Ministry for the
Environment
Manatū Mō Te Taiao

Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand

MODULE 3
Site assessment

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3 Site assessment

This module discusses the approach and scope for assessing a site to determine the nature and extent of contamination and provide the data needed to evaluate the potential risks to human health and the environment. Specific details on field investigation techniques, sampling strategies and protocols, and quality assurance procedures are also included in this module.

It is difficult to provide prescriptive guidance regarding site assessment as every site is different and the environmental professional must be allowed flexibility to ensure adequate data is gathered given site-specific constraints. The aim of the sampling plan is to provide regulators and site owners with some indication of the type of data that must be gathered to adequately characterise a site.

In designing and carrying out any site investigation it is important to establish at the outset the aims or goals of the investigation. Pertinent questions to ask include:

- What are you trying to accomplish?
- What is already known about the site/situation?
- What will the data be used for?

The answers to these questions will help to define the level of site work required, the media to be targeted, the analytical requirements and the need for consultation with the regulatory authorities.

Site investigations are normally carried out in two phases: the initial site assessment and the detailed site investigation. The level of effort for the initial site assessment and detailed site investigation is dependent on the complexity of the site. An initial site assessment typically involves a desk top study and a site visit. Very little sampling, if any, is typically performed during the initial site assessment. The initial site assessment is used to assist in focusing the detailed site investigation.

The purpose of the detailed site investigation is to characterise the nature and extent of contamination and subsurface at the site so that an evaluation of the potential health and environmental hazards can be assessed. The information gathered during the detailed site investigation may also assist in selecting appropriate technologies for managing the site, if necessary. Intrusive and non-intrusive field investigation techniques are used to define the extent of contamination. Soil samples are almost always collected. Groundwater, surface water and sediment samples can also be collected if they could be affected. It is typically most cost effective to perform the detailed site investigation in stages.

Section 3.1 discusses the approach and typical scope of an initial site assessment. The approach and scope of a detailed site investigation is discussed in Section 3.2. Field sampling strategies are discussed in Section 3.3. Field sampling techniques and protocols necessary to ensure all data have an appropriate degree of accuracy and reproducibility and that the samples collected and field measurements taken are appropriately representative of actual field conditions are discussed in Section 3.4. Quality assurance/quality control issues are addressed in Section 3.5.

3.1 Initial site assessment

The initial site assessment comprises a desk study, site reconnaissance (if possible), development of a conceptual model, design of the detailed investigation, and a report summarising the results of the initial site assessment (optional). The complexity and level of effort of the initial site assessment depends on the complexity of the site and the objectives of the investigation programme. This section presents the steps required for a thorough initial site assessment at a relatively complex site.

A desk study involves gathering and compiling as much information as possible about the site so that a conceptual model can be developed. The conceptual model details the nature and extent of contamination, the potential migration pathways and identifies potential receptors as much as possible. Data gaps and uncertainties are identified during the preparation of the conceptual model which assists in designing the detailed investigation. The detailed investigation is then designed to confirm (or refine) the conceptual model and fill the data gaps. Finally, a report is prepared that summarises the information gathered, presents the conceptual model and outlines the detailed investigation.

3.1.1 Desk study

The background information gathered should include as much as possible of the following:

- the chronological history of previous uses, industries supported, and activities or processes carried out on the site
- the nature of the probable/possible contamination (petrol, diesel, petrochemicals etc.) including list of chemicals used on site
- any published or otherwise known information in order to establish whether adjacent property owners are, or have been, potential sources of contamination, including consents held for the site, if applicable
- location, age and construction material of above-ground and underground chemical or fuel storage tanks on the site. If integrity testing of storage tanks has been undertaken, the results of such tests should be reviewed.
- locations and construction details of underground services (which could potentially impact on the investigation or future remediation activities)
- present zoning of the site and details of the zone categories of properties surrounding the site
- contour or topographic maps
- likely future use of the site
- identification of equipment and areas where the likelihood of contamination resulting from historical or current work practices is high, including accidental spillage of chemicals
- source information (e.g. current and past site management) in order to establish the history of previous releases and waste disposal practices
- the results of any previous investigations of the site or surrounding land
- locations of surface water bodies (creeks, rivers, estuaries, wetlands), particularly where these may be adversely affected by contaminated groundwater or surface drainage from the

site. Surface water bodies should be evaluated to determine environmental values, beneficial uses, sensitivity to change, and physical, chemical and biological characteristics

- hydrogeological information which should include:
  - the extent and use of aquifers in the area
  - estimated depth to groundwater
  - probable direction of groundwater flow and gradient
  - soils and soil properties (soil type, porosity and hydraulic conductivity)
  - location of any springs
  - sources of local municipal water supply, and the location of registered private or industrial wells or bores
  - tidal information.

Potential sources for the information discussed above can include:

- maps (current and historical), including topographical maps, geological survey maps and town plans
- statutory authorities: local authorities, port companies, Ministry of Health, Department of Labour, Land Information New Zealand etc.
- trade information from directories, trade associations, etc.
- photographic records
- current and past site managers and workers
- technical information and material safety data sheets (MSDS)
- company records.

3.1.2 Site reconnaissance

A visual inspection of the site supplements the information gained from the desk study and allows an appreciation of the practicalities involved in the ensuing investigation. Information gathered might typically include:

- site access restrictions (commercial and physical)
- location of buildings and hard-standing
- location of overhead power cables and canopies
- availability of water and electricity supplies
- confirmation of location of underground services
- proximity and type of potential exposure pathways (e.g. old bores and wells not on council records, nearby schools, sensitive ecological habitats)
- anecdotal site history information
- site topography and surface run-off patterns/collection
- site ground surface covering
- signs of surface straining

- condition of nearby vegetation
- age and condition of tanks
- neighbouring land uses
- construction of foundation of nearby buildings (e.g. slab on grade, piling)
- any signs of off-site migration of products.

The information gathered in the desk study and the site reconnaissance should enable a conceptual model of the site to be developed.

3.1.3 Conceptual site model

The objective of a conceptual site model is to detail the nature and extent of contamination, the potential migration pathways and to identify potential receptors to the extent possible based on information gathered from the desk study and site visit. Data gaps and uncertainties are identified during the preparation of the conceptual model, which assists in designing the detailed investigation.

The conceptual model can be a simple site diagram in plan and cutaway views showing the potential sources of contamination (such as underground storage tanks, fuel pumps and piping), general geology beneath the site including expected depth to groundwater, likely migration pathways (such as service trenches, migration to groundwater and migration to nearby surface waters), potential exposure points (such as nearby wells, surface water and basements), and potential receptors (such as children, site visitors, and workers). Analytical results from previous investigations should also be shown on the diagram, if available.

The complexity of, and level of effort expended on, the conceptual model depends on the complexity of the site and objectives of the investigation programme.

3.1.4 Design of a detailed investigation programme

Once the conceptual model has been prepared, a detailed investigation programme can be designed to confirm (or refine) the conceptual model and fill the data gaps. The detailed investigation should be flexible to allow incorporation of new data into the conceptual model to further refine it as the investigation progresses. It is typically most cost effective to perform a detailed investigation programme in stages. The overall aim of the first stage is to determine whether contaminants are present at, or moving from, the site at concentrations that constitute an unacceptable adverse environmental or health risk as cost effectively and quickly as possible.

The detailed investigation programme, specified as part of the initial site assessment, should list the types of sampling to be performed, the number of samples to be collected, the proposed location of each sample, and the laboratory analyses to be performed. See Section 3.2 for a discussion of the scope of a detailed site investigation.

3.1.5 Initial assessment report

The initial assessment report is optional. If the site is complex enough to warrant a thorough evaluation of data gathered during this phase, then the report should summarise the information gained from the desk study (Section 3.1.1), present the conceptual model for the site (Section 3.1.3) and outline the sampling strategy for the detailed site investigation. The initial assessment report should contain the following information:

- **Introduction.** This section should detail the purpose of the initial site assessment, describe the site in detail and provide an outline of the report. The description of the site should include location of underground service trenches.
- **Background.** This section should outline the resources used and summarise the data obtained in the desktop study. Information such as historical land uses at the site, local and regional land uses, regional geology and hydrogeology, and a list of chemicals used on site should be included in this section.
- **Conceptual model.** This section should detail the nature and extent of potential contamination, the potential migration pathways and identify potential receptors to the extent possible as discussed in Section 3.1.3.
- **Recommendations.** This section should include recommendations for the type of sampling needed to further define the nature and extent of contamination. The conceptual model and experience should be used as the basis for determining which environmental media should be targeted (e.g. soil, groundwater, surface water, sediment) and at which locations on the site.
- **Appendices.** All data (e.g. maps, drainage plans, historical photographs, etc.) obtained from the sources discussed in Section 3.1.1 should be provided in appendices.

3.2 Detailed site investigation

The purpose of the detailed site investigation is to characterise the nature and extent of contamination and subsurface conditions at the site. The information gained from the detailed site investigation will be used to assess the risks to human health and the environment from a potential release at the site and screen technologies for managing the site.

