESCS.

Table 1 gives the main purposes for site investigations according to their types. Details are also provided for the purpose of NESCS-specific site investigations.

2.1.2 Investigation objectives

It is crucial to understand the investigation purpose from the outset to be able to set appropriate investigation objectives. The site investigation design and strategy hinge on the investigation objectives. Setting clear investigation objectives will direct the various steps of a site investigation towards a successful result.

Objectives should, where possible, be SMART (specific, measurable, achievable, realistic and time-bound) to ensure the progress of the project can be tracked against them.

Without clear and appropriate objectives, the site investigation is at risk of deviating from its purpose, as well as resulting in unnecessary work, expense and delays.

Investigation objectives are varied and specific to the investigation, and for example, may address the following tasks:

- researching and collating relevant existing information (for example, a PSI)
- designing the sampling and analysis plan
- selecting:
  - analytes to be investigated
  - field techniques
  - analytical techniques and methods
  - statistical methods
  - guideline values or regulatory standards
- analysing laboratory results, comparing against appropriate SCSs and compiling remedial action plan
- establishing the requirements for QA/QC and chain of custody.

An example of an investigation objective is “complete a site history investigation and draft PSI report consistent with CLMG 1, prepared for review by a SQEP within three weeks of project start date.”

Every investigation will be constrained by limitations, which will shape the investigation. Considering limitations allows the constraints to be understood and acknowledged, and for informed choices to be made before committing to the investigation. It also determines whether the investigation should proceed. The first step in defining the investigation’s objectives should therefore be to understand:

- the investigation purpose
- any constraints on the assessment – financial, spatial, regulatory, timing and logistical
- the specific questions the investigation seeks to answer
- what decisions are to be made, and what is needed to support these decisions
- how the results of the site investigation might be applied in subsequent decision-making.

In practice, it is likely several objectives will be necessary to satisfy the purpose of a site investigation.

The purpose and objectives of a site investigation can change as new information becomes available. The SQEP should review the impact of new information to determine whether the purpose and objectives remain relevant, and, where necessary, make appropriate changes.

CLMG 1 should be consulted where a site investigation purpose or objective is to report on contamination at a site.

2.2 Preliminary site investigation

A preliminary site investigation (PSI) involves researching and collating existing information about previous and current land uses. A PSI may also include new information such as a site inspection (or walkover) and/or interviews, and/or preliminary sampling.

The purpose of a PSI is to understand:

- whether there has been (or there is more likely than not to have been) a potentially contaminating land use
- the nature and source of potential or likely contaminants
- the possible locations of contamination
- known or potential exposure pathways by which identified receptors (refer to section 3.1) could be exposed to the contaminants whilst undertaking the current or proposed future land use
- known or potential human and ecological receptors (refer to section 3.1) that could be exposed to contaminants.

A site inspection is recommended as part of the PSI to observe and identify potential sources, pathways and receptors. The site inspection will also confirm the site setting and layout, if that is not provided by existing information.

Samples do not usually form part of a PSI. However, limited sampling may be used for information purposes and to inform the conceptual site model (CSM). Collecting samples for this purpose does not constitute a DSI (refer to section 2.3). If samples are to be relied upon, the appropriate field techniques, analytical methods and quality assurance procedures described in these guidelines should be followed.

An understanding of contaminant distribution, transport and possible exposure pathways is fundamental to the CSM. A comprehensive CSM should provide the basis for any assessment of risk posed by contaminants.

A SQEP should update the CSM during or following a site investigation. They may determine that more information is needed to provide sufficient certainty for risk-based decisions, in which case a DSI may be required.

The information required to write a PSI report is outlined in the current edition of CLMG 1. Guidance on the information required to inform a PSI is described in this guideline in section 3.3.

The NESCS defines a preliminary site investigation (PSI) as an investigation that:

- is done by a suitably qualified and experienced practitioner
- is reported on in accordance with the current edition of CLMG 1
- results in a report that is certified by the practitioner.

A PSI may be used for purposes other than the NESCS. A prospective purchaser may wish to understand potential liabilities with a property before purchase. This may be achieved through the described PSI process where enough information exists.

2.3 Detailed site investigation

A detailed site investigation (DSI) involves collecting field data and samples to characterise the nature and extent of contamination at a site in a statistically robust manner.

A DSI can be a targeted investigation with a narrow focus for a specific purpose, or a broader investigation that quantifies and describes the full range of contamination at a site.

A PSI may recommend that a DSI is required where uncertainty or data gaps exist. A DSI should address the uncertainties or data gaps and generate the information required to provide sufficient certainty for risk-based decisions.

Uncertainties or data gaps may include:

- the likely location of potentially contaminating activities
- the potential or actual sources of contamination
- the concentration of contaminants in environmental media
- the pathways between contaminants and receptors
- any other information that could narrow the scope of the investigation design process.

When undertaking a DSI that is based on a PSI, the SQEP should confirm that the PSI is current and there have been no significant changes to site conditions, before designing and undertaking the DSI.

More information on the requirements for PSIs, DSIs and CSMs is provided in section 3.3. The information required for reporting on a DSI is outlined in the current edition of CLMG 1.

Section 3 of the NESCS defines a detailed site investigation (DSI) as an investigation that:

a) is done by a suitably qualified and experienced practitioner, and

b) is done in accordance with the current edition of C*ontaminated land management guidelines No 5 – Site investigation and analysis of soils*, Wellington, Ministry for the Environment, and

c) is reported on in accordance with the current edition of C*ontaminated land management guidelines No 1 – Reporting on contaminated sites in New Zealand,* Wellington, Ministry for the Environment, and

d) results in a report that is certified by the practitioner.

A DSI may be used for purposes other than the NESCS, for example:

- benchmarking site conditions before and at the end of occupancy as part of an environmental indemnity agreement between parties
- as part of due diligence
- assessing the extent and severity of contamination at a site
- complying with a condition of a consent or as part of enforcement proceedings
- assessing site contamination conditions, before remedial planning.

2.3.1 Supplementary or multi-stage site investigations

Supplementary investigations are investigations undertaken to fill data gaps and address uncertainty that cannot be carried out as part of the investigation for planning or practical reasons.

A supplementary investigation may be necessary to provide additional information when new and unexpected issues, data gaps or uncertainties are identified that could not be addressed within the scope of an initial DSI (refer to figure 1 of these guidelines).

Limitations around timing, resourcing, finances, or relating to physical restrictions at the site during a DSI could result in a need for a supplementary investigation. Sometimes a DSI cannot be planned or completed in its entirety before starting the investigation. An example would be where soil beneath a building must be sampled, but the building must first be demolished.

Supplementary investigations usually target a specific location, contaminant or suite of contaminants about which additional information is needed to increase statistical reliability to a level sufficient to evaluate risk.

A DSI may be planned and undertaken in multiple stages. This adaptive approach would allow a SQEP to plan later stages of an investigation as information becomes available.

The adaptive approach enables the practitioner to ensure the investigation remains focused on fulfilling its objectives, which can be updated to include newly discovered information.

The CSM, investigation objectives and the sampling and analysis plan, should be updated as necessary, to reflect the requirements and findings of the supplementary site investigation(s).

The investigation's scope and objectives can then be tailored to keep them in line with the original purpose.

Supplementary or multi-stage site investigations may be undertaken to provide:

- data on new areas of concern discovered, but not investigated, during the initial DSI
- a clearer delineation or definition of an area or depth of contamination
- additional targeted sampling for specific analytes
- information about potential impacts on ecological receptors
- information to address specific technical matters (such as to confirm the applicability of a remedial option)
- data about additional environmental media
- information to refine a CSM.

2.4 Site validation investigation

Site validation is the process of assessing whether the remedial action plan has been undertaken as proposed and the remedial objectives for the site have been achieved.

A site validation investigation (SVI) is a specific DSI. Its purpose is to collect the data and information required to validate that the remedial objectives outlined in the remedial action plan (RAP) have been achieved.

The findings of the SVI will inform the conceptual site model (CSM) and confirm whether the site is fit for purpose for its intended use. An SVI should be planned, undertaken and reported on to the same standard as a detailed site investigation (DSI).

The investigation objectives, which guide the investigation design, will differ between a DSI and an SVI.

Examples of SVI objectives may include demonstrating:

- successful implementation of the RAP
- the degree of contaminant concentration reduction achieved

- the extent to which remedial objectives have been met
- isolation of the contamination source has been achieved.

Site validation may be a regulatory requirement, to determine whether a site complies with relevant district and/or regional rules or conditions of a resource consent.

The SVI should provide data that provides a sufficient level of statistical confidence to make risk-based decisions about whether the site is suitable for its intended purpose.

The SQEP should provide assurances that data collected during the SVI is sufficient, relevant to the objectives of the investigation, and meets the expectations of the regulator and/or report recipient.

The level of statistical confidence required for an SVI depends on the overall investigation purpose and the proposed use of the site.

For information about statistical confidence and reliability, see section 4.2.4 and section 7.

A site validation report (SVR) documents the post-remediation conditions at a site and, where appropriate, statistically demonstrates compliance with the appropriate guideline values.

CLMG 1 details the information requirements for SVRs (CLMG 1 – Section 2.8.2).

2.5 Further reading

Further information on investigation and assessing environmental media other than soil may be found in the following.

ASTM D5092-04. 2010. *Standard Practice for Design and Installation of Groundwater Monitoring Wells*. Pennsylvania, USA: ASTM International

ASTM D 5621. 2005. *Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers*. Pennsylvania, USA: ASTM International

Canadian Council of Ministers of the Environment (CCME). 2016a. *Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment; Volume 1 Guidance Manual*. Winnipeg, CA: Canadian Council of Ministers of the Environment (CCME).

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3 Conceptual site model

3.1 What is a conceptual site model?

A conceptual site model (CSM) is a representation of the source (contaminants) and receptors (such as site users or the environment), and any exposure pathways. These are the three essential components of a CSM. Risk exists where a receptor is exposed to a contaminant by means of a complete pathway.

A CSM may be presented in written, pictorial or graphical format, or as a table or flow diagram, or a combination of these. A CSM should take into account the complexity of the site and be able to be used as a tool for communicating with stakeholders. Examples of CSMs are presented in appendix A.

A SQEP should rely on both scientific knowledge and professional judgement when developing a conceptual site model.

The most common purposes for a CSM are to:

- understand and quantify the risk/s posed by contaminants at a site
- provide a basis for the design of a detailed site investigation (DSI)
- support a risk assessment
- establish whether a proposed activity for a site is appropriate.

3.2 Developing and refining a conceptual site model

The CSM should describe three essential components, namely the source, the pathway and the receptor, where:

a **source** refers to the source(s) of the contaminant(s) present that could affect a receptor

a **pathway** is a means by which a receptor can be exposed to, or affected by, a contaminant under current or proposed land use (see figure 2)

a **receptor** can be any organism, population or ecosystem that could be affected by the contaminant, including humans.

A SQEP should identify all sources and receptors, and then investigate whether any complete and potential pathways exist.

Risk exists where a receptor is exposed to a contaminant by means of a complete pathway.

To be able to confirm a risk exists, a SQEP must be able to demonstrate the likelihood of a receptor being exposed to contaminants that are present at a site.

The characteristics of the source, including the specific chemical form present, and its physico-chemical characteristics, bioavailability, concentration, spatial location and distribution (including depth in soil) affects risk posed to the receptor.

The potential or actual pathways influence the level of risk experienced by receptors. Pathways include inhalation of vapours and dust, direct contact with the contaminant or contaminated media, ingestion (dust that covers food or enters the mouth, or directly from hand-to-mouth contact).

How a receptor is affected by a contaminant of concern (CoC) will depend on many factors, most importantly the duration and intensity of the exposure. Different land-use scenarios

therefore represent different exposure durations and intensities. The exposure scenario used as a basis for modelling the effects of contaminants on the receptor should reflect the current and proposed land use.

You must consider the sensitivity of the receptor when assessing risk. The sensitivity of a receptor is influenced by many factors such as its age, body weight, gender, specific behavioural characteristics, and how long it is exposed to the contaminant.

When undertaking a site investigation, the CSM detailing the sources, pathways and receptors and their linkages can be used to derive an understanding of risk. For a PSI, this will be based on historical land information and will therefore not be quantitative. The CSM developed using information gathered during a DSI can be used to quantify risk. Data with measurable statistical confidence is necessary when undertaking health risk assessments.

Some types of site investigations do not require the development and/or refinement of a CSM. These include those that do not require risk assessment such as site benchmarking investigations.

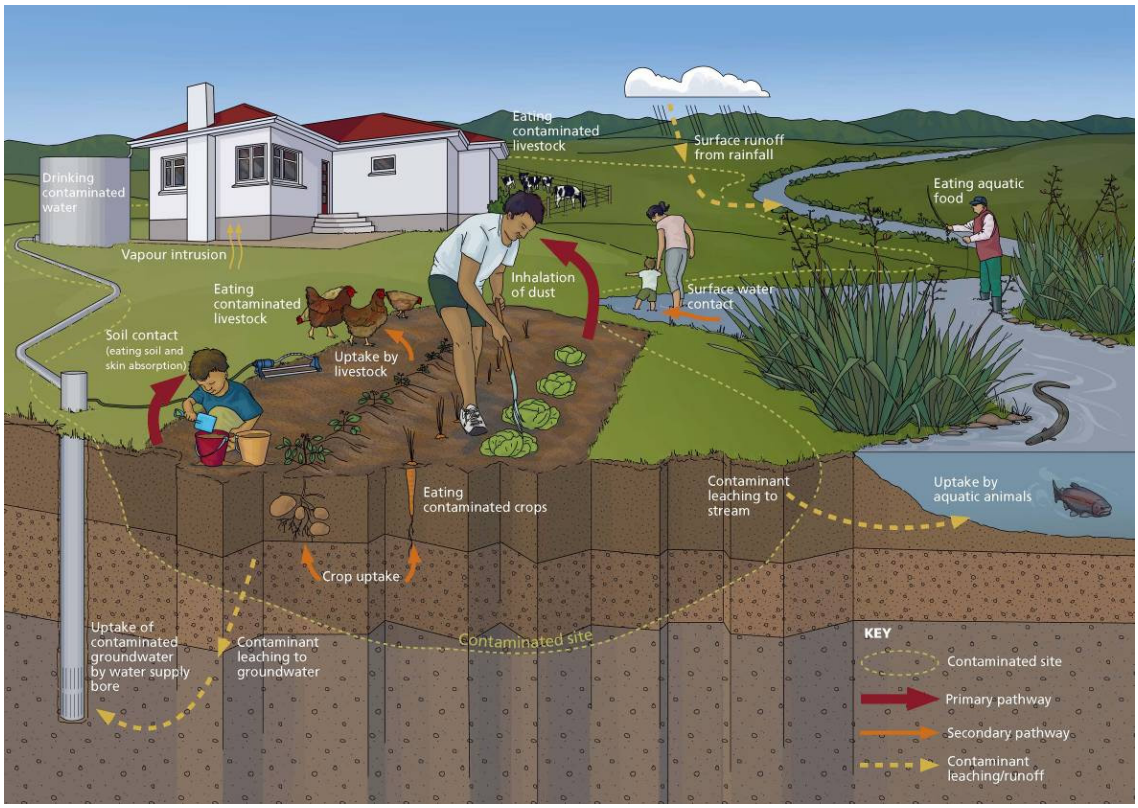
Many factors need to be considered when developing and refining a CSM. The information and/or data that should be included in, and communicated through, a CSM includes:

- the environmental setting at the site – for example, the topography, soil, geology, infrastructure, hydrogeology, hydrology and weather (wind speed and direction and rainfall at the site)
- the environmental media affected
- the location, distribution and concentration of the CoC
- the environmental fate of the source
- the toxicity of the source to humans
- the physico-chemical and transport characteristics of the source
- the ecotoxicity of the source to environmental receptors
- all actual and potential exposure pathways
- current and proposed future land use/s
- details of receptors including details of any especially sensitive receptors or land uses
- ecological receptors present, either on or off site, which could be affected by discharges from the site.

These factors have the potential to interact with one another, and to influence contaminant source, pathways and receptors at a site.

The process of developing a CSM is an iterative process, rather than a single event. The process involves assimilating data from multiple sources, sometimes spanning numerous phases of work. The SQEP should continually evaluate the model to ensure its accuracy and completeness.

Figure 2: Pathways by which receptors can be exposed to a contaminant source



3.2.1 Objectives of a conceptual site model

Objectives for the CSM can be determined once its purpose is understood. The objectives should be clear and relevant and aligned with the CSM purpose.

Objectives for a CSM relate mainly to:

- clearly understanding the past land use at the site, from a contamination perspective
- identifying and evaluating relevant sources of information and/or data
- identifying the contaminants present at a site
- identifying exposure areas across the site (see section 4.2.3)
- determining which contaminants pose a risk and are a CoC
- identifying receptors and land-use scenarios at a site
- quantifying the risk posed by CoCs to receptors
- determining potential and actual pathways that exist for each CoC
- evaluating the CSM for accuracy and completeness
- identifying sources of uncertainty and data gaps
- revising and updating the CSM with new information and/or data.

3.2.2 Reviewing and refining a conceptual site model

A CSM is not a static document and should be reviewed and updated as new information and/or data becomes available. A SQEP should assess the information and/or data and determine whether it is relevant to the investigation objectives and changes the understanding of contamination at the site. Part of the review process includes looking for uncertainties and

data gaps and addressing these as part of the refining process. The SQEP should provide comment on whether multiple exposure areas exist within the site.

3.2.3 Data gaps and uncertainty

Identifying data gaps and assessing uncertainty are core activities when refining a CSM.

This could be where the data provides insufficient statistical certainty, or where information and/or data about specific aspects of the site, including the site history, is absent or incomplete.

Data gaps and uncertainty may arise because of:

- poor data quality
- the use of inappropriate field techniques or methodology
- inappropriate selection of analytes for investigation
- the presence of obstacles or buildings that limit the ability to collect samples or data
- too little information and/or data available to inform the source–pathway–receptor model
- variability of the natural environment being investigated, such as changes in topography, lateral and vertical variations in soil properties or lithology, or changes in contaminant levels over time and space
- failing to consider or correctly identify all exposure areas (see section 4.2.3) that may exist within a site
- accuracy and level of statistical confidence of field and laboratory data
- whether data is current and still valid
- The SQEP compiling the CSM should therefore address:
- whether information and/or data relied upon provides a full site history and is reliable, and where required, statistically robust
- poor field techniques, inappropriate analyte selection and inadequate number of samples, and so on
- how relevant the identified data gaps are to the objectives of the site assessment.

Data gaps and uncertainty that have no effect on the CSM objectives may not need to be addressed.

3.2.4 Complexity in conceptual site models

In some cases, when appropriate, a conceptual site model (CSM) can be highly specific and focus on just one contaminant, pathway and/or receptor. However, CSMs frequently cover multiple sources and receptors over a wide and/or heterogeneous physical area.

The CSM should represent the scale and complexity of the known or potential impacts of contamination, and the range of exposure pathways and receptors. Complexity increases when multiple contaminants, pathways or receptors are present.

In complex situations, where a CSM may need to represent multiple contaminants of concern (CoCs), pathways, and receptors, the expertise and experience of a range of experts may be required, eg, toxicologists, ecologists and geohydrologists.

Where multiple contaminants exist within a source, synergistic interactions that could increase the effects of specific contaminants on receptors should be considered.

All pathways, whether complete, potential or incomplete that may become complete in the future, should be identified in the CSM. For example, a matrix can be developed that shows sources and receptors, and pathways that link these. This matrix would enable complex interactions to be recorded, allowing each to be expanded upon individually.

3.3 Information requirements for a CSM, PSI and DSI

The following sub-sections provide guidance on the type of information required to complete a site investigation in accordance with the current edition of CLMG 1.

Table 2 shows which component of the CSM (source-pathway-receptor) the information relates to and how all the information requirements are necessary for compiling a robust CSM.

Table 2: Information that adds to the source-pathway-receptor model

Information requirement	Source	Pathway	Receptor
Proposed site use (section 3.3.2)	×	✓	✓
Environmental setting (section 3.3.3)	✓	✓	✓
Site layout (section 3.3.4)	✓	✓	✓
Current site use (section 3.3.5)	✓	✓	✓
Surrounding site use (section 3.3.6)	✓	✓	✓
Historical site use (section 3.3.7)	✓	✓	✓
Site inspection (section 3.3.8)	✓	✓	✓
Preliminary sampling (section 3.3.9)	✓	✓	×
Sampling and field screening (section 3.3.10)	✓	✓	×
Risk assessment (section 3.3.11)	✓	✓	✓

Information gaps will weaken the CSM. All reasonable steps should be taken to obtain information necessary to ensure the resulting CSM will be robust. Any omissions should be recorded and justified, especially where missing information can affect the reliability of the CSM.

3.3.1 Site identification

The site must be identified, including the site name, address, legal description, site boundaries, a map reference and geographic coordinates. A SQEP can obtain information about site identification from the site owners and/or occupiers, maps, land and property information services and/or databases, and from current certificates of title. The land area where contaminants may be present, or suspected, may not correspond with legal boundaries and site identification should establish the boundaries of the study.

