National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April

Schedule B2

GUIDELINE ON

Site Characterisation

The following guideline provides general guidance in relation to characterisation of contaminated sites.

This Schedule forms part of the National Environment Protection (Assessment of Site Contamination) Measure as varied 2011 and should be read in conjunction with that document, which includes a policy framework and assessment of site contamination flowchart.

It aims to ensure consistency in characterisation of potentially contaminated soils, groundwater, vapour and soil gases in order to inform appropriate human health and ecological risk assessment. It should be read in conjunction with other Schedules to the Measure.

This Schedule replaces Schedule B2 to the National Environment Protection (Assessment of Site Contamination) Measure 1999.

The National Environment Protection Council (NEPC) acknowledges the contribution of a number of individuals and organisations towards the development of these guidelines; in particular, the WA Department of Environment and Conservation, CRC CARE, CSIRO Land and Water, WA Department of Health, and individual officers of the NSW Department of Climate Change and Water, the QLD Department of Environment and Resource Management, EPA Victoria, and the Commonwealth Department of Health and Ageing.

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1 Introduction

Adequate site characterisation is the foundation for acceptable assessment of health and environmental risks associated with site contamination. This guideline provides information on the design and implementation of soil, groundwater and vapour sampling programs and the presentation of site assessment reports.

Risk of explosion or other acute exposure hazard should be addressed immediately and is not within the scope of this guidance document.

The investigation components of a contaminated site assessment are:

- establishing the objectives of the site assessment
- desktop study and detailed site inspection
- development of a conceptual site model (CSM)
- identification of data gaps
- development of data quality objectives (DQOs)
- design of a sampling strategy and optimisation of a sampling and analysis plan (SAP)
- data collection (delineation of potential and known contamination)
- data validation, analysis and interpretation (including risk assessment and iterative development of CSM)
- coherent presentation and reporting.

2 Stages of investigation

Source: Davis et al. (2006) and Clements et al. (2009)

Schedule A in the Measure shows the staged site assessment process which indicates that this guideline applies to both preliminary and detailed site investigations.

Many site investigations proceed in multiple stages due to the complexity of site conditions and of contaminant properties and/or the discovery of unexpected contamination. Poorly planned and executed site investigations are likely to result in time delays and additional costs (both during the investigation and any subsequent remediation), and inadequate or misleading data which may result in risks to human health and/or the environment not being addressed.

Site investigation efforts should be purpose driven, adequate in scope and of sufficient quality to meet the purpose of the assessment. They should provide representative site data. In order to achieve these objectives, the recommended procedures are to clarify the purpose of the investigation, develop a CSM, develop DQOs and identify data gaps. A SAP can then be designed and implemented to achieve the desired objective(s).

Depending on the proposed land use and the results of initial site history investigations, the preliminary and detailed investigations may be incorporated into a single phase of investigation. Proponents and site assessors may also wish to adopt an accelerated site characterisation approach whereby rapid and 'real-time' sampling and field analytical methods, and on-site interpretation and iteration of field data are undertaken in order to expedite the characterisation process. Further information on accelerated site characterisation methods can be found in Clements et al. (2009), and at <www.triadcentral.org/tech>, as well as on the Environment Canada website at <www.on.ec.gc.ca/pollution/ecnpd/contaminassist_e.html >.

Regardless of the approach taken, the site investigation must cover all the components which enable an appropriate level of risk assessment for human health and the environment to be undertaken.

2.1 Preliminary site investigation

Preliminary site investigations (PSIs) usually include a desktop study to identify the site characteristics (site location, Aboriginal heritage considerations, site layout, building construction, geological setting, historical land uses and activities at the site) and a site inspection (including interviews with site representatives). The preliminary investigation should be sufficient to determine potential contaminants of concern and to identify areas of potential contamination.

It is not necessary to delineate any contamination at this stage. Limited sampling may be included in a PSI, providing sufficient information is available to inform an appropriate site health and safety plan. Any investigations undertaken, however, are usually confined to areas where potentially contaminating activities have occurred and involve a site history-based sampling plan. This Schedule provides more detail on the scope of preliminary investigations. If thorough preliminary investigation shows a history of non-contaminating activities and there is no other evidence or suspicion of contamination, further investigation may not be required.

2.2 Detailed site investigation

A detailed site investigation (DSI) is required when the results of the preliminary investigation indicate that contamination is present or is likely to be present and the information available is insufficient to enable site management strategies to be devised. Potential or actual contamination will usually require further delineation. Potential contamination may have been indicated by the presence of underground structures (for example, underground fuel or chemical storage tanks), the presence of fill (for example, ash, odorous material or various types of waste), or staining of soil. Actual contamination may have been detected in the form of contaminants which are not naturally occurring or as elements or compounds which are above background levels or exceed the investigation levels (see Schedule B1 for more information).

The detailed investigation stage should identify the nature of the contamination and delineate its lateral and vertical extent to a sufficient degree that an appropriate level of risk assessment may be undertaken and, if necessary, to provide the basis for the development of an appropriate remediation or management strategy.

3 Basic site information

The purpose of collecting basic site information is to identify potential contaminants and potential areas of contamination by reviewing the site history, local geology and hydrogeology and site conditions. A site inspection should be undertaken (including interviews with site representatives past and present where practicable) to confirm the findings of the desktop study and site history and to identify any additional relevant site information. It is essential that the location of the site and the significant features involved in its contamination history be accurately and clearly identified. The information collected forms the input to the initial CSM.

3.1 Site identification

The current legal description (real property description, for example, lot on plan) of all affected parcels and the street number and name and suburb should be obtained, together with a copy of the current certificate of title. It is also useful to list any common name or description by which the site is/has been known.

Where multiple lots are involved, plans which show lot boundaries in relation to significant features should be obtained. Maps (including street maps), plans or diagrams should be used to clearly identify the location of all affected land parcels in relation to surrounds, for example, street access, neighbouring property boundaries, parks, local watercourses and any areas of environmental significance.

3.2 Current and proposed use

The following details should be obtained:

- current uses of the site
- map and narrative description of proposed use(s) for the site
- current land zoning of the site, for example, industrial, mixed commercial, residential, educational
- type of proposed use - in the context of the categories detailed in Schedule B1
- density of residential use (if proposed)
- type of users, e.g. residents (adults and children), workers, ecological
- local government approval(s) for proposed use (and date).

3.3 Site history

Source: Edwards et al. (1994) & EPA NSW (1997)

A site history should contain, as far as practicable, all available information which assists in identifying the nature and extent of site contamination. It should address the following issues:

3.3.1 Site plan and aerial photographs

It is essential to have a locality map and a current plan of the site, with scale bar, indicating the site orientation (including north) and general topography of the property, local water drainage and other environmentally significant features. A review of the site history deduced from current and historic aerial photographs should be included (where available) with dates.

3.3.2 Zoning

Necessary records include previous, present and proposed zoning, and relevant development and building approval records.

3.3.3 Present owners, occupiers and current users of the site

If these are not the parties responsible for the assessment and management of the site then those who are (or thought to be) responsible should also be identified.

3.3.4 Previous owners and occupiers of the site

These should be listed chronologically noting any periods during which ownership or tenancy is unknown or uncertain.

3.3.5 Previous activities/uses

A chronological list of land uses should be compiled, focusing on industrial uses or other potentially contaminating activities, and including any periods during which the land use is unknown or uncertain. While ′small tannery′ may be seen as an imprecise description, it nonetheless provides some information about the nature, severity and distribution of any potential contamination. Precise industrial capacities of properties should be cited if available. The chronology should include dates when areas of the site were sealed, for example, by concrete slabs, in relation to the occurrence of potentially contaminating activities to prevent unnecessary under-slab sampling, although the potential for the migration of contamination underneath hardstands from adjacent sources will need to be taken into account. Consideration should also be given to uses on adjacent sites that could be a source or receptor of contamination.

3.3.6 Previous and present building and structures

These are generally best illustrated by a series of annotated site maps showing the locations of permanent and semi-permanent structures, offices, sheds, reaction vessels, storage tanks, etc. These should be presented in chronological order to show how the site developed. Key building design features such as the nature of foundations, presence or absence of crawl spaces or basements should also be included.

3.3.7 Industrial processes carried out on site and the products manufactured

A list should detail the products from the industries and/or activities identified above.

3.3.8 Raw materials used

A list of raw materials stored or used at the site should be compiled. Chemicals should be identified by systematic names as well as common or trade names.

3.3.9 Intermediate products

These are important in both batch and continuous production processes. Residual reaction components and intermediate products may have been discharged from reaction vessels prior to production runs. Quality assurance procedures may also have included sampling points from intermediate stages in the manufacturing process which may have been allowed to drain away or be otherwise discarded on site.

3.3.10 Wastes produced

This requires an understanding of the processes being performed in the industries and activities identified above. Wastes may be identified specifically (for example, waste degreasing solvents including carbon tetrachloride) or more generally (for example, acid slurry).

3.3.11 Waste disposal locations and imported fill

Locations of solid waste disposal areas and liquid waste lagoons, settling tanks, sumps and soak wells should be identified in the maps and figures described above. The location of any wells on site should be indicated as these may have been used historically for liquid waste disposal.

Site contamination is commonly caused by landfilling of wastes and importing contaminated fill. Historically, many industrial wastes and diverse contaminated fill materials were considered a low-cost source of material to level or elevate sites. Wastes may have originated from on-site industrial activities or have been introduced from unknown off-site sources. Residential and industrial/commercial areas around major industries (for example, coal gas works, power stations, and mineral processing plants) may have been filled with ash, coke, hydrocarbon impacted fill, metal waste and various wastes originating from the industrial activity.

Sites should be assessed for areas of fill, particularly if there are reasonable grounds to suspect the original land form has been altered such as by filling gullies and watercourses.

3.3.12 Discharges to land and water

The types of waste currently and historically discharged should be identified. Where practicable, the quantities should also be established.

3.3.13 Product spills, losses, incidents and accidents (including fire)

These should be listed chronologically, together with an indication of the material spilled, estimates of quantity, extent of fire damage and structures affected.

3.3.14 Services to the property (including sewer and underground services)

Site plans showing the location of sewers, stormwater drains and underground utilities (such as communication infrastructure) should be included as these may assist in identification of preferential contamination migration pathways.

3.3.15 Chemical storage and transfer areas

Locations should be indicated on the scaled site plan and chemicals stored/transferred at each area identified.

3.3.16 Power generation

Many historical activities required steam as part of the process or for power generation. Before the advent of electric power, generation of steam could have progressed from solid to liquid fuels requiring fuel storage and disposal of ash. This may have resulted in contamination by fuel and combustion products, for example, PAHs (polycyclic aromatic hydrocarbons). If the power requirement was large, a sub-station with a transformer(s) may have been on site with the attendant risk of PCB (polychlorinated biphenyls) spills. In addition, fibrous asbestos may have been used for insulation purposes.

3.3.17 History of adjacent land uses

It is possible that contamination on a site may not be associated with any of the activities carried out on that land but may be a result of the migration of contamination from adjacent or nearby sites. Past and present uses of surrounding properties which may have caused a contamination impact should be identified where practicable.

3.3.18 Interview information

Interviews with past property or business owners and occupiers and employees should be documented where practicable.

3.3.19 Earth moving activities carried out on the site.

This information will assist in determining the source and location of any imported fill.

3.4 Sources of information

A log of all sources consulted for site history information should be kept so that the completeness and reliability of the information collected, and hence confidence in the desktop study results, may be assured. Personal recollections and anecdotal records should be cross-checked where possible and any limitations of the information noted.