The detailed site investigation must be planned carefully to ensure that all needed data is obtained in the most cost-effective manner. In many cases, a detailed investigation is performed in stages. Given the variability in size and complexity of petroleum hydrocarbon sites, it is not possible, or appropriate, to provide detailed advice on the development of field investigation programmes. However, the following must be considered:

- **objectives of the site investigation including data quality objectives**: A clear objective of why the data is being collected and what it will be used for will help focus the investigation. The data quality objectives (described in Section 3.6) list how the data will be used, the type of data needed (i.e. screening or definitive), the detection limits required, and how data quality will be assessed.
- **the number, type, and locations of the samples to be collected**: The rationale behind the sampling strategy should be well defined as should the types of analyses required for each sample. The conceptual model and experience should be used as the basis for determining which environmental media should be targeted (e.g. soil, groundwater, surface water, sediment) and at which locations on the site. Various sampling strategies are discussed in Section 3.3
- **the most appropriate (and cost-effective) field sampling procedures for each of the targeted environmental media:** Decontamination of equipment between sampling should be considered as should protocols such as identification, preservation, handling, packaging,

and shipping requirements. Field investigation techniques and sampling protocols for petroleum hydrocarbon contaminated sites are discussed in Sections 3.4 and 3.5 respectively.

- **permits and resource consents required to perform the field work:** Typically, a consent (and fee) would be required if a bore or well were constructed on site.
- **identification of health and safety issues (Section 3.4.1):** Fire and explosion hazards at a site should be evaluated before the field investigation. Other hazards to consider include confined space entry and entering an excavation.

A site sampling plan can be prepared prior to any field activity to define the steps required to meet the objectives of the site investigation. The level of detail of this plan should be commensurate with the complexity of the sampling program. In some cases, the sampling and analysis plan can be a one- or two- page document. For activities that are generally similar, such as tank removals, an overall sampling and analysis plan can be prepared for a particular type of work and then referred to in a letter along with any exceptions that may be required for a specific site.

Concurrent with preparation of the sampling plan, all necessary permits and resource consents should be obtained and personnel training should be performed. Once the sampling and analysis plan has been agreed to by all responsible parties and the permits have been obtained, the field activities can begin. Information obtained in the field, such as depth to groundwater or site-specific geology, should be assessed against the conceptual model. Field sampling strategies can then be modified if necessary.

At the completion of the detailed site investigation, a contamination assessment report should be prepared. The contamination assessment report should contain the following sections:

- **Executive summary.** This section should discuss the purpose of the investigation, summarise the findings of the investigation and risk assessment, and present the conclusion and recommendations.
- **Introduction.** This section should detail the purpose of the site investigation and describe the site in detail. The site description should include a detailed history of the site including the location of any known or suspected petroleum hydrocarbon storage or use, or any other activities which may have posed a risk to human health or the environment.
- **Background.** This section should include information such as historical local and regional land uses, regional geology and hydrogeology, climatology, and a list of chemicals used on site. The regional hydrogeology section should include a discussion of the proximity of surface waters and other sensitive receptors.
- **Field investigation.** This section should describe the sampling performed at the site including how the samples were collected, the location and number of samples collected, and the analyses performed.
- **Field and analytical results.** This section should summarise the information obtained during the field investigation including site-specific geology, hydrogeology and analytical results. The discussion of the site geology and hydrogeology should include physical characteristics of the soil (variation with depth) and groundwater (depth, flow rate, flow direction). Figures showing sample locations with analytical results are especially helpful.

- **Conceptual model.** This section should detail the nature and extent of potential contamination, the potential migration pathways and should identify potential receptors as discussed in Section 3.1.3. The conceptual model in the contamination assessment report should be an updated version of the one presented in the initial assessment report.
- **Risk assessment.** An evaluation of the potential risks to human health and the environment should be presented in this section. Typically, a Tier 1 assessment would be performed. A Tier 1 assessment involves comparing site concentration data with the appropriate acceptance criteria. See Modules 4-6 for information on how to perform a risk assessment.
- **Site management options.** It may also be desirable to include in the contamination assessment report an evaluation of the site management options for mitigating the adverse risks to human health and the environment. Site management options for petroleum contaminated sites are discussed in Module 7.
- **Appendices.** The following information should be included in appendices:
  - boring logs
  - well detail diagrams
  - laboratory reports
  - copies of permits and/or resource consents.

3.3 Sampling strategies

Once the conceptual model is developed for a site, a cost-effective sampling strategy can be developed. The components of a sampling strategy should include number, type and locations of the samples to be collected for all environmental media of concern as well as the types of analyses required for each sample.

The overall sampling strategy may involve several sampling rounds if little information is known regarding the contaminant source or if the site is large. For example, a soil gas survey may be undertaken at a site to provide an initial assessment of the extent of contamination. The results of the soil gas survey may be used to identify locations of test pits or boreholes for soil sampling in follow-on investigations. Analytical data obtained from the soil investigation can be used to determine the need for additional soil sampling to further define the extent of hydrocarbon contamination and the need for additional groundwater sampling. If information is available regarding the nature of the release and site-specific geology and hydrogeology, or sampling indicates no significant contamination is present, then only one sampling round may be necessary to characterise the site adequately.

The rationale for choosing the number of samples, sampling method, location, and analyses for soil is discussed in Section 3.3.1. The rationale for choosing the location and number of groundwater monitoring wells and recommended analyses for groundwater is discussed in Section 3.3.2.

3.3.1 Soil

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

3.3.1.1 Sampling method and location

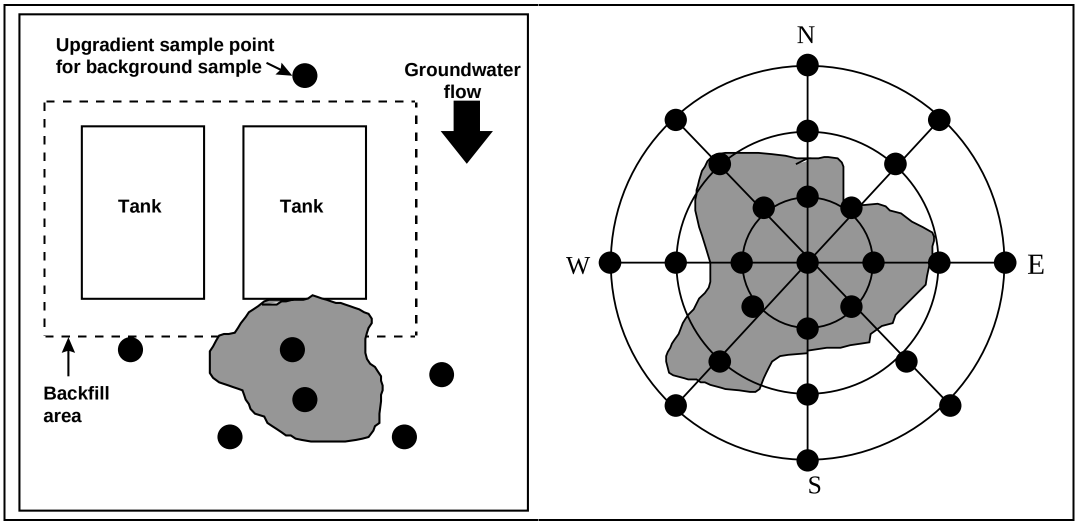
The overall aim of the first round of sampling in the assessment process is to determine as cost effectively as possible whether contaminants are present at, or moving from, the site at concentrations that constitute an unacceptable adverse environmental or health risk. The most cost-effective and timely approach is to target the areas most likely to be contaminated. However, the effectiveness of a targeted sampling strategy is dependent on the thoroughness of the information gathered during the desk study (Section 3.1).

In general, when the source of contamination is known or is suspected to be limited to a specific area, sampling points are located relative to the suspected source. This usually involves judgmental sampling if hydrogeological information is available, or it may involve systematic grid sampling emanating from the contaminant source if hydrogeological information is not known. The differences between judgmental and grid sampling are illustrated in Figure 3.1 and Table 3.1.

The method selected will depend on the conceptual model of the site. In practice, a combination of methods may be used for different parts of a site. For example, where no identifiable source exists, or the existence of petroleum hydrocarbons appear to be widespread, a grid might be laid out and samples taken either systematically or randomly, depending on the objectives of the study. To delineate or determine the lateral extent of hydrocarbons from a known source, a judgmental approach might be used with results fed back into the conceptual model as the investigation progresses. Samples would be collected initially close to the contaminant source. If petroleum hydrocarbons are detected at these sampling points, additional samples may be collected at points farther from the suspected contaminant source (with spacing judged from the conceptual model) until no contamination is found.

Systematic sampling may be used in cases where the chance of an omission could cause a significant detrimental decision or outcome, or where time is a factor. Systematic sampling is also used during evaluation of remediation options such as land farming (Section 7.5.3 of Module 7) or where little or no information is available on a site.

Simple random sampling is often used in sampling for land farm monitoring, biopile remediation, soil excavation piles, testing of fill material and in cases of site acquisitions where little or no historical and or hydrogeological information is available.



Example of judgmental sampling

Example of a systematic grid relative to a suspected source

Figure 3.1 Sampling methods
Source: Schwerko (1994)

Table 3.1 Advantages and disadvantages of site sampling approaches

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

3.3.1.2 Number of sample points and samples

The purpose of an investigation is to obtain an accurate assessment of the contamination (or lack of it) in a particular area. This is accomplished through the analysis of representative samples. The larger the number of points sampled, the greater the degree of confidence (statistical probability) that the analytical data represents the true overall picture, but the higher the cost of the investigation.