Defining the extent of a site

At the start of any investigation, the physical boundaries of the land area that is the subject of the site investigation ('the site') should be clearly defined. A site may be a whole property parcel, several properties or only part of a property. For guidance on land to which the NESCS applies ('the piece of land'), please refer to the *Users' Guide: National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health* (Ministry for the Environment, 2012).

3.3.2 Proposed site use

What a site is to be used for will determine who is present at the site (the receptors), how they will be exposed to the contaminant source, and for how long. A SQEP should consider all potential exposure pathways and receptors that are relevant to the current and proposed future land use, when developing the CSM, and when selecting the guideline values against which to compare sample results.

Information on the proposed site use may include:

- a description of the proposed land use at the site
- any parts of the site that will differ in land use
- the works to be undertaken to facilitate the proposed use
- the layout of the proposed site use.

Within a site there may be one or multiple 'exposure areas', that is, the area over, or from which, a receptor may be exposed to the contaminants of concern. Each exposure area must be identified during the development of the CSM to allow a comprehensive risk assessment to be undertaken (refer to section 3.3.11.)

3.3.3 Environmental setting

The local and site-specific topography, climatic conditions, geology and hydrogeology, in conjunction with the physico-chemical characteristics of the contaminant(s), influence the fate and transport potential for contaminants on and from a site, and the potential exposure pathways to human health and environmental receptors.

For example, soil and aquifer permeability influences both the potential viability of an aquifer for potable water supply, as well as the rate and extent of migration of a contaminant in an aquifer, to the point of contact with a receptor. The depth to groundwater is also relevant where contaminants in soil may leach into groundwater, or into air as gas or vapour.

Contaminants can migrate to, around, or from the site through transport mechanisms such as:

- surface run-off
- vertical migration and/or leaching from soil to groundwater
- transport in groundwater
- airborne particles including dust, fibres (asbestos) and smoke
- volatilisation and vapour migration
- movement by earthworks.

Contaminant mobility is affected by both its physico-chemical characteristics and the environment, and different contaminants may have very different rates and patterns of movement in the same environment.

Some environmental characteristics may affect the behaviour of contaminants present, including effects such as increasing or retarding mobility or solubility.

Soil pH should be measured when soil samples are taken, as it may affect how readily certain metals, and especially cadmium, are able to leach from soil.

Movement of contaminants, especially liquids or dissolved contaminants in groundwater, may follow features at a site such as surface cover, sealed and unsealed surfaces, service lines, pipes or other infrastructure. Contaminant movement may also be diverted or retarded by obstacles or barriers such as footings, sheet piles or other structures. A SQEP should gather information on the environmental setting of the site including the:

- location of surface watercourses, drains and stormwater drainage features
- extent, depth, direction of flow and use of groundwater aquifers in the area
- underlying geology and soil type and structure, and information on fill material (if present)
- potential preferential pathways for contaminant migration (for example, underground services or permeable geological unit).

Typical information sources include topographical and geological survey maps, New Zealand soil classification publications, regional council records and information from previous environmental or geotechnical investigations, as well as observations made during site inspections.

3.3.4 Site layout

The site layout should include information about the location of specific infrastructure related to land-use activities that have taken place. Such information provides the SQEP with the likely location of potential sources of contamination.

The location and type of activities identified informs the likely presence and distribution of contaminants, contamination pathways and the risks to receptors.

The site layout is generally confirmed during the site inspection, as detailed in section 3.3.8.

Reporting on site layout will typically include a figure(s) depicting current buildings, services and relevant site features. These will include, where relevant, historical site features and buildings. As-built plans may be helpful to a site investigator.

Information about the site layout informs the sampling and analysis plan design (refer to section 4.2), to ensure the investigation remains relevant to its purpose and objectives and takes site characteristics and features into account.

3.3.5 Current site uses

The current use of a site describes the most recent activities that have taken place there.

A list of activities and industries that are considered to have a higher potential for land contamination is contained in the current edition of the Hazardous Activities and Industries List (MfE, 2011c) (HAIL). You can use this list to help identify current or historical activities or industries that could cause land contamination, and the hazardous substances that are typically associated with those activities.

Information about current uses could include current HAIL land uses, non-HAIL activity, or that the land is unoccupied or unused.

Such information may give clues about the presence of specific contaminants, their distribution, attenuation, transport and fate. Including current site use in a site investigation provides information that is relevant for the CSM, and could affect risk-based decision-making.

Information on the current site uses should include, where relevant:

- a description of the activities undertaken at the site
- infrastructure associated with activities, such as workshops, processing plants and underground services
- types of materials (eg, chemicals) stored and used at a site
- presence of chemical containment facilities or structures, and their condition
- the condition and composition of buildings and structures on a site
- locations of chemical storage, transfer, mixing, usage and disposal
- details of the application of any input to land such as bio-solids, fertilisers, herbicides or pesticides
- wastes produced at the site and how and where they are treated or disposed of
- locations of spills, losses, incidents and accidents including intentional and accidental fires.

3.3.6 Surrounding land use

Past or present HAIL land use on adjacent or nearby properties could affect the site being investigated, especially if the land use involved chemicals that could cause contamination. The use of hazardous substances on adjacent or nearby land could result in contaminants migrating to the site being investigated. As a result, information about surrounding land use may be valuable to a SQEP, in that it informs the *source–pathway–receptor* model (refer to section 3.1) by providing an understanding of potential contaminants and contaminated areas, exposure pathways and receptors. Such sites may affect the site, or be affected by contamination from the site. Information on surrounding site uses may include that listed in sections 3.3.3, 3.3.4, 3.3.5 and 3.3.8.

3.3.7 Historical site use

Certain industries or industrial activities are often linked to specific contaminants. Where the historical contaminants are persistent and immobile, they may still be present decades after the contaminating activity ceased. This makes historical information potentially relevant to present and future receptors at a site.

A chronological history of the site and previous site uses should be traced from the present day (see section 3.3.5) back to the earliest known use (as far as is practicable). The following should be identified:

- previous activities and processes undertaken on the site
- chemicals and products used, manufactured, stored or disposed of to land at the site
- any previous investigation and remediation work
- any gaps in the history in the information recorded.

Depending upon the investigation objectives, the sequence of review may be interrupted as soon as it is clear a site is HAIL or not. For example, a detailed site investigation (DSI) may not be required if a PSI demonstrates that a site is not HAIL.

The investigation should build up a weight of evidence, from as many reliable sources as possible. Sources of information should include the following:

- obtaining the current site use, layout and operational information (generally from the owner)
- collating historical information including environmental reports and recent online aerial photographs (eg, councils' online geographical information systems and satellite imagery, or Google Earth and Street View images)
- searching council records and contaminated land databases (also known as listed land-use registers or selected land use registers, or by other designations), if available
- reviewing photographic records including historical archives such as www.retrolens.nz, local libraries and the National Library collection. We advise looking at properties surrounding a site as well
- interviewing people with knowledge of the site and its history including present and past owners, workers, neighbours and residents with knowledge of the site and its history, about known incidents, work and management practices, waste disposal and any hazardous substance storage areas
- obtaining and reviewing readily available historical society records, newspaper archives, and online resources or relevant literature relating to the site
- reviewing information held by local government on the property file. These files generally contain details about building and land-use consents, trade waste permits, historical dangerous goods or hazardous substances licences, historical layout ('as-built') drawings, and relevant registers and databases
- reviewing information held by the regional authorities, such as consents to discharge to air, land or water, land-use consents for earthworks, environmental reports, and relevant land-use registers or databases.

Additional sources of information may include:

- certificates of title however information may not be directly related to land use
- land information memoranda (LIMs), which contain information prescribed by the Local Government Official Information and Meetings Act.

Fire and Emergency New Zealand (FENZ), which may be able to provide information about fires, incidents or spills at a site.

Any gaps in the timeline of land-use information should be reported on if the information is not available.

3.3.8 Site inspection

A site inspection involves a walkover on the site being investigated, often with a landowner or occupier present to point out features or areas of interest to the investigation. The objective of the site inspection is to augment or confirm the findings of the available information, identify features not recorded in available information, and any constraints or obstructions, to improve the design of any subsequent site investigations. Photographs should be taken to document any observations made.

Site inspections should be undertaken during a PSI to add information to the preliminary CSM, and whenever questions arise and site conditions need to be verified. Information gathered during a site inspection typically includes:

- general site condition, current use, local topography and surrounding environmental setting
- the nature of the buildings and ground surface across the site (eg, whether any buildings on site have basements or sub-floor voids and activity areas are sealed)
- the type and condition of the construction materials used for any infrastructure eg, asbestos, lead paint and cracks/holes in sealed surfaces
- the location and condition of surface watercourses, drainage systems and any groundwater wells
- the location and type of underground services that may act as a preferential migration pathway for contaminants
- visible signs of contamination or potential contamination, such as evidence of spills or leaks, surface staining, the absence of plants, or stressed vegetation, and odours
- visible signs of areas of fill, stockpiled materials, waste, ground disturbance, burnt areas and former building foundations
- the location and condition of chemical storage and transfer areas, bunding, waste storage areas, discharges to ground and existing tanks, pits, drains, pipelines and sumps
- the land use of neighbouring properties that have the potential to impact on the site or be affected by contamination from the site
- the location of former buildings, processes or activities undertaken on the site.

3.3.9 Preliminary sampling

Preliminary sampling involves collecting samples to give insight into contamination at a site, without a high degree of statistical reliability. It generally refers to targeted sampling, using prior knowledge of the site to select the contaminants to be analysed and to focus on known, suspected or point source areas of contamination. Preliminary sampling, if undertaken, is completed as part of a PSI or before designing a site investigation (refer to section 4).

Because of inherent bias in selecting the location of samples, preliminary sampling has limited application in assessing risk in a statistically reliable way. Preliminary sampling may be useful in identifying and confirming areas of contamination and the presence of specific contaminants.

Preliminary sampling may give insight into:

- whether there has been a potentially contaminating land use
- contaminants that may be present and their possible locations.

Samples collected during a preliminary sampling exercise should be collected in accordance with section 4 and section 5 of these guidelines, and analysed in accordance with section 6 of these guidelines.

Preliminary sampling can confirm the presence of contaminants and refine the suite of contaminants to be tested in a DSI. Preliminary sampling cannot confirm the absence of contamination. This requires statistically reliable data, derived from a sufficiently large number of samples, which exceeds the scope of a PSI.

If a small number of preliminary samples are collected from across a site that is not physically homogenous and that has had varied land uses, the samples should not be composited for analysis. See section 4.2.6.

Preliminary sampling is not a substitute for a DSI or a site validation and therefore cannot be used for risk assessment.

3.3.10 Sampling and field screening as part of site investigations

Intrusive site investigations, field screening methods and/or laboratory analyses (refer to section 4, section 5 and section 6) may be necessary to provide sufficient certainty for making decisions about a site and/or a risk assessment to be completed (refer to section 3.3.11). They may also be required to confirm whether contaminant sources exist, the extent and nature of these sources and to confirm or modify the CSM.

Although these guidelines are concerned mainly with the investigation and analysis of soil, the collection and analysis from other media such as air, groundwater, sediments or surface waters may also be integral to generating a CSM and assessing risk, depending on the investigation objectives.

Sampling and analysis should provide a level of statistical certainty that is appropriate to the investigation, providing data that increases the accuracy and reliability of the CSM. To this end, a SQEP should design site investigations to ensure data collected is of an appropriate standard.

3.3.11 Risk assessment

Risk assessment is the process of evaluating the *source-pathway-receptor* model generated by the CSM to determine the probability that a *source* and complete *pathway* exists on the site, and that there will be any effects on any *receptors*. The risk assessment process involves the following steps as necessary:

- characterise the source/s through adequate delineation of contamination horizontally and vertically, and assess contaminant concentrations
- identify and characterise potential pathways and receptors for each exposure area by assessing geology, hydrogeology, building construction, site use, underground services, other preferential pathways and relevant site characteristics
- identify receptors and how they may be exposed
- determine the likelihood the source poses a risk to all potential receptors
- evaluate the magnitude of each risk
- consider cumulative or synergistic effects
- describe the limitations of the data collected, and the assumptions and uncertainties inherent in the data and models used (refer to section 7.3.2).

The scope of the risk assessment process is dictated by the investigation objectives. If there are data gaps that cannot be addressed, further field screening and/or sampling may be necessary to provide the level of statistical certainty required for the type of investigation being undertaken.

A SQEP should assess the data generated from a site investigation against the preliminary CSM, and review the location, extent, trends and likely movement of contaminants. Field observations and analytical results should enable the CSM to be refined, and issues relating to contaminant source, pathway and receptors to be identified and assessed.

Refining the CSM is an iterative and ongoing process as data gaps are identified and filled, and new information becomes available. Any changes to the *source*, *receptor* or *pathway* are likely to affect the risk assessment, which should be reviewed when this occurs. Such changes could include changes to the existing or proposed land use, changes in the contaminant source (such as the discovery of new contamination or remediation of existing contamination) and changes to the receptor's exposure, such as the time spent on the site.

A SQEP should review the CSM once the field observations and interpretation of analytical results have been incorporated to determine if sufficient information has been collected to address the investigation objectives. The appropriateness of the investigation objectives should also be reviewed at this time, as these may change in the light of new information.

The outputs of a risk assessment will help determine whether further remedial action or management practices will be required to reduce the level of risk, and guide the development of management strategies and methods to mitigate identified risks.

3.4 Further reading

You can find further information about developing CSMs in the following reports.

ASTM E1689–95. 2014. Standard guide for developing conceptual site models for contaminated sites. Pennsylvania, USA: ASTM International.

ASTM E2531–06. 2014. Standard guide for development of conceptual site models and remediation strategies for light non-aqueous-phase liquids released to the subsurface. Pennsylvania, USA: ASTM International.

Clements et al. 2009. *Characterisation of sites impacted by petroleum hydrocarbons: guideline document*, CRC CARE Technical Report no 11. Adelaide, South Australia: CRC for Contamination Assessment and Remediation of the Environment.

Davis GB, Wright J and Patterson B M. 2009. *Field assessment of vapours*, CRC CARE Technical Report No 13. Adelaide, Australia: CRC for Contamination Assessment and Remediation of the Environment.

Environment Agency (EA). 2000a. Guide to good practice for the development of conceptual models and the selection and application of mathematical models of contaminant transport processes in the subsurface. NC/99/38/3. London, England: Environment Agency.

4 Site investigation design

4.1 Overview

Designing a site investigation can help ensure the investigation objectives are achieved, through proper planning and resourcing, and accurate and appropriate scoping.

Proper investigation design will help ensure the investigation:

- focuses on collecting data that will inform the investigation objectives
- avoids wasted time or resources.

Clear qualitative and quantitative sampling objectives that are appropriate to the investigation objectives form the basis of the investigation design (refer to section 2.1). Sampling objectives will be site-specific, and their complexity and scope will be affected by:

- the purpose of the investigation
- the complexity of the contaminant source(s) and the number of contaminants
- the current (and/or proposed) site use(s)
- the receptors at risk and the exposure mechanisms
- the statistical level of confidence required for the investigation objectives to be achieved.
- Some examples of sampling objectives include:
- establish the type and location of sources of contamination
- identify contaminant hotspots on a site
- quantify depth to groundwater and the direction of groundwater flow
- determine the concentration of a contaminant or suite of contaminants across the site
- determine if the concentration of contaminants are at or below background levels for NESCS purposes or exceed relevant guideline values for the proposed land use
- characterise contaminant concentration and distribution to define exposure areas
- measure the concentration of a contaminant in stockpiled material to determine if it is acceptable for re-use, or whether it meets specific landfill waste acceptance criteria
- monitor trends in contamination at a site over time.

Sampling objectives are not always static, and may change as understanding of the site evolves and the conceptual site model (CSM) is updated. An investigation may need to address new uncertainties revealed by the initial investigation.

4.2 Sampling and analysis plan

A sampling and analysis plan is a working document based on the CSM. It is used to plan and describe everything related to how the sampling objectives will be achieved. The plan includes detailed information about the analytes being investigated, media to be sampled, the location and number of sampling locations, field techniques used to collect samples, and the chosen equipment and laboratory analytical techniques.

The analytes to be investigated and the land-use scenarios that apply to the site will inform the selection of the guideline value that is applicable for an analyte. The guideline value dictates

which laboratory analytical techniques are suitable, which in turn influences how samples should be collected and stored.

A suitably qualified and experienced practitioner (SQEP) should develop the sampling and analysis plan before conducting fieldwork. A good sampling and analysis plan will help to ensure:

- the number and location of samples will provide sufficient data
- appropriate sampling techniques and analytical methods are selected
- proper equipment and sample containers are used when collecting samples
- samples will provide appropriate and representative information.

Laboratories may have specific requirements that must be met before they will receive samples for analysis. These may include, but are not limited to, the amount of each sample, specific container requirements, and packaging, preservation and transport times. The SQEP should discuss any requirements with the laboratory before finalising the sampling and analysis plan.

A sampling and analysis plan should include:

- the investigation objectives
- the sampling objectives
- site information (eg, location, history, current and intended future land use)
- details of the CSM including presence of actual or potential receptors and pathways
- the media to be sampled (soil, groundwater, soil vapour etc)
- the choice of analytes (based on the CoCs identified by the CSM) and relevant guideline values
- the sampling pattern and strategy to be used (sampling design)
- the location, depth, type and number of samples to collect. This should include consideration of the number of samples required to allow statistical analyses of the sample results and to achieve the statistical confidence that might be required to meet the investigation objectives (refer to section 7)
- the sampling method(s) to be used (including field screening or on-site testing requirements, if any), as well as sampling equipment and appropriate sampling containers
- laboratory holding requirements and compositing considerations
- the decontamination procedures
- the order of sample collection (where practical, sampling should start at the part of the site suspected to be least contaminated to minimise the possibility of any cross-contamination)
- sample handling, preservation and transport requirements
- the laboratory analytical suite including required detection levels and holding times
- appropriate laboratory analytical methods for the analytical suite (eg, total recoverable metals vs acid soluble metals vs TCLP)
- quality assurance and/or quality control requirements
- the laboratory contact details.

- contingency for opportunistic or grab samples (one-off samples of material or soil that appear to be of interest and observed by the sampler during a site inspection or sampling event) including soil stains, burn patches or pits, filled areas, treated timber stockpiles, and so on.

The sampling and analysis plan should be included in a DSI report,[3] a remedial action plan (RAP)[4] and a site validation report (SVR),[5] either as part of these reports or as a standalone appendix. The plan can be amended in response to on-site observations as the works progress. A SQEP should document and justify any changes in the final report.

4.2.1 Analyte selection

Before beginning field sampling, the appropriate analytes must be selected based on the CSM, to ensure information obtained from sampling and analysis is adequate to address data gaps and refine the CSM.

A SQEP should use professional judgement and experience to assess available information, including the site history and land use, and other site-specific information, to determine the analytes to be investigated. This selection is informed by:

- the investigation objectives (refer to section 2.1)
- information about current and previous land use on the site and adjacent land, especially regarding chemical use or storage and HAIL land use
- information from previous site investigations
- any preliminary site inspection or preliminary soil sampling undertaken (refer to section 3.3.8 and section 3.3.9).
- The analytical techniques available for environmental media often range from broad screening techniques or methods to ultra-trace analysis for individual chemicals or suites of chemicals.

Once the analytes have been selected, a laboratory analytical method must be chosen that can deliver results at an appropriate detection limit, based on the environmental guideline values (EGVs) to be applied. The laboratory method will determine the sampling method, the type of sample containers to be used, the quantity of the sample, and any preservation requirements.

To help with the final data interpretation, the detection limits must always be below the guideline value. The lower the detection limit is relative to the associated guideline value, the greater the confidence in the results of the analysis. As the concentration of the analyte decreases and approaches the detection limit, it becomes increasingly less reliable. Guidance on detection limits and laboratory selection is provided in section 6.

4.2.2 Contaminant guideline values

Contaminant guideline values, also known as environmental guideline values, represent the level at which a particular contaminant is known to pose a specific risk to a specific receptor. In these guidelines, the general term ‘guideline value’ has been used when referring to the concentration against which analytical results are to be compared.

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[3] See CLMG 1 – 2.3.2 and tables A3, A4 and A5

[4] See CLMG 1 – 2.7.2

[5] See CLMG 1 – 2.8.2

Guideline values are usually expressed in the form of concentration ratio, stated as the measured amount of contaminant per unit amount of media (for example, mg/kg) of contaminants.

Guideline values are calculated based on many factors, including the toxicity of the contaminant and the sensitivity of the receptor under a specific set of conditions to represent a specific level of risk. They represent the maximum concentration of a contaminant at which, under a set of pre-determined circumstances, a particular level of risk is acceptable. Guideline values provide limits against which contaminant concentrations can be compared, to determine whether further action or management is recommended or required.