Sources of information for compiling a site history include:

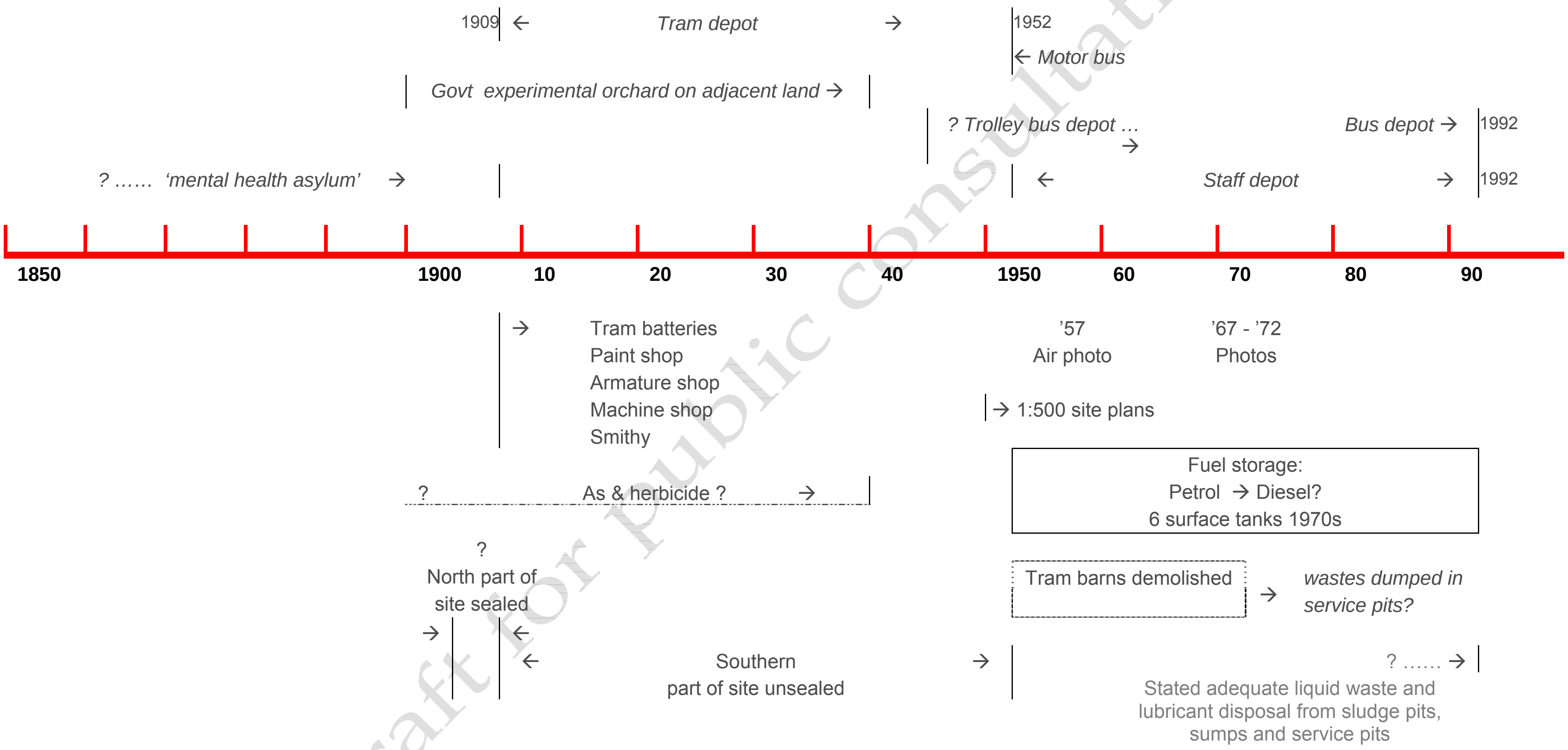
- past and current owners and occupiers, operators or workers at the site and adjacent properties
- local knowledge of residents
- aerial and ground photographs
- past involvement with government authorities or consultants
- trade and street directories
- historical societies and local, state or territory government libraries
- historical titles back to original deeds
- local literature, including newspapers
- technical literature, including plumbing and building permits/plans, flammable and combustible liquid storage and handling licences
- complaint history and information from environmental licences and trade waste permits held by local government or state government departments
- geological survey maps and reports
- local government development approval records, sewer and underground service plans
- site layout plans.

Table 1. An example of a site chronology table where the gaps in the data and inadequacies of information are readily identified

Date	Owner	Occupant	Industry or land use	Process equipment plant	Chemicals inputs by-products waste	Buildings, structures and services	Soil cover vegetation paved areas	Fill and excavation	Comments
1993 (to Mar)	PD Nominees	PD Nominees	Springwater bottling	Confidential					
1986 (from Sept)	PD Nominees	PD Nominees	Vinegar bottling		Acetic Acid	20x30 m Warehouse built Nov 1986	Site completely covered by a concrete slab		Soil logs available from the warehouse Construction
1979 (11 Jun)	PD Nominees	R McLaren	Motor vehicle repair and car park		Oils solvents lubricants	No buildings on site unfenced	Half of site covered by 150mm of coarse gravel	Coarse gravel...	Surface oil waste contamination
1979 (10 Jun) 1978 (5 Nov)	F. Bath	F. Bath	Electrical workshop		Solders, capacitors, mercury switches	Workshop destroyed in fire			Burning building associated with colourful flames
1979 (5 Nov) 1972	R. Bath								
1972 1965	R. Bath	R. Bath and Sons	Process control and electrical motor maintenance	Burnt coatings off copper wire for scrap copper sales					(some complaints under the Clean Air Act)
1965 1958 (Sept)	R Bath and D Fergusson	R Bath and D Fergusson	Electrical motor rewinders			Tannery building converted to workshop (property still fenced), drying shed removed		Tannery pits filled	
1958 (Sept) 1958 (Feb)	D Muldoon Land being subdivided	Unoccupied due to closure of tannery							Cadastral survey records show ground level at 0.35 metres lower than in the 1979 survey

Source: van Alphen (1993)

Figure 1. An example of the representation of site history information on a time line, to enable a check of the completeness of available information. *This graphic illustrates 5 pages of site history text.*



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Source: van Alphen (1993)

3.5 Local geology and hydrogeology

The local and site-specific geological and hydrogeological settings influence the fate and transport of potential contaminants in the vicinity of and at the subject site.

Where contaminants are present, their distribution across the site is mainly influenced by the local geology and natural or man-made/altered drainage features in the area or at the site. Their distribution within the sub-surface is influenced by geological structures, variations in the permeability of soil and rock, geochemical, biological and mineralogical variations and the presence of preferential pathways such as loose fill around services.

Certain sites may be located in areas that are naturally enriched with mineral resources and can appear to contain elevated levels of metals and metalloids in soil, surface water and/or groundwater. For this reason, it is essential to have an understanding of the background quality of these media and to evaluate potential contamination of this type of site in terms of the beneficial uses of the site and its water resources.

The geological/hydrogeological component of the desktop investigation may include review of the following types of published data:

- surface elevation
- regional and site-specific soil and geological records
- geophysical data
- drilling logs which clearly identify imported and locally derived fill (including refuse) and natural strata
- well logs including strata, casing or construction details, and water level, quality and pump/discharge rate information
- aquifer types (unconfined, semi-confined, confined) and aquitards/aquicludes present
- direction and rate of groundwater flow
- values for soil bulk density and porosity
- storativity or storage
- soil organic matter content
- cation exchange capacity (CEC)
- soil pH and redox (Eh) potential measured in situ
- regional and site-specific hydrogeologic information, including groundwater quality
- hydraulic and piezometric heads and hydraulic gradients
- hydraulic conductivity
- transmissivity
- current usage/resource potential
- existing monitoring wells and records of registered production wells or survey of surrounding landholders to determine the existence of wells where the resource may potentially be used in the vicinity of the site
- other parameters as appropriate.

Appendix III of the *Guidelines for groundwater protection in Australia* (ARMCANZ & ANZECC 1995) gives helpful advice on hydrogeological desktop studies.

These data form the basis of an initial appraisal of the potential risk to a receptor. When the likelihood of an unacceptable groundwater impact is identified, Schedule B6 should be consulted.

3.6 Site inspection

A site inspection should be conducted by a professional who is suitably qualified and experienced in the assessment of contaminated sites. For further information on suitable qualifications and experience, refer to Schedule B9.

A comprehensive site inspection is a critical stage of the site assessment process to validate anecdotal evidence and historical information and to identify additional evidence of potential contamination. Generally, site history and site inspection work are best conducted in tandem.

The complexity and detail in a site inspection may vary depending on the level of historical information and anecdotal information relevant to the site and the complexity and detail of the site itself. The following features, amongst others, should be noted:

- current uses of the site and surrounding land
- disturbed coloured or stained soil
- bare soil patches
- disturbed or distressed vegetation
- unusual odour
- quality of surface water
- sheens on water surfaces
- site topography and surface water drainage
- presence of groundwater abstraction bores on the site and adjacent landholdings
- condition of groundwater bore headworks
- measurement of groundwater (water table and/or piezometric) levels
- condition of buildings, concrete and bitumen floors and roads, etc.
- building construction (slab on ground or other, presence or absence of crawl spaces and basements)
- presence or absence of asbestos containing materials (ACM) on the ground surface
- presence of stockpiles, fill, containment areas, sumps, drains and landfill sites – operational and closed
- presence and condition of chemical containers, holding tanks, bunds, etc.
- underground structures that may be associated with sub-surface contamination
- condition of materials storage and handling facilities and any solid or liquid waste disposal areas
- any evidence of on-site spillage of dangerous goods and/or off-site migration.

4 Conceptual site models

4.1 Overview

A conceptual site model (CSM) is a representation of site-related information regarding contamination sources, receptors and exposure pathways between those sources and receptors. The development of a CSM is an essential part of all site assessments and provides the framework for identifying how the site became contaminated and how potential receptors may be exposed to contamination either in the present or in the future.

Typically, the CSM should be presented in written format and illustrated with suitable graphics. Example graphics can be found in Clements et al. (2009) and Davis et al. (2009a).

The CSM can be a useful tool for informing discussions with stakeholders regarding the investigation and management of potential and known contamination impacts.

4.2 Iterative development of conceptual site models

Source: Clements et al.(2009); SA EPA (2009) and Davis et al. (2009a)

The initial CSM is constructed from the results of the PSI which is used to identify data gaps and inform a decision on whether detailed investigation is required. The CSM is a dynamic process and should be reviewed and refined as further information is obtained and used to inform decisions on whether further investigation or management is necessary. Note changes to the CSM may also involve revision of the data quality objectives (DQOs) – see section 5.

The CSM should identify complete and potential pathways between the known or potential source(s) and the receptor(s). Where the pathway between a source and a receptor is incomplete, the exposure to chemical substances via that pathway cannot occur, however, the potential for that pathway to be completed (for example, by abstraction of groundwater or a change in land use) should be considered in the assessment.

Data gap identification and uncertainty assessment are key activities in developing and refining a CSM during site assessment. Subsequent investigative efforts should be proportional to the uncertainties identified and their relative importance to the assessment objectives. The identification of data gaps should be carried out in a logical, structured manner, to facilitate the assessment of uncertainty and significance of those data gaps.

The complexity of the CSM should correspond to the scale and complexity of the known or potential contamination impacts.