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

- size of the site
- extent of suspected release
- degree of confidence required (data required for regulatory purposes or on-site decision)

- costs
- future land use
- availability of suitable equipment
- time-scale.

There is no prescribed requirement on the number of sample points needed at each site. However, documents are available from the oil companies, the American Petroleum Institute (API), US Environmental Protection Agency (USEPA), and American Standard and Testing Methodologies association (ASTM) which can be used as a guide in selecting the number of sample points.

The number of soil samples collected from each sampling point is chosen to adequately characterise the extent of contamination and can vary depending on various factors:

- homogeneity of the soil
- depth of the excavation or depth of suspected contamination
- the quantity of product known or suspected to have been released
- existence of pathways by which contamination might migrate vertically
- number and kind of analyses to be run
- analytical precision and accuracy needed to meet the project objectives.

The suggested minimum numbers of soil samples for a variety of possible scenarios are summarised in Table 3.2. In general, five soil samples (one on each side and one at the base) are enough to adequately characterise a tank pit. If groundwater is encountered in the pit during excavation, the soil samples should be collected at the water interface, because that is the area likely to have the highest concentrations of contamination.

To determine the depth of petroleum hydrocarbons in soil during drilling or in test pits, samples should be collected at fixed intervals (e.g. 0.3 - 1.5 metres), at any change in lithology, and any other depth at which impact is observed via sight, smell or field screening methods such as hand-held organic vapour analysers. Samples should be collected until the groundwater table is reached or when the presence of hydrocarbons is no longer indicated by the field screening method. At least one sample should be collected below the point at which contamination is indicated by the field screening method to confirm the vertical extent of contamination.

Table 3.2 Minimum recommended number of soil samples

Location	Number of Samples	Action
Aboveground storage tank bunded area	2 per tank 2 per bund	Collect samples from 200 mm into natural soils at inlets, outlets, vents, drains, or other areas where product could collect.
Underground storage tank pit	5 per tank pit	Collect samples from 200 mm into natural soils on each wall of excavation and at the base.
Bowser area	1 per bowser island	Collect samples from 200 mm into surrounding soils.
Underground fuel line	1 per 5m of line	Collect samples from 200 mm into surrounding soils. Target sampling at stained areas.
Above ground fuel line	1 per 10m of line	Collect samples from 200 mm into surrounding soils. Target sampling at stained areas and at joints.
Drum storage and cleaning areas	1 per 25 m^2	Collect samples in areas of known spill/leaks or otherwise below area at two intervals: 200 mm and 300-600 mm.
Used battery storage area	1 per 25 m^2	Collect samples from 200 mm into natural soils.
Waste disposal area	1 per 25 m^2	Collect samples from 200 mm into natural soils.
General excavation	1 per 25 m^2 of excavation wall area	Collect samples from 200 mm into natural soils on each wall of excavation and at the base.
General borehole drilling	5 per borehole	Collect samples at fixed intervals (e.g. 0.3 to 1.5 metres), at any change in lithology, and any other depth at which impact is observed or measured.

3.3.1.3 Types of samples

Either discrete or composite soil samples can be obtained. Compositing is a technique where soil is collected from several locations, mixed together, and then sampled. Discrete samples are preferred. The samples should be collected in a way that will avoid the introduction of bias. Samples collected for the analyses of volatile compounds should be separate from samples collected for other analytes.

In general, composite samples are taken when an “average” value is being evaluated. For example, composite samples are appropriate during land farming (Section 7.5.3 of Module 7) to screen large areas or for evaluating the concentration of total petroleum hydrocarbons (TPH) in stockpiles of material.

Samples collected for the analysis of volatile organic components (BTEX, lighter fuels) should not be composited since compositing can cause the loss of the more volatile components. Transferring samples between containers or during compositing compromises the integrity of the samples because residue can be left on the container. Compositing is also not recommended when hot spots of petroleum hydrocarbons need to be delineated.

3.3.1.4 Types of analyses

The types of analyses to be performed on soil samples collected at petroleum hydrocarbon impacted sites are based on the product type and are summarised in Table 3.3. The results from these analyses are required to perform the risk-based evaluations discussed in Modules 4-6. In general, all of the samples would be analysed for TPH and the results would be fractionated as follows: C_7 to C_9, C_{10} to C_{14}, and C_{15} to C_{30}. Module 4 discusses the reasoning behind the fractionation of TPH. Because the TPH method recommended does not include reporting of C_6, soil samples associated with a petrol spill must also be analysed for aromatic volatile organic compounds (AVOCs) which include BTEX.

A Tier 1 risk analysis (as discussed in Module 4) for soils impacted with diesel can usually be performed using the TPH values. However, in some cases it may be necessary to obtain analytical results for the polycyclic aromatic hydrocarbons (PAHs) present in diesel. All of the results should be reported on a dry weight basis.

TPH can be performed on the soil samples as a gross indicator of fuel contamination. The TPH analytical method can be used to obtain a chromatographic boiling point distribution of the petroleum hydrocarbons in the sample. This fingerprint can be very helpful in tracing spills from multiple sources as it allows the identification of the type(s) of hydrocarbon present. A document titled *Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water* (OIEWG, 1999) is available from the Ministry's web site www.mfe.govt.nz/issues/contam.htm). Refer to it for the latest information on laboratory analyses.

If product type is unknown, it is recommended that a few of the samples be subjected to TPH, AVOC, and PAH analyses.

Table 3.3 Recommended laboratory analyses for soil samples

Suspected Source	Parameter	Method
Petrol Aviation fuel Light-end petroleum fractions	AVOCs Banded TPH (C_6 to C_9, C_{10} to C_{14}, $>C_{15}$)	Refer to sampling and analytical guidelines document
Diesel Kerosene Middle distillates	PAHs Banded TPH	Refer to sampling and analytical guidelines document
Heavy-end petroleum fractions Bunker fuels Residual fuels Crude oil	PAHs	Refer to sampling and analytical guidelines document

AVOCs = aromatic volatile organic compounds (e.g. BTEX)
PAHs = polynuclear aromatic hydrocarbons
TPH = total petroleum hydrocarbons

3.3.2 Groundwater

Groundwater monitoring systems are installed to determine the concentrations of petroleum hydrocarbons in groundwater and to collect hydrogeological and geological data around and downgradient from the potential hydrocarbon source. The rationale for choosing the location and number of groundwater monitoring wells and recommended analyses for groundwater are discussed in this section.

3.3.2.1 Location and number

The number and location of groundwater monitoring wells will depend on the conceptual model and scope of the investigation. The placing of wells and determination of sampling depths are complicated processes and should be performed under the supervision of qualified geologists or hydrogeologists. Consideration must be given to:

- potential or known sources (e.g. tanks, pipe work, soakage pits etc.)
- confidence in conceptual model (e.g. flow direction)
- potential upstream sources (necessitating background monitoring)
- anticipated spread of contamination
- bore separation to determine hydraulic gradient.

Well locations and completion depths must be selected to ensure that all probable petroleum hydrocarbon flow paths are monitored. A minimum of three monitoring wells per site is typical; the actual appropriate number of wells will depend on the conceptual model. A minimum of three spatially-distributed wells are necessary to determine flow direction and hydraulic gradient.

Sampling points may be located around the perimeter of the tank, pipe, or other potential sources of contamination or wherever the greatest probability of petroleum hydrocarbons exists. If petroleum hydrocarbons or a release are discovered, the sampling plan may need to be modified to include additional sampling points to determine the extent of the contamination. If potential sources of petroleum contamination exist upgradient of a site, it may be desirable to install a monitoring well to monitor the quality of water entering the site.

Groundwater contaminant concentrations vary over time in response to rainfall, and other seasonal changes. Groundwater from monitoring wells must be sampled periodically to provide sufficient data to obtain an accurate picture of the groundwater quality. For example, a spill during winter may create a smear zone which is stranded above the water table in summer. Summer sampling may fail to identify the magnitude of the contamination, whereas sampling after rainfall or in winter might present a worst-case scenario.

Quarterly or semi-annual sampling for the first year from the monitoring wells would typically provide sufficient data to develop a baseline of the nature of the contamination. Seasonal fluctuations in groundwater levels can affect contaminant concentrations. Less sampling may be acceptable, depending on whether hydrocarbons are detected. In some situations, particularly where groundwater is used as a drinking-water supply, more frequent monitoring may be required. Annual sampling after the first year is recommended until contaminant concentrations on- or off-site reach acceptable levels to assess the effectiveness of the site management or remediation option(s). Groundwater levels should be measured whenever groundwater quality samples are collected.

3.3.2.2 Type of analyses

The types of analyses to be performed on groundwater samples collected at petroleum-contaminated sites are based on the product type and are summarised in Table 3.4. The results from these analyses are needed to perform the risk-based evaluations discussed in Modules 4-6. Tests for total petroleum hydrocarbons (TPH) can also be performed on the groundwater samples as a gross indicator of fuel contamination. The TPH analytical method can be used to obtain a chromatographic boiling point distribution of the petroleum hydrocarbons in the sample to characterise the type of hydrocarbon product present. This fingerprint can be very helpful in tracing spills from multiple sources. See the OIEWG sampling protocols (available from the Ministry’s web site www.mfe.govt.nz/issues/contam.htm) for more information.