The selection or derivation of an appropriate guideline value for a specific analyte depends on factors such as the objectives of the investigation, the receptors likely to be present, and the land use proposed for the site. For example, if the investigation objective is to determine an appropriate disposal location, then the analytical results should be compared with appropriate waste acceptance criteria. Alternatively, if the objective is to complete a risk assessment, then the sample results should be compared with appropriate guideline values that are protective of the relevant receptor (eg, human health, environmental receptors, and so on) for the expected exposure scenario/land use.

Guideline values to protect human health are developed for a range of exposure pathways (eg, ingestion, inhalation, skin absorption) and tailored to specific exposure scenarios.

The actual or proposed land-use scenario for a site will guide the selection of an appropriate guideline value.

The land-use scenario that best represents the land-use at a site will determine the appropriate guideline value to apply to laboratory analytical results. The guideline value/s selected should be included in the sampling and analysis plan.

The NESCS has adopted the following five standard land-use scenarios:

- rural residential and/or lifestyle blocks
- residential
- high-density residential
- parks and/or recreational
- commercial and/or industrial outdoor worker and/or maintenance (unpaved).

These land-use scenarios are described in more detail in section 7 of the *Methodology for deriving standards for contaminants in soil to protect human health* (Ministry for the Environment, 2011) (referred to hereafter as the Methodology), which is incorporated by reference in the NESCS (regulation 7(1)).

In a case where the proposed land use is not a standard land-use scenario, a site-specific assessment of exposure to contaminants may be required. Such an assessment is referred to as a Tier 2 risk assessment. Tier 2 risk assessments are addressed in the Methodology and CLMG 2.

Guideline values under the NESCS

Under the NESCS, guideline values are referred to as soil contaminant standards (SCS), and are regulatory limits that are protective of human health.

Under the NESCS, a SQEP must use the SCSs that exist for 12 priority contaminants and for five standard land-use exposure scenarios. These are described in more detail in the Methodology.

If a contaminant of concern (CoC) for a site is not included among the 12 priority contaminants, guideline values must be selected from national or international guideline values in accordance with CLMG 2.

The SCS or guideline value selected should be appropriate to the contaminant, the environmental media, and the current or proposed site use (the receptors) that have been identified in the CSM.

4.2.3 Sampling design

Statistically robust and reliable data depends on a properly designed sampling plan.

The field investigation part of a site investigation usually requires forethought and planning to ensure the samples collected can be analysed by the laboratory, and will provide data that meets the investigation objectives. Without a clear understanding of the investigation objectives, there is a risk of inappropriate, insufficient or excessive sampling.

The purpose of sampling design is to ensure investigations focus on obtaining sufficient data that is fit for purpose and that satisfies the investigation objectives. Good sampling design can optimise efforts and resources spent to achieve the investigation objectives by avoiding unnecessary repetition or waste of resources.

Samples are not the site, but do represent it. It is not possible to define the level of contamination over an entire site from a single concentration measurement. Statistical certainty increases as the number of samples taken increases. The minimum number of samples required for site characterisation depends on the type of investigation, the investigation objectives, the complexity of the contamination, the level of confidence required and the level of knowledge about the site.

A clear definition of the sampling objective is the first step to developing the sampling design. The design of the sampling programme must always be informed by the CSM.

Examples of sampling objectives

Example 1: The detailed site investigation (DSI) is generally driven by the objectives to:

- gather information about the type, extent and severity of contamination
- provide sufficient supporting data to determine, with an acceptable level of confidence, the contamination status of a site relative to guideline values
- inform the CSM and risk assessment regarding the level of risk posed by contamination to human health and/or environmental receptors.
- Example 2: The site validation investigation (SVI) is generally driven by the objectives to:
- gather up-to-date data about contamination conditions at the site after remediation
- provide sufficient supporting data to determine, with an acceptable level of confidence, that the contamination on the site has been reduced below a threshold value
- inform the CSM in order to refine the understanding of residual risk at the site.

If it is intended that statistical analysis of the sample results will be undertaken to fulfil the investigation objectives, then the sampling programme must be appropriately designed to allow this to occur.

When designing a sampling and analysis plan, the upper confidence level that will be required should be taken into account when planning the number of samples to be collected.

For the purposes of a DSI or SVI to meet any requirement under the NESCS, the 95 per cent upper confidence level (95 per cent UCL) of the mean for a contaminant is the appropriate confidence level for assessment. The 95 per cent UCL is appropriate to many other investigation types where statistical certainty is a requirement.

Further detail is provided in section 7.

Exposure areas

Some sites have complex contaminant distribution patterns, and concentrations of contaminants that vary significantly from one part of the site to another.

The concept of exposure areas simplifies the tasks of characterising a site and developing and refining a CSM by dividing the larger complex site into smaller areas where:

- the contaminant distribution and concentration is expected to be relatively homogenous
- site conditions such as geology, soil type, fill material, topography and so on are similar
- a receptor could expect to receive a similar level of exposure when undertaking a particular land use or activity.

By dividing a site into exposure areas, a SQEP can potentially:

- limit the analytes to be investigated to those specific to each exposure area
- manage areas with high contaminant concentrations (hotspots) as individual exposure areas
- determine the appropriate guideline values for each exposure area
- simplify the statistical analytical procedures
- focus resources on the more complex and/or high-risk exposure areas.

These exposure areas can then be assessed individually and, where necessary, either have specific remedial/management actions designed for each exposure area, or the assessments combined to derive an overall site characterisation.

Failing to identify exposure areas on a site can result in incorrect data interpretation, leading to incorrect assumptions and conclusions about the risk posed by contamination at a site.

Information requirements for site investigations and conceptual site models

Once the sampling objective has been established, the sampling pattern can be determined. The selection of a sampling pattern is informed by:

- the collection and assessment of information derived from the proposed site use
- records of current, surrounding and previous land use
- any preliminary site inspection and preliminary soil sampling, or historical investigations undertaken (refer section 3.3).

A SQEP should consider how representative the soil samples collected would be of the area to be assessed. A representative set of soil samples is one in which each individual soil sample is representative of the location from which it was taken, and where the set as a whole provides a representative measure of the contaminant concentrations that a receptor may be exposed to.

In addition, a SQEP will also need to consider the physical constraints imposed by site conditions and the characteristics of the contaminants present.

These may include:

- access constraints including the location of buildings, hard-stand, canopies and underground services, as well as other issues that could pose physical challenges to the design and implementation for potential site investigations
- the location of physical hazards such as overhead and underground power cables
- the availability of water and electrical supply for use during site investigations
- physico-chemical properties of the contaminant/s, for example, density, water miscibility, transmissivity, persistence and volatility.

Selecting an appropriate sampling pattern requires professional knowledge and experience and should be supported by clear justification. There are two main approaches to sampling design:

- targeted sampling, also termed judgemental sampling, which focuses on known, suspected or point source areas of contamination
- probability-based or systematic sampling, which can be used to statistically characterise contamination within a defined area of a site or volume of a stockpile.

In practice, more than one sampling pattern may be used to satisfy the different objectives. Typical sampling patterns are illustrated in figure 3. A guide to selecting the sampling pattern, based on some examples of sampling objectives and various scenarios, is provided in table 3.

Figure 3: Sampling patterns

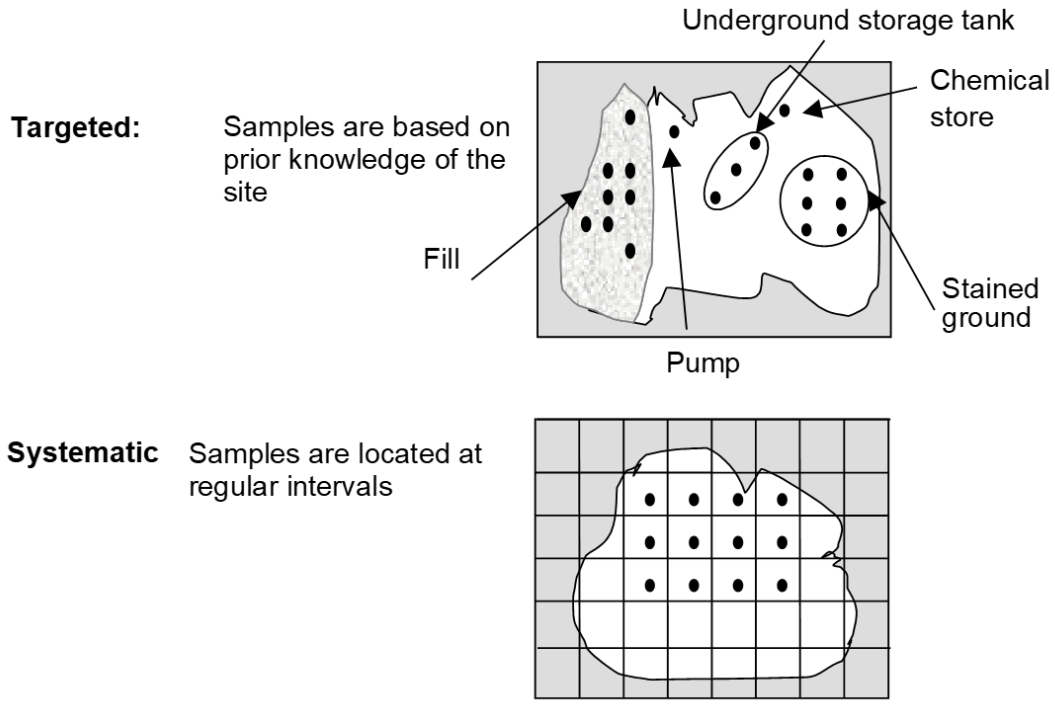


Table 3: Sampling pattern selection guide

When. . .	and there is. . .	consider using . . .	to . . .
completing *preliminary sampling,* augmenting a systematic sampling design, or performing an investigation of a relatively small-scale problem	a limited budget and/or a limited schedule, and where contamination sources are located is known	targeted sampling	assess whether further investigation is warranted, which may include a statistical probabilistic sampling design.
developing an understanding of where contamination is present	an adequate budget for the number of samples needed	systematic sampling	acquire coverage of the area of concern with a given level of confidence of detecting a hotspot of a given size.
estimating a population mean	an adequate budget for the number of samples needed	systematic sampling	provide an estimate of mean contaminant concentration in the exposure area.

Source: Adapted from USEPA, 2002.

Targeted sampling

Targeted sampling makes use of a judgemental sample technique for site selection. This technique involves selecting sampling locations based on expert knowledge or professional judgement, usually informed by a well-developed CSM or site-specific knowledge. The quality of targeted sampling depends heavily on the quality of knowledge about site conditions and the proposed, current and historic site usage, as well as the experience of the individual selecting the sample sites.

Targeted sampling will probably not be capable of satisfying investigation objectives that require assessment of risk over an entire site, but may be able to meet simpler objectives, such as determining the boundaries of a contaminated area and whether the site should be investigated further. However, this sampling design can be used in combination with other sampling designs to produce effective sampling for defensible decision-making (NEPC, 2013).

Targeted sampling is often used to good effect to:

- provide insight into what chemicals may be present from particular activities that have occurred
- confirm the presence or level of contamination at a specific location (eg, a 'worst case' location)
- provide screening information to help scope subsequent investigation phases (eg, in PSIs with limited sampling).

Data derived from targeted sampling have both advantages and limitations that need to be considered before the method is employed. Advantages of targeted sampling include:

- cost effective, as it is focused on specific, pre-determined locations and contaminants
- requires less planning before sampling
- can be used to confirm presence and severity of contamination.

Limitations of targeted sampling include:

- very limited statistical application due to inherent bias
- cannot be used to confirm the absence of contamination
- cannot reliably assess statistical precision

- relies on accurate site knowledge
- limited statistical application due to inherent assumptions determining sample locations.

Targeted sampling introduces bias, making it generally unsuitable for statistically confirming the absence of contamination at a site (for example, for human health risk assessment or validation sampling). A systematic sampling design is recommended for investigation objectives driven by a need for statistical reliability, especially when relying on data for risk assessment.

Irrespective of the sampling strategy, the selection of analytes and analytical method, collection of samples, QA/QC and chain of custody requirements must meet the investigation objectives.

Example – Targeted sampling

A timber treatment site is being investigated using targeted sampling. Based on the preliminary site inspection, aerial photographs and discussions with workers, samples are located around the edge of the drip pad, along vehicle tracks where treated timber is carried, under an aboveground diesel tank, and under the piles of treated timber stored in the yard. Samples are also taken at the delivery point for bulk copper-chromium, arsenic solution, which is where the pentachlorophenol antisapstain bath used to be located, as well as the area where sludge from the treatment operations used to be dumped.

Systematic sampling

Systematic sampling, otherwise known as grid sampling, is a probability-based sampling pattern where sampling locations are selected at regular intervals throughout the investigation area. The first sampling location is chosen at random to reduce bias.

Grid patterns may include square, triangular, radial and herringbone shapes, and are selected based on factors such as the size and geometry of the site, and an understanding of the potential distribution of contaminants associated with the identified site use.

Transect sampling (where samples are spaced out along lines) can also be regarded as a type of systematic sampling technique, as long as transects are systematically spaced.

Systematic sampling is used to search for hotspots and to infer means, percentiles or other parameters. It is also useful for defining spatial patterns or trends over time. Situations appropriate to the use of systematic sampling include:

- general site characterisation in the absence of adequate site history
- detecting hotspots when possible locations are not known
- estimating the mean concentrations of contaminants across a site or exposure area (as an estimate of average exposure of a receptor) for risk assessment purposes
- validation of remaining *in-situ* or treated soil and any imported backfill material following remediation
- assessing the acceptability of the level of risk posed by contaminants for human health risk assessments.

If the property and/or trend of interest is aligned with the grid, systematic sampling has the potential to introduce bias (over or under representation) to the results.

Example – Appropriate grid spacing

A former vineyard had grapevines in rows, each supported by copper chromium arsenic (CCA) treated posts, spaced at regular intervals. In determining an average concentration of contamination for human health risk assessment, an appropriate grid spacing would represent both the soil within the grapevine rows and the spaces between the rows.

An additional, finer grid would also need to be devised to ensure residual contamination from CCA-treated posts could be sampled and the results included in the CSM. The grid spacing and location should be based on the calculation in **appendix B** for finding a hotspot of a particular radius. The size of the hotspot the investigation is seeking to find would be related to the size of the contamination halo around the postholes.

Where site infrastructure (for example, existing residential building) impedes the SQEP's ability to execute a grid system, the SQEP should consider and report on the significance of the data gap from not collecting the sample (refer to section 3.2.3).

Example – Converting commercial property to residential use

A commercial property is being converted to residential use. The existing building will remain on the site and is being 'refitted' to accommodate the residential use. Sampling in the curtilage is possible but soils underlying the building cannot be sampled without damaging the building floor. The initial CSM indicates that volatile contaminants are unlikely to be present on the site and therefore vapour intrusion into the building is considered unlikely. The decision is made not to complete sampling under the building as it is considered unlikely to produce a significant data gap. The sampling undertaken in the curtilage confirms the absence of volatile contaminants and is considered adequate to characterise the risk from other exposure pathways. The absence of sampling under the building is noted in the subsequent report and the rationale as to why the data gap is not considered significant is described.

Where areas of interest or uncertainty exist on a site, the grid pattern may be intensified in that area (see note on exposure areas in section 4.2.3) or grid sampling may be combined with additional targeted sampling to provide greater confidence or understanding.

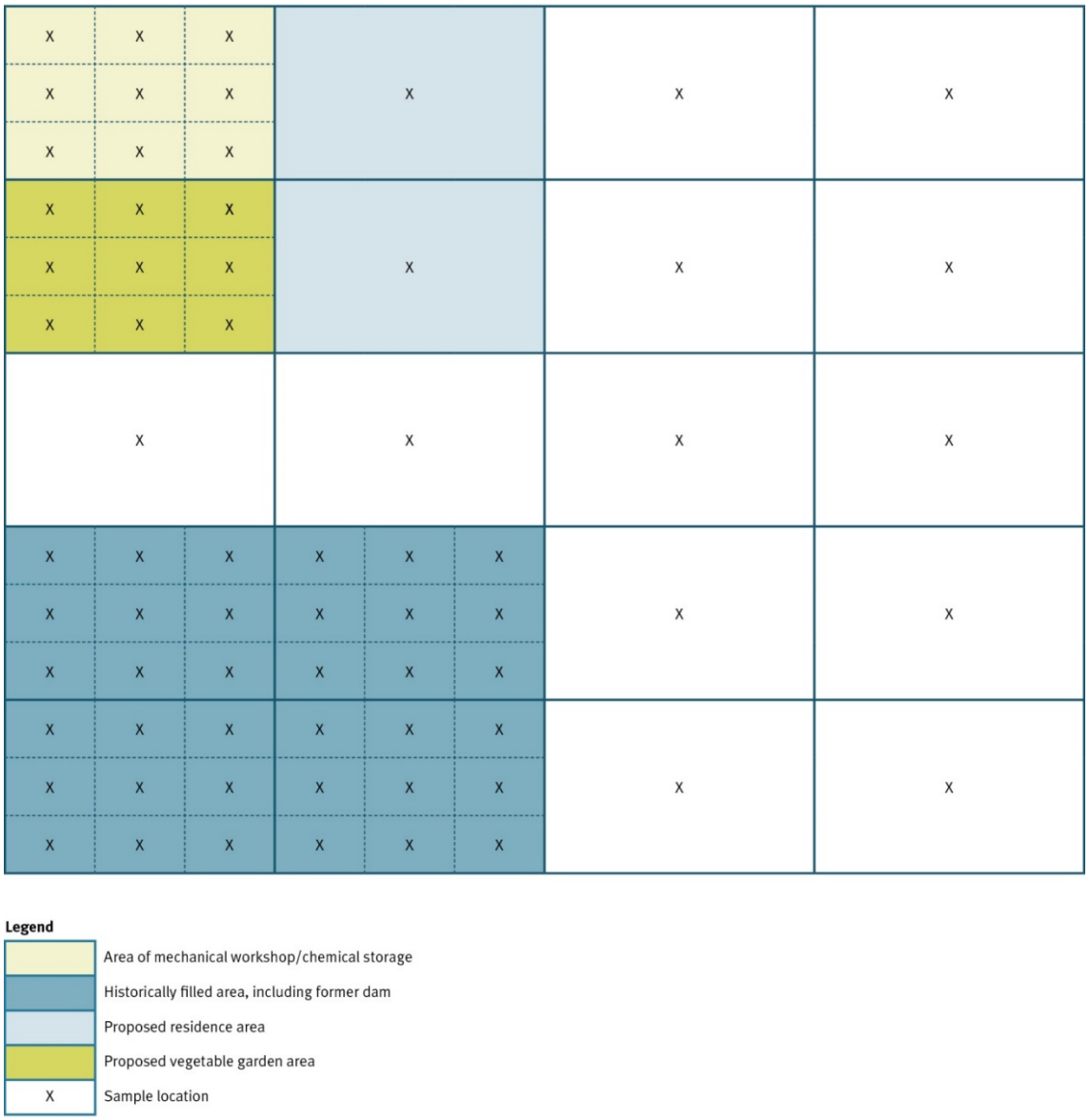
Example – Multiple grid patterns on a single site

The preliminary CSM indicated a former orchard was likely to have had low-level, broad-scale and uniform impacts from herbicide sprays in its 'production' area. However, the site also included a mechanical workshop/chemical storage area and a historical dam, which was backfilled with imported fill of unknown origin. These additional areas provided the potential for alternate contaminants to be present and a varying distribution trend of contamination in comparison to the wider site. The preliminary CSM also showed the proposed site use included a vegetable garden and residence.

From the preliminary CSM, a generic grid pattern based on the detection of an appropriately sized hotspot was adopted for the entire site. In addition, a more detailed grid for the mechanical workshop/chemical storage area and historically filled area was completed due to expected varying contaminant distribution. A more detailed grid was also applied in the proposed

vegetable garden area as the acceptable hotspot for such an area was considered to be smaller than that for the wider site area. **Figure 4** depicts the varying grid patterns used.

Figure 4: Multiple grid patterns on a single site



Grid size selection

Appendix B provides a methodology for calculating a grid size based on detecting circular hotspots with 95 per cent confidence and subsequently the number of samples required. Determining grid size/sampling density from mathematical formulae is not an acceptable approach without considering the distribution of likely contaminants and acceptable hotspot size.

A hotspot is a localised area of elevated contaminant concentrations relative to the remainder of the exposure area under investigation. Whether a hotspot presents a potential risk to human health or the environment will depend on its size, location, contaminant concentration levels and the receptors that can interact with it. Current and historical use of the site may indicate the likely location of hotspots.

Table B1 in appendix B provides examples of the number of samples required for varying grid sizes on a variety of sized sites when using the formula. Table B1 is provided as a guide and is not intended to give the default number of samples for a given site size. In all cases, site-specific information, the investigation objectives and the CSM should be considered when using professional judgement to select an appropriate grid size.

The following are considerations when determining what size hotspot a systematic sampling system should detect:

- the activity undertaken at the site and the likely distribution pattern of contaminants resulting from that activity
- investigation objectives (refer to section 7).
- toxicity of the likely contaminants and likely exposure pathways present, the sensitivity of likely receptors and the likely duration of receptor exposure
- the physico-chemical properties of the contaminants of concern.