The essential elements of an initial CSM are:

- Known and potential sources of contamination and contaminants of concern
- potentially affected media (soil, groundwater, surface water, air)
- human and ecological receptors
- potential and complete exposure pathways.

For the assessment of vapours, additional detail will be needed about the design of buildings and/or planned buildings at the site — including the location of sub-surface utilities, foundation construction and condition, and ventilation and heating (Davis et al. 2009a).

A spreadsheet tool for assessing gaps and uncertainties in CSMs, and assessing their level of significance, can be found in Clements et al. (2009).

Further information about developing CSMs can be found in:

- ASTM E1689–95 (2008) *Standard guide for developing conceptual site models for contaminated sites*, ASTM International.
- ASTM E2531–06 (2006), *Standard guide for development of conceptual site models and remediation strategies for light non-aqueous-phase liquids released to the subsurface*, ASTM International.
- Clements, et al. 2009, *Characterisation of sites impacted by petroleum hydrocarbons: guideline document*, CRC CARE Technical Report no. 11, CRC Contamination Assessment and Remediation of the Environment, Adelaide.
- Clements, et al. 2009a, *Field assessment of vapours*, CRC CARE Technical Report no.13, CRC Contamination Assessment and Remediation of the Environment, Adelaide, South Australia.
- ITRC 2007a, *Vapor intrusion pathway: a practical guideline,* VI-1, Vapor intrusion team, Interstate Technology & Regulatory Council, Washington, DC.
- ITRC 2007b, 'Vapor intrusion pathway: investigative approaches for typical scenarios', a supplement to *Vapor intrusion pathway: a practical guideline,* Technical and regulatory guidance supplement prepared by the ITRC vapour intrusion team, Interstate Technology & Regulatory Council, Washington, DC.
- NJDEP 2005, *Vapor intrusion guidance*, New Jersey Department of Environmental Protection. (Available online at <www.nj.gov/dep/srp/guidance/vaporintrusion/vig.htm>).
- ODEQ 2010, *Guidance for assessing and remediating vapor intrusion in buildings*, Report no. 10-LQ-007, Oregon Department of Environmental Quality, USA.
- SA EPA 2009, *Site contamination: guidelines for the assessment and remediation of groundwater contamination*, Environment Protection Agency, Adelaide, South Australia.

5 Data quality objectives and sampling and analysis plans

The DQO process comprises a seven-step iterative planning approach which is summarised in Appendix B. The process is used to define the type, quantity and quality of data needed to support decisions relating to the assessment of site contamination. It provides a systematic approach for defining the criteria that a data collection design should satisfy, including when, where and how to collect samples or measurements; determination of tolerable decision error rates; and the number of samples or measurements that should be collected.

The DQO process should be applied to all site investigation sampling programs and include development of the following:

- a statement of the DQOs for field and laboratory procedures, including quantitative DQOs
- the SAP to achieve the DQOs
- procedures to follow if the data do not meet the expected DQOs.

More detailed information on the DQO process can be found in US EPA (2000a, 2000b), US EPA (2006), and ODEQ (2010).

The CSM should guide the development of the DQOs which follows on from the consideration of any data gaps. The objectives for sampling may include:

- determining the nature and extent of contamination
- delineating the lateral and vertical extent of contamination
- developing an understanding of the geology and hydrogeology
- the identification of potential and actual contaminant migration routes
- determining whether relevant investigation and/or screening levels are exceeded
- determining whether further investigation or management is required.

Subsequent objectives may be to determine whether relevant investigation levels are exceeded and whether further action is required (additional investigation or management of some form). As understanding of the site will evolve over time, the iterative development of the CSM may also have implications for the DQOs and the SAP.

A SAP will generally include the following components:

- site investigation objectives and a brief background including appropriate plans and diagrams
- a review of existing information indicating reliability and usability of any existing data (data gap analysis)
- DQOs including a quality assurance (QA) plan and details of quality control (QC) samples to be collected
- pre-mobilisation tasks (e.g. preparation of a site-specific health and safety plan)
- media to be sampled (soil, sediment, groundwater, vapour, NAPL (non-aqueous-phase liquids), biota, surface water, deposited dusts, indoor air, outdoor air)
- details of analytes/parameters to be monitored
- number, location (coordinates) and depth (elevation AHD) of sampling points
- frequency and pattern of sampling

- sampling procedures and/or field screening methods
- analysis methods
- the methods for analysing and interpreting field data obtained (for any dynamic or reactive sampling).

The scope of the SAP will vary according to the site-specific circumstances and the stage of the investigation. Flexibility in the SAP is advisable so that changes may be made during the course of the investigation in response to identified data gaps such as the specific location of sub-surface utilities (which can act as potential conduits for volatile organic compounds (VOCs) and other gases) or evidence of more widespread contamination than expected (for example, widespread distribution of contaminated fill).

Professional experience and judgement will be required to ensure that the SAP contains adequate coverage (spatial and temporal) of all the relevant media to obtain representative samples which can satisfy the DQOs. If the sampling pattern and density are adequate, a further increase in the density or frequency of sampling is unlikely to change the site-assessment outcomes.

Approaches and methods for assessing soils, groundwater, and vapours and gases are discussed throughout this Schedule.

6 Soil investigations

6.1 Soil sampling strategies

The site investigator should select an appropriate sampling strategy based on accurate and reliable site-specific information as far as practicable to obtain sufficient representative data to address the DQOs. An explanation of, and justification for, the sampling strategy selected should be provided in the assessment report.

The site should be subdivided into assessment areas based on the information collected in the preliminary site investigation (site history, local geology and hydrogeology and site conditions) and anticipated exposure areas (for example, size and location of proposed residential lots) and the sampling patterns and densities adjusted according to the characteristics of the different sub-areas.

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(s) using judgemental sampling stepping out from the suspected source location, or systematic grid sampling centred on that location.

Specialised professional advice should be sought in developing sampling plans for rock soil mixtures at waste rock dumps, tailings dams, heap leach pads, and other artificial structures associated with mining site contamination.

6.1.1 Site history-based (judgemental) sampling

Sampling is localised to known or potentially contaminated areas identified from knowledge of the site either from the site history or an earlier phase of site investigation. Although judgemental sampling can invalidate some statistical methods, particularly where the sampling size is small, alternative methods using non-parametric approaches are available. Further information may be found in Gilbert (1987) and US EPA (2007).

6.1.2 Grid (systematic) sampling

Grid sampling may be worth considering where there is an inadequate site history, or a large area of potential contamination requires characterisation (for example heterogeneous fill materials). Grid sampling involves the application of a regular or offset grid or herringbone pattern. The site assessor should select a pattern which is suitable for the size and topography of the assessment area. The grid origin and orientation can be based on random selection or aligned with or around a convenient site feature.

Determining grid size/sampling density from mathematical formulae which require concentrations to be normally distributed (for example, Appendix D to Standard AS 4482.1-2005 which is based on NSW EPA (1994)) should be used with caution, as contamination sample data commonly exhibit a skewed (non-normal) distribution of results.

6.1.3 Stratified sampling

The potentially contaminated area of the site is divided into sub-areas (based, for example, on site history, soil type, depth) which are more homogeneous than the whole assessment area. Different sampling patterns and densities may be used in the different sub-areas.

6.1.4 Transect sampling

Transect sampling may be appropriate when specific spatial characteristics of the contamination are to be targeted, for example, where there is a predictable contaminant distribution downwind/downgradient from a point source of contamination.

6.2 Sampling density and depth of sampling

The aims of a sampling and analysis plan are to reduce the likelihood of under assessment (that could result in significant adverse effects from unidentified contamination) or over assessment (concluding that a site requires further investigation when in reality it does not) and to enable an appropriate level of remediation of contamination that is sufficient to protect human health and the environment.

Consideration of the CSM and DQOs should inform the requirements for sampling density and depth of sampling. The amount of sampling required will depend on an integrated appraisal of factors including:

- proposed use(s)
- the likely heterogeneity of any surface fill and underlying geological units
- the size of contaminated areas to be detected
- the number of stages of sampling considered feasible
- the size of the site and final subdivided lots if the site is to be subdivided
- the distribution of uses on the site and the disposition of structures
- the site history (which may vary across the site).

If a site is to be subdivided, the size of the subdivided lots should be taken into account when determining the sampling density. While predictions may be made on a 'macro' scale, residents or owners may seek information about their own particular area of land and the risks associated with this land, especially if the potential contamination on the original site was uneven in distribution and type.

The detection of 'hot spots' is an important issue for sites to be used for residential purposes or other sensitive uses where children have regular access to soil or where there is potential groundwater contamination. A greater sampling density is usually required for these sites. The toxicity of the contaminant, and the size and magnitude of the potential hot spot(s) needs to be considered in determining the sampling density.

The development of a suitably detailed CSM will inform decisions about the depth of sampling required. For health and ecological risk assessment, the soil strata to which people and other receptors could feasibly be exposed should be adequately sampled. This will result in a weighting towards near surface sampling unless the history or the nature of the soil and the presence of groundwater suggests it should be otherwise. On residential sites, the maximum excavation depth (such as for a swimming pool) is unlikely to extend beyond three metres, but much deeper soil disturbance may occur on a commercial site.

If dealing with volatile contaminants such as light fraction petroleum hydrocarbons or chlorinated solvents, then vapour transport from depth and through a shallow soil zone may pose a risk. Deeper sampling to determine the nature and extent of the source of the vapours and risk may be required—refer section 8.

The risk to groundwater needs to be assessed according to jurisdictional requirements, especially if receptors may be exposed by current or realistic future use of the groundwater resource—refer Schedule B6.

To delineate contamination laterally, typically samples should be taken until either no further contamination is detected or concentrations are below the relevant investigation levels or site-specific risk-based criteria.

The nature and appearance of drill cores will influence sampling at depth. It is essential that samples are taken from within a natural stratum or fill horizon and not across strata.

At the surface, samples at 0–100 mm or 0–150 mm should be taken unless there is evidence of a thin superficial layer of contamination. Where there is good evidence that contamination is restricted to a thin superficial layer, a shorter sampling interval may be appropriate; however, a subset of deeper samples should be analysed to inform/confirm the CSM. At greater depths, sample intervals should be less than 300 mm to avoid a compositing effect.

6.3 Site investigation methods

Soil samples may be collected using a variety of methods and equipment depending on the depth of the desired sample, the type of sample required (disturbed or undisturbed), the contaminant type (volatile or non-volatile) and the soil type. The most commonly used investigation techniques are test pits, trenching and drilling of shallow boreholes.

Samples from shallow depth are generally obtained from test pits and trenches. Samples from greater depths may be obtained using hand augers or a range of drilling methods including direct push, hollow stem augers, split spoon, Shelby tube, mud rotary and sonic drilling. Methods capable of providing continuous or near-continuous soil cores, such as direct push, split spoon and sonic drilling, are preferred. Air drilling and solid flight augers provide highly disturbed samples and poor depth control which limits their value for site characterisation purposes.

A number of 'real-time' tools are also available which can provide detailed logs of the sub-surface; for example, the laser-induced fluorescence and membrane interface probe tools which can be used in a reactive or adaptive field sampling program particularly for volatile substances where trial pitting and some coring methods are not as applicable. Laser-induced fluorescence and membrane interface probe methods may be used in both unsaturated and saturated zone investigations. A comparison of site investigation techniques applicable to soil, soil vapour and groundwater is presented in Clements et al. (2009).