Table 3.4: Recommended laboratory analyses for groundwater samples

Suspected Source	Parameter	Method
Petrol Aviation fuel Light-end petroleum fractions	AVOCs	Refer to sampling and analytical guidelines document
Diesel Kerosene Middle distillates	AVOCs PAHs	Refer to sampling and analytical guidelines document
Heavy-end petroleum fractions Bunker fuels Residual fuels Crude oil	PAHs	Refer to sampling and analytical guidelines document

AVOCs = aromatic volatile organic compounds (e.g. BTEX)
PAHs = polynuclear aromatic hydrocarbons

3.4 Field investigation techniques

This section describes the most common field investigation techniques used to characterise a site potentially impacted by petroleum hydrocarbons. These techniques include soil gas surveys, test pits, boreholes, and groundwater monitoring wells.

Prior to initiating any field investigation, health and safety issues must be considered. Typical health and safety issues found at petroleum sites are discussed in Section 3.4.1. Soil gas surveys, test pits, boreholes, and installation of monitoring wells are described in Sections 3.4.2 through 3.4.5 respectively.

3.4.1 Health and safety issues

Under the Health and Safety in Employment Act 1992, a place of work must be investigated to identify the hazards present, these hazards must be assessed for their significance, and those identified as significant must be eliminated, isolated or minimised as appropriate. Existing documentation regarding safety practices, such as oil industry hot work and confined space permitting procedures and the codes of practice for petroleum sites, should be reviewed thoroughly before investigating site contamination.

A hazard which may be encountered at petroleum hydrocarbon contaminated sites during field investigations is the build-up of explosive levels of gases and vapours in boreholes, test pits or structures. Specific control measures must be applied to minimise these hazards. Hence welding must be strictly prohibited on site. Casings for boreholes should be prepared off-site and, for shallow holes, casings should be removed by winching or jacks without the need for cutting. In no circumstances should welding or cutting be carried out in an operating service station. If such work is absolutely necessary the pumps must be closed and special precautions must be taken. All ignition sources (e.g. sparks from concrete cutters etc.) should be maintained at least 8 metres away from any operating pumps.

Entry into a pit or other confined space at a petroleum hydrocarbon contaminated site may be especially hazardous since, if no remedial measures have been taken, the build-up of hydrocarbon vapours within the space can reach levels within the explosive range, and may easily exceed levels which represent a significant toxicity hazard. In addition the vapours, which are heavier than air, will displace the air and may give rise to an atmosphere within the space which is significantly deficient in oxygen. There is also the potential for pit walls to collapse affecting the safety of workers and the integrity of nearby structures.

To avoid health and safety risks the space should be thoroughly ventilated before a worker enters. Oxygen and hydrocarbon vapour levels should be monitored using appropriate equipment, and the entering worker should be continuously observed by a second worker stationed outside the space. Under certain conditions, microbial generation of methane and carbon dioxide may also cause a safety hazard on a site. Hydrogen sulphide may also be an issue at some sites. Full protective clothing should be worn by the entering worker. A work permit may be required from the site owner to perform welding at a site.

3.4.2 Soil gas surveys

Soil gas surveys can be a useful tool in determining the spread of volatile organic compounds (VOCs) resulting from hydrocarbon spills or leaks. They are generally undertaken as a preliminary screening tool to identify potential hot spots of soil contamination and free product to assist in the design of a detailed investigation using trenches or boreholes and monitoring wells. Soil gas survey results provide a relative measure of contamination at a site. Before conducting any soil gas survey, the user must have knowledge of the subsurface lithology.

The process involves driving a hollow spike, or otherwise creating a hole through which gases can pass, and drawing the soil gas to the surface where it is passed through a measuring device. Sampling depth is limited by the ability to drive a stake into the ground and is normally 1-2 metres. The sampling technologies typically used to measure organic vapours are:

- portable PIDs (photoionisation detectors) and FIDs (flame ionisation detectors
- portable gas chromatograph
- gas detection tubes (such as Draeger tubes).

It is important to carry out field checks and recalibration while these instruments are in use.

Soil gas surveys are best suited to light hydrocarbon products in shallow soils that contain principally volatile compounds (such as petrol). It is also a requirement that the underlying strata are relatively permeable. The survey is also most appropriate where a shallow water table exists. Interpretation of the results tends to be complicated where contamination at depth is suspected, where historic or multiple spills have occurred, and where relatively heterogeneous/impermeable strata are present. Caution should be taken due to the possibility of false positives with soil gas surveys.

Where soil gas surveys are undertaken the initial grid spacing between holes should be 3-10 metres depending on the size of the site and the nature of the underlying strata. The grid spacing should be reduced near sample locations that show evidence of hydrocarbon vapours to provide more definitive data for drawing isoconcentration contours of the results.

3.4.3 Test pits

Test pits are holes excavated using a mechanical digger such as a backhoe or excavator for the purpose of obtaining soil samples. Test pits are used for near-surface soil sampling to enable site contamination to be characterised. Test pits have the advantage that they enable a full appreciation of ground conditions throughout the vertical extent of the excavation. If contamination is encountered, it can be more easily and cost effectively traced using an excavator than a drilling rig by extending the hole or relocating to a nearby position.

Disadvantages include:

- The depth of the pit is limited to the reach of the mechanical excavator being used.

- Monitoring wells can not be easily installed.
- Large areas are required for the digger, hole and excavated soil, which restricts use at most service station sites.
- Adequate recompaction of backfill is required.
- The expense of replacing forecourts can be prohibitive.

Factors to consider when choosing an excavator include the reach of the excavator arm, the size of bucket available, whether the machine is track or wheel mounted, and whether the buckets can be changed using a quick-release system.

3.4.4 Boreholes

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

On sites covered by concrete paving, drilling should be preceded by concrete coring of a size to accommodate both drilling activities and subsequent well completion, including installation of wellhead protectors. To prevent the fallback of cuttings into the hole, accumulated drill cuttings should be removed from the borehead area as drilling progresses. For open-hole drilling methods, a short length of casing should be installed at the surface to minimise fallback.

Material handling and quality control measures should be directed towards clean drilling conditions and the elimination of down-hole contamination as a result of drilling operations. Specific quality control measures for machine drilling are as follows:

- The drilling rig to be used should be in sound working order and free of oil leaks and cleaned prior to arriving at the site.
- A cleaning pad should be established on the site where the drilling rig and other large equipment can be cleaned without risk of contamination to sampling locations. Power and water are needed nearby to allow use of a steam-clean unit.
- All drilling equipment should be cleaned between boreholes.

All drill cuttings should be properly disposed of. If the soil is obviously stained then it should be sent to a landfill or local treatment facility. If the soil is relatively clean it can be backfilled. Care should be taken to prevent cross-contamination between confining layers. Grouting holes that pierce through confining layers are recommended to reinstate the integrity of the confining layer.

Logs of the soil encountered should be prepared on standard borehole log sheets. The soil should be logged using the Unified Method of Classification and Standard Abbreviations from the New Zealand Geomechanics Society *Guidelines* (1988). Drilling methods are described below. Soil classification is discussed in Section 3.4.5.

3.4.1 Hand auger

Hand-held or motor driven augers are comprised of an auger head on a metal shaft. This is manually or mechanically turned to advance the head into the ground. Soil collects in the auger head, which must be frequently withdrawn to remove the soil to allow the auger to advance. Soil samples can be collected from the soil that has collected in the augerhead or a split-spoon type sampler can be advanced into the ground.

Bores should be advanced at a larger diameter than the sampling auger so that a temporary PVC casing can be placed in the hole and the base of the bore should be cleared before sampling. Further advance is then made by removing the casing and augering out the larger diameter.

Advantages	Light, portable and inexpensive to operate. Enables soil samples to be taken and the sediment or rock to be accurately identified. Small diameter monitoring wells can be installed.
Disadvantages	Limited as to soil type and depth. Cannot be used in gravel, rock or fill material which contains solid objects or other obstructions. Suitable only for stiff sands, clays or similar fine-grained, homogeneous material. Not suitable where collapse is likely, e.g. in running sands. Labour intensive.

3.4.4.2 Continuous flight auger

A continuous flight auger is comprised of a shaft with a continuous screw. The screw advances into the ground and passes the disturbed soil up the outside of the screw to the surface. A split-spoon type sampler that can be advanced into the ground is the preferred method of collecting samples. However, soil samples can be collected from the soil that has been advanced to the surface. As with hand augering, a temporary casing can be installed during sampling.

Advantages	Quick and cost effective for shallow holes in suitable soils. Can be used to install monitoring wells provided the stratum is stable below the water table.
Disadvantages	Difficult to obtain a representative sample if a split-spoon type sampler is not used. Cannot penetrate large boulders or hard rock. Cross-contamination (due to smearing and fallback) is possible even if the auger is withdrawn from the hole and a split-spoon type sampler used. Not generally suitable for well installation in unconsolidated sediments beneath the water table due to bore collapse when the auger is withdrawn. Suitability for sampling at depth is limited to very stable ground conditions.

3.4.4.3 Hollow stem auger

Hollow stem auger (HSA) method is the preferred drilling method. The auger flight is fixed to a hollow tube or stem. The drilling augers are rotated and advanced using drill rods and a bit which is connected to the centre plug. This plug is inserted into the hollow centre of the cutterhead to prevent soil from coming up inside the auger. As the auger rotates, material being removed by the drilling bit is carried by the flights to the surface via the annular space between the wall of the borehole and the exterior auger wall. Either split-spoon type samplers or core-barrel samplers can be used to collect soil samples from inside the hollow stem.