When an unexpected hotspot is discovered during a DSI, a SQEP should understand why it exists and express an opinion on what its detection means in relation to both the assumptions of the sampling methodology used, and the achievement of the DSI's objectives. This may involve determining if the higher concentrations are a result of the heterogeneous nature of the site, an error, or an indication of a previously unknown source of contamination. Section 7 of these guidelines provides guidance on data interpretation.

Reducing the confidence level that a hotspot will be detected reduces the number/density of samples to be collected but also increases the risk of not detecting a hotspot or adequately characterising an area of concern. Using a 95 per cent confidence level is recommended.

When applying the systematic sampling method, it is critical the SQEP records the assumptions used to determine the grid size, and any potential limitations to the approach used in the DSI. This includes the statistical confidence level, the size of the hotspot, and any other relevant factors that could influence the outcome.

When complying with the NESCS, the DSI report should justify the number of soil samples collected and potential limitations of the sampling methodology adopted in the context of the investigation objectives.

Alternative sampling patterns

Several other sampling designs may be used, where appropriate, to characterise site conditions including *stratified sampling*, *adaptive sampling,* and *random sampling*.

In stratified sampling, the site is divided into non-overlapping exposure areas. Each sub-area is expected to be uniform in character, with differing sampling densities and patterns applied to each. Prior knowledge of the sampling sub-areas is combined with likely contaminant behaviour to determine where to sample.

Adaptive sampling designs use a probability-based screening investigation to inform the need for higher-density sampling around areas of interest. Typically, a specific condition (such as a sample having a contaminant concentration over a guideline value) is used to trigger the need for further sample collection and analysis around a sample location. In this way, sampling density increases around areas of particular interest.

A random sampling design is the simplest probability-based sampling design. The sampling pattern is generated using random number tables or other random number generation methods, to select the locations to be sampled. Simple random sampling ignores all prior information of site conditions and professional knowledge.

Random sampling protects against bias, but sampling points are unlikely to be uniformly distributed. This may cause clustering of sample points, with the effect of reducing coverage. This clustering of sampling locations may be overcome by increasing the number of samples.

Random sampling is most useful on relatively homogeneous sites where contaminant distribution patterns or hotspots are expected. However, as most site investigations deal with non-uniform distributions of contamination, simple random sampling may be combined with other patterns of sampling.

Further discussion of the various sampling designs, their limitations and appropriate uses are provided in USEPA, 2002; CIEH, 2008; and EA, 2000.

4.2.4 Number of samples

The sampling objectives should be considered when determining the number of samples required to provide statistically reliable data. The number of samples required will depend on the level of confidence and robustness required for decisions that will be based on the information obtained (refer to section 7).

Characterising contamination at a site for risk-based decision-making should be based on statistically reliable data.

Collecting and analysing a small number of samples may not provide the level of statistical certainty necessary, while collecting too many samples is wasteful and inefficient.

There is a wide range of possible sampling objectives, and not all relate to assessing potential health risk. Examples of sampling objectives could include:

- initial site characterisation
- detailed contamination characterisation (within an identified area or part of a site)
- determining the presence or absence of specific contaminants
- human-health risk assessment
- assessment of environmental effects
- determining remedial requirements
- determining contaminated material/soil disposal options
- validating the effectiveness of remediation.

Sampling objectives are site specific so there are no simple rules for determining the number of samples. Sampling objectives may vary from acquiring information to designing a cost-effective remedial plan, to detailed human-health risk assessment in a land-use change or subdivision scenario. The different objectives or stages of sampling will generally require different sampling strategies, and therefore a different number of samples.

Determining the appropriate number and location of samples requires professional judgement and the investigator should draw on the investigation objectives, the CSM developed to date, and the significance of any data gaps. Decisions about the number and location of samples in the sampling and analysis plan and/or DSI report should be clearly documented.

Number of samples for assessment of risk

Quantifying risk requires statistical certainty in the data. Statistical certainty relies on collecting and analysing an appropriate number of samples using appropriate field techniques and analysing the data with appropriate statistical methods.

In determining the number of sampling locations for risk assessment, the sampling and analysis plan should define the exposure area/s within a site and the statistical analyses to be undertaken within each exposure area. See note on exposure areas in section 4.2.3.

For risk assessment purposes, the site investigation should characterise contaminant concentrations to an acceptable level of confidence for each exposure area. An exposure area will, despite general similarity, show some degree of variability. An appropriate number of samples will be needed from within an exposure area to obtain statistically reliable information on contaminant concentrations.

In practice, a high sampling density may be required to characterise a small area that has multiple sources, pathways and receptors adequately. Conversely, a large site expected to have a uniform exposure scenario may require a lower sample density to achieve a statistically reliable result. You should assess each site according to the source-pathway-receptor model, to determine an appropriate number of sample locations for each exposure area accurately.

Sampling density should be determined using statistical calculations. The number of samples determined should be justified using arguments based on the extent of the exposure area and the likely size of any hotspot. Table B1 should not be used to justify or determine the number of samples for a site, as it only serves as an example of a variety of situations.

Justifying the number of soil samples collected and potential limitations of the sampling methodology adopted is a reporting requirement in CLMG 1 for a detailed site investigation report, when complying with the NESCS. It is also good practice for reporting for purposes other than the NESCS.

Number of samples for petroleum storage system investigations

Specific guidance on the minimum number of samples required for investigating underground petroleum storage systems (UPSS) and hydrocarbon contamination is provided in *Guidelines for assessing and managing petroleum hydrocarbon contaminated sites in New Zealand* (MfE, 2011b). It needs to be emphasised these are guidance numbers and represent the *minimum* number of sampling locations. Further samples may be required to produce representative data for contamination at a site (for example, several tanks may be included in one tank pit so the guidance on the minimum number of samples of five per tank pit may need to be increased).

Number of samples for characterising stockpiles

Soils may be stockpiled in preparation for placement on a site (as part of a site development or during remediation) or for off-site disposal.[6] Stockpiles may include contaminated soil, and may need to be sampled to assess the suitability of the soil for re-use or to determine disposal options.

A SQEP can approach assessing stockpiles for re-use in two ways:

initial sampling in the stockpile at a rate to gain sufficient assurance the soil is likely to be acceptable after spreading, followed by validation sampling after spreading at a rate based on the final use, or

a greater rate of sampling within the stockpile equivalent to the number of samples that would be required if the soil had already been spread.

[6] For further information, see: https://www.epa.vic.gov.au/~/media/publications/iwrg702.pdf.

A SQEP should address the following specific points where stockpiles are investigated, for example:

- the source of the stockpiled soil
- contaminants from the source of the soil
- potential contaminants from the current site activities
- the end use of the soil
- the volume of stockpiled soil
- if stockpiles are to be spread, the area that the soil will cover so as to determine the number of samples based on the future exposure areas (eg, residential lots).

Sampling plans for stockpiles should not assume the stockpiles are homogenous, unless this can be demonstrated by site history information or preliminary sampling. Any assumption of homogeneity should be carefully and deliberately checked with the available sample data.

A SQEP should also investigate and account for soil mixing (whether incidentally or intentionally) between stockpile and final resting place in determining the sampling frequency if a stockpile is to be re-used.

It is best practice to sample within the body of stockpiles, rather than just from the surface. This takes account of heterogeneity caused by grain-size segregation that is likely to occur at the surface when the stockpiles are built. To sample within the body of stockpiles, cut a series of appropriately spaced transects through the stockpile and take multiple samples at different distances and heights at each transect. The number of transects, and the number of samples per transect will be a matter for judgement at the time, informed by the CSM for final use (see above), the shape of the stockpile and the source and nature of the material.

If there is information the stockpile is likely to be homogeneous, or if the soil will receive deliberate mixing at the time of re-use, it may be appropriate to analyse samples from each transect as one or more composite samples (see section 4.2.6).

Where soils are sourced from a site with the potential for contamination, or heterogeneous contaminant distribution is identified during stockpile sampling, further validation of the stockpiled material following placement is appropriate to support risk assessment.

The sampling design should be consistent with the end use of the re-instatement area and general site assessment guidance provided in this guideline.

Sampling contaminated soil for off-site disposal is necessary to ensure that landfill acceptance criteria are met. Landfill acceptance criteria vary between disposal facilities, as do the sampling requirements to confirm whether applicable waste acceptance criteria are met. When disposal is to occur, a SQEP should confirm sampling requirements with the approved disposal facility before disposal.

A SQEP should consider regulatory requirements and liability for contaminated soil when determining where such soil may be stockpiled, managed or disposed of.

4.2.5 Sample depth

The concentration and distribution of contaminants can vary significantly at different depths in the soil or groundwater at a site. The proposed land-use scenario at a site will determine whether surface or near surface samples will suffice, or whether deep samples must be collected. This may include removing surface soil, excavating basements or trenches, or other development requirements.

Refer to the sampling objectives when determining the depth for collecting samples. This information should be documented in the sampling and analysis plan.

The contaminant distribution at a site is influenced by:

- the nature of the contaminant source (point source, diffuse source, surface, subsurface, single or multiple releases, length of time since discharge, preferential pathways, and so on)
- the nature of the breakdown products of primary contaminants
- contaminant and breakdown product characteristics and behaviours (specific gravity, solubility in water, mobility, toxicity and persistence, among others)
- the type and physical nature of the soils and geology (such as their permeability, porosity and grain size)
- pathways for contaminant transport (through air, soil or water or preferential pathways such as bores or underground services)
- physical disturbance of the contaminants.

Example – Effect of release location on contaminant distribution

A loss from an aboveground tank could cause contamination of the soil profile from the ground surface down. However, a loss from an underground storage tank may result in contamination of subsurface soils but little or no impact on surface soils due to the underground location of the release and subsequent horizontal and descending migration of contaminants.

The exposure scenarios for the priority contaminants listed in the Methodology include soil ingestion, dermal exposure and produce ingestion.

When assessing soil ingestion or dermal exposure pathways, samples are typically collected from between 0 and 75 mm below the ground surface to represent soil that receptors (mainly people) are exposed to in their day-to-day activities. Collecting samples intended to represent the surface over a deeper interval than 0 to 75 mm increases the possibility of diluting the surface soil sample by mixing with less contaminated subsurface soils.

Samples should be collected within the root zone for the plant concerned when assessing the potential effect on plants, or assessing the produce ingestion pathway. This is typically between 100 and 300 mm below the ground surface.

The need to collect samples from multiple-depth profiles will be driven by the sampling objectives, CSM, field observations and analytical laboratory results. Examples where surface samples or near-surface samples may be all that are required include:

- investigations using targeted sampling to determine the locations of surface spills and whether further investigation is required
- sites where only non-volatile contaminants are expected to be present and exposure pathways are confined to surface or near-surface soil.

If deeper soil samples are required, they should be collected from throughout the soil profile at regular intervals, from the surface down to the depth at which contamination is anticipated or observed, and/or to the groundwater table, and from below the groundwater table where the specific conditions require it.

Samples should be collected where the soil type or geological differences suggest contaminants could collect (for example, immediately above low-permeability layers, at

mineralised layers that could bind contaminants, and at the water table) but should generally not be collected from across different strata (for example, across the boundary between natural ground and fill) or below the groundwater table.

Examples where deeper samples should be taken include:

- where volatile contaminants are likely to have migrated downwards or the contaminant source is at depth (such as an underground petroleum storage tank), presenting a potential risk at the surface from the inhalation of volatiles
- if there is uncertainty about the probable vertical behaviour of a given contaminant in a particular soil, and there is concern for the groundwater or inhalation pathways
- when redevelopment plans (or foreseeable redevelopment) will remove surface layers, exposing deeper contamination to surface contact
- for planning remediation (eg, soil removal or mixing)
- where excavation will result in surplus soil needing to be assessed for disposal
- as a simple benchmarking exercise, regardless of whether deeper soil presents an existing or foreseeable risk.

The number of samples may be weighted towards near-surface sampling for assessing health and ecological risks from exposure to soil contaminants (for example, through skin contact for human health risk). If groundwater is considered a potential pathway or receptor, then an increased number of samples collected from near the water table may be selected for analysis. This is particularly the case where contaminants of concern include light, non-aqueous-phase liquids.

If dealing with volatile contaminants such as light fraction petroleum hydrocarbons or chlorinated solvents, then vapour transport from depth and through a shallow soil zone may pose a risk. Deeper sampling to determine the nature and extent of the source of the vapours and the risk they represent may be required.

Example – Sampling locations appropriate to investigation objectives

A petrol leak from the base of an underground storage tank has caused contamination below the base of the tank pit only, with little or no impact on shallower soils. The top one metre of the ground surrounding the tank comprises boiler ash containing arsenic and residual diesel from an earlier surface spill. The sampling objectives are directed at assessing the impact of benzene on groundwater, which lies several metres below the base of the tank. No sampling of the fill materials is undertaken during the site investigation, and soil samples need to be collected from the depth of the base of the tank down to the groundwater table.

4.2.6 Composite samples

Composite sampling involves collecting individual samples from different locations, typically between two and six samples, and mixing an equal mass of each of the samples (called sub-samples) together to form one composite sample. A composite sample can then be analysed and the results will represent the average of the constituent sub-samples.

Compositing can be cost effective where the analysis costs are high, relative to sampling costs. However, a SQEP should consider its use with caution because of the potential for high concentrations in one of the sub-samples to be masked by low concentrations of the other

sub-samples. Its use is also dependent on there being no safety concerns or potential biases (for example, loss of volatile compounds) associated with the compositing process.

Composites may be useful in conjunction with other sampling designs or when the objective is to estimate the contaminant concentration mean and information on spatial or temporal variability is not needed. Composite sampling may be more applicable in the early stages of an investigation, where information on general contamination conditions is required.

Adjusting guideline values or sample concentrations when assessing composite samples is no longer considered appropriate for drawing conclusions regarding the risk to human health. Adjustment may be appropriate for other sampling objectives, for example, where an estimate of the maximum concentration is required.

Where the average concentration represented by the composite sample exceeds the adopted guideline value, analysis of individual samples should be undertaken to clarify the contaminant distribution. Where background levels of contaminants approach the guideline value, or where the laboratory detection limits are close to the guideline value, comparing composite results to guideline values may be inappropriate.

When undertaking composite sampling for an investigation conducted for NESCS purposes, the following guidelines must be adhered to.

1. The CSM must indicate that low-level and homogeneous contamination exists across the area where the composite samples are being taken.
2. The maximum number of sub-samples that may be composited together is four.
3. A minimum of four composite samples from within each exposure area (comprising no more than four sub-samples each) must be analysed.
4. The sub-samples that comprise the composite sample must be within the same statistical population or exposure area (for example, the same soil type, same exposure to contaminants, similar depth).
5. The location, depth and soil type of each sub-sample the composite is made up of must be recorded and included in the DSI report.
6. Composite sampling can only be undertaken for non-volatile contaminants.
7. For soils that are not easily mixed (for example, clay), particular care should be taken to homogenise the primary samples before taking sub-samples, for example, drying and mechanical disaggregation (not grinding), before mixing.
8. The composite must be assembled by the laboratory and not in the field.
9. The composite must comprise an equal mass of each constituent sub-sample.
10. The number of sub-samples that make up the composite must be recorded and included in the DSI report.
11. Contaminant concentrations across the area being investigated must be demonstrated to exhibit statistically low heterogeneity. If statistical analysis of variability among the results of composite sampling reveal significant variability in contaminant concentrations across an area, a revision to the CSM will be necessary, and the sub-samples that comprise the composite sample will need to be individually analysed.
12. Adequate laboratory holding times need to be specified when taking composite samples to ensure the original samples are available for re-analysis. If the laboratory has disposed of the original samples, then new samples cannot replace the originals, and the composited sample results will have no value.

13. When comparing the results of composite samples to guideline values, the laboratory reported concentration or guideline value cannot be adjusted.

Example – inappropriate use of composite sampling

A large historical commercial site is to be redeveloped into a residential subdivision. The site history indicates there were several discrete potential point sources of contamination in different areas of the commercial site, along with the potential for widespread, low-level distribution of contamination across much of the site. To lower analysis costs, the cleared commercial site is divided into four sampling areas, each representing a quarter of the site, with 10 sub-samples collected from within each sampling area and the sub-samples combined for analysis.

This is an inappropriate use of composite sampling because sub-samples should only be collected from areas with the same historical-use profile and potential for contamination. In this instance, the potential for hotspots from point sources of contamination is likely to be masked by the compositing process. Further, the sampling described above does not take into account the future exposure areas represented by the residential lots that are to be created, and does not quantify the contamination risk within these exposure areas.

Example – appropriate use of composite sampling

A field has been used for disposal of a liquid waste over several decades. The liquid waste has been pre-processed by a treatment plan and, as a result, the composition of the liquid waste has been consistent over time. The liquid waste has been applied to the field in a uniform way, and as such, it is expected any distribution of contaminants in near surface soils will be homogeneous. A field is divided into a sufficient number (calculated according to statistical methods) of small sampling areas on a systematic basis. Four samples (which are in effect sub-samples) are taken from each of these small sampling areas. Each group of four sub-samples is composited in the laboratory.

This is an appropriate use of composite sampling because the contaminant type is the same across the sampling area and its spread is likely to have been homogeneous. The collection of four discrete samples allows for further analysis of the original samples should greater resolution be required in a particular area as a result of the analysis of the composite samples.

4.2.7 Background samples

The background concentration of a contaminant is an estimate of the natural concentration of a substance (element, compound or mixture) that would exist in the absence of any anthropogenic input, usually on a regional, sub-regional or catchment basis. For chemical elements in soils, the background concentration is expected to show some variation depending on the geochemical nature of the parent materials.

Some regional councils have information on background concentrations of common contaminants (usually metals) in the main types of natural soils in their region. Additional details, including references, can be found in *Contaminated land management guidelines No 2: Hierarchy and application in New Zealand of environmental guideline values* (MfE, 2011a) (CLMG 2).

In some cases, collecting background samples can help to interpret contaminant conditions at a site, specifically, the extent to which the identified conditions reflect a natural background concentration. Suitable locations for background samples should be chosen based on the similarity to the site being investigated in terms of:

- proximity of the background sample to the site under investigation
- site geology (background concentrations of metals are related to the parent rock types)
- site history (this should indicate no disturbance or anthropogenic activities at the location)
- topography (sample collection should not be from any low-lying areas, such as ditches, but from areas of raised ground).

Background samples can also help show whether contaminants present on a site are due to wider area effects, either natural or artificial. In this situation, a sufficient number of background samples will need to be taken to demonstrate statistically that the samples are representative of the soil type at the locality.

Further reading

Recommended further reading on regional background concentrations and sampling methodologies includes:

Ministry for the Environment. 2011a. *Contaminated land management guidelines No 2: Hierarchy and application in New Zealand of environmental guideline values*. Wellington: Ministry for the Environment.

Auckland Regional Council. 2001. *Background concentrations of inorganic elements in soils from the Auckland region*. Retrieved from http://www.aucklandcity.govt.nz (Accessed November 2020).

URS. 2003. *Determination of common pollutant background soil concentrations for the Wellington region.* Retrieved from http://www.gw.govt.nz/ (Accessed November 2020).

Ministry for the Environment. 2009. *Land and soil monitoring: A guide for SoE and regional council reporting*. Retrieved from http://www.environment.govt.nz (Accessed November 2020).

Petterson J, Salomon V and Davies H. *Background concentrations of trace elements in the major Canterbury soil groups – user guide*. Retrieved from http://ecan.govt.nz/ (Accessed November 2020).

Bay of Plenty Regional Council. 2011. *Trace elements in Bay of Plenty soils*. Retrieved from https://www.boprc.govt.nz (Accessed November 2020)

Cavanagh J. 2015. *Background concentrations of trace elements and options for managing soil quality in the Tasman and Nelson Districts*. Retrieved from http://www.envirolink.govt.nz (Accessed November 2020).

Cavanagh J, McNeill S, Arienti C and Rattenbury M. 2015. *Background soil concentrations of selected trace elements and organic contaminants in New Zealand.* Envirolink Tools Grant: C09X1402. Retrieved from http://www.envirolink.govt.nz (Accessed November 2020)

Cavanagh J. 2013. *Cleanfill criteria for the Marlborough District. Envirolink Advice Grant 1295-MLDC86 Retrieved from* https://www.marlborough.govt.nz *(Accessed November 2020).*

4.2.8 Soil sampling techniques

The soil sampling method used during a detailed site investigation (DSI) will depend on a variety of factors, including the guideline values and laboratory analytical technique selected, the investigation objectives, cost, access, whether the site is active or inactive, the tolerable degree of disturbance, and reinstatement requirements.

Often a variety of sampling methods are used as part of an investigation, but whichever technique is used, the soil sampling must be representative of the area sampled and undertaken in a way that ensures appropriate sample integrity.

The following techniques can be considered when undertaking soil sampling:

- surface and shallow sub-surface grab sampling
- hand auger sampling
- test pit sampling
- borehole sampling.