There is a range of geophysical techniques available such as metal detectors, magnetometers, electromagnetic conductivity surveys, electrical resistivity— or electrical impedance tomography— and ground-penetrating radar. These techniques can be used to locate sub-surface anomalies such as underground storage tanks, buried drums, disposal pits, services and other sub-surface structures, as well as, in some cases, to delineate contamination (see Clements et al. 2009).

Further information about geophysical techniques can be found in the *Standard guide for the surface ground penetrating radar method,* ASTM D6432-99 (2005), the *Standard guide for selecting surface geophysical methods,* ASTM D6429-99 (2006), and on the US EPA CLU-IN Characterisation and monitoring webpage at < www.clu-in.org/characterization/>.

Further information on soil investigation methods can be found in Clements et al. (2009) and Standard AS 4482.1-2005 as well as standard soil references such as McDonald et al. (1990).

6.3.1 Test pits and trenches

Test pits and trenches are generally excavated by hand using a shovel to shallow depths or by machine (back hoe or long arm excavator) to greater depths. Samples may be collected from the walls of a test pit when they are shallow and it is safe to do so in accordance with the site health and safety plan. Only freshly exposed surfaces are suitable for sampling volatile and semi-volatile contaminants. Tests pits and trenches expose a large surface area for visual assessment of soil profiles and potential contamination and generally allows the investigator to gain a better appreciation of soil features and soil heterogeneity than that obtained with an individual borehole.

6.3.2 Intact soil coring

In general undisturbed samples obtained from near-continuous soil cores are preferred to grab samples for inspection and analysis. Intact soil coring is typically conducted by advancing a hollow rod or thin-walled metal tube into the sub-surface by direct push or other method such as sonic drilling. Direct push methods eliminate the need for a drilling fluid and avoid potential interferences from introduced fluids.

Auger and split-spoon samplers fitted with clear acetate sleeve liners may also be used to collect soil samples; however, sample quality is generally not as good as that obtained using direct push or sonic drilling methods.

Once soil cores have been obtained, samples from specific depth intervals can be taken and suitably preserved for laboratory analysis. Where an entire core is to be taken, the soil core tube should be quickly capped, labelled, wrapped and packed (preferably on dry ice to keep the sample in a relatively undisturbed state) and dispatched to the laboratory for analysis.

6.3.3 Cone Penetrometer Testing

Cone penetrometer testing (CPT) is an in-situ form of direct push drilling where sensors are mounted in a cone at the tip of the drill rods. As the cone is advanced, the sensors measure the resistance of the soil to the force of the advancing cone and the data is relayed to an on-board computer which interprets the soil stratigraphy and other parameters. A range of additional sensors may be used with CPT for simultaneous measurement of multiple parameters. The range of available sensors includes pressure head transducers (allowing permeability and hydraulic conductivity assessment), conductivity probes (allowing soil types and saturation to be estimated) and nuclear and pH probes.

CPT is a useful tool for providing rapid, continuous profiles of sub-surface stratigraphy and can save considerable time and money, particularly at large sites with complex geology.

6.3.4 Membrane interface probe

The membrane interface probe (MIP) tool consists of a heated probe equipped with a semi-permeable membrane mounted on a direct push or CPT drilling rig. VOCs diffuse across the membrane and enter a carrier gas within the probe. The carrier gas transports the contaminants to a gas chromatograph at the surface which can be equipped with various detectors for measurement of a wide range of VOCs: an electron capture detector (ECD) for chlorinated organics, a photo-ionisation detector (PID) for aromatic hydrocarbons, and a flame ionisation detector (FID) for straight-chained hydrocarbons.

For sites containing light non-aqueous phase liquids (LNAPL), MIP is typically used to locate and delineate dissolved-phase groundwater and soil-vapour plumes, while laser induced fluorescence (LIF) (see below) is used to delineate the LNAPL source zone.

The MIP tool is usually equipped with an electrical conductivity sensor to interpret soil lithologies. The combination of sensors enables an increased understanding of contaminant distribution particularly in heterogeneous lithologies.

One or more background MIP borings upgradient of each assessment area should be advanced in order to determine the background response. The MIP response can be used to determine concentrations of specific contaminants if it is calibrated with soil and groundwater samples from across the investigation area.

The MIP tool is typically used in the context of an adaptive sampling approach using a dynamic sampling plan and DQOs, that is, the investigation proceeds in a step-wise approach with the location and depth of each subsequent boring being determined in the field based on the results and interpretation of the preceding boreholes using a predetermined decision framework. QA/QC procedures should be developed for MIP surveys as part of the DQO process.

With multiple MIP locations and appropriate data interpolation and visualisation software, MIP data can enable a 3-D depiction of NAPL source zones in both the unsaturated (vadose) and saturated zones.

6.3.5 Laser-induced fluorescence

The laser-induced fluorescence (LIF) tool consists of an ultraviolet (UV) or visible wavelength laser connected to a sapphire window mounted on the side of a direct push/CPT probe tip.

The LIF laser transmits light through the sapphire window which is then absorbed by any PAHs in contact with the window causing the material to fluoresce at a characteristic wavelength. The fluorescence emission is recorded continuously by a detection system as the probe is advanced.

LIF tools are available which, depending on the wavelengths monitored, are capable of differentiating different types of product. UV LIF systems are appropriate for light fuels up to mid-range oils, but often fail to adequately respond to heavy fuel oil, heavy crudes, coal tars and creosotes. Visible wavelength systems detect heavy fuel oil, heavy crudes, coal tars, and creosotes but do not respond to light fuels such as petrol and kerosene. If possible, an appropriate NAPL sample should be tested to ensure the appropriate wavelength LIF is used.

One or more background LIF borings upgradient of each assessment area are recommended in order to determine the background LIF response. If NAPL is present at the site, a LIF borehole should be advanced adjacent to a well where NAPL has been measured to calibrate the LIF response to the specific NAPL contamination present at the site. The LIF data should also be validated with soil and groundwater sampling to determine concentrations of specific contaminants throughout the investigation area.

As for MIP, the LIF is combined with an electrical conductivity sensor to interpret lithologies and is used in a similar reactive sampling approach. Similarly, with multiple LIF locations and the use of data interpolation and visualisation software, LIF data can enable a 3-D depiction of NAPL source areas in both the unsaturated (vadose) and saturated zones.

6.3.6 Ground penetrating radar

Ground penetrating radar is the most commonly used of the geophysical methods and is typically conducted by rolling a radar unit across the site in a grid pattern and recording and processing the data collected to provide a two-dimensional or three–dimensional image of the surveyed area. Metal objects or near–surface features (such as pipes or utilities) can cause noise on the measured signal; if the location of these features is known, their effect can be minimised in the data processing stage. Ground penetrating radar surveys can also be used to define the lateral and vertical extent of NAPL plumes in shallow soil or groundwater — see Clements et al. (2009).

6.4 Field description of soils

Accurate documentation and careful consideration of field observations is essential as this can greatly improve understanding of the variability of contaminant distribution across a site.

All boreholes (including groundwater monitoring wells) and test pits should be logged and the presence of all strata, moisture, seeps or water-bearing zones, elevation of the water level/hydraulic head, imported fill and odorous or stained materials carefully noted. These logs are essential for interpretation of chemical data to establish the extent of contamination and to assist in the design of more detailed investigations. Example logs are included in Appendix D.

Further information on description of soils can be found in standard soil references such as the *Australian soil and land survey field handbook* (McDonald et al. 1990) and the *Australian Soil Classification* (Isbell 2002).

Field checklists to aid documentation of essential information are available for download from the EPHC website at <www.ephc.gov.au>.

6.5 Composite sampling

In contrast to a sample taken from a single location and analysed individually, a composite sample is taken by combining a number of subsamples, usually a maximum of four, into a single well mixed sample for analysis. Care should be taken to take the sub-samples from the same soil horizon or stratum. Composite sampling is not suitable for heavy clay soils as sub-samples are difficult to mix adequately. Consideration should be given to the moisture content of the soils to be sampled as subsamples are mixed without drying whereas laboratory results are reported in terms of dry weight.

Composites may be useful in the initial stages of an investigation but should not be considered unless there is a high degree of confidence in the site history.

Composite sampling is generally unsuitable for the definitive assessment of site contamination due to the inherent uncertainties in the resultant data (Lock 1996). However, where non-volatile contaminants are present (for example, metals or heavy oils such as heating oils) it may be adopted as a low-cost method for achieving low resolution data for screening purposes and for characterisation of stockpiled materials.

Composite sampling is not suitable for the assessment of volatile substances and is generally not suitable for site-specific health and ecological risk assessments.

Where composite sampling has been used, the relevant assessment level should be divided by the number of sub-samples in the composite and compared with the laboratory result. Further information may be found in Lock (1996) and SA EPA (2005).

6.6 Stockpile sampling

An in-situ soil sampling program informed by site history, inspection and contaminant form is the preferred approach for site assessment. On occasions it is necessary to stockpile soils that have not been assessed or only partially assessed in situ, and to devise a thorough stockpile sampling plan.

6.6.1 Excavation and inspection of the stockpile

Excavation may result in mixing of low-level or uncontaminated soil with smaller quantities of contaminated soil, having the effect of diluting higher concentrations. It is preferable for assessors to supervise excavation and, as far as practicable, segregate stockpiles according to soil and contaminant types and to avoid unnecessary dilution.

Excavated material often lacks homogeneity resulting in mixing of strata and different fill and soil types. Stockpiling may cause some segregation of grain sizes particularly on the exterior slopes. Specific grain sizes may contain the contaminant source and concentrate in some stockpile locations; for example, finer material may tend to accumulate at the toe of batters and coarser material towards the crest. Sticky clay material may be distributed into a different part of the stockpile than loose soils. The age and surface condition of the stockpile should be assessed, particularly if it has been weathered and subjected to leaching.

The composition of the stockpile should be documented by inspection of its external presentation and excavations into the stockpile by shovel (for small stockpiles) or excavator bucket where a shovel cannot reach the centre of the stockpile. The stockpile dimensions should be determined noting its regular or irregular shape and a 3-D plan prepared. The volume of material present should be estimated.

6.6.2 Number of samples

Table 2 below provides the recommended number of samples for assessment of stockpiles up to 200 m^3. Jurisdictions may apply alternative frequency rates based on site-specific conditions (for example, degree of homogeneity, known contaminant types and concentration range) and local policy requirements for off-site disposal of contaminated soil. Lower sampling frequencies may be derived for soil quantities greater than 200 m^3 with statistical analysis to achieve acceptable confidence limits for contaminant levels for non-normal or unknown distributions (for example see EPA Victoria, 2010). In-situ samples taken prior to excavation may be included in assessment and to determine the number of samples required for stockpile assessment.

Table 2. Minimum number of samples recommended for assessment of stockpiles

Stockpile volume, (m^3)	No. of samples
<75	3
75 - <100	4
100 - <125	5
125 - <150	6
150 - <175	7
≥200	8

6.6.3 Sample point distribution

The stockpile should be sectioned into an appropriate distribution of sampling locations based on inspection, site history and other assessment data about the nature of contaminants present. If a section of the stockpile is known to have a higher level of heterogeneity and greater contamination risk and the balance of the stockpile is relatively homogenous with low-level contamination, sampling bias to the more contaminated section may be considered. If this information is not known, a uniform sample point distribution should be used. A plan should be developed of the stockpile sections and the corresponding sample locations that represent each section. This will allow physical separation of portions of the stockpile for further characterisation, if required, after receipt of the analytical results.