Advantages	Extraneous material (such as air or mud) is not introduced into the formation. Facilitates accurate formation logging and identification of water bearing zones. Minimises well development requirements and facilitates collection of samples for geotechnical analysis.

Disadvantages	Not suitable for use where gravels or hard rock are likely to be encountered. Limited drilling depth.

3.4.4.4 Air rotary drilling

Air rotary drilling is accomplished by rotating a cutting bit into the ground at the end of a length of drill pipe. The air escaping through orifices on the drill bit carries the cuttings to the surface via the annular space between the wall of the borehole and the drill pipe. Air used for drilling should be filtered to remove compressor oil. Air rotary drilling allows fairly accurate logging and identification of water bearing zones and minimises well development requirements. Either split-spoon type samplers or core-barrel samplers can be used to collect soil samples and lithologically log the borehole.

Advantages	Fast in consolidated and semi-consolidated rock. Facilitates fairly accurate formation logging and identification of water bearing zones when split-spoon type samplers are used. Minimises well development requirements and facilitates collection of samples for geotechnical analysis.
Disadvantages	Representative samples difficult to take because of introduction of air. Cannot penetrate fine-grained cohesive material without the addition of water. May present a health risk from dust and vapours in highly contaminated ground. The size of the rigs may prevent access at some sites.

3.4.4.5 Mud rotary drilling

Mud rotary drilling is accomplished in much the same way as air rotary drilling, except mud is used to carry cuttings to the surface rather than air. The use of mud should generally be avoided. This method does not allow accurate logging and identification of water-bearing zones or sampling for geotechnical analysis. Drilling mud should be mixed in portable mud tubs and should be composed entirely of pure bentonite. The mud should not contain any polymer additives or chemical constituents which may interfere with the chemical analyses to be completed at the site.

Advantages	Good for deep holes. Suitable for clay, silt, compacted sand and silt, and soft rock.
Disadvantages	Possible smearing of bore walls with mud or other drilling fluid reducing permeability and possibly requiring extensive development. Mud may interfere with water quality samples and invade permeable zones in the strata. Expensive.

3.4.4.6 Driven well

A steel casing is driven into the ground. When the desired depth is reached a well is installed and the casing withdrawn. Alternatively the casing is left in the ground.

Advantages	Inexpensive and widely available.
Disadvantages	Soil sample recovery not possible. The casing can obscure changes in strata and water-bearing zones. Suitable for unconsolidated soils only; boulders and bedrock cannot be penetrated. Can be slow.

3.4.4.7 Cable tool (shell and auger)

In this system an open-ended steel shell is driven into the ground and retracted when full. Samples are taken using a sampling cone which is fitted in place of the shell once the required depth is reached.

Advantages	Cable tool drilling is suitable for all soil types and can be used for almost any depth and size. Monitoring wells can be easily installed. Enables recovery of undisturbed samples.
Disadvantages	This is a slow drilling method and can be expensive compared to other methods.

3.4.5 Soil classification

Logging of soils must follow a consistent methodology and format to reduce the subjective nature and widely varying content of descriptions. In part, this arises from the numerous different systems brought to the multi-disciplinary field of site assessment. Engineering, geological and soil science disciplines have different emphases, and accordingly, there are different strengths and weaknesses associated with these approaches.

The most widely used soil classification system in New Zealand is that outlined in the New Zealand Geomechanics Society's 1988 "*Guidelines for the Field Description of Soils and Rocks in Engineering Use*". This system is based on use of a standard series of soil descriptors. Soil grain size distribution is described with the use of proportional terms for particle size ranges as a percentage of the soil mass. It also includes the Unified Soil Symbols reflecting the dominant soil type and the properties of grading. For consistency, it is recommended that the terminology set out in these guidelines is adopted for all site assessment work.

A more detailed system for graphically representing soil conditions is contained in the New Zealand Geological Survey 1982 report "*Revised Guide to Recording Field Observations in Sedimentary Sequences*". This system has standard bore log symbols for a comprehensive range of soil types and should be used as the standard guide to recording observations on the graphic representation column of bore logs.

3.4.6 Groundwater monitoring wells

Groundwater monitoring wells are typically constructed of 32, 50 or 100 mm, Class D polyvinyl chloride (PVC) with 3-5 metres screen intervals, as shown in Figures 3.2 and 3.3. Conventional solvent glues should not be used because they could introduce chemicals into the water and would affect interpretation of sampling results. Instead, mechanical screw fittings should be used on all casing and screen joints. If necessary, screen and casing should be adequately cleaned to remove trace contaminants.

Screen lengths and slot size should be determined on site, under the supervision of a qualified hydrogeologist, after drilling has established the location of the water-bearing zone. Slot sizes should be selected based on the geology at the site. The slots should be small enough to prevent subsurface material from entering the well yet large enough to not impede groundwater or product flow. In general, a nominal slot width of 0.5 mm with two rows of slots per screen length and average spacing of 5 mm and between slots is adequate. The slots should be machined and the machined cuttings removed before the screen is employed. A minimum of 0.5 metres of unslotted casing with a well-end cap should be provided below each screen, to act as a sump for collection of any fines that may pass through the screens.

The top of the screen should be placed between 1.0 and 1.5 metres above the water table as logged during drilling or at the discretion of the field engineer/geologist where the depth to groundwater is less than 2.0 metres. The intention is to identify the presence of any floating product and allow for seasonal fluctuations of the water table level. There should be at least 1.5 metres of standing water in the well at all times.

Following screen and casing installation, graded sand (generally in the 1-4 mm range, depending on soil type) should be placed around the screen and to a height of approximately 200 mm above the uppermost screen slots. Sand filter material should be pre-washed and screened to eliminate foreign material. A clean pipe must be used for deep holes to ensure correct placement of the sand.

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

Holes should be backfilled or grouted above the bentonite seals to approximately 250mm below ground level. The final completion at the surface should comprise a concrete collar seal and protective covers to provide security of the well and prevent accidental damage. The wells should be equipped with lockable covers. Where vehicular traffic poses a problem, the installation should be fitted flush with the ground surface using a toby cover for protection. In this event, a sump should be provided around the top of the casing to allow build up of drainage water around the borehead to be purged before opening the bore. Generalised design drawings are provided in Figures 3.2 and 3.3.

3.4.6.1 Pitfalls to monitoring well design

Possible problems to be avoided with well design and installation are:

- insufficient depth so that water and product are not encountered throughout the year, or adequate samples cannot be recovered
- screen placement at the wrong depth to supply the required information (e.g. screen too low so that floating product is excluded)
- use of hand-slotted screens with insufficient slot coverage to detect floating product
- use of filter packs or filter fabrics which reduce hydrocarbon movement into the well
- use of monitoring well materials which might absorb contaminants or release contaminants into the groundwater (e.g. PVC solvent glues)
- cross-contamination of otherwise clean strata or aquifers through poor bore construction and/or penetration of confining layers
- poor surface sealing at the bore head so that contaminants enter the bore from the surface
- consideration should be given to stratification of contamination within groundwater