Table 4 summarises the main techniques, and some of their advantages and disadvantages.

Table 4: Soil sampling techniques

Technique	Advantages	Disadvantages
Grab sampling (trowel, push tubes, shovel or scoop – plastic or stainless steel)	• Low cost • Quick • Minimal access restrictions • Minimal soil disturbance	• Depth limit: surface to 0.5 m • Impractical in difficult soil conditions
Hand auger, driven split-barrel devices	• Low cost • Quick • Minimal access restrictions • Minimal soil disturbance • Can be used for installing groundwater and gas monitoring wells	• Depth limit: 2–3 m • Impractical in difficult soil conditions • Sample quality may be compromised from cross-contamination within the hole • Limited ability to observe the nature of the material • Labour intensive
Test pits (machine dug)	• Lower cost than boreholes • Relatively quick • Ability to make detailed observations of the strata • Ability to recover samples	• Large extent of soil disturbance, occupational exposure, reinstatement • Depth limit: 3–5 m depending on the excavator and ground stability • Impractical in unstable soil conditions and hard rock • Not suitable for installing monitoring bores due to disturbance
Boreholes (rotary and direct push rigs – solid and hollow-stem auger, with and without drive-tube sampling, rotary coring, direct push coring and sonic)	• Minor disturbance of soils • Limited occupational exposure • Accurate recovery of samples • Ability to sample at depth • Suitable for most ground conditions • Can be used for installing groundwater and gas monitoring wells	• More expensive than other techniques • Limited ability to observe materials • Air rotary rigs not suitable for volatiles • Can cause preferential pathways for contaminant migration if not appropriately constructed

Factors to take into account when selecting the sampling technique include the:

- sampling objectives
- target analytes
- sampling depth
- physical constraints at the site (height and access obstructions, topography)
- ground conditions (ground cover, soil type, stability, groundwater depth)
- reinstatement requirements
- costs, including laboratory analytical costs
- health, safety and environmental implications associated with the sampling techniques
- specific limitations of the available sample collection techniques
- potential for sample contamination by sampling equipment and consumables.

Surface and shallow sub-surface grab sampling

Soil samples can be collected using an appropriate hand trowel, push tube, plastic scoop, shovel or freshly gloved hand. A push tube, or soil corer, is a stainless-steel tube pushed into the ground by hand, foot or drop-hammer to a set depth (typically 75 mm to 100 mm) to collect soil. All hand tools must be appropriately decontaminated between samples and sample locations. The main disadvantage of near-surface grab sampling is the depth restriction.

Hand auger sampling

A hand auger is a sampling device manually or mechanically driven into the soil, typically between 40 mm and 150 mm in diameter. Sampling depths up to 2–3 m can be achieved, depending on soil type, and greater depths are sometimes possible. Soil samples can be collected from the auger head or from an auger fitted with a split-spoon-type sampler. Augers can be used to sample locations with restricted access, and to install a monitoring well in the hole excavated.

The disadvantages of auger sampling are the limited sample size, depth restrictions and the potential for cross-contamination with depth if the sample is collected off the auger flight. Some loss of volatiles can occur from samples collected from the auger head or flight. Hand augering below the water table is generally not possible in soft or unconsolidated soil.

Test pit sampling

Test pits or trenches are typically excavated using a hydraulic excavator but also may be hand dug. The test pit size will depend on the bucket size, the reach of the excavator and the stability of the pit and strata. Soil samples should be collected from the centre of the excavator bucket, to avoid the danger of entering the pit, and care taken to avoid cross-contamination.

Test pits enable visual inspection of the shallow strata and can be extended into trenches to observe the extent of the strata or visible contamination. A disadvantage of test pits is the disturbance caused to the ground. For this reason, they may not be suitable for collecting undisturbed soil samples and are generally unsuitable for installing wells for groundwater or soil gas monitoring.

When excavating test pits, the excavated material should be laid out at the side of the pit in the order of excavation. When reinstating test pits, the spoil excavated should, as far as

practicable, be replaced in the same order as it was excavated (material from the base of the pit is returned to the base, and so on).

Borehole sampling

Boreholes can be made using a range of different drilling and push-tube-type techniques. These techniques are suitable for soil sampling and installing soil gas and groundwater monitoring wells. Boreholes are typically 100 mm to 200 mm in diameter and can extend many metres in depth. The type of drilling technique selected will depend on the depth of the bore, the geology and the type of sampling proposed.

Drilling techniques such as hollow-stem auger and coring, when fitted with a push split-spoon or push-tube-type sampler, can generate relatively undisturbed, near-continuous soil cores. Dedicated direct push techniques, such as direct-push and sonic drilling, can also be used to obtain near-continuous soil cores. Air-flush percussion drilling will not provide undisturbed samples. Rotary coring techniques may provide continuous cores, depending on geology and the flushing employed.

The advantages of boreholes include the ability to collect relatively undisturbed samples at depth, and the option to install groundwater or soil-gas monitoring wells. Disadvantages of using soil bores for sampling include the limited amount of soil that can be examined and the possibility of introducing preferential pathways for the migration of contaminants. Appropriate drilling and borehole construction techniques must be used to mitigate migration of contaminants.

Some drilling techniques require the use of a flushing agent, such as air, water or mud during drilling, and the use of lubricants, which may impair the integrity of the sample. Where possible, drilling should be undertaken with minimal water added, and non-hydrocarbon-based lubricants should be used if soil core samples are to be tested for organic compounds.

Understanding the influence that drilling techniques may have on sample integrity is necessary to enable selection of an appropriate drilling technique for a particular situation.

4.2.9 Sampling techniques for other media

The media, the contaminant and the environment will dictate the appropriate sampling techniques. A SQEP should seek guidance on available and appropriate techniques from regulatory agencies, industry bodies, and certification bodies and standards organisations. Before using a novel sampling technique, it is recommended you consult the relevant regulatory agencies to confirm the technique is acceptable.

4.3 Quality assurance and quality control

Quality assurance (QA) and quality control (QC) are essential elements of the systematic planning process for site investigation and should be documented in the sampling and analysis plan. The terms ‘quality assurance’ and ‘quality control’ are often used interchangeably. Quality assurance relates to the planned activities implemented so that quality requirements will be met, whereas quality control relates to the observation techniques and activities used to demonstrate the quality requirements have been met.

Soil samples collected during an investigation should be as representative as possible of the area to be characterised and the location to be sampled. Common sources of errors and uncertainty in site investigations include:

- poor sampling design
- inaccurate recording of observations and other information

- inappropriate sampling
- improper handling and storage of samples
- laboratory errors
- data interpretation errors and inappropriate interpretation methodology.

This section describes QA/QC considerations and procedures specific to information and sample collection.

4.3.1 Field quality assurance

Quality assurance involves all the planned and systematic actions, procedures, checks and decisions undertaken to ensure the representativeness and integrity of samples collected for analysis, and the accuracy and reliability of the analytical results. The field QA measures that must be included in the sampling and analysis plan and implemented during the DSI are:

- ensuring the qualifications, training and experience of staff carrying out the work, particularly the field staff, are appropriate for the work requirements
- ensuring the qualifications, accreditation, equipment and experience of sub-contractors are appropriate for the work requirements
- selecting appropriate sampling and preservation methods, sample containers and sample storage to minimise sample contamination and analyte losses
- selecting appropriate decontamination procedures for cleaning tools and equipment before sampling and between samples
- accurately recording the work carried out, including any observations and conditions at the time of sampling that may help interpret the data, and any alterations made to the sampling plan
- accurately labelling each sample container with a unique sample identifier, the date sampled and the time sampled. This information should be transcribed onto field notes, which will also include a description of the soil type
- accurately recording the sample's location and other site locations in field notes and on a site plan
- accurately completing chain of custody paperwork before dispatching the samples to the laboratory, including accurately specifying the analytical requirements
- ensuring delivery to the laboratory in good condition (appropriately preserved and at the appropriate temperature, where relevant) and within the timeframes required for the particular analytes
- ensuring verification is received back from the laboratory that the samples have been received and the requirements understood.

4.3.2 Field quality control

Quality control covers those parts of an investigation that involve monitoring and measuring the effectiveness of the QA procedures. Adequate QA is achieved when QC results demonstrate that agreed quality objectives – such as freedom from sample cross-contamination, sampling method accuracy and precision – can be reliably achieved. In the field, this involves practices such as checking sampling equipment cleanliness by collecting equipment rinsate blanks for analysis and collecting and analysing duplicate samples.

The extent of QC will depend on the sampling objectives and should be documented in the sampling and analysis plan. The following QC procedures can help to assess the investigation quality objectives.

Duplicate samples

A duplicate sample, also referred to as a field duplicate, involves collecting two separate (duplicate) samples from a single sample location, storing these in separate containers, and submitting them for analysis to the laboratory as two separate samples. Samples should be given separate sample numbers so the laboratory does not know the sample is a duplicate.

A duplicate sample measures the contaminant concentration difference between the two samples because of soil heterogeneity, the variability or error within the laboratory analysis and the variability or error related to field sampling technique.

Rinsate blank

A rinsate blank (also referred to as an equipment blank) is collected after equipment decontamination and is obtained by running deionised water through the sampling equipment and collecting the water. The rinsate blank is tested for any residual contamination, which provides an indication of the potential for cross-contamination between samples as a result of poor decontamination procedures.

Rinsate blanks for soil sampling are collected from equipment that comes in direct contact with the samples (for example, auger head, trowel), and where cross-contamination of samples is likely to affect the validity of the sampling and assessment process (for example, moving from an obviously contaminated area to a less contaminated area).

4.4 Preparing for fieldwork

All work should be carried out in accordance with prevailing workplace health and safety regulatory requirements. Before beginning fieldwork a SQEP should ensure:

- a health, safety, quality and environment plan is completed
- applicable regulatory controls on the proposed works are clear
- the necessary permits from regulatory agencies for undertaking the work are obtained
- conditions of any consent for work (eg, land-use consents for borehole installation) are clear and understood
- permission has been obtained to access the site and all sampling locations, including off-site sample locations
- underground and above-ground service clearance ('dial before you dig') has been completed
- suitably trained and qualified site personnel will be available at the appropriate times
- all documentation is available, such as copies of consent conditions, sample labels, field sheets, chain of custody forms, and courier labels
- sample delivery arrangements have been confirmed
- the sampling and analysis plan has been reviewed
- appropriate sampling equipment and consumables are available, including sample containers from the analytical laboratory, storage containers, chilly bins, cooling material, and transport for the samples are arranged
- material, such as tape or labels, to secure samples for chain of custody
- samples can be kept at the required temperature during sampling and storage, and sufficient chilling material or ice is available
- field instruments are charged and calibrated, as necessary
- decontaminated equipment or consumables are available for each sample
- arrangements are in place for sampling equipment to be decontaminated between samples, if uncontaminated equipment or materials are not available for each sample
- arrangements are made for the suitable disposal of wastes such as excess soil, wash water and any contaminated materials (such as gloves, PPE, tubing and containers)
- all required contractors are suitable and available
- weather and atmospheric conditions are monitored, and fieldwork will be re-scheduled if weather conditions makes work unsafe or impractical.

5 Undertaking detailed site investigations

A detailed site investigation (DSI) is a contaminated land investigation that is based on a conceptual site model (CSM) or preliminary information to fulfil specified investigation objectives. It provides the investigator with reliable data about the nature, distribution and concentration of the contamination that is sufficient to complete a robust risk assessment.

A DSI can be a targeted investigation with a narrow focus for a specific purpose, or a broader investigation that quantifies and describes the full range of contamination at a site.

A DSI completed for the purposes of the NESCS means an investigation that—

- is undertaken by a suitably qualified and experienced practitioner (SQEP)
- is undertaken in accordance with the current edition of CLMG 5
- is reported on in accordance with the current edition of CLMG 1
- results in a report that is certified by the practitioner.

5.1 Geophysical surveys

Geophysical surveys are non-intrusive techniques used to identify irregularities or hidden features in the subsurface (for example, the edge of a landfill, buried objects and the location of foundations). Such surveys typically involve taking measurements of, and detecting a contrast in, subsurface properties such as density, conductivity and electrical resistivity. They can provide an efficient way to obtain wide-scale information.

Depending on the investigation objectives, non-intrusive techniques may help build the CSM and have the potential to make the DSI more focused and cost effective.

The work should be performed and the results interpreted by qualified specialists. The choice of geophysical technique will depend on the site-specific conditions, such as the purpose of the survey, ground conditions and depth to the water table. It should also take into account any potential sources of interference and ground conditions, and whether the proposed method will be able to achieve the investigation objectives.

5.2 Sample collection and handling

Field techniques used to collect samples should result in high-quality samples that represent the site being investigated. The field technique must be able to provide the laboratory with a sample that is suitable for analysis using the selected analytical method, and not contaminated by the sampler, the equipment, or the consumables used in the field.

For a given analyte, the applicable guideline value influences the selection of laboratory analytical methods, which in turn influences the field techniques that can be used to collect a sample. Field techniques should be matched to the relevant laboratory method detection limit (MDL).

Laboratory analytical techniques have an influence over the following aspects of the field techniques:

- sensitivity to contamination of samples by equipment and consumables
- decontamination of person and equipment between sample locations

- sample container requirements (size, material, preparation, preservatives)
- whether a duplicate is required as a backup (for example, VOC vials)
- exclusion of air from sample containers to prevent oxidation or volatilisation of analytes
- storage and transport requirements
- refrigeration of samples
- sample holding times.

Samples may be contaminated by handling the sample, and by the composition of equipment, containers and consumables used to collect the sample. Field techniques should be selected to ensure sample contamination is minimised.

5.2.1 Soil logging

When investigating a site, soil samples are often collected at various depths and throughout different soil profiles.

Soil logging refers to the recording of soil structure, colour, grain size, and all other features of a soil profile. This information gives important clues about the behaviour of contaminants in the soil and groundwater.

The soil profile must be logged using a consistent method and format for soil descriptions. A useful soil logging guide is the *Field description of soil and rock: Guideline for the field classification and description of soil and rock for engineering purposes* (NZ Geotechnical Society Inc, 2005).

The soil description should include the general appearance, colour, soil type, strength, moisture content and particle shape. For environmental investigations, evidence of contamination (for example, visual signs, obvious odours and non-natural colouration) and specific information on the nature of any fill materials should also be recorded.

5.2.2 Sample locations and labelling

Samples should be clearly and uniquely labelled, and records kept on the label and in a notebook or on a field sheet for each sample. Sampling records should be made with a waterproof pen, or other indelible writing instrument, and dated. Pre-printed labels can also be used, provided they are durable and will not detach from the container.

Information recorded should include:

- a project or site reference
- a unique[7] sample reference number
- the sampling location, date, time, depth and/or location in strata
- the sampler's name or identifier
- notable characteristics of the sample such as colour, odour, clarity, viscosity, texture, etc.
- relevant site observations, including weather conditions and tide.

Weather conditions before and at the time of sampling are important, because:

- rainfall may flush contaminants from or into drains or waterways

[7] Unique sample numbers are to ensure samples can be identified beyond reasonable doubt, and to maintain the chain of custody. The numbering system to be used should be clear before the project starts.

- barometric pressure affects vapour and landfill gas concentrations and emissions
- temperature may affect pH and dissolved oxygen measurements.

The site's identity, the exact sampling location, the depth of soil at which the sample was collected and any observations or measurements that could influence the results or the interpretation of data should be recorded, for example, in a field notebook or field-sheets. The sample locations can be documented by photographs with a reference location marked on a board.

5.2.3 Sample handling

The analytical laboratory should supply sample containers. These must be clean and of an appropriate size and material for the analyses to be undertaken. They should be handled in a way that ensures the integrity of the sample is not compromised during storage. Samples should be kept in sealed containers protected from heat and light sources.

Recommended holding times suggest how long samples can be held before analysis. These will vary depending on the contaminants to be analysed. If in doubt, ask the analytical laboratory about appropriate sample containers, sample preservation (including chilling), handling requirements or holding times for the contaminants to be analysed.

In some instances, the accuracy of analysis required will determine the sample collection and handling requirements. For very low detection limits, such as required for some organic compounds (eg, dioxins, PFAS), samples may need to be handled very carefully to avoid contaminating them. In such samples, minute quantities of sample contamination could exceed the guideline value of the contaminant being sampled for, producing false positive results.

Sampling for volatiles

Soil samples collected for volatile contaminants must be collected quickly, with as little disturbance as possible. Identify the limitations of the sampling method at the reporting stage. Recommended equipment for sampling soils for volatiles includes:

- hollow-stem augers
- split-spoon samplers
- ring samplers
- push tubes.

In all cases, the sample should be collected in a way that minimises loss of volatile compounds. This usually involves completely filling a glass container so that no headspace remains. (This will be sub-sampled in the laboratory using a corer). Other methods include:

- a zero headspace sampler that is sealed and transported to the laboratory where it can be interfaced directly to the analytical instrumentation
- solvent extraction sampling with a coring device and then transferred to a pre-weighed vial containing a solvent.

Sample preservation can include samples being collected and sealed then – where a sample could degrade in transit (for example, hydrocarbons, organic pesticides and some inorganic compounds) – being placed in an opaque, chilled container such as a chilly-bin, as soon as practicable and kept within the temperature range recommended by the laboratory. Samples should not be frozen because glass sample jars can crack or break.

Laboratory recommendations for preserving samples for the analytes being investigated should be followed.

Where field screening for volatiles is required (eg, head-space testing), a separate sample must be collected. All samples for volatiles should be delivered to the laboratory as soon as practicable after sampling. If delays are likely, get advice from the laboratory.

5.2.4 Trace and ultra-trace sampling

Trace and ultra-trace sampling and analysis need the utmost care and skill when collecting, storing and analysing the sample. Ensuring the sample is not contaminated by equipment, and keeping the sample stable between collection and analysis, is critically important to the accuracy of an analysis. For example, the potential presence of PFAS in common consumer products and in equipment often used to collect groundwater samples, means collecting PFAS samples requires special handling and care.

Methods for trace and ultra-trace sampling and analysis should be documented in detail and followed exactly.

5.2.5 Chain of custody procedures

Chain of custody refers to the processes and procedures that must be followed to guarantee the identification and integrity of samples, from collection through reporting of test results.

Chain of custody is usually required to ensure the evidential integrity of all samples and data will withstand scrutiny in a law court. It should include sample bottle preparation, sample collection, container possession, storage (including storage conditions such as temperature), handling and handover of samples and data from the time of collection through to reporting. This can be ensured by using documented chain-of-custody procedures.

Chain-of-custody documentation covers sample collection, handling, possession and transport procedures from the point of collection at the site to the laboratory. It can include instructions for the laboratory analysis. The chain of custody can include the transfer of samples within the investigation team and transport by courier.

All parties in the chain (sampler, dispatcher and laboratory) should complete the chain-of-custody documentation so it gains the status of a valid record of sample transfer to the laboratory.

The chain-of-custody form details the links in the transfer of samples from collection to arrival, and must contain at least the following information:

- time and date of sample collection
- name of person transferring the samples
- time and date of sample receipt at the laboratory
- name of person receiving the samples
- name and contact details of the sampling organisation representative
- urgency of analysis (routine or priority turnaround)
- consignment identifier or job reference.

5.3 Decontamination

Decontamination procedures include the process of washing, rinsing and removing material from exposed surfaces of equipment and clothing that can, or have, come into contact with the sample. Any decontamination must be undertaken in a way that avoids contaminating areas to be sampled, or the spread of contamination around or off the site. Rinsate blanks (refer to section 4.3.2) should be collected to assess the effectiveness of the decontamination process. The level of decontamination adopted should be appropriate to the sampling objectives, while still being practical.

It may not be necessary to do the same level of decontamination in every case. For example, when sampling for PFAS, a source of water that has been confirmed as free of PFAS is a requirement for decontaminating equipment, whilst deionised water will suffice for decontaminating equipment when sampling for metals.

Decontamination procedures may include the following:

- personnel who are handling soil samples replacing their gloves between each sample
- scraping or brushing off any soil adhering to the sampling equipment, clothing or boots
- washing equipment in suitable, laboratory-grade detergent , followed by rinsing with tap water, and then rinsing in high-purity, analytical-grade deionised water
- storing tools in a way that prevents recontamination/cross-contamination (eg, wrap tools in clean aluminium foil or plastic bags).

For sampling gross organic contamination, or when seeking trace organic concentrations, remove visible contamination with a brush and detergent if necessary. Then:

1. rinse with water
2. rinse with acetone
3. in some cases, do a final rinse with hexane (acetone and hexane solvents should not be used if sampling for volatile organics).

For trace metal analysis, implement a triple rinsing procedure between samples after removing gross contamination with an appropriate cleaning agent or detergent (and a brush if necessary), then:

1. first rinse with tap water
2. second rinse with clean tap water
3. final rinse with distilled/deionised water.

For ultra-trace contaminants (such as dioxins, dioxin-like PCBs, furans, PFAS and certain pesticides) – single use[8] equipment may be required to achieve the level of decontaminating necessary, and where decontaminating reusable equipment in the field may not be possible.