6.6.4 Sampling

Collection of samples from the exterior 300 mm of the stockpile should be avoided due to the higher risk of weathering and grain size grading errors.

Samples for inorganic and non-volatile components should be taken at various depths towards the centre of the stockpile from 300 mm below the stockpile surface. Compositing may improve the reliability of samples for inorganic analysis. Composites should be based on equal quantities of material from 4-5 random locations and depths in the area of the stockpile allocated to the sample. The trowel should be cleaned after soil collection at each random location and the collected material thoroughly mixed on a clean surface, sub-sampled and preserved for chemical analysis.

Composites should not be prepared for VOCs including TPH (total petroleum hydrocarbon). Samples for these materials should be taken without delay from a freshly excavated surface 500 mm or greater depth below the stockpile surface.

Systematic sampling directly from excavator buckets during the excavation and stockpile formation process or for appraisal of larger stockpiles using appropriate QA/QC processes is an acceptable strategy in site assessment. Further guidance on stockpile sampling may be obtained from EPA Victoria's *Industrial waste resource guidelines* (2010).

6.7 Leachability tests

Contaminants in soil can leach to groundwater under certain conditions. Leachability is particularly affected by soil pH, contaminant solubility and redox (Eh) conditions.

The leachability characteristics of contaminated soil can be used to help predict the likely impact of leaving contaminated materials on site (for example, potential impacts on groundwater resources if relevant) and to assess whether some form of on-site management is required if the material is to remain on site. Information about leachability tests applicable to contaminated sites can be found in Schedule B3.

Treatment and disposal of excavated contaminated soils should be in accordance with jurisdictional legislation or guidelines for re-use and/or disposal of contaminated soils.

6.8 Choice of analytes

6.8.1 General

Analyte choice should be informed by the site history findings and data gaps identified in the development of the CSM and the DQO process. Depending on the available history, potentially contaminated fill may require a more extensive suite of analytes. The appearance, odour and texture of soil samples and cores may influence the selection of analytes.

Appendix A provides a list of possible analytes by contaminant grouping. Specific information on the assessment of asbestos and dioxins can be found later in this Schedule. Additional information on the selection of possible analytes is available in the *Standard guide to the investigation and sampling of sites with potentially contaminated soil* (AS 4482.1-2005), WA Department of the Environment (2004), and Turczynowicz (1991).

6.9 Field testing

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

The most commonly used field tests include:

- gas detector tubes
- colorimetric test kits
- headspace testing using PIDs and FIDs
- field portable x-ray fluorescence spectrum analysers
- field gas chromatography
- immunoassay test kits.

These techniques can be used to gain a general understanding of the field conditions and the presence of possible contamination and may assist in the selection of samples for laboratory analysis. PID measurements, for example, may be useful as a field guide to indicate areas of volatile compounds. However, their role in providing real-time data needs to be augmented by laboratory chemical analysis.

Their use as the sole source of analytical data in the assessment of potentially contaminated sites is inappropriate as they may give falsely high or low results. For example, naphthalene is commonly reported in petroleum hydrocarbon impacted soils and will evoke a response from a PID, in contrast to benzo(a)pyrene (a more significant PAH in terms of human health), which will not be detected by a PID. As these measurements do not always correlate well with laboratory results they are generally not suitable for validation sampling.

Prior to use of any field monitoring equipment there should be:

- a determination that they are capable of detecting relevant contaminants
- adequate understanding of the methods of use for the particular instrument, its limitations and site conditions that may affect the results
- appropriate calibration (and recording of the calibration data) for the substances being measured
- an appraisal of site conditions that may affect the results, for example, high soil moisture may result in artificially high PID results for benzene.

Further information on field characterisation techniques may be found on the US EPA CLU-IN website at <www.clu-in.org/characterization/>.

6.9.1 Gas detector tubes

Detector tubes have been developed which measure volatile gases including individual compounds, for example, hydrogen sulphide, or groups of compounds, for example, petroleum hydrocarbons. They can provide a direct measure of the analyte in ambient air or an indirect measurement of soil and groundwater contaminant concentration when used in field test kits for measurement of soil gas and headspace for liquids. The reagents in the tubes may react with compounds of similar chemical properties, consequently, false positives and inaccurate results are possible and should be identified in the DQO process.

6.9.2 Colorimetric test kits

Colorimetric tests rely on the chemical reactions of indicator compounds with individual compounds or classes of compounds. Tests are generally performed by mixing reagents in specified amounts with the soil sample to be tested and comparing the resultant colour change with a colour chart or using a field colorimeter to determine concentration.

Colorimetric tests have been developed for a wide range of substances including BTEX, total PAHs, chlorinated hydrocarbons, PCBs and various individual pesticides and classes of pesticide. The detection limits in soil are generally in the low ppm range (lower detection limits are achievable in water as no extraction stage is necessary). Although these tests are relatively simple to perform, depending on the kit, they can suffer from interferences from other co-contaminants or naturally occurring materials or organic matter. Their usefulness for specific site-characterisation purposes can be evaluated by comparison of field colorimetric results with laboratory results over a range of analyte concentrations.

6.9.3 Headspace testing using photoionisation and flame ionisation detectors

Field headspace testing is a commonly used method for screening soil samples for volatile and semi-volatile organic compounds. The procedure involves partially filling an airtight container with a fresh soil sample and then analysing the headspace vapour using an appropriately calibrated portable instrument, typically a PID or FID.

A FID uses a hydrogen flame to ionise the organic vapours whereas a PID uses an ultraviolet lamp to ionise the vapours. The instrument response is related to the electric current generated by the ionised compounds. FIDs are most sensitive to aliphatic hydrocarbons as these compounds burn more efficiently than aromatic compounds. PID instruments are most sensitive to aromatic hydrocarbons (for example, BTEX compounds) and can measure most VOCs in the range of C6 equivalent carbon atoms (for example, benzene) to C10 (for example, naphthalene). Neither instrument is effective for detecting non-volatile compounds such as highly weathered hydrocarbons. Care should be taken when using PIDs since a positive bias may result from water vapour or moist air and/or dust being drawn into the instrument. FIDs are not sensitive to water vapour.

A standardised field procedure for headspace testing should be followed and the details of the test method documented (size of jar, soil volume, equilibration time and ambient temperature) in the investigation report.

6.9.4 Field portable x-ray fluorescence

X-ray fluorescence (XRF) is a rapid screening tool that can be used to measure metal concentrations in soil. Performance is dependent on the metal, the soil matrix and soil moisture content. Although a range of heavy metals can be simultaneously detected, there are potential interferences that influence the method accuracy and precision. The US EPA has developed a methodology to guide XRF analysis (US EPA 2007a).

The advantages of XRF include real-time results, when used in scanning mode on surface soil, or near real-time results when deeper samples are collected and analysed in the field. The usefulness for specific site-characterisation purposes can be evaluated by comparison of results from split samples analysed by field XRF with laboratory results over a range of analyte concentrations.

6.9.5 Field gas chromatography

Field gas chromatography (GC) may be used for the analysis of volatile and semi-volatile compounds in soil, soil-gas and water. The two main components of a GC are a column to separate the individual constituents and a detector (such as a PID or FID) to measure the signal response of the constituents. The analysis is compound-specific and potentially has the greatest accuracy of all the commonly used field analytical techniques.

6.9.6 Immunoassay test kits

Immunoassay test kits, utilising antibody-antigen reactions, can be used to measure petroleum hydrocarbons in soil and water. For most kits, the intensity of the colour development is inversely proportional to the amount of substance present. The concentration is determined by comparison with a reference standard or with a portable photometer.

6.10 Quality assurance and quality control

Quality assurance (QA) involves all of the planned and systematic actions, procedures, checks and decisions undertaken to ensure the representativeness and integrity of samples, and the accuracy and reliability of analysis results.

Quality control (QC) involves those parts of an investigation which serve to monitor and measure the effectiveness of the QA procedures by comparison with the relevant DQOs. In the field, this may include checking of sampling equipment cleanliness by keeping rinses for analysis, duplicate sampling and inclusion of 'field blanks' and 'field spikes'.

Further information may be found in Appendix C.

6.10.1 Quality assurance

In the field QA includes:

- selection of appropriate sampling and preservation methods, documentation and sample storage
- cleaning of tools before sampling and between samples
- cleaning of containers
- maintenance of sample environment to minimise sample contamination and analyte losses
- delivery to the laboratory in good condition and within the timeframes required for the particular analytes.

For site assessors, Section 8 of the *Standard guide to the investigation and sampling of sites with potentially contaminated soil* (AS 4482.1-2005) provides a basis for developing a program of quality assurance. As many sites are small with limited sampling, the rate of blind replicates and split samples should be adjusted to an appropriate level to ensure sufficient quality assurance.

Laboratory QA and QC procedures are discussed in Schedule B3.

6.10.2 Quality control

Adequate QA is achieved when QC results demonstrate that agreed objectives such as freedom from contamination, method accuracy and precision can be reliably achieved. Selecting an appropriate level of QC is, therefore, imperative to ensure that DQOs are met.

Standard AS 4482.1-2005 recommends the use of a variety of QC samples including blind replicate samples and rinsate blanks collected in the field which are sent to the primary laboratory to determine the precision of the field sampling and laboratory analytical program, and split samples (collected in the field) sent to a secondary laboratory for analysis to determine the accuracy of the analytical programs.

As a general rule, the level of QC required is that which adequately measures the effects of all possible influences upon sample integrity, accuracy and precision, and which is capable of predicting their variation with a high degree of confidence.

6.11 Sample handling, storage and transport

6.11.1 Sample integrity

Integrity of all soil samples must be considered, particularly when dealing with VOCs and SVOCs. Reference should be made to Standards AS 4482.1-2005, and AS 4482.2-1999.

Weathering and biodegradation by soil micro-organisms will result in a loss of volatile hydrocarbon components from the surface of affected sites. An example situation would be an underground fuel storage site where the tanks have been removed and the excavation has been left exposed for several months. In these circumstances, collecting samples from sub-surface layers (at least 500 mm below the surface of the excavation) may provide a more accurate representation of contamination.

Samples should be placed in appropriate sample containers, preferably prepared by a laboratory, with gas-tight, non-absorptive seals, allowing no headspace, and kept on ice until arrival at the laboratory. Arrangements should be made to ensure delivery of chilled samples to the laboratory within the holding time of the specified analysis. Samples must remain preserved and be analysed within the time limitations which apply for the analyte and laboratory method. Additional information on sample integrity and appropriate procedures is available in Standard AS 4482.1-2005.

6.11.2 Chain of custody

Site investigators must complete chain-of-custody documentation which details the following information:

- site identification
- the sampler
- nature of the sample
- collection time and date
- analyses to be performed
- sample preservation method
- departure time from site
- dispatch courier(s).

An example chain-of-custody form can be found in NSW EPA (1994).

A copy of the receiving laboratory's advice should be included in the assessment report and provides the following information:

- the condition in which the samples and chain-of-custody documentation were received and the container type
- cross-checking information on sample identification numbers and paperwork received
- confirmation of preservation method.

7 Groundwater investigations

A risk–based approach to the assessment of groundwater contamination is outlined in Schedule B6.

The process involves a staged risk-based approach to delineation of contamination using guidelines such as the *Australian and New Zealand guidelines for fresh and marine water quality* (AWQG) (ANZECC & ARMCANZ 2000) , the *Australian drinking water guidelines* (ADWG) (NHMRC & NRMMC 2004) and the *Guidelines for managing risk in recreational water* (GMRRW) (NHMRC 2008) as appropriate as investigation and response levels. The process may include a detailed assessment of contaminant concentrations over time using fate and transport modelling to predict the current position and future movement of groundwater contaminants to assess potential risk to receptors.