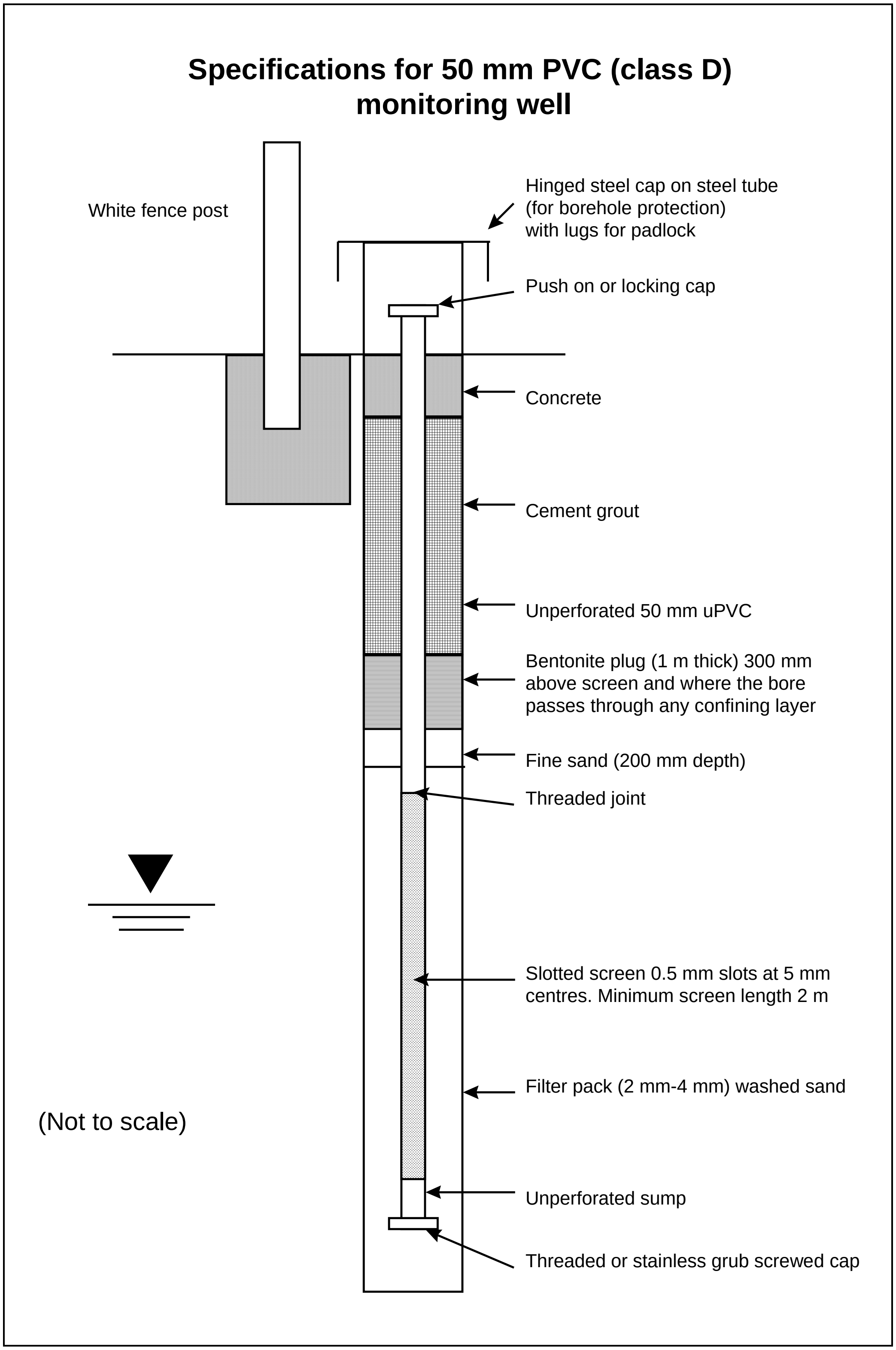


Figure 3.2 **Details of monitoring well**

Specifications for 50 mm PVC (class D) monitoring well with toby box and road cover

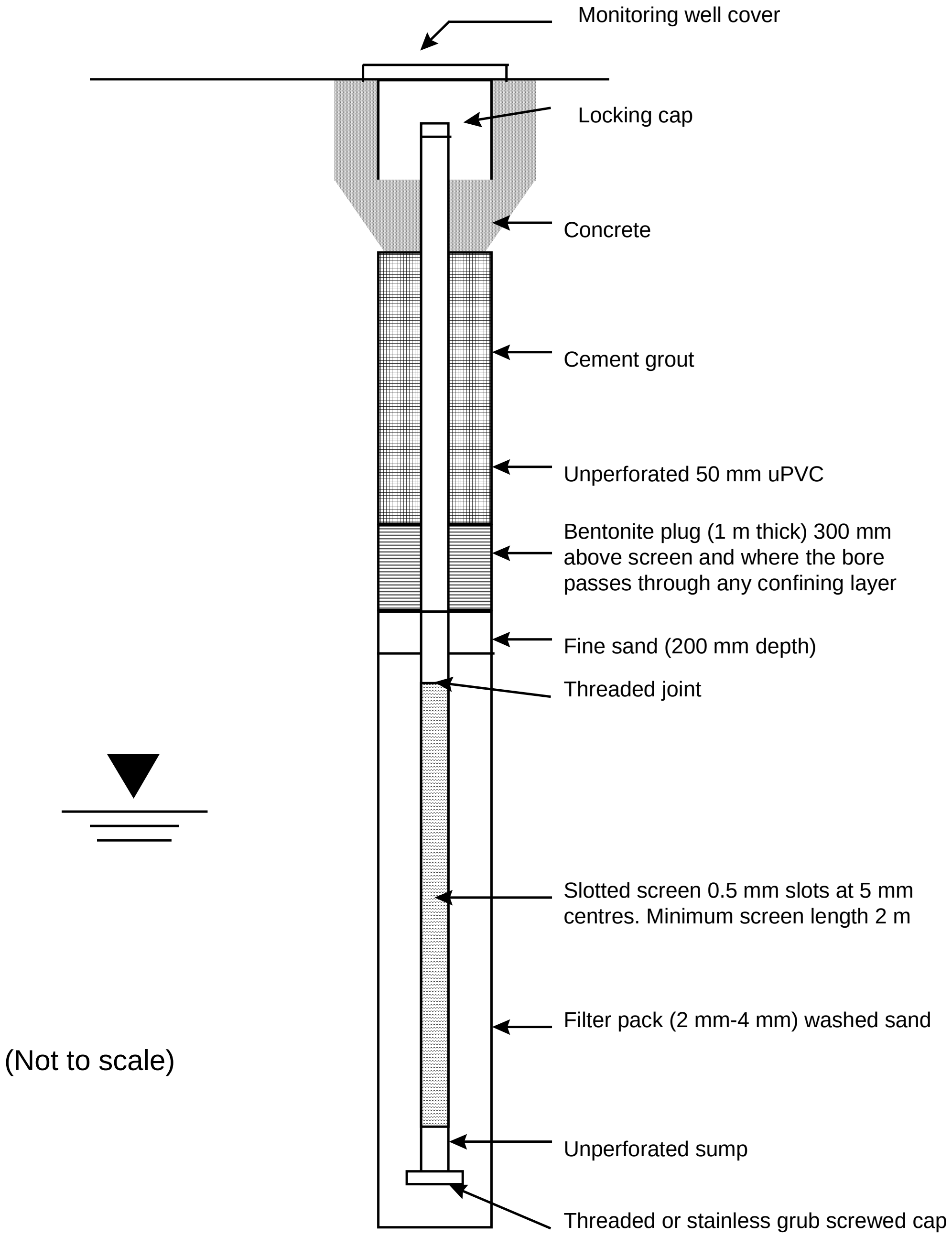


Figure 3.3 **Details of monitoring well with toby and road cover**

3.4.6.2 Well development and aquifer testing

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

- surging with bailer or surge block
- compressed air pumping with gentle surging
- bailing
- pumping
- combinations of the above.

Provision must be made for disposal of development water. In general, the water is relatively clean and can be discharged to the ground. If free-phase product is present, the water must be collected and properly disposed in accordance with local regulations and practices. Any monitoring well with free product must be developed carefully to prevent product being drawn down into the gravel screen and affecting subsequent water sampling. Product should be bailed-off prior to any significant draw down of water level during development.

Adequate development must be verified on the basis of stabilisation of basic water chemistry parameters including electrical conductivity, pH, temperature, and turbidity. Records of development must be maintained. Effectiveness of development should be checked by measuring total bore depth before and after pumping. Additional development or rehabilitation may be required if substantial sediment enters the borehole, sump or screen areas.

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

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

Slug tests are the least expensive aquifer testing method but are limited to zones with low to moderate transmissivity. Slug testing involves introducing or removing a slug of known volume into a well and recording the water level changes that result from either the instantaneous insertion or instantaneous withdrawal of the slug. The rate of recovery observed in the well is a function of the hydraulic properties of the aquifer and of the well itself. The transmissivity of the aquifer can then be estimated using appropriate well-flow equations.

Slug tests stress only a small portion of the aquifer adjacent to the well, and therefore, slug tests are incapable of evaluating hydrogeologic boundary conditions, hydraulic anisotropy, storage coefficients, and pumping characteristics of the well. However, slug tests commonly provide a cost-effective means of gathering point hydraulic conductivities across a large area. Slug tests are commonly considered as a first step in characterising an aquifer because of the relative low cost and effort requirements. Additionally, slug tests do not generate large volumes of groundwater. Therefore, the method is often used to initially characterise water-bearing zones beneath hazardous waste sites, where disposal options of contaminated groundwater may be limited or costly.

Pumping tests are most feasible for relatively high transmissivity zones, such as alluvial sand and gravel aquifers, or extensively fractured aquifers unless low discharge pumps (e.g. Grundfos) are available. In these types of aquifers, a long-term pumping test is the most accurate means of evaluating aquifer properties, and for evaluating other hydrogeologic factors such as boundary conditions, heterogeneity and anisotropy.

Several different types of pumping tests can be conducted to determine aquifer properties, although the fundamental principles of all tests remains similar. The principle of a pumping test involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response to that stress by monitoring draw down as a function of time in the pumping well and/or observation wells or piezometers at known distances from the well. These measurements are then incorporated into an appropriate well-flow equation to calculate the hydraulic characteristics of the aquifer and pumping well.

Numerous different types of pumping tests and well-flow equations exist that may be implemented for nearly all hydrogeologic settings. The overall approach for each test, including capabilities, limitations and assumptions are described below.

Step test involves pumping from a single well at a relatively low flow rate until draw down has stabilised. The pumping rate is then increased to a higher discharge rate until drawdown once again stabilises. This procedure is continued for at least three separate flow rates. Each flow rate is typically 20-40% greater than the previous rate, with a duration of typically 30 minutes to 120 minutes (Kruseman and de Ridder, 1991; Driscoll, 1986) per test.

In general, step tests are relatively short duration tests that are capable of providing general well performance characteristics and aquifer transmissivity and storativity in the vicinity of the pumping well. A step-test provides specific capacity data, and therefore should always be conducted prior to a long-term pumping test if no previous pumping data for the well exist. Step-tests are generally considered less effective for determining hydraulic anisotropy, leakage between layers, boundary conditions, and recharge areas than long-term pumping tests.