Large sampling equipment, such as the excavator bucket and drill casings that come into contact with the soil, should be cleaned between sampling locations where there is a risk of transferring contamination around the site, as follows:

- remove any loose soil by brushing, scraping or wiping

[8] 'Single use' includes reusable equipment that has been appropriately decontaminated before sampling, and that will be used once in the field before being decontaminated again. It does not necessarily require the use of disposable single-use equipment, although in some cases, that may be appropriate.

- steam clean or wash with a high-pressure washer
- rinse with potable water.

5.4 Field-screening techniques

A variety of field-screening techniques are available that can provide immediate (real-time) information about the concentration and distribution of contaminants on contaminated sites. These tests, by their very nature, are less rigorous and reliable than analytical tests conducted in a laboratory. However, they provide cost-effective and quicker results to guide the design of further sampling strategies for site assessment or remediation.

In some cases, field techniques can be used to sample additional locations with reasonable reliability, if the field technique is robust.

Verification of field-screening results could include collecting field-screened samples for laboratory analysis and comparing the results of the field-screening technique against the laboratory results to establish whether the statistical variability between the methods is significant. Verification of field-screening results should be undertaken in accordance with the methodology detailed in the sampling and analysis plan.

Field-screening tests include, among others:

- water monitoring instruments, for parameters such as pH, ORP, DO, EC, and temperature
- gas detector tubes
- photo-ionisation detector (PID) or flame ionisation detector (FID) and gas detector
- field-portable, X-ray fluorescence (XRF) spectrum analysers.

These techniques can be used to gain a general understanding of the field conditions and presence of possible contamination, and may help select samples for laboratory analysis. Photo-ionisation detector measurements, for example, may be useful as a field guide to indicate areas of volatile organic compounds. However, their role in providing real-time data should be augmented by laboratory chemical analysis, and any field-screening technique must be appropriately validated.

Field screening should be undertaken by competent, appropriately trained personnel. The limitations of the field-screening techniques should be specified at the reporting stage (for example, accuracy limitations because of interference between two substances being analysed and depth limitations).

Before using any field-screening equipment there should be:

- competent, appropriately trained operator/s available to use the equipment
- a determination that the instruments and techniques used are capable of detecting the identified contaminants at appropriate detection limits
- an adequate understanding of the methods used for the particular instrument and any inherent limitations that could affect the results
- appropriate calibration (and recording of the calibration data) for the field screening instruments used
- an appraisal of site conditions that may affect the results (for example, high soil moisture may result in artificially high results from the photo-ionisation detector for benzene and also affect the results of XRF analysis of soils)

- a method for validating the screening technique for the contaminants and the site-specific conditions, such as analysis of a percentage of field-screened samples by an accredited laboratory.

Further reading

Further information about doing detailed site investigations can be found in:

ASTM D6432-99. 2005. *Standard guide for the surface ground penetrating radar method.* Pennsylvania, USA: ASTM International.

ASTM D6429-99. 2006. *Standard guide for selecting surface geophysical methods.* Pennsylvania, USA: ASTM International.

ASTM D5753-05. 2010. *Standard guide for planning and conducting borehole geophysical logging.* Pennsylvania, USA: ASTM International.

Clements et al. 2009. *Characterisation of sites impacted by petroleum hydrocarbons: guideline document, CRC CARE Technical Report no 11.* Adelaide, South Australia: CRC for Contamination Assessment and Remediation of the Environment.

Ministry for the Environment, Wellington. 2019. *PFAS Investigation, response and funding guidance*.

New Jersey Department of Environmental Protection (NJDEP). 2005a. *Field sampling procedures manual.* Retrieved from https://www.state.nj.us/dep/srp/guidance/fspm/pdf/fsmp2005.pdf (Accessed November 2020).

US EPA. 2007. *Field portable X-ray fluorescence spectrometry for the determination of elemental concentrations in soil and sediment, method 620*0. Retrieved from www.epa.gov (November 2020).

Waikato Regional Council. 2015. *Guidance for analysis of soil contamination using a portable X-ray fluorescence spectrometer*. Waikato Regional Council technical report 2016/22. (Accessed November 2020)

Lemiere, Bruno. 2018. *A Review of pXRF (Field Portable X-ray Fluorescence) Applications for Applied Geochemistry*. Journal of Geochemical Exploration, j.gexplo.2018.02.006 hal-01740950

Additional information on site investigation techniques can be found on the *USEPA CLU-IN characterisation and monitoring webpage*. (Accessed November 2020).

6 Laboratory analysis

6.1 Selecting a laboratory

The effort and expense of properly planning and executing sampling may be wasted if samples are not analysed appropriately and to a high standard by the selected laboratory.

You should consider laboratory analytical requirements before sample collection. Liaising with the laboratory will confirm whether the laboratory has the ability to provide the required services.

You should select an analytical laboratory for sample analysis based on its experience and ability to carry out the selected analyses to the required standard. This suitability can be verified in a number of ways, including:

- accreditation by bodies such as IANZ[9] or NATA[10] to the NZS ISO/IEC[11] 17025 General Requirements for the Competence of Testing and Calibration Laboratories
- past experience of the type of work undertaken at the laboratory
- where possible, the laboratory uses an accredited analytical method.

Accreditation by an independent third-party auditing body such as IANZ or NATA provides formal recognition the laboratory meets the minimum standards of NZS ISO/IEC 17025. To achieve accreditation, a laboratory must demonstrate it has suitable technical expertise, facilities, instrumentation and quality management systems to carry out the testing involved.

Note that a laboratory's accreditation does not imply all test methods it uses are accredited. To achieve accreditation for an individual test method, the laboratory must demonstrate to an independent technical assessor it has:

- a documented test method
- validated the method
- suitable equipment
- staff with the training, knowledge, experience and competence to carry out the test as documented.

Not all laboratories offer analysis of non-routine media types and low levels of detection (ultra-trace). Therefore, you may need to engage more than one laboratory to analyse samples.

Certificates of accreditation for laboratories are available at: www.ianz.govt.nz/directory/ and http://www.nata.com.au/nata/orgs-and-facilities.

9 International Accreditation New Zealand – http://www.ianz.govt.nz

10 National Association of Testing Authorities, Australia – http://www.nata.com.au/nata

11 New Zealand Standard / International Organisation for Standardisation / International Electrotechnical Commission.

6.2 Planning laboratory analytical test requirements

Effective site investigations require systematic planning. This includes the selection of laboratory analytical methods. A SQEP should discuss the analytical test requirements with the laboratory before the start of sample collection. The discussion with the laboratory should cover:

- the matrices to be sampled
- the analytes, analytical methods and detection limits required to meet the investigation objectives
- the minimum sample size/volume required for analysis
- the sample collection containers
- any specific sample preservation requirements
- storage and transport conditions, including refrigeration
- the provision of trip blanks
- the required turnaround time for results (a non-routine 'priority' turnaround may need to be specially organised with the laboratory)
- compositing of samples and provision for reanalysis of individual original samples
- specific laboratory requirements or restrictions for highly contaminated samples
- dealing with non-homogeneous samples (for example, soils with particles > 2 mm)
- sample retention after testing.

Samples that contain high levels of contaminants or analytes, including saline samples, can damage sensitive analytical equipment and contaminate other samples being analysed.

It is good practice to provide the laboratory with the anticipated or likely level of contamination in a sample on the submission form when samples are submitted to the laboratory. This allows the laboratory to take precautions to protect their equipment from damage, and try to match the anticipated concentration range to an appropriate sample preparation and analytical methods, in consultation with the SQEP. This will help avoid the need for re-analysing samples using smaller sample amounts, or dilutions, which slows turnaround.

Accurate site characterisation relies on sample results that are above the method detection limit (MDL). The selected guideline value should be at least three times greater than the MDL to be able to provide results reliably at concentrations lower than the guideline value. Refer to appendix C for more information.

You should document any laboratory requirements for sample handling, transport and analysis in the sampling and analysis plan.

6.3 Sampling and analysis documentation

While the value of the information obtained from sampling depends on how well the process is conducted, it is just as important how well the process of sampling is documented. For a sample result to be reliable, its identity and integrity must be traceable from the time it is collected through to the end of the laboratory analysis process.

Knowing who collected the sample, how it was collected, where it was collected from, what method was used to analyse it, what it was analysed for, as well as any other relevant details,

is crucial to interpreting data. Sample results obtained using different analytical methods, or collected with different sampling techniques, should be treated with caution when being compared.

All samples that will be relied upon should be sent to the laboratory for analysis with appropriate documentation. This may include a sample sheet, with instructions for the laboratory field sheet, and details of the samples plus a chain-of-custody form. For each sample, there must be a record of:

- the unique identifiers (which must match those on the sample containers)
- the matrix type
- which analytes require analysis
- whether specific test methods are required (these should be discussed with the laboratory beforehand).

Other useful information to supply to the laboratory includes:

- how the laboratory results are to be reported (for example, any combination of hard copy, phone and/or electronic, pdf, csv, xml, ESDAT)
- an indication of possible concentrations of contaminants in the sample, especially if high concentrations are suspected
- known or suspected hazards associated with the samples submitted for analysis, for example, the possible presence of acutely toxic substances such as cyanide, explosives, radioactive material or biological hazards and asbestos (this is so laboratory staff can take appropriate precautions when handling and analysing these materials)
- a laboratory quote or reference number for pre-arranged work
- the name, address and contact details of another laboratory if samples are to be forwarded for further analysis and reported and/or invoiced directly to the sampling organisation.

Record keeping or archival requirements should also be adhered to, to ensure documentation is retained, as may be required by contracts, legislation or other requirements.

6.4 Sample handling

6.4.1 Receipt at the laboratory

The laboratory should give each consignment of samples a unique identification reference to ensure each sample can be individually identified. All samples must be able to be tracked through every stage of analysis in the laboratory.

Once received by the laboratory, all samples should be unpacked, checked against the chain-of-custody form and placed in appropriate storage as soon as possible. The chain-of-custody form should be completed with the date and time of receipt, laboratory identifier, name of the laboratory representative responsible for the samples, and any comments (eg, sample identifiers on the chain-of-custody form do not match those on the containers, containers are missing or broken, or the temperature of the sample container).

The completed chain-of-custody form should be returned to the contact person listed in the laboratory submission documentation, to confirm sample receipt and the condition of the samples on arrival at the laboratory.

6.4.2 Sample holding times

Analytical laboratories may routinely dispose of a sample once they have completed their analysis and verification, unless they are told to retain the sample. Samples may be held to repeat an analysis, or expand the suite of contaminants analysed as a result of the findings. Individual samples used to make up composite samples by the laboratory may also be analysed to investigate areas in more detail, based on results of composite samples.

How long a sample can be held by the laboratory depends on many factors. Sample holding times for individual or groups of analytes should be available from the analytical laboratory. These holding times are recommendations, rather than standards, and useful for reference only as times may vary depending on the particular sample matrix. Any analytical results obtained by analysing a sample after the end of the holding period for the particular sample may have questionable validity.

Once a sample has been collected, the nature of the analytes present may change as a result of:

- loss by volatilisation
- degradation by exposure to light
- degradation by exposure to oxygen or other chemicals
- degradation by living organisms
- analytes that cannot be retained (for example, microbiological samples would not be retained, while samples for most metals can be stored for long periods).

The rate of sample degradation or loss will depend on the analyte, the matrix, storage conditions, and other environmental factors. These changes can be minimised by collecting samples in appropriate containers, using preservatives (if appropriate), keeping samples chilled, cold or frozen, and doing the analysis as soon as possible. Sample preservation methods should be appropriate for that analyte, implemented and documented.

Example – Sample holding times

Samples of soil were collected and sent to a laboratory for compositing and analysis for heavy metals, with instructions to hold the samples for 30 days. The reported results for one composite sample were higher than expected. As a result, the client asked the laboratory to analyse the four original sub-samples individually. This was possible, as the laboratory had not disposed of them. One subsample contained significantly higher levels than the other three, indicating a localised area of elevated concentration, which could then be investigated in more detail without having to resample from the original locations or investigate the entire area again.

A SQEP should consider guideline sample holding times before analysis when setting the sampling objectives and take account of the:

- type of sample and analytes
- required turnaround
- location and transport
- number of samples and laboratory capacity
- possible need to re-analyse samples at a later date.

6.4.3 Specific requirements for sample preparation and analysis

There are specific requirements when testing soils for human health protection that may not be relevant for other environmental media. Human exposure to contaminants is associated with the naturally occurring fine fraction of a soil. For such samples, analytical testing should be undertaken on, and apply to, the fraction of soil particles that are naturally less than 2 mm in diameter, and larger clumps that can be gently crushed to fit through the 2 mm sieve. Therefore, larger materials (such as rock and mineral fragments, small pebbles or shingle) should not be milled. The presence of significant amounts of such material in the portion of the soil sample analysed will, in most cases, dilute sample results that would apply to the soil fraction that is naturally smaller than 2 mm.

Where crushing using a 2-mm sieve may result in loss of the contaminants of concern (for example, for total petroleum hydrocarbons and polycyclic aromatic hydrocarbons), it is appropriate to analyse samples 'as received'. When sub-sampling for 'as received' tests, larger particles (such as stones and twigs), which may be present in the sample, are excluded but small gravel may be included. The laboratory may use a small portion of the sample for the analysis. The nature of the sample will have an effect on sub-sampling uncertainty and should be taken into account when interpreting results.

Where tests are carried out on the 'as received' sample, a separate sub-sample is dried to determine the dry weight, and the analysis results are corrected mathematically to a 'dry-weight' basis. For wet samples, this correction may raise the detection limit significantly.

No adjustment should be made to analytical results to accommodate the presence of larger grain sizes in the sample.

Laboratory results for soil samples must be reported on a dry-weight basis when used for risk assessment purposes because soil contaminant standards are calculated on a dry-weight basis.

For metals and metalloids, preparing samples for chemical analysis should be the equivalent of 'total recoverable' (for example, consistent with USEPA Method 200.2; USEPA, 1994). It is also permitted to use more aggressive digestion techniques or X-ray fluorescence analysis techniques that give 'total' concentrations. However, the results from such techniques will be a more conservative comparison than results from total recoverable techniques. Also, note that X-ray fluorescence results not corrected for sample moisture content may result in un-conservative (low) results.

Some analytical methods rely on less aggressive extraction techniques than USEPA Method 200.2, such as TCLP or SPLP methods. Results from such techniques should never be compared against relevant guidelines, or compared with results of USEPA Method 200.2 analyses.

Many methods are available to extract analytes from the sample matrix and the subsequent detection of analytes when analysing environmental samples. It is recommended that a SQEP should discuss with the laboratory the available analytical techniques to be used when developing the sampling and analysis plan, to ensure the selected technique is appropriate for both the target analytes and matrix.

6.4.4 Sample retention after analysis

Samples can be retained at the laboratory after the tests have been carried out in case further tests are requested or there are queries about the results. The length of time samples may be held without compromising quality will depend on:

- the analyte/s being investigated
- the sample medium

- storage conditions
- sample holding times
- space considerations.

A SQEP should discuss any special requirements with the laboratory in advance.

The nature of the analytes and possible loss or degradation should be considered when requesting further analyses from retained samples.

6.5 Laboratory quality assurance and quality control

Any laboratory analysing samples of contaminated media must be able to show it has in-house quality assurance procedures and quality control checks (QA/QC) to ensure accurate testing and reporting of analyses. IANZ, or equivalent overseas accreditation, is a good indication a laboratory has appropriate QA/QC in place. Confidence in the analytical results is essential to interpreting the analytical data.

Laboratory accreditation demonstrates that, at a minimum, every batch of analyses includes:

- calibrating standards
- a laboratory 'blank'
- replicate samples at an appropriate frequency (usually 1:10 or 1:20) to test both sample homogeneity and laboratory precision.[12]

Other QA/QC methods may include:

- 'spiked' samples to check adequate extraction ('recovery') of the analyte from the sample matrix. These are difficult to prepare in such a way that the spike is in the same form as in the native soil because an analyte added to a soil sample will be absorbed on the outside of the soil particles, but in the soil itself the analyte may occur throughout the particles
- laboratory QC samples. For soils, these are usually well-homogenised samples, which the laboratory has analysed many times to determine mean and standard deviation for the analytes.

The laboratory should provide the QA/QC information with the analytical results, usually contained in the laboratory report.

6.6 Laboratory reporting

The laboratory report should include the following information:

- client company and contact name
- batch identifier or job reference
- date received
- date reported
- the name and signature of an accredited signatory.

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12 A replicate sample, also known as a *lab replicate,* is a sample that is split into subsamples at the lab. Each subsample is then analysed and the results compared. They are used to test the precision of the laboratory measurements.

For each sample there should be:

- the sample identity, usually as recorded by the sampler on the container
- the result for each analyte including a specific definition (eg, 'total copper' not just 'copper').

For solid samples, the moisture content is important. Appropriate units of measurement should be specific (eg, 'mg/kg dry weight' or 'mg/kg as received', not just 'mg/kg'). Specific comments should also be included if the sample received is not in the normal form of 'field moist' for soils (eg, 'already dried and sieved', 'freeze-dried').

Dry-matter percentage should be requested separately if results are reported in mg/kg as received, and a comparison to guideline values undertaken, as guideline values are derived in mg/kg dry-weight terms.

For each analyte, or group of like analytes, there should be:

- a description of the test method used including any extraction/digestion procedure and detection, and/or quantitation method, and the source reference if appropriate
- the accreditation status of the method
- the detection limit for each analyte
- QA/QC data.

6.7 Uncertainty of measurement

For every numerical result reported by a laboratory, there is an associated uncertainty of measurement (UoM). This may vary from a few per cent for simple one- or two-step procedures (such as a weighing or titration) to 100 per cent (or more) for a complex, organic analytical analysis involving extraction, concentration, clean-up, derivatisation and chromatographic determination at close to detection limits. Precision (ie, repeatability) is only one component of the overall uncertainty in a measurement.

Knowledge of the UoM helps with interpreting the results against the sampling objectives, particularly when analytical results lie close to guideline values. ISO/IEC 17025 accredited laboratories must be able to provide UoM information with analytical results. However, UoM information may need to be specifically requested from the laboratory, as not all laboratories provide this by default. UoM information should be fit for purpose, and reflect the uncertainty associated with the combination of test method and sample matrix analysed.

7 Basics of data interpretation

7.1 Data quality review

The quality of the data should be reviewed before data interpretation is carried out. At a minimum, this should include the following:

- checking the completeness of the data against the sampling objectives
- checking the representativeness of the samples collected against observations made on site
- checking the accuracy of the reported data (all samples should be correctly identified by location, depth, type, units of measurement and so on)
- identifying any obviously anomalous results that are inconsistent with the conceptual site model (CSM) (eg, an unexpected hotspot, field observation or a possible labelling or laboratory error)
- identifying invalid data (eg, where the field or laboratory record indicates sample integrity may have been compromised).

The investigator should understand any discrepancies, and the reasons for these, before interpreting the data. In the case of anomalous results, the laboratory should be queried and, as necessary, samples reanalysed.

7.2 Data assessment

The basis of the sampling design (whether targeted or statistical sampling patterns are used) will influence how the data is assessed. Only systematic or unbiased sampling data should be subject to statistical analysis, since it is only from this type of data that inferences can be drawn about conditions of the sampled body of soil as a whole. This does not mean targeted sampling has no value, or that data obtained from targeted sampling cannot be used to develop a broad understanding of the nature or spatial distribution of the contamination on a site. Similarly, small deviations from an otherwise genuinely unbiased sampling plan (for example, to avoid physical obstructions or site services) do not necessarily preclude the use of statistical techniques.

Data obtained using a combination of targeted and systematic sampling approaches is collated and considered separately. The formal use of statistical techniques should be confined to unbiased sample data only.

In preparing for a data assessment, a SQEP should carry out a preliminary screening of the data including:

- determining how numbers below or close to the detection level will be interpreted
- reviewing the data for potential outliers that should be considered (and possibly managed in the site context) separately
- determining the data distribution, where statistical assessment is to be carried out to determine the most appropriate statistical assessment method.

Further details of these steps are provided in the following sections.

7.2.1 Interpreting numbers close to or below the detection limits

Results of samples that are reported as being below the method detection limits do not imply the contaminant does not exist in the soil sample, only that the analytical method was not sufficiently sensitive to detect that level of contaminant. The contaminant may be present at a concentration below the reported detection limit, or it may not be present in the sample at all (the concentration in the sample is zero).

The method detection limit, typically reported as a '<' (less than) concentration, as described in appendix C, represents the concentration below which the laboratory cannot reliably state the analyte exists, using the adopted analytical method.

Analytical methods should be chosen so detection limits are well below the adopted guideline value (ideally at least 10 times lower). This will minimise the potential for uncertainty when comparing contaminant concentrations close to method detection limits with guideline values.

When interpreting numbers below detection limits, do not treat the numbers as 'missing', and do not omit non-detected results from the results.