This section deals with the basic requirements for groundwater investigation, including installation of monitoring wells, sampling of groundwater, presentation of data and delineation of groundwater contamination.

Site assessors should be aware of (and comply with) relevant jurisdictional requirements such as groundwater protection policies and licensing requirements for the construction of monitoring bores and groundwater abstraction.

The collection and assessment of groundwater data and the selection and use of fate and transport models should be undertaken by appropriately qualified and experienced professionals.

7.1 Groundwater investigation approaches

7.1.1 Introduction

There are several methods for collecting groundwater data. In general, these methods involve collection of:

- in-situ measurements to calculate hydraulic head, groundwater flow direction and rate
- in-situ measurements of apparent product thickness (NAPL, immiscible with water)
- in-situ physical and/or chemical measurements of groundwater quality, for example, redox potential, electrical conductivity, pH, and dissolved oxygen
- collection of groundwater samples for ex-situ measurement/analysis.

The main issues that determine the selection of the appropriate method(s) are:

- the DQOs
- site-specific conditions such as depth to water table, soil/rock competency
- analyte-specific characteristics
- financial and logistical constraints.

Careful consideration and appropriate weighting of each of these issues will assist in determining the most appropriate method(s) of groundwater investigation.

7.1.2 Scope of investigation

The appropriate scope of the investigation is determined through the development of the site CSM and the DQOs. As for soil investigations, this would generally include a preliminary investigation comprising a desktop review of relevant background information and a site visit followed by one or more intrusive field programs to update and refine the CSM until the DQOs of the site assessment are met.

Typically this will include consideration of the following:

- the site history/land use assessment
- the type and location of known and/or potential contaminant source zones and associated contaminant plumes
- site geological and hydrogeological conditions (identifying aquifers, confining layers etc)
- upgradient groundwater quality to assist in determining background groundwater quality
- hydrogeochemistry of relevant aquifer units
- groundwater flow domain including location of recharge and discharge areas
- location of any abstraction wells
- current and future realistic use(s) of the groundwater resource and nearby surface water resources
- known and/or perceived risks to the environment and/or human health including the presence of potential pathways between contaminant source(s) and potential receptors.

7.1.3 Site-specific conditions

Site-specific conditions that may limit or govern the choice of groundwater investigation techniques include:

- hydrogeological conditions including the depth to groundwater, soil/rock types and the presence of multiple aquifers
- potential risks to uncontaminated aquifers and/or surface water resources
- restrictions with regard to accessibility due to topography, ground bearing capability, site infrastructure or interference with site operations
- risks to the environment and/or public safety
- geotechnical limitations such as soft or saturated ground, cavernous or karstic terrains and stability
- natural events such as flooding and shifting sand dunes.

Any of these conditions may limit the applicability of certain methods of drilling, bore installation and groundwater sampling and make other methods more practical and cost-effective.

Appropriate measures should be taken to minimise the spread of contamination by not creating migration pathways from the surface to groundwater or between different aquifers. For example, where a monitoring well is targeting a deeper aquifer unit and contamination is present in a shallow aquifer unit or overlying fill horizon, this should be cased off so as not to permit cross-contamination between the two units.

7.1.4 Analyte-specific characteristics

The physical and chemical characteristics of contaminants have a profound effect on their sub-surface distribution and/or occurrence in groundwater at a given site. Physical and chemical characteristics that may have an effect on the distribution of contaminants include:

- contaminant solubility
- presence of NAPLs
- relative density (e.g in the case of NAPLs, LNAPLs such as oils are less dense than water, whereas dense NAPLs (DNAPLs), such as some solvents, are denser than water; for aqueous liquids, relative salinities are important)
- stability (chemically and microbiologically)
- partitioning characteristics (e.g. sorption and volatility)
- aquifer redox conditions. .

These characteristics will determine if contaminants are:

- capable of leaching through a soil profile and/or are soluble in the groundwater
- more or less dense than the groundwater, such that there is a likelihood for them to be present close to the water table (e.g. LNAPLs or where low salinity water infiltrates into more saline groundwater) or more extensively throughout the aquifer (e.g. with DNAPLs or where saline water infiltrates through fresh groundwater)
- relatively susceptible to effects of volatilisation, reaction with other chemicals/substances in the sub-surface, biodegradation, dispersion or other forms of attenuation.

Where there is a potential for contaminants to be present in an aquifer it is important to understand and predict where they are most likely to be concentrated prior to selecting the appropriate groundwater investigation method. Without this consideration, there is the potential for errors, some of which may result in:

- cross-contamination within and/or between aquifers
- non-detection of groundwater contamination
- inaccurate or misleading data
- expenditure of excessive resources where more simple and cost-effective methods could have been used.

7.2 Monitoring well establishment

In general, most groundwater investigations in Australia are conducted using information obtained from cased, semi-permanent or temporary cased groundwater monitoring wells. Monitoring wells are used for a range of applications including:

- groundwater sampling for ex-situ analysis
- monitoring and/or profiling in-situ groundwater parameters
- monitoring of groundwater level fluctuations
- aquifer testing.

Bores retained as part of a monitoring network should be properly maintained to ensure the integrity of the sample data collected. Damaged or abandoned bores may provide conduits for future contamination unless properly decommissioned. Monitoring wells which are no longer required or are unsuitable for continued monitoring should be decommissioned in accordance with jurisdictional requirements.

7.2.1 Logging of boreholes

A careful record of the geology encountered during drilling should be described and classified in accordance with relevant standards such as *Geotechnical site investigations,* AS 1726-1993. Example logs are included in Appendix D.

Field check lists are available on the EPHC website at <www.ephc.gov.au> to aid documentation of essential information including the soil profile and well construction.

Monitoring wells may also be logged using various geophysical survey techniques, for example, to determine lithology or groundwater quality.

7.2.2 Well construction

Monitoring wells should be constructed to an appropriate standard and from suitable materials to ensure that high quality samples can be collected over the projected lifetime of the well. The assessor should ensure that the well construction materials selected are compatible with the monitoring objectives.

A decision on the appropriate means of constructing monitoring wells involves consideration of a number of factors including the hydrology, geology and geochemistry of the formation, the nature of the contamination, the chemical resistance and leaching properties of the construction materials, the cost and the necessity to maintain the integrity of samples. Further information may be found in EPA Victoria (2006), SA EPA (2007) and UK EA (2006).

There are several standard drilling methods available including hollow-stem auger, air and mud rotary, cable tool, sonic and direct push. The assessor should consider drilling methods which minimise the introduction of drilling additives wherever possible. This overview of drilling methods is based on information in EPA Victoria (2000) and SA EPA (2007). More detailed information may be found in Aller et al. (1989), Driscoll (1986), and *Practice for design and installation of groundwater monitoring wells,* ASTM D5092 (2004e1). Additional information can also be found in the *Manual of methods, applications and management* produced by the Australian Drilling Industry Training Committee (ADITC 1997).

Certain drilling techniques can cause smearing (for example, rotary auger) or compaction (cable tool) of borehole walls and may also promote transport of geological formation materials and drilling fluids into different aquifer zones. In a worst-case scenario, this can result in almost complete blockage of the well screen resulting in non-representative groundwater samples when the boreholes are monitored.

Drilling fluids are used to clean and lubricate the drill bit, to remove rock cuttings from the borehole and to keep the borehole open during drilling. These may include air, water and specific drilling mud formulations or native clay slurries. Drilling fluids can have a range of effects on groundwater quality such as the following:

- air may severely disturb hydrochemical profiles through oxidation processes, for example, oxidation of ferric Fe2+ to ferrous Fe3+)
- water may dilute or flush groundwater near the borehole and cause precipitation of minerals, thereby blocking or obstructing groundwater pathways
- mud may invade the permeable formations and block pathways to the well screen.

Care should be taken to avoid contamination of the borehole and surrounding geology during drilling and construction of the well through the inappropriate use of lubricants, oils, grease, solvents, or materials with incompatible coatings. As some drilling-related effects are frequently long lived or even permanent, it is important to record drilling method, fluids used and details of bore development on the well logs.

Incorrect installation of wells can result in costly cross-contamination of aquifers. For example, the use of bentonite pellets in isolation to form a seal in the vadose zone is discouraged as the bentonite pellets can set dry and crack, resulting in an ineffective seal between the aquifer and contamination near the ground surface. In these circumstances it is preferable to hydrate the bentonite at surface and then install as a paste.

It is essential to correctly finish all monitoring wells at the surface such as with a suitable bentonite plug and cement seal, to ensure that runoff does not collect at the wellhead and leak down the outside of the casing. Casing materials such as PVC, ABS, Teflon, etc. which project from the ground can easily be damaged and should be protected by a steel or similar outer protective collar. All wells should be secured to prevent vandalism or malicious actions.

7.2.2.1 Screen depth and length

Groundwater investigations should be designed to target the part, or parts, of the aquifer most likely to be affected by contamination.

Under laminar flow conditions, contaminated groundwater flows in discrete zones controlled by the physical properties of the aquifer and the presence of any preferential pathways such as higher permeability units (such as the cleanest sands in an interbedded sand and silt sequence) and fractures. The location and length of the well screen is therefore critical to obtaining a representative sample of contaminated groundwater.

The selection of screen length depends on the objectives for the monitoring well; however, in general, well screens should be kept as short as possible to avoid potential dilution effects. The interval of aquifer potentially contributing to flow includes the filter pack either side of the well screen as well as the screened interval itself. To minimise the potential for vertical flow within an aquifer via the well bore, screens should not be installed across different geological units or water-bearing zones. The screen should be located such that at least part of the screen remains within the saturated zone throughout the year.

In the initial phases of investigation, well screen lengths of 3 m or more are common. However, once contamination is suspected or confirmed, shorter screens of the order of one metre long located specifically within the zone of interest are recommended since small-scale heterogeneities are important in controlling contaminant flowpaths. Where the geological unit of interest exceeds 1 m–2 m in thickness, multiple wells completed in well nests or vertical groundwater profiles are recommended to evaluate and define the contamination. In thick homogeneous granular aquifers, the benefits of short well screens are more limited, given that mixing and contaminant dilution will occur within the aquifer itself (UK EA 2006). However, consideration should still be given to the potential for vertical gradients within thick aquifer systems.

Monitoring dissolved contaminants in plumes requires consideration of the likely plume characteristics and its behaviour in the aquifer. Plumes are typically elongated in the direction of groundwater flow and will undergo longitudinal, lateral and vertical dispersion.

Plumes will also tend to 'dive' or 'plunge' as additional recharge is added to the aquifer downgradient of the plume source area (UK EA 2006).

Correct slot size and location of well screens is particularly important when dealing with NAPLs. Representative samples of the dissolved phase can only be obtained if the screened interval is outside the influence of any mobile or residual NAPL. Interface meters and tapes with oil-indicating pastes can be used to confirm the presence and thickness of NAPLs.

General guidance on the selection of appropriate screen length is given in Table 3 below.