Constant discharge pumping test involves pumping from a well at a continuous, known, constant discharge rate over an extended period of time. This type of test typically involves monitoring draw down in several observation wells or piezometers, although the test may also be performed as a single-well test. Long-term, constant discharge pumping tests are the most accurate means of evaluating aquifer hydraulic properties. If properly designed and conducted, these tests can evaluate the following aquifer hydraulic characteristics: hydraulic transmissivity, storativity, hydraulic anisotropy, leakage from overlying or underlying layers, boundary effects, recharge areas, etc. Additionally, well performance characteristics such as well capacity, well yield, and well efficiency may be determined.

Recovery test should generally accompany a constant discharge tests and step tests. A recovery test measures the residual drawdown (s) following the pumping test. The recovery test provides the data required to calculate the transmissivity of the aquifer, thus providing an independent check on the results of the pumping test while costing very little in terms of the total cost of the pumping test (Freeze and Cherry, 1979; Kruseman and de Ridder, 1991). A recovery test is invaluable if the pumping test is performed without the use of piezometers or observation wells to evaluate potential borehole storage effects of the pumping well. Additionally, residual draw-downs are more reliable than draw downs measured during pumping, due to difficulties in the field of maintaining absolutely constant discharge from a pumping well (i.e., all pumps have a level of discharge variability).

3.5 Sampling methodology and protocols

This section discusses specific procedures for collecting soil, groundwater, surface water, sediment, and drain samples. Sample handling, identification, preservation, packaging, and shipping are also discussed. The OIEWG has prepared "*Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water*" (available from the Ministry's web site www.mfe.govt.nz/issues/contam.htm). It contains further detailed information to that presented in this section and will be updated regularly. Refer to it for the latest information.

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

- the sampling area is isolated to minimise potential for cross-contamination
- sampling equipment arrives at the site clean and wrapped
- samples are collected in a manner which minimises risks of cross-contamination
- samples are placed in containers and labelled
- samples are placed in cool storage
- quality assurance samples are collected
- samples are transferred with documentation to the laboratory.

3.5.1 Sampling area preparation

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

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

- All sampling equipment should be cleaned prior to obtaining each sample.
- Field personnel should wear clean PVC/latex gloves whilst handling sampling equipment and whilst taking samples.
- A clean pair of gloves should be used for each sample.
- Care should be taken when sampling to avoid any opportunity for excess aeration of the sample.
- Sampling equipment must be operated in a manner which avoids stirring up sediment.
- All organic samples should be well sealed using aluminium foil or Teflon.
- Water samples for VOCs analyses (i.e. hydrocarbons or BTEX) should be filled.according to laboratory specifications. The bottle should be inverted and gently tapped - if any air bubbles are present, the sample must be recollected.
- If free product is present, a sample of water with floating product should be collected for possible fingerprint analysis. Another sample, free of any product can be collected to assess levels of dissolved hydrocarbons. The water sample should be collected by floating off any

bubbles or product sheen. If the water sample has a sheen, this must be noted on the chain-of-custody and in the field book since such samples can only be of indicative value.

- During groundwater sampling the temperature, pH, turbidity, and electrical conductivity of each sample should be recorded.
- Each sample container should be labelled as outlined in Section 3.5.7. Sampling details and other pertinent data should be recorded.
- All samples should be kept under 4°C in iced chilly bins. Samples should be dispatched to the laboratory for analysis on the day of sampling.
- Chain-of-custody documentation should be completed for each sample.

3.5.2 Soil sampling procedures

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

The borehole/test pit numbering system adopted should conform with that specified in the sampling plan. Every soil sample should be collected, labelled and documented in the manner described in Section 3.5.7.

3.5.2.1 Soil sampling by machine excavator

Where a backhoe is used to recover soil samples the following precautions should apply:

- The backhoe should be in good condition and free of oil or hydraulic fluid leaks.
- The backhoe bucket and boom should be steam cleaned prior to each test pit and at the end of each day's work, ensuring residual grease and oil is removed.
- Following excavation to the target depth, all loose dirt should be removed from the backhoe bucket and a sample representative of the material at the target depth should be recovered using the backhoe.
- A sample should be recovered from the backhoe bucket using a cleaned sample spoon or trowel, taking care to select material that has not contacted the sides of the bucket. The sample should be placed in a clean glass jar with a foil or Teflon-lined cap.
- All holes should be backfilled and reinstated as nearly as possible to original condition.

3.5.2.2 Soil sampling by hand auger

Soil sampling procedures specific to hand auguring are as follows:

- All auger parts should be pre-cleaned and wrapped in aluminium foil until used.
- Care should be taken to select material such that the possibility for cross-contamination is minimised.
- All equipment should be cleaned between each sample point.
- All holes should be backfilled and reinstated as close as possible to original condition.

3.5.2.3 Soil sampling by drilling

Soil sampling procedures specific to drilling are as follows:

- The drill string should be steam cleaned before starting each borehole.
- All sampling equipment should be cleaned before getting each sample.
- Samples should be recovered by driving a split-spoon type sampler into undisturbed material.
- All field staff should change to a clean pair of gloves before handling each sample.
- Where monitoring wells are not required, boreholes should be sealed with cement grout at the completion of the drilling.

3.5.3 Groundwater sampling from monitoring wells

The following measurements should be taken prior to sample collection:

- standing water level
- total depth of the well
- depth to the top of floating product.

Water and product levels should be measured from the lip of the standpipe or well cover. The reference point should be noted and surveyed to a relative datum.

After determination of water levels in all wells on site, sampling can begin. The method of purging a well prior to sampling has received a great deal of attention in the United States. Numerous studies have been performed to determine the need for purging. A report prepared for the Western States Petroleum Association (WSPA) by SECOR International Incorporated (1996) states that "... data analysis indicates that the degree of variability introduced into the sampling process by the absence of purging is no larger than, and in many cases, much smaller than, the variability introduced by the choice of purging method."

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

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

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

- A low pump rate should be used for purging to reduce mobilisation of sediment.
- The bailer or pump should be lowered gently to avoid disturbance of any sediment that may still be in the bore and to avoid damage to the bailer or the rope.
- Samples should be recovered from the slotted section of the standpipe.

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

If product is present in the groundwater sample, the analytical results are considered biased and should only be used for indication. These results should not be used in the risk analysis.

3.5.4 Surface water sampling procedures

Observations of surface water flow, substrate, aquatic life, staining, odour and recent weather must be recorded in the field book and referenced to each sampling location. Samples should be recovered from the surface water body at locations designated in the sampling plan. Surface water samples should be recovered from below the water surface to prevent accidental sampling of surface slicks. A suitable sampling device, able to recover samples from a designated depth and prevent ingress of surface water, should be employed. Such devices are readily available. If possible, the sample should be taken directly into the sample container prepared by the laboratory. Surface slicks should be noted and sampled separately.

Care must be taken when sampling to avoid aerating the sample. Additional requirements are as follows:

- Observations such as river gauge levels, colour etc. and particularly how the sample relates to the general stream or drain bed must be recorded in the field book.
- Samples should be collected in an upstream direction to avoid disturbance of sediment which might affect downstream samples.
- Where sample bottles contain a preservative, surface water samples should be collected in a suitable container and transferred to the preserved sample container.
- Each sample collected should be recorded on a sample collection record form.
- Sample containers which have been immersed in water to collect samples shall be placed in clean polyethylene bags to minimise the potential for cross-contamination.

3.5.5 Drain sampling procedures

Water samples may be collected from drains across the site, as designated in the sampling plan, using a stainless steel bailer, stainless steel sampling container or glass jar. Sampling of drains may require field personnel to enter manholes in order to recover the samples. Appropriate confined space procedures should be followed when entering manholes:

- Samples should be collected progressively in an upstream direction to avoid disturbance of sediment which might affect downstream samples.
- The sampling equipment should be lowered gently to avoid disturbance of any sediment.
- Where sample bottles contain preservatives, water samples should be collected in a suitable container and transferred to the preserved container.
- Each sample collected should be recorded on a sample collection record form.

- Sample containers which have been immersed in water to collect samples should be placed in clean polyethylene bags to minimise the potential for cross-contamination.

3.5.6 Sediment sampling procedures

Sediment samples are typically collected from the finest fraction of the stream or lake sediment load, unless sampling objectives suggest other locations. Additional requirements are as follows:

- Observations such as river gauge levels, colour, etc. and particularly how the sample relates to the general stream, lake, or drain bed must be recorded in the field book..
- Sediment samples should be obtained using a grab sampler or other suitable device.
- Sampling should commence at the furthest downstream location working back upstream.

3.5.7 Sample identification, packaging, preservation, shipping, and documentation

This section outlines specific procedures for identifying, packaging, preserving, and shipping soil and water samples.

3.5.7.1 Sample identification

Each sample should either be individually labelled at the time of collection using waterproof, indelible ink or pre-labelled by laboratory personnel. If pre-labelled, pre-preserved sample bottles are provided by the laboratory for specific analyses, other pertinent information should be added to the label at the time of collection. Self-adhesive labels should be securely affixed to the sample container not to sample lid or cap. Sample's identification should be written on the cap in indelible ink in case the label comes off. Using tags or any type of labelling which can be accidentally separated from the sample should be avoided.