Data below the detection limit can cause problems with statistical analysis. Any data set with more than 25 per cent of the results below the detection limit should not have any form of confidence intervals reported. In other cases, sensitivity testing of the analysis should be undertaken, using the detection limit, half the detection limit or zero as a replacement value, to see if the results differ markedly. If they do, more sophisticated statistical methods are required. If they do not differ markedly, then the small proportion of the data set below the detection limit has little influence on the statistical analysis, and the results can be used.

Numbers below detection limits can also cause problems when calculating sums or weighted sums for contaminants such as polycyclic aromatic hydrocarbons, which are assessed by benzo(a)pyrene toxic equivalency. In such cases, a similar sensitivity test, using values at the detection limit and half the detection limit for each analyte is appropriate.

7.2.2 Identifying outliers

Site investigation data can comprise contaminant concentrations spanning several orders of magnitude. This, among other things, reflects heterogeneity in soil conditions – including the spatial variability of contaminant concentrations at both large and small scales – differing sources of contamination, and uncertainty associated with laboratory analysis. Extreme values can also result from poor or inappropriate sampling techniques, lack of proper chain of custody, poor laboratory analysis processes, measurement system problems, transcription or data entry errors, and the use of incorrect units in reporting and recording analytical results.

In general, outliers should be only excluded from a data set where they are:

obvious and demonstrable results of an error that can be identified and explained – whenever possible the correct data should be identified and the data set amended, otherwise the erroneous value should be excluded and a written justification provided

clearly part of a different sample population within the overall data set, and this can be justified by the CSM. Splitting the data set into different populations is relevant where sub-areas (investigation areas) can be remediated or managed independently, in which case it is valid to remove sample results from specific sub-sets of data.

In all other cases, outlying data should be assumed to be genuine and to reflect the full range of results.

The failure to remove true outliers from a data set or, conversely, the removal of values that are not in fact outliers, has consequences for the conclusions arising from the site investigation.

To assess whether an apparent outlier represents genuine soil concentrations or is the result of an error, assessors should:

- re-examine field records (eg, test pit and borehole logs) to establish whether observations made at the time the samples were collected can explain the results obtained
- check for the presence of an error in methodology (eg, any recording error, laboratory error, abnormal conditions during sampling, poor sampling technique)
- check calculations
- determine whether or not the suspect data point is consistent with the precision of the method (if this is known)
- retest the suspect sample by repeating the analysis, or collect another sample for testing, to enlarge the overall data set. Note, however, that failure to confirm an original test result may not necessarily mean the original result was wrong, especially where contaminant concentrations are highly variable.

Various statistical outlier tests are available to identify anomalous data in a data set, each with their own advantages and disadvantages (refer to section 7.3). Outliers can also be identified by cross-comparing the concentrations of several similar analytes in the same area, referred to as multivariate outliers. Outlier tests should be appropriate to the distribution of the data set.

7.2.3 Data distribution

Statistical methods are typically based on assumptions about the distribution of the data being analysed, such as the one-sample t-test, which assumes the data being assessed is approximately normally distributed. In many cases, the contaminant concentrations measured during site investigations are not normally distributed.

Before applying a statistical test, it is important to know what these assumptions are and if they are reasonable for the data set under scrutiny. There are two main ways of testing whether the data follows a particular distribution:

1. using graphical presentations such as frequency histograms and probability plots
2. using statistical tests, such as the Shapiro-Wilk normality test.

More information about using graphical methods can be found in *Data quality assessment: statistical methods for practitioners EPA QA/G-9S*; USEPA, 2006a. However, many other formal statistical tests can be used to assess whether the data is normally distributed or follows another type of distribution. Many of these tests are difficult to do by hand, and it is advisable to use a statistical programme (eg, USEPA's ProUCL).

7.3 Using statistical methods for data assessment

7.3.1 Statistical analysis

Statistical analysis can be used in a number of different ways to analyse data from contaminated site investigations, including to:

- summarise complex information (eg, minimum, maximum, mean, variance, interquartile range (IQR), and 95 per cent upper confidence limits) – these types of statistical analysis are sometimes referred to as descriptive statistics
- calculate the desired sample size for a certain confidence limit
- compare the results with an appropriate guideline value or remediation target
- determine the representativeness of sampling that has already been undertaken.

Statistical analyses are useful for contaminated site assessments because they can provide an unbiased estimate of the uncertainties associated with sample collection and analysis. Knowledge of the limitations of the data can help improve the reliability of the decisions but may also reduce the cost of investigations and site development.

Statistical reports can be generated for data from site investigations that have been appropriately designed (refer to **section 4**). For valid statistical analyses (for example, calculation of the 95 per cent UCL) to be performed on a data set, the following criteria must apply.

1. A sufficient number of data points must be present to allow the analysis to be performed with accuracy (refer also to section 7.3.3). The number of data points will vary depending on the statistical test to be performed.
2. Statistics that rely on the assumption of a normal distribution should be performed only on data that is demonstrated to be normal (however, as discussed in section 7.2.3 data from environmental investigations are often not normally distributed). If statistical tests show the data are not normally distributed, then the data may be able to be transformed using an appropriate transformation (eg, taking logarithms) or non-parametric methods may be able to be used.
3. The data should be from the same statistical population (eg, no inclusion of results representative of 'hotspots' in data sets used to calculate averages or means) (refer also to section 4 and section 7.4).
4. There must not be an over-representation of sample results that are below the laboratory limit of detection (refer to section 7.2.1).

As discussed in section 7.2, only data derived from systematic or random sampling can be used for statistical analysis, although some techniques may allow data collected from a targeted sampling pattern to be used. For all other data sets, the use of data in statistical analysis should be justified, and the degree of bias that may be introduced as a result should be taken into consideration, and if used, documented in the report.

Two commonly used statistical terms ('average' and 'variability') are explained below.

Average

The average or mean of a data set is an estimate of the central tendency of the data set. It is used:

- in other statistical tests (such as determining the desirable number of samples to be collected from a site)
- for estimating exposure of a person(s) to a contaminant.

A mean concentration over an area is used to estimate exposure over that area on the assumption a person spends a similar amount of time being exposed at every point within that area.

The sample mean is an arithmetic average for simple sampling designs. For complex sampling designs, such as stratification, the sample mean is a weighted arithmetic average. The sample mean is influenced by extreme values (large or small) and the treatment of non-detects. Because of the uncertainty associated with estimating the true average concentration at a site, the 95 per cent UCL of the mean is used. The 95 per cent UCL provides reasonable confidence the true site average will not be underestimated.

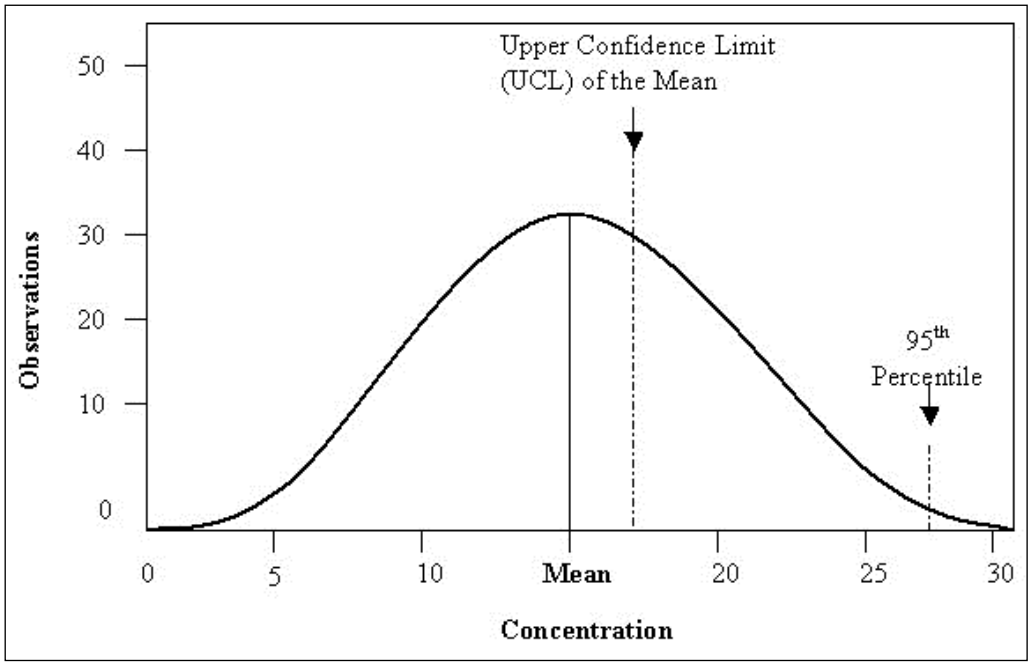
Variability

Variability is another important characteristic of data. It can be described by the range but this may not be useful if it is affected by extremes of data. The variance, or its positive square root (the standard deviation), is often used to measure variability and given in the same units as the original data.

The coefficient of variation (standard deviation divided by the mean) is more useful because it is comparable among different samples and is a dimensionless measure. The 95 per cent confidence level is often used as a measure of variability when interpreting a statistically designed site investigation. This is useful in appropriately designed, validation sampling but it assumes the data is normally distributed.

When reporting statistical summaries of site investigation data, it is advisable to ‘over-report’ the results by listing the number in the sample, the standard deviation and the 95 per cent confidence level. This gives subsequent users the flexibility to derive other confidence intervals (such as the 99 per cent confidence interval). The 95 per cent confidence level should not be confused with the 95th percentile. The 95th percentile is the value that is greater than or equal to 95 per cent of all values in a distribution. This is presented graphically in figure 5.

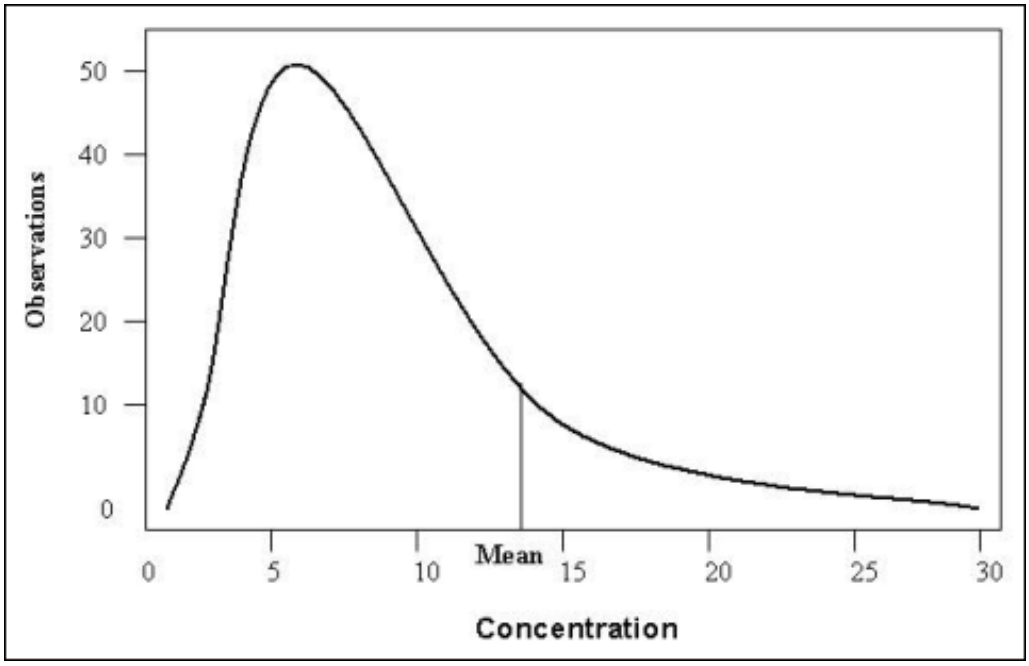
Figure 5: Illustration of normal distribution, the 95 per cent upper confidence limit of the mean and the 95th percentile



Note: As the sample size increases, the 95 per cent UCL of the mean moves closer to the true mean, while the 95th percentile of the distribution remains at the upper end of the distribution.

A more typical distribution for contaminant concentrations measured during site assessment is illustrated in figure 6, with this right-skewed form representing a few samples with notably elevated contaminant concentrations and most samples falling below the mean.

Figure 6: Right-skewed distribution



If appropriate, the following statistics should be reported and can be summarised for each area of interest (defined by the CSM and the nature of the results):

- number of samples
- sample mean
- sample median
- sample range
- sample standard deviation
- coefficient of variation
- 95 per cent upper confidence limit.

7.3.2 Uncertainty in data

Precision

Uncertainty in the analytical data can be determined by analysing duplicate and replicate samples, which provides an indication of the precision of the sampling and analysis procedures. Precision is a quantitative measure of the variability (or reproducibility) of data and is measured by the coefficient of variance or standard deviation of the mean of duplicate and replicate samples, or relative per cent difference (RPD) of the samples.

Information regarding statistical uncertainty or precision of the analytical results should be considered before starting the statistical interpretation of the investigation findings or when comparing sample analytical results to guideline values. A worked example of determining uncertainty using duplicate and replicate samples is provided in appendix D.

Accuracy

In analytical chemistry, accuracy refers to how close a measured value is to the true value. The true value is usually not known, and systematic errors in analytical measurements can compromise accuracy. Accuracy is usually assessed by one of two methods:

- sending a sample duplicate for analysis at a different laboratory (inter-laboratory comparison), or
- analysing samples of a certified reference material.

Certified reference materials are homogeneous reference samples that have been previously analysed many times, and in which the true values of contaminants can be assumed. These are available in a range of sample types, such as soils, plants and foods, but are not available for all analytes. They essentially represent inter-laboratory comparison in a bottle and are available from a number of international standards agencies, including LGC Standards (UK), the International Atomic Energy Association (IAEA, Vienna) and the National Institute of Standards and Technology (NIST, USA).

7.3.3 Minimum sample size requirements for statistical analysis

Statistical methods can calculate means and standard deviations using very small data sets (ie, three, four or five discrete data points). However, the minimum number of samples required for accurate statistical analysis depends on the test to be performed. For example,

the US EPA recommends at least 8 to 10 discrete observations[13] from each sample population before using estimation and hypothesis testing methods (such as t-tests and 95 per cent UCLs). Although the US EPA recommends at least 8 or 10 observations **at a minimum** are collected, more observations are desirable.

Software such as the US EPA's ProUCL provides warnings in the output if the number of samples is insufficient to be confident of the calculated statistics. These warnings should be heeded.

The minimum recommended number of samples collected excludes duplicate samples and blank samples that are collected to provide information on the quality of sampling, handling and analysis of the samples. See section 4.3.2.

7.4 Comparison to guideline values

Whether results should be compared with guideline values will depend on the investigation objectives. When the objective is risk assessment for NESCS purposes comparing results with guideline values is required.

A main part of data interpretation for risk assessment is considering the guideline values used and how appropriate they are for the site-specific conditions. The results should always be assessed in the context of the CSM, the basis for the derivation of any guideline value should be understood, and the appropriateness for use considered in the context of the site.

When comparing results to guideline values there are three possible outcomes:

- concentrations in the area represented by the samples are clearly below the guideline value
- concentrations in the area represented by the samples are indistinguishable from the guideline value because they are in the range around the guideline represented by ordinary sampling and analytical variability
- concentrations in the area represented by the samples are clearly above the guideline value.

Further detail on the comparison of sample analytical results to guidelines values is provided below.

7.4.1 Use of averages

The use of an average contaminant concentration is helpful for determining the suitability of a site for a particular purpose of land use. However, a SQEP must exercise caution when doing so, or hotspots on the site may be 'lost' in the process. A small number of high concentrations can be masked by a large number of lower concentrations, when averaging is applied inappropriately, potentially leading to unaddressed risks to receptors.

Averaging the concentration of contaminants across a site should only be applied where a statistically designed investigation has been undertaken. Averaging cannot be relied upon if the investigation design included too few samples to enable statistically robust analysis of the data (see section 4.2).

When used, average contaminant concentrations should be calculated in the context of exposure areas.

[13] Multiple results below the limit of detection are not discrete observations.

Averaging a data set is not always appropriate. Generally, localised areas where contaminant concentrations are more than twice the guideline value should not be included in site average calculations, as the hotspot should be addressed as an exposure area in its own right.

Failing to identify exposure areas on a site can result in incorrect data interpretation, leading to incorrect assumptions and conclusions about the risk posed by contamination at a site.

The 95 per cent upper confidence limit of the arithmetic mean (95 per cent UCL) should be used for interpreting data against a soil contaminant standard (SCS) or alternative guideline value.

7.4.2 Compliance with a contaminant standard and guidelines

Soil contamination is not considered to exceed the applicable standard for NESCS purposes if, in the context of the investigation objectives and the CSM, the following conditions are met:

- the guideline values used are appropriate for the proposed land use
- the sampling methodology used was appropriate
- the area(s) assessed has (have) been sufficiently characterised to allow a decision on the protection of known future user health
- the data set used for the calculation is representative of the area(s) assessed
- the QA and/or QC assessment indicates the data is suitable for the purposes of this investigation
- allowing for uncertainty associated with the sample design and analytical method:
  - all reported concentrations are at or below the guideline, or
  - the 95 per cent upper confidence limit of the data set is at or below the guideline value, or
  - no individual result in the data set used for the calculation is more than twice the 'applicable standard', and
  - the data set is appropriate for statistical calculations.

It is important to consider laboratory results in the context of the CSM as a whole and, in particular, the investigation objectives. Considering laboratory numbers in isolation from other evidence (spatial distribution of results and field notes), or the assumptions and limitations of the investigation, can lead to a conclusion that a site is excessively contaminated when it is not, or vice versa (refer to **section 7.5** for common mistakes in data interpretation).

The principles above are also applicable to compliance with guideline values for purposes where compliance is required other than for the NESCS.

7.5 Common mistakes made in data interpretation

Common mistakes and pitfalls to be avoided in data interpretation include:

- failing to identify information gaps in the data, such as insufficient numbers of sample results at a specific location or depth to enable a valid and relevant conclusion to be drawn
- drawing definite conclusions in the absence of supporting data
- using an inappropriately designed site investigation strategy (eg, using targeted sampling for a site validation, or collecting soil samples from the incorrect depth based on the CSM)

- applying an inappropriately designed sampling pattern, resulting in collected samples not being sufficiently representative of the exposure areas and site as a whole
- inappropriately using statistical analysis on varying matrices or varying areas
- including analytical results of unrepresentative samples (eg, samples collected using inappropriate methods, such as using air-flush drilling techniques for volatiles or without proper decontamination of equipment between samples)
- misinterpreting analytical results through the incorrect application of statistics
- considering laboratory numbers in isolation from other supporting evidence (ie, not considering the CSM or the field notes)
- assuming contaminant results below detection limits imply the contaminant does not exist in the soil
- assuming natural strata within the site are the same as background soil (which may not be true if the natural strata have been affected by contaminants).

Further reading

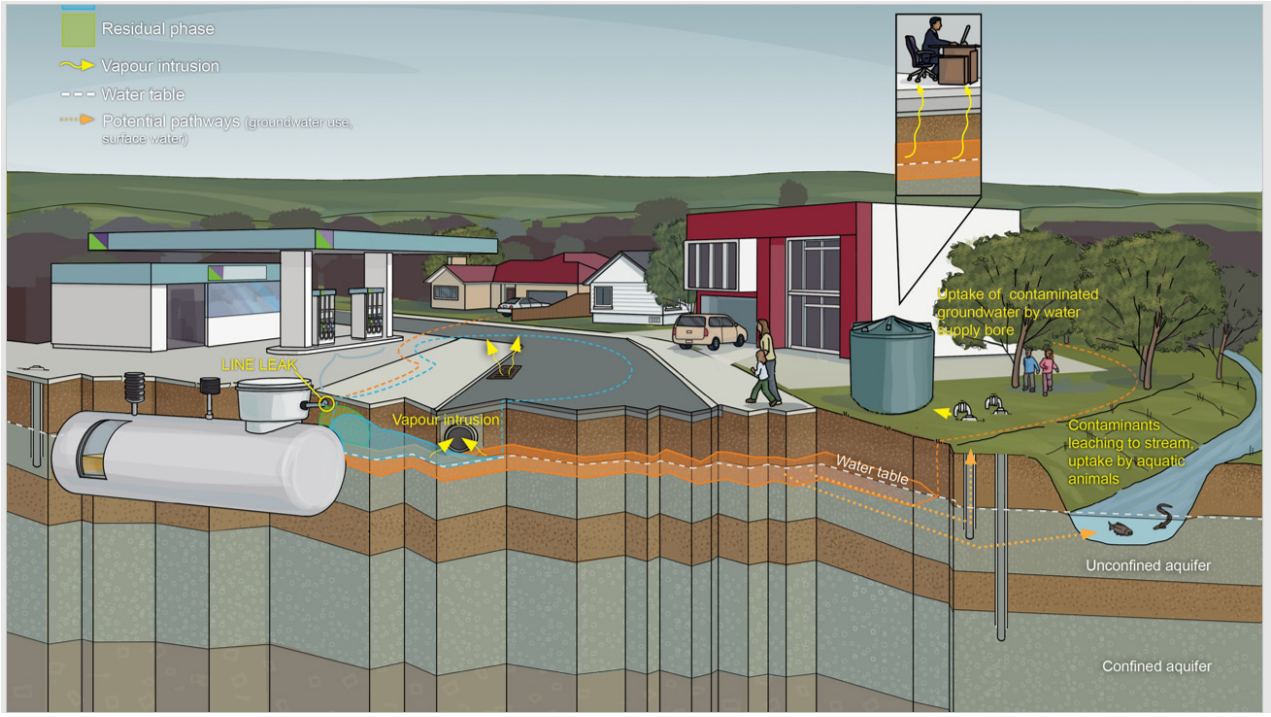
Charted Institute of Environmental Health (CIEH). 2008. *Guidance on comparing soil contamination data with a critical concentration*. London, UK: CIEH.