Table 3. Guide to monitoring interval selection

Aquifer conditions/ monitoring objectives	**Screen length**			
	Multi-level	**Very short (<1 m)**	**Short (1 – 2 m)**	**Long (3+ m)**
Monitor general water quality (thick aquifer)	√√	X	√√	√√√
Monitor general water quality in thin or heterogeneous aquifer	X	√	√√√	√
Monitor LNAPL (fluctuating water table aquifer)	X	X	√√	√√√
Monitor DNAPL	X	√	√√√	√√
Detailed delineation of contamination	√√√	√√	√√	X

Key:

X	Not appropriate	√√	Appropriate
√	Appropriate but not ideal	√√√	Most appropriate

Adapted from UK EA (2006)

Further information on sampling LNAPLs can be found in Clements et al. (2009). Further information on sampling and identification of DNAPLs can be found in Keuper and Davies (2009) and Keuper et al. (2003).

7.2.2.2 Filter packs and filter socks

A filter or gravel pack is used to minimise the entry of fine grained material into the well screen. In general, the gravel pack should extend no more than 1.0 m above and 1.0 m below the well screen in the well annulus, taking care not to extend the gravel across geological units or water bearing zones. The filter pack material should be chemically inert.

Filter socks are not recommended for use in bores intended for monitoring groundwater quality. The redox conditions, and therefore biological activity, within the mesh can be different from that present in the aquifer which can produce misleading sample results. Where LNAPLs are present, a greater thickness of NAPL would be required to overcome the increased surface tension forces present in the fine mesh compared with the well screen.

7.2.2.3 Well development

All bores intended for monitoring water quality should be developed after drilling to remove fine sand, silt, clay and any drilling mud residues from around the well screen. Development usually involves agitating the water column in the well bore and pumping the water out until it runs clear. After development, bores should be left for a period until borewater chemistry can be demonstrated to have stabilised (generally between 24 hours and seven days) before samples are collected. Longer periods are applicable to reduced groundwater conditions where it may take days to weeks to fully equilibrate, depending on the aquifer properties.

During development, bore yield should be estimated by monitoring the rate of recovery of water in the bore after pumping. This information can then be used to select suitable methods for subsequent purging and sampling (SA EPA 2007).

Care should be taken to dispose of any contaminated water responsibly and not to allow it to enter the stormwater drainage network or to impact uncontaminated soils at the site.

7.2.3 Groundwater sampling

It is essential that groundwater sampling methods result in the collection of samples that are representative of aquifer conditions. Management decisions that may involve considerable expenditure and potential inconvenience to the public will be based on these results. In many circumstances, budgeting for additional sampling and analysis costs for site characterisation for definition of groundwater contamination problems could save further assessment expenditure and costly delays to property transactions and site development.

Where possible, established ‘standard methods’ from recognised sources such as Standards Australia, United States Environmental Protection Agency (US EPA), American Public Health Association (APHA) and International Standards Organisation (ISO) should be used. The general reference used by laboratories for the analysis of groundwater is *Standard methods for the examination of water and wastewater* (APHA et al. 2005).

Overviews of groundwater sampling procedures are readily available; for example, SA EPA (2007) includes information about:

- development of monitoring plans
- pumping and sampling equipment
- sampling methods
  - groundwater level measurement
  - purging
  - sample collection methods
  - filtration
  - NAPL sampling
  - decontamination
- sample identification, transport and storage
  - labelling and identification
  - preservation techniques
  - QA/QC.

Detailed information can be found in Standard AS/NZS 5667.11-1998; MDBC (1997); Barcelona et al. (1985); Barber and Davis (1987, 1994); Scalf et al. (1992); EPA Victoria (1991); and Weaver (1992).

There are many suitable methods to collect groundwater samples from monitoring wells. In general, these methods include the use of the following equipment which should be appropriately selected in relation to the target analyte and involve borehole purging to remove stagnant casing water:

- submersible pumps
- non-submersible pumps
- bladder and inertial pumps
- peristaltic pumps
- bailers
- micropurge equipment for low-flow sampling
- air compressor equipment
- field filtration devices.

In general, the use of low-flow submersible pumps or positive-displacement pumps capable of controlling flow rates and minimising purging requirements are the preferred methods for groundwater sampling. Traditional purging and sampling methods using bailers or high speed pumps can result in non-representative samples of groundwater by introducing high levels of turbidity and degassing of samples. These sampling-induced turbidity problems can often be mitigated by using low-flow purging and sampling techniques (Puls & Barcelona 1996). Further information on purging, including low-flow purging and purging of low recharge wells, can be found in SA EPA (2007) and ASTM Standard D6771-02.

Generally, the same methods should be used each time the wells are purged and sampled to avoid introducing sampling method-related uncertainties to the analytical data (SA EPA 2007). Where an improved technique becomes available, it is recommended that it is trialled in combination with the existing sampling method to establish the nature and magnitude of any changes in analytical results as a result of the new sampling method.

Passive sampling devices (for example, passive diffusion bags for VOCs) do not require pumping or purging of groundwater to acquire a sample. These sampling devices are placed at a selected depth in the well and rely on ambient flow through the well screen for sampling. Three types of passive sampling technologies are available:

- devices that recover a grab sample of groundwater
- devices that rely on diffusion of the analytes for the sampler to reach and maintain equilibrium with the sampled medium
- devices that rely on diffusion and sorption to accumulate analytes in the sampler.

Some of these techniques are applicable to surface waters and vapour as well as groundwater. Further information can be found in ITRC (2005).

The selection of the appropriate equipment for a groundwater investigation should be based on careful consideration of the attributes of the target analytes, the likely contaminant distribution, cost and logistical issues, field filtration requirements, and decontamination requirements:

7.2.3.1 Target analytes

Certain analytes are prone to effects of aeration and agitation and sampling equipment should be selected to cause minimal agitation and chemical alteration of the sample, for example, low-flow techniques are recommended for quantitative assessment of VOCs and semi-volatile organic compounds (SVOCs); bailers are not appropriate.

Information on monitoring and sampling LNAPLs using oil-water interface probes, oil indicator pastes and special bailers can be found in Clements et al. (2009).

Sampling equipment should also have negligible capacity for sorption, precipitation and oxidation of analytes of interest.

7.2.3.2 Contaminant distribution

Due to a range of chemical and/or physical characteristics, contaminants may be concentrated in certain parts of the aquifer under investigation. The sampling equipment should be capable of targeting the depth interval most likely to contain the target analytes. For example, special bailers are available for the sampling of NAPLs, while bottom-loading bailers are available for investigating DNAPLs.

7.2.3.3 Decontamination requirements

All equipment used in the sampling procedure which either enters the well bore or holds the groundwater sample should be decontaminated before and after each sample is collected. Samples of the rinsate should be included in the QA/QC program. Depending on the potential for cross-contamination between wells or within the profile of a single well, certain equipment may be relatively difficult to decontaminate and it may be necessary to opt for more simple sampling systems or to dedicate sampling equipment to a particular well or interval.

7.2.3.4 Field filtration

In surface water bodies, a substantial amount of metals can be transported adsorbed to suspended particles and filtering needs to be undertaken to identify the truly dissolved component (that is, < 45 µm). This is much less the case in groundwater systems where particles cannot easily pass through the porous matrix. High levels of suspended particles in a groundwater sample usually indicates either a bore construction problem or, more commonly, a sampling problem where the groundwater has been altered by pumping at an excessive rate relative to the local hydrogeological conditions (Sundaram et al. 2009). For example, if using too high a pump rate, metals can be hydrolysed and precipitated on suspended iron and aluminium oxyhydroxide particles during transport to the surface and filtering in these circumstances would lead to an artificially low result for metals.

Filtration should not be necessary if using a low-flow technique and the flow rate has been adjusted to the local hydrogeological conditions.

If field filtration is undertaken, in-line disposable filters are preferred and ensure that the sample has minimum exposure to the atmosphere. Sample filtration devices should be decontaminated between uses or discarded to prevent cross-contamination and ensure continued effectiveness. Further information may be found in SA EPA (2007) and EPA Victoria (2000).

7.2.4 Monitoring and profiling groundwater parameters

Some physicochemical parameters cannot be reliably measured in the laboratory as their characteristics change over a very short timescale. Parameters that should be measured in situ include pH, electrical conductivity (EC), temperature, dissolved oxygen (DO), redox potential (Eh) and alkalinity. It is recommended that field parameters are measured in a flow-through cell to avoid contact between the groundwater and the atmosphere. A flow-through cell can also enable continuous measurement and monitoring of key parameters during purging to identify when a representative sample may be obtained.

There is a wide range of equipment available for the measurement and logging of these parameters. It is important that quality assurance protocols are developed and implemented. The procedures should include the use of suitable calibration standards, where the calibration spans the anticipated range of results, and accuracy checks. Where measurements are made over a number of hours, periodic readings of appropriate reference solutions should be incorporated to ensure that the calibration is stable. Calibration procedures vary between meters and between manufacturers so it is important to follow the manufacturer's instructions for correct and accurate operation of each piece of equipment. Further information can be found in SA EPA (2007) and Sundaram et al. (2009).

7.2.5 Groundwater levels and flow direction

Groundwater level measurements are essential to determine groundwater and contaminant flow directions within aquifers and interaction with surface water bodies. These measurements can provide information on lateral and vertical head distribution and hydraulic gradients within individual aquifers and between aquifers in layered aquifer systems (EPA Victoria 2000). Long-term groundwater monitoring data provide information on temporal trends in groundwater levels (and hence flow directions and rates) due to seasonal, climatic and groundwater pumping effects (EPA Victoria 2000).

The groundwater elevation (standing water level) in a monitoring well is an expression of the hydraulic head of the aquifer unit in which the well has been screened. The standing water level should be measured relative to a permanent surveyed reference point (such as the top of the casing) before any purging or sampling takes place using a calibrated pressure transducer and/or purpose-built tape or meter. The data should be reported relative to a common datum, preferably Australian height datum. Bores installed at multiple depths within an aquifer are required to assess vertical groundwater flow direction(s).

Relative groundwater elevations within the same aquifer unit indicate the hydraulic gradient between wells and, given at least three wells spaced roughly equilaterally, a groundwater flow direction may be calculated. Where the wells are completed with long screens and/or at different relative depths within the aquifer, inconsistencies may arise if there are vertical groundwater gradients present. Groundwater flows may vary significantly at a site so it is recommended that groundwater contour maps are based on several bores monitored over a period of time to determine groundwater flow directions and variability across the site over time.

Where LNAPL is present, it will affect the groundwater elevation inside a cased well. If significant amounts of LNAPL are present, groundwater level corrections are necessary and are based on the measured thickness and relative density of the product. However, due to the uncertainties involved, corrected groundwater elevations from wells affected by LNAPL should not be used to definitively determine groundwater flow direction.

Water level measurements for a given study area should be taken on the same day or at shorter intervals if tidal effects are involved. Saline and hot groundwater conditions also require that measured groundwater elevations are corrected for density effects.

The hydraulic heads measured in wells screened in different aquifers should not be used to infer lateral groundwater flow direction at a site; however, they may be used to determine the relative hydraulic head, or potential for vertical flow between aquifers.

If vertical (downward) hydraulic gradients are present, there is the potential for a dissolved-phase contaminant plume to dive or sink to greater depths in the sub-surface with increasing distance along the flow path resulting in the existence of a region of uncontaminated water overlying sections of the contaminant plume (API 2005).

7.2.6 Groundwater velocity and hydraulic conductivity

Knowledge of aquifer hydraulic (hydrogeological) properties is important for:

- the assessment of potential migration of contaminants in groundwater
- calibration and development of numerical models
- determination of applicable groundwater remediation methods.