Each sample label should include the following information:

- site name
- sample ID code or number (which should also be recorded on the lid)
- name of sample collector
- date and time of collection (this starts the holding time clock)
- depth of sample
- preservatives used (or absence of any preservatives)
- analyses requested.

A single sample may not be sufficient for multiple analyses since different analyses may require different preservatives and/or different sample containers.

3.5.7.2 Sampling packaging and preservation

The analytical methods guideline presents information regarding sample volumes, size and type of sample containers, preservatives, and holding times required. In most cases, preservation includes refrigeration of the sample (4ºC) from the time of sampling to laboratory analyses.

As a general rule of thumb, unless the cohesive-sample soil core method of sampling is used, volatile constituents (for example, BTEX, and TPH) usually require a separate sample container from the sample container used for semi-volatiles and metals analyses. Care must be taken to prevent water-containing samples from freezing because this can cause degassing, fracturing of the sample or separation of a slightly immiscible phase. Preservatives should be prepared in the laboratory using reagent grade chemicals and distilled water and stored in tightly sealed containers, away from sources of contamination. If sample containers are not pre-preserved in the laboratory, aqueous preservatives can be taken to the field in small dropper bottles to facilitate field preservation procedures.

3.5.7.2 Shipping

Samples should be properly labelled, recorded on the chain-of-custody form and shipped to the laboratory as soon as possible (usually daily). Care should be taken to preserve the integrity of the samples in transport by keeping them cool (4°C). This may be accomplished with the use of reusable frozen gels designed to maintain a cool temperature or bags of ice. Letting samples sit in the hot sun or car for several days seriously compromises analytical data. Again, care must be taken to prevent water-containing samples from freezing because this can cause degassing, fracturing of the sample or separation of a slightly immiscible phase.

Samples should be packaged in a proper shipping container to avoid leakage, breakage or contamination. Acceptable packing materials include polyurethane chips, vermiculite, plastic bubble wrap and sawdust. As an extra precaution, volatile sample containers can be doubled-wrapped in plastic bags to prevent cross-contamination. All samples should be accompanied by a sample analysis request/chain-of-custody record.

The forwarding and return addresses, along with phone numbers, should be written legibly in waterproof ink. The receiving laboratory should be notified of the expected date of arrival of the samples. In this way, if the samples are not received in a reasonable length of time, the sender can be notified so that samples lost in transit can be traced expediently. The analytical laboratory should notify the project contact of any samples not received intact.

3.5.7.4 Field documentation

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

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

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

- job number
- sampling location number
- sample number
- sample depth
- date.

Each sample should be labelled with the same information, correlating directly with the record of sampling to be kept by the field supervisor.

A chain-of-custody record is required for all samples. Its purpose is to trace sample possession from the time of collection through analyses. The following information should be included in a chain-of-custody record as a minimum:

- sample identification numbers which can be referenced to specific sampling points and times
- name or number of the sample collector
- sample collector’s signature
- date and time of collection
- location of site
- sample type
- analyses requested (if chain-of-custody form is also used as Analysis Request form)
- signatures of persons involved in the chain of custody (sampler, transporter, laboratory personnel who accept the sample)
- dates of sample possession (when relinquished, when accepted).

3.6 Data quality objectives

The purpose of data quality objectives (DQOs) is to guide decisions and processes for collecting, analysing and evaluating data that will satisfy the overall programme objectives. General considerations used to establish DQOs are:

- why the environmental datum is needed and how it will be used
- the consequences of an incorrect decision being made as a result of inadequate or invalid environmental data
- level of uncertainty in the results derived from the environmental data that the decision maker is willing to accept.

Additionally, the development of DQOs requires specifying the following:

- sample locations and frequency
- sample collection procedures
- sample handling procedures
- measurement of constituents
- analytical methods used to measure the constituents.

3.6.1 Data categories

There are two data categories, each with specific quality assurance/quality control (QA/QC) elements to ensure data will be of known quality. The categories include screening data and definitive data. Screening data are generated using less precise methods to provide analyte identification with relatively imprecise quantitation and less stringent QA/QC procedures. Definitive data are generated using rigorous analytical methods and QA/QC procedures.

Definitive data generated can be used in the following tasks:

- risk assessment
- site characterisation
- alternative evaluation
- engineering design
- monitoring during implementation.

Screening data are typically used for real-time health and safety monitoring or organic vapour concentrations and measurement of water quality parameters during purging and sampling activities.

3.6.2 Levels of concern and detection limit requirements

The level of concern specifies a concentration range above which some action may need to be taken and therefore, the level of concern is intimately linked with the guidance levels (see Modules 4-6). The selected level of concern directly affects data quality requirements. The sampling and analysis methods used must be accurate at the level of concern. The analytical technique chosen has a detection limit well below the level of concern.

3.6.3 Data quality indicators

Data quality refers to the level of reliability associated with a particular data set. The data quality associated with environmental measurement data is a function of the sampling plan rationale and procedures used to collect the samples, as well as the analytical methods and instrumentation used in making the measurements. Each component has its own potential sources of uncertainty and biases which may affect the overall accuracy and/or precision of measurement.

Sources of uncertainty that can be traced to the sampling component of environmental data collection are poor sampling plan design, inconsistent use of standard operating procedures (SOPs) and incorrect sample handling or storage. The most common sources of uncertainty that can be traced to the analytical component of the total measurement system are problems associated with calibration and instrument contamination. Uncertainty cannot be eliminated entirely from environmental data. The amount of uncertainty that is tolerable depends on the objective of the sampling programme and the intended use of the data collected.

Data quality will be assessed in terms of precision, accuracy, representativeness, completeness, and comparability (PARCC) of the data. The PARCC definitions and QC procedures used to evaluate the PARCC criteria are presented below.

- **Precision.** Precision is the reproducibility of measurements under a given set of conditions. Precision is evaluated by comparing the relative percent differences (RPDs) of field duplicates and laboratory duplicates to acceptance limits.
- **Accuracy.** Accuracy measures laboratory method bias and/or the level of agreement between a measurement and a known true value. Accuracy is assessed by comparing the percent recoveries laboratory control samples against the acceptance limits.
- **Representativeness.** Representativeness is a qualitative parameter used to evaluate whether the data represent the actual environmental conditions during sample collection.

The representativeness evaluation includes review of sample collection, handling methods (holding times, cooler temperatures and temperature blanks) and trip, equipment rinsate and laboratory method blank results.

- **Completeness**. Completeness is defined as a percentage of measurements that are judged acceptable in terms of precision, accuracy, representativeness, and comparability. Completeness is calculated by dividing the number of acceptable sample results by the total number of sample results.
- **Comparability.** Comparability is a qualitative expression of confidence with which one data set can be compared to another. The assessment of comparability includes a review of sample collection and handling methods and laboratory sample preparation, analysis and quantitation procedures.

3.6.4 Field quality control (QC) samples

Field QC samples include field duplicate samples, equipment rinsate blank samples, and field blank samples. Field QC samples assess sample collection techniques and monitor possible cross-contamination between samples and/or equipment. The various types of field QC samples are as follows:

- **Field duplicate samples.** Field duplicate samples are collected from a single sample location in conjunction with field samples and submitted to the laboratory without indication of the association between the two samples (i.e. a ‘blind’ sample). The field duplicate sample analyses assess the consistency of the sampling technique and the precision of the analytical laboratory. One field duplicate sample is typically collected for every 10-20 field samples.
- **Equipment rinsate blank samples.** Equipment rinsate blank samples are collected after a sampling device has been decontaminated to assess potential cross-contamination between samples as a result of poor decontamination procedures. One sample per day is typically collected.
- **Field blank samples.** Field blank samples are bottles of deionised water prepared in the field and included in each sample cooler containing VOC samples. Field blank samples are used to evaluate sample representativeness by identifying any volatile compounds that may have been introduced into the field samples during sample collection, transportation or storage at the laboratory.

3.7 References and further reading

American Petroleum Institute (API). 1996. **A Guide to the Assessment and Remediation of Underground Pe troleum Releases.**

Australia and New Zealand Environment and Conservation Council (ANZECC), National Health and Medical Research Council. 1992. **Australia and New Zealand Guidelines for the Assessment and Management of Contaminated Sites.**

Driscoll, F.G. 1986. **Groundwater and Wells.** 2nd Ed., Johnson Division of Wells, St. Paul, Minnesota.

Freeze, R.A., and J.A. Cherry. 1979. **Groundwater.** Prentice-Hall, Inc., Englewood Cliffs, N.J.

Kruseman, G.P., and N.A. de Ridder. 1991. **Analysis and Evaluation of Pumping Test Data.** 2nd Ed., National Institute for Land Reclamation and Improvement/LRI, Wageningen, The Netherlands, 377p. Available through the NWWA Bookstore.

New Zealand Geological Survey Report. 1982. **Revised Guide to Recording Field Observations in Sedimentary Sequences**.

New Zealand Geomechanics Society. 1988. **Guidelines for the Field Description of Soils and Rocks in Engineering Use.**

OIEWG 1999. **Draft Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water.** (available from the Ministry's web site http://www.mfe.govt.nz/issues/contam.htm)

Schwerko, E.M. 1994. **Sampling and Analytical Methods for Petroleum-Contaminated Soil and Groundwater. An Overview**

SECOR International Incorporated. 1996. **The California Groundwater Purging Study for Petroleum Hydrocarbons.** Prepared for The Western States Petroleum Association. Glendale, California.