USEPA. ProUCL user guides. Retrieved from http://www2.epa.gov/land-research/proucl-software (Accessed November 2020).

Appendix A: conceptual site model examples

Example A1: Illustrative conceptual site model for exposure to hydrocarbon fuels at petroleum retail site

Figure A1: Example of a CSM for exposure to petroleum hydrocarbon at fuel retail sites



Example A2: Text conceptual site model for exposure to petroleum hydrocarbon at fuel retail site

A plume of free-phase and dissolved-phase hydrocarbons is present in shallow groundwater in the area of a former underground petroleum storage tank pit. The plume has been delineated and its extent is contained to the area immediately surrounding the former underground petroleum storage tank pit and within site boundaries. The hydrocarbons comprise mainly C7 to C9 range hydrocarbons and BTEX (benzene, toluene, ethylbenzene and xylene), and are characteristic of weathered petrol. Groundwater monitoring data collected over the past five years indicates both free-phase and dissolved-phase plumes appear to be relatively stable and there is a low potential for off-site migration.

Dermal contact and soil ingestion pathways from contaminated soils to on-site receptors were considered incomplete due to the depth of the hydrocarbon release, and because a continuous concrete cover exists across the entire site. If this concrete cover was altered, an updated risk assessment should be performed. Dermal contact and soil ingestion pathways for off-site receptors were considered incomplete because the hydrocarbon impact was contained within the site boundaries.

Soil vapour monitoring indicates volatilisation of hydrocarbon vapour from soil and groundwater to indoor and outdoor air does not present a risk to on-site commercial land occupants or off-site receptors.

The risk to maintenance and/or excavation workers from the volatilisation of hydrocarbon vapour from soil and groundwater, dermal contact and soil ingestion was not assessed. If excavations will be carried out near the plume, a risk assessment should be carried out before the works begin.

The following potential pathways from the contaminant source to the environment, and the status of each pathway, is summarised in the table below.

Table A1: Example summary of exposure pathways

Potential pathway	Risk pathway status	Reasoning
Dissolved-phase hydrocarbon discharge off-site	Incomplete	Conducted groundwater monitoring over the past five years indicates the hydrocarbon plume is stable and contained on-site; the nearest groundwater wells are over one kilometre distant; and the nearest surface water body is over one kilometre from site. If future groundwater monitoring indicates a change in plume stability, an updated risk assessment should be performed.
Dermal contact and soil ingestion (on-site commercial land occupants)	Incomplete	Depth of hydrocarbon impact and concrete cover over site. If concrete cover was altered, an updated risk assessment should be performed.
Dermal contact and soil ingestion (off-site receptors)	Incomplete	Hydrocarbon impact contained within site boundaries. If future groundwater monitoring indicates a change in plume stability, an updated risk assessment should be performed.
Volatilisation of hydrocarbon vapour from soil and groundwater to indoor and outdoor air (on-site commercial land occupants and off-site receptors)	Incomplete	Soil vapour monitoring indicates volatilisation of hydrocarbon vapour from soil and groundwater to indoor and outdoor air does not present a risk for on-site commercial land occupants or off-site receptors. If on-site land use changes to a more sensitive use, or changes in hydrocarbon plume status are reported, an updated risk assessment should be performed.
Dermal contact, soil ingestion and volatilisation of hydrocarbon vapour from soil and groundwater to indoor and outdoor air (maintenance and/or excavation workers)	Not assessed	If excavations in the vicinity of the plume are to be conducted, a risk assessment should be carried out before the works begin.

Example A3: Simple text conceptual site model

The following conceptual site model (CSM) was used to describe the rationale for soil sampling being undertaken on an industrial site, which was required to support an application for consent for soil disturbance. There was no change to the use of the site.

The site is an unsealed storage area, currently used for industrial purposes. No change in land use is proposed. Soil disturbance has been proposed as part of the extension to the building. The area has been used for storing hazardous substances, namely kerosene and diesel, as well as lubricating oils, for at least the past 35 years. There is no site-specific information about specific contaminants present, their concentration and their distribution across the site and into the soil. From soil and geological maps, the site geology and pedology is understood to be well consolidated, silty-clay soils over sandstone and mudstone, with low hydraulic transmissivity.

Potential sources of contaminants include diesel and kerosene. Diesel contains polycyclic aromatic hydrocarbons as well as hydrocarbons. Kerosene contains hydrocarbons. None of these contaminants is highly mobile in soil or groundwater. Off-site passive discharges of these contaminants are highly unlikely.

Management practices at the site have historically been less than ideal, and there are signs of spills as well as a strong odour at parts of the site.

Exposure pathways include direct contact with soil at the storage yard, as well as vapour inhalation and ingestion of dust (complete pathway) in the storage yard and, to a lesser extent, across the rest of the site (likely an incomplete pathway) when the soil is disturbed. There are no surface water bodies on the site (incomplete pathway), with stormwater being directed by the natural fall of the land to a drain near the main gate. Surface water is not considered to be a pathway. There is no groundwater take at the site (incomplete pathway), with the closest being 170 metres up gradient from the site according to regional council records. Groundwater is not considered to be a complete contaminant pathway.

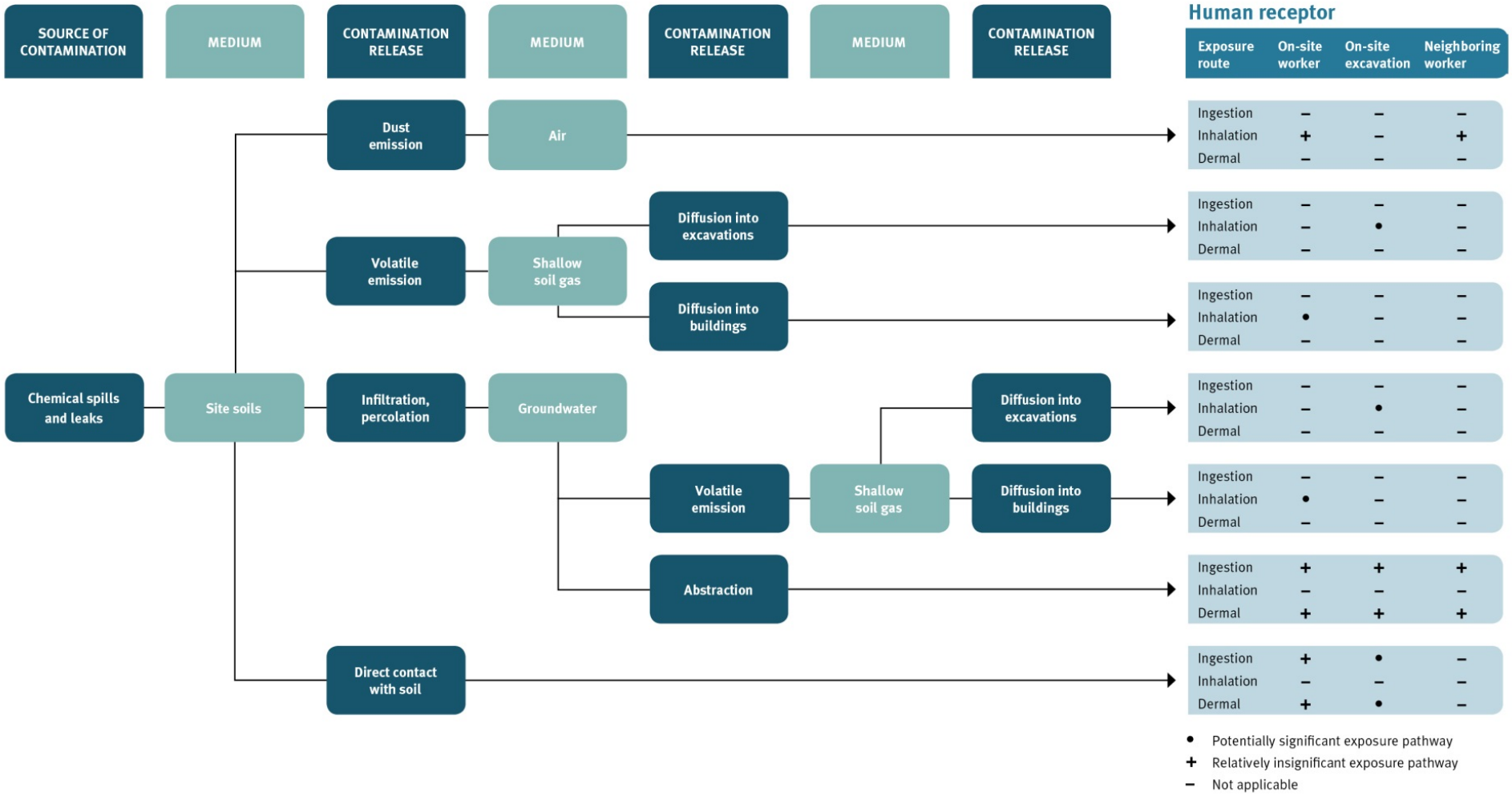
Potential receptors during the proposed earthworks will be the outdoor site workers, who may be exposed to contaminants in the soil during their day-to-day activities, and construction workers, who may be exposed to contaminants during the proposed works. Office workers are at a low risk of vapour inhalation (mainly from the possible presence of kerosene) during the proposed works as the warehouse and office building is separated from the storage area by a sealed road.

Uncertainties include the actual contaminants present in the soil, as well as their distribution and concentration. Land use before 1990 has yet to be confirmed.

A detailed site investigation will be undertaken to determine the distribution and concentrations of petroleum hydrocarbons in soil, including excavated material. This will determine disposal options for contaminated material and to quantify the risk posed by direct contact, and inhalation and ingestion of dust, as the only complete pathways on the site.

Example A4: Flow diagram conceptual site model

Figure A2: Flow diagram example of a conceptual site model



Appendix B: Hotspot detection

The method used to calculate the number of sampling points required for hotspot detection is based on detecting circular hotspots with 95 per cent confidence, using a square-grid sampling pattern. Hotspots are very seldom circular and may be a wide variety of shapes and sizes. Their likely size and shape, and the way the contaminant migrates from a point source to form the hotspot, is related to a combination of site-specific factors including:

the physico-chemical properties of the contaminant which is the point source of the hotspot

soil type, ground coverage and infrastructure

surface water drainage.

Therefore, a knowledge of the contaminant type and site conditions is important when determining the size and shape of the hotspot.

To detect hotspots of other shapes and at other confidence levels, or by using other sampling patterns, consult the following reference materials:

Gilbert R O. 1987. *Statistical methods for environmental pollution monitorin*g. New York: Van Nostrand Reinhold.

Ferguson C C. 1992. *The statistical basis for spatial sampling of contaminated land.* Ground Engineering 25(1): 34–38.

Equations used:

$$G = \frac{R}{0.59} \qquad (1)$$

$$N = \frac{A}{G^2} \qquad (2)$$

where:

G = distance between two sampling points (the grid size of the sampling pattern, in metres)

R = radius of the smallest hotspot that the sampling intends to detect, in metres

0.59 = factor derived from 95 per cent detection probability assuming circular hotspots (based on $\beta = 0.05$ and S = 1.0, see figure 10.3 of Gilbert, 1987)

N = number of sampling points needed

A = size of the sampling area, in square metres.

Method

1. Determine the radius (R) of the hotspot that needs to be detected.
2. Calculate the grid size, G, from equation 1.
3. Determine the number of sampling points required, N, from equation 2.

Example table

Determining the hotspot size must be undertaken on a site-by-site basis appropriate for the contaminant type that is the point source of the hotspot. Decision(s) must be made on the investigation findings. Table B1 provides examples of the number of samples for varying site and grid sizes. It may be appropriate to use a smaller grid size than those provided in table B1

to address areas most likely to contain smaller hotspots and/or areas where a higher degree of confidence is desirable. For example, unpaved areas or garden areas where an exposure pathway is complete. Selecting an appropriate-sized hotspot, and determining the number of samples required to locate a hotspot, requires professional knowledge and experience and must be supported by clear justification.

Table B1: Example of calculated number of samples for varying grid and site sizes based on Appendix B equation

Important: This table is not a prescriptive or exhaustive list of grid, hotspot or site sizes. Investigators must provide an explanation for the grid system they apply and justify the diameter of the hotspot they seek to identify. The minimum and maximum sampling points listed below are not provided as blanket approval of minimum or maximum sampling points required for a detailed site investigation, as site conditions may dictate that fewer or more samples are required to provide the necessary level of confidence.

Grid spacing size (m)	1.5	4.5	7.5	10	12.5	15	20	30
Circular hotspot size able to detect (m^2)	2	22	62	109	171	246	437	984
Hotspot diameter (m)	2	5	9	12	15	18	24	35
Assessment and/or exposure area (m^2)	Number of samples required to detect hotspot with 95 per cent confidence							
100	45							
250	112	13						
500	223	25	9					
750	334	38	14	8				
1,000	445	50	18	10				
2,000		99	36	20	13	9		
4,000		198	72	40	26	18	10	
5,000		247	89	50	32	23	13	
7,500		371	134	75	48	34	19	9
10,000		494	178	100	64	45	25	12
15,000			267	150	96	67	38	17
20,000			356	200	128	89	50	23
25,000			445	250	160	112	63	28
30,000			534	300	192	134	75	34
35,000				350	224	156	88	39
40,000				400	256	178	100	45
45,000				450	288	200	113	50
50,000				500	320	223	125	56

Notes:
(1) Circular hotspot used for calculation.

(2) The sampling points calculated are located in a plane and do not take into account the vertical distribution of contamination throughout the soil profile (ie, the sampling point is the lateral location at which a soil sample is collected). Where the contamination is located in different soil strata, the number of sampling points may need to be increased to reflect the different vertical distribution of contaminants.

(3) Table B1 must not be used to determine the number of samples required to characterise a site using a systematic sampling approach. It is only intended to provide guidance on the size of the hotspot that a given grid size will detect.

Appendix C: Detection limits

As sample concentrations decrease, all methods of chemical analysis ultimately reach a point below which the signal generated by the sample within the analytical instrument cannot be distinguished by the analytical instrument's detector from the background signal. Before reaching this point, measurements become increasingly unreliable.

In analytical chemistry, several terms can be used to characterise various aspects of this loss of measurement capacity. These may include the:

method detection limit (MDL): refers to the minimum concentration of a substance that can be measured and reported in the sample units, considering all of the analytical operations performed on a sample (sub-sampling, extractions, digestions, dilutions, reagents, instrument parameters, and so on). This corresponds to the 'criterion of detection' used by the American Society for Testing and Materials

instrumental detection limit (IDL): refers to the inherent (and ideal world) detection capability of the analytical instrument

limit of detection (LOD): represents the smallest concentration of an element that can be detected with reasonable certainty

limit of quantification (LOQ): the smallest concentration involving both reliable detection and achievement of predefined goals relating to accuracy and precision

practical quantitation limit (PQL): refers to the lowest level of quantitation that can be reliably achieved during routine operations.

Any one of these may be referred to as a 'detection limit' depending on context.

Of these methodologies, the MDL is considered to be the most useful, and should be used to define analytical requirements and appear on laboratory reports, because:

- it is calculated for a real sample matrix
- it reflects all steps in the test method
- it is calculated using a robust and well-documented method
- all laboratories should calculate MDL the same way, making comparisons between laboratories possible.

The LOD, LOQ, and PQL should not be used because they are not rigidly defined as their application varies between laboratories, commonly making their meaning uncertain. The IDL is not useful for 'real world' situations.

When selecting a laboratory analytical method, a SQEP should consider the guideline value that applies to a contaminant and the MDL for the particular method. As a general rule of thumb, a guideline value that is an order of magnitude greater (10 times) than the MDL allows for this certainty. Results obtained where the MDL is close to the guideline value should be treated with caution. When undertaking trace or ultra-trace sampling, a guideline value of 10 times greater than the MDL may be appropriate.

Appendix D: Example of determining uncertainty using duplicate and replicate samples

Table D1: Summary of duplicated samples

Sample	Concentration (mg/kg) Contaminant X	Contaminant Y	Contaminant Z
A	71	215	183
A2	72	206	182
Mean	71.5	210.5	182.5
B	52	180	181
B2	59	174	204
Mean	55.5	177	192.5
C	17	43	70.1
C2	20	49	73.6
Mean	18.5	46	71.85
D	42	127	84.2
D2	48	137	96.1
Mean	45	132	90.15

Table D2: Extracted precision data from replicate samples

This method assumes samples themselves were replicated at each location, so the variation measured represents the sum of analytical and sampling variation.

Sample	% of mean of replicate pair Contaminant X	Contaminant Y	Contaminant Z
A	99.30	102.14	100.27
A2	100.70	97.86	99.73
B	93.69	101.69	94.03
B2	106.31	98.31	105.97
C	91.89	93.48	97.56
C2	108.11	106.52	102.44
D	93.33	96.21	93.40
D2	106.67	103.79	106.60
Mean (%)	100	100	100
Standard deviation (%)	6.6	4.3	4.9
95% error (%)[a]	5.5	3.6	4.1
Example guideline value (mg/kg)	30	370	300
Lower than guideline value: any value below (mg/kg)[b]	28.4	356.7	287.6
Higher than guideline: any value above (mg/kg)	31.6	383.3	312.4
Indistinguishable from guideline (mg/kg)	28.4 to 31.6	357 to 383	287 to 312

a The samples taken are not the site, but they do represent it. Student's t-test 95 per cent error is the best method to establish whether or not we can say the underlying population mean for the site (that a given sample was collected from) is distinguishable from the guideline.

b Example for contaminant X: calculated as 30 mg/kg minus 5.5 per cent of 30 mg/kg.

Appendix E: Role of suitably qualified and experienced practitioners

Not all environmental practitioners are suitably qualified to do all types of contaminated land assessment and investigation work. This work requires practitioners with specific skills, experience and technical expertise. The NESCS does not specify any requirements for being a suitably qualified and experienced practitioner (SQEP), however the following describes three main ways to check if a practitioner is a SQEP:

1. **Do they hold a current** Certified Environmental Practitioner (Site Contamination Specialist) (CEnvP(SC)) **accreditation?** Following the publication of the NESCS Users' Guide, a contaminated land industry accreditation scheme has been established (similar to a 'certified engineer' or a 'master builder') and is available to New Zealand (and Australian) environmental practitioners. Practitioners who hold this accreditation should be considered to be "suitably qualified and experienced" under the NESCS, as the scheme's requirements are generally consistent with the criteria outlined in the NESCS Users' Guide.
2. **Check their experience and qualifications are aligned with the guidance in the** NESCS Users' Guide**.** Not all contaminated land practitioners hold the CEnvP(SC) accreditation, yet councils may consider some non-certified practitioners to be suitably qualified and experienced. To check whether they are suitable, **use the guidance** provided in the NESCS Users' Guide "*who is a suitably qualified and experienced practitioner?*" and check with the council to which the reports will be submitted.
3. **Ask your local council for advice.** If solely relying on verification that experience and qualifications are aligned with the guidance in the NESCS Users' Guide, it may also be worthwhile confirming with the council that it agrees the non-certified practitioner is a SQEP. Councils may use their discretion to consider practitioners without a site contamination specialist accreditation as "suitably qualified and experienced", but it is worth checking with them before you commit to work that may not be accepted by the council.

Why do I need a SQEP?

There are many good reasons to use a SQEP when investigating potentially contaminated and contaminated land. Three of the main reasons are:

- **Contaminated land can pose significant risks to people and the environment, as well as commercial risks.** It is therefore important this land is adequately and methodically investigated by suitably qualified and experienced practitioners, so any risks can be identified, assessed and managed if necessary. Inadequate investigations and assessments can overlook or miss risks that may result in ongoing or even increased exposure to people and the environment, as well as possible commercial or financial risks.
- **A report certified by a SQEP may be required under the NESCS.** If the investigation is required to support a resource consent application under the NESCS, this regulation requires a "suitably qualified and experienced practitioner" certifies the preliminary and detailed site investigation reports. Regardless of whether the investigation of your land is required by the NESCS or for another purpose, selecting a practitioner that is suitably qualified and experienced is more likely to ensure the best outcome is achieved.

- **Clients are more likely to achieve the best outcome for them and their community.** Choosing a suitably qualified and experienced practitioner will help get you the best advice and can save time and money by ensuring the service and advice they provide is fit for purpose from the outset.

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Additional information

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