In particular, knowledge of the rate of groundwater flow or groundwater velocity is essential for determining the timescale in which contamination may migrate off-site or threaten a receptor. Where the nearest receptor lies some distance from the site, screening level estimates may suffice; however, where greater certainty is required (for example, presence of nearby or sensitive receptors) then a more precise estimation method will be required.

Groundwater velocity in a porous medium aquifer can be estimated using a modified version of the Darcy equation:

$$v=Ki/n$$

where v is the advective groundwater velocity, K is the hydraulic conductivity, i is the hydraulic gradient and n is the effective porosity of the aquifer unit. The groundwater velocity calculated by this method assumes plug flow of contaminants and ignores dispersion. In reality a proportion of contaminant mass may arrive at a monitoring point (or receptor) much more quickly than is predicted by this method.

Hydraulic gradient is generally calculated based on contoured groundwater elevation data (groundwater flow maps). Effective porosity (the percentage of interconnected pore space) is rarely measured in site contamination assessments and typically falls in a relatively narrow range for defined lithology types, for example, 20%–40% for sandstones. Hydraulic conductivity, K, may be estimated with varying accuracy by a variety of methods depending on the level of acceptable uncertainty. Commonly used methods include:

- literature approaches (screening level data only)
  - literature values based on grain size/lithology descriptions
  - hazen formula with grain size analysis
- aquifer tests
  - slug tests which provide an indication of local hydraulic conductivity at the well bore
  - pumping tests which provide information on a much larger volume of aquifer compared with slug tests
  - tracer tests (in which the travel time of a conservative anion such as chloride is monitored between two points over time to directly estimate velocity).

More information on literature and aquifer test methods can be found in Fetter (2001) and other hydrogeology textbooks.

In general, aquifer testing involves the determination of a range of hydraulic properties within an aquifer. This is accomplished by stressing the aquifer at a test well, either by the addition or removal of water (or an equivalent volume of water using a weight or 'slug') and measurement of the hydraulic response at one or more observation wells within the test area. Depending on the type of aquifer testing carried out, it is possible that groundwater monitoring wells could be used either as test wells and/or observation wells. However, most aquifer test methods require specific well construction procedures such as screening of the full aquifer thickness. Further information on aquifer testing can be found in Standard AS 2368 (1990) and Kruseman and de Ridder (1994).

Using pumping tests to determine average hydraulic conductivity in an area of severe groundwater contamination can be undesirable (for example, where there is a risk of exacerbating DNAPL contamination) and in these circumstances less intrusive methods such as slug tests or using the Hazen formula with grain size analysis (Fetter 2001) may be appropriate.

Fractured rock aquifers require special consideration. Further information on groundwater flow in fractured rock aquifers can be found in Cook (2003).

7.3 Delineating groundwater contamination

7.3.1 Lateral delineation of groundwater contamination

The groundwater monitoring bore network should cover an appropriate study area to delineate the lateral extent of the contamination; the groundwater flow system for the geological units of interest; and to assess the risk to relevant receptors. Generally the number of monitoring wells should be sufficient to define, at an appropriate scale, the lateral and vertical extent of the plume exceeding relevant assessment levels (for example, GILs, HSLs and/or site-specific risk-based criteria) and to understand any seasonal or longer-term variation in groundwater flow direction and rate of plume advance or retreat.

Although the number of bores, locations, depths and screen intervals are site-specific, groundwater site investigations require as a minimum:

- one upgradient bore to establish the quality of groundwater entering the site (one for each aquifer or geological unit of interest)
- two or three bores to monitor groundwater quality immediately downgradient and also lateral to each contaminant source (for each aquifer or geological unit of interest).

Sites with significant contamination and/or complex hydrogeology will require numerous bores at various depths to assess the lateral and vertical extent of contamination and the nature of any temporal variation.

The initial investigation bores should be:

- close to each potential contamination source, at both shallow and deep levels
- installed with similar construction technique to minimise sources of variation and uncertainty in the data

and, where appropriate,

- screened across the water table to locate any LNAPL and to identify contamination derived primarily from surface spills and leaching.

The number and spacing of follow-up wells is a site-specific consideration and the installation of bores without consideration of hydraulic gradient and conductivity values may result in bores being sited at improper spacings. However, as a general guide for plumes estimated to be < 200 m long, well spacing should be of the order of 20 m–50 m in the direction of groundwater flow and 10 m–20 m perpendicular to flow. Well spacing should generally be less than 10 m for the delineation of source zones.

Consideration should be given to installing one or more ′sentinel′ wells to monitor the migration of an expanding or detached plume or to provide confirmation of the continued absence of contamination at a particular location. For example, in some situations it may not be possible to delineate the position of the contaminant plume front due to logistical constraints such as the presence of buildings. However, in this case an acceptable approach would be to install sentinel wells upgradient of the relevant receptors to provide an early warning of any significant plume advance. The location of the sentinel wells would ideally allow the implementation of management actions to protect the receptor if the plume were to advance significantly.

7.3.2 Vertical delineation of groundwater contamination

Source: Clements et al. (2009)

Vertical delineation of vertical variability in groundwater chemistry is critical for risk assessment and remediation planning and reliance on too few monitoring points can lead to inaccurate estimation of contaminant distribution and behaviour.

Multiple wells may be required to adequately characterise the vertical groundwater profile and contaminant distribution. Samples obtained from short, targeted, multiple screens are more likely to be representative of the maximum concentrations present in the aquifer as they are less likely to be affected by the dilution which may occur with a longer well screen. Multiple monitoring wells should be considered where contaminant distribution is likely to be complex (for example, presence of numerous migration pathways or presence of pooled and residual NAPLs).

There are several methods available for screening multiple depths, including installing multiple wells in a small area, nesting multiple wells in the same borehole, and using a pre-fabricated bundle of multi-level wells. There are cost and technical considerations with each approach. Nested wells are cheaper to install; however, if poorly installed, cross-contamination may occur between screens. Bundled multi-level wells (consisting of multiple small diameter tubes in a bundle) can provide confidence in samples at relatively low cost. Multiple wells are typically more expensive, but provide greater confidence in monitoring results.

As an alternative to installing more monitoring wells, consideration may be given to reducing uncertainty in contaminant distribution by using in-situ direct push technologies such as MIP and LIF and/or soil vapour surveys.

Consideration should be given to the potential for a 'diving plume' to develop under the influence of natural or anthropogenic recharge or in response to large scale groundwater abstraction (for example, public supply or industrial process water). The depth to which a plume will dive in an unconfined aquifer is dependent on the recharge rate and the groundwater seepage velocity.

Generally, greater recharge rates will result in a greater magnitude of dive but the recharge effects will be less at higher seepage velocities (API 2006). The US EPA provides an online tool which can be used to estimate plume diving caused by recharge and assuming simplified flow in a water table aquifer (see < www.epa.gov/athens/learn2model/part-two/onsite/index.html>).

7.3.3 Special considerations for DNAPLs

Source: Keuper and Davis (2009) and UK EA (2003)

DNAPLs are only slightly soluble in water and therefore exist in the sub-surface as a separate phase immiscible with both water and air. Common types of DNAPLs include timber treating oils such as creosote, transformer and insulating oils containing PCBs, coal tar, and a variety of chlorinated solvents such as trichloroethene (TCE) and tetrachloroethene/perchloroethylene (PCE). DNAPLs have the potential to migrate to significant depth below the water table through unconsolidated and consolidated materials and fractured bedrock, where they slowly dissolve into flowing groundwater and give rise to aqueous phase plumes.

Due to their physicochemical properties, DNAPLs migrate through the sub-surface in a very selective and tortuous manner and as a result can be challenging to investigate with traditional drilling techniques. Upon release, DNAPL will move and distribute itself into disconnected blobs and ganglia of liquid (residual DNAPL) and in connected distributions (pooled DNAPL). Residual DNAPL is found both above and below the water table within the migration pathways and typically occupies between 5% and 30% of pore space in porous media and rock fractures. Residual DNAPL is trapped by capillary forces and typically will not enter an adjacent monitoring well, even under the influence of aggressive pumping.

Pooling of DNAPL occurs above capillary barriers, typically layers, and lenses of slightly less permeable materials. Penetration through silts and clays may occur if windows are present within the layers or if the layers are penetrated by preferential pathways, for example, tree roots. The presence of dipping fractures, bedding planes, joints and faults may enable a DNAPL to continue to migrate downwards. Downward migration of chlorinated solvents may cease within a few months to a few years of release in relatively permeable media compared with many decades for high viscosity DNAPLs such as creosote and coal tar to cease migration.

The DNAPL source zone comprises the overall rock volume of the sub-surface containing residual and/or pooled DNAPL. In addition to the DNAPL, there may be significant amounts of contaminant mass that has diffused in to low permeability zones. Back diffusion of sorbed contaminant mass from the aquifer to groundwater may sustain dissolved-phase plumes for significant periods of time (decades to hundreds of years).

Above the water table, volatile DNAPLs can vaporise into air-filled pore spaces and for DNAPLs with significant vapour pressure such as chlorinated solvents, this can lead to expanded vapour-phase plumes in the unsaturated zone. In warm dry conditions, the persistence of some DNAPLs such as chlorinated solvents can be relatively short (months to a few years) in unsaturated media. The absence of residual and pooled NAPL in the unsaturated zone may not, therefore, be sufficient evidence to conclude that DNAPL has not migrated below the water table at the site of interest.

Determining the presence or absence of a DNAPL is an important component of the CSM. If the presence of DNAPL is suspected, care should be taken to avoid dragging or spreading pooled DNAPL beyond the current location.

It is now commonly accepted that direct visual observation of DNAPL does not occur at most DNAPL sites and instead, the presence of DNAPL is usually inferred from converging lines of evidence. Site-specific considerations will dictate which lines of evidence (see below) should be pursued. Care, however, should be taken to ensure that a negative response to one or more lines of evidence is not simply attributable to inadequate characterisation and an insufficient amount of data.

The site investigation methods and related interpretation techniques (lines of evidence) which can be useful for characterising DNAPL source zones include:

- visual observation in groundwater samples or drill core
- chemical saturations in soil above threshold DNAPL saturation
- chemical concentrations in soil above equilibrium partitioning threshold
- mapping of a vapour-phase plume if present
- hydrophobic dye testing of DNAPL in soil or water samples or using a down-hole ribbon sampler impregnated with dye
- interpretation of groundwater concentration data and trends with depth and over time (for example, groundwater concentrations in excess of 1% effective solubility may indicate that the groundwater has come into contact with DNAPL).

Further information may be found in Keuper and Davis (2009) and references therein. A tabulation of parameters and other information that may be needed at various stages of site investigation, risk assessment and selection of management options can be found in UK EA (2003). Values of 1% solubility concentration for various chlorinated solvents can be found in Appendix B of US EPA (2009).

7.3.4 Attenuation of groundwater contaminants

(Source: UK EA 2000a)

Assessors should be aware that dissolved contaminants may move at different rates not only as a result of physical processes, but also because of chemical interactions with soil and aquifer components. Attenuation processes include advection, dilution, dispersion, diffusion, sorption, degradation (biotic and abiotic), water washing and volatilisation.

Consideration should be given to the fate of the contaminant(s) as it moves along the migration pathways. This requires that chemical, physical and biological interactions between sources and sub-surface materials are taken into account. The CSM should describe the processes that control the movement of contaminants in soil and the unsaturated and saturated zones.

Degradation can be a significant process in decreasing contaminant mass. The actual rate of biodegradation varies according to a range of factors including contaminant type, microbial populations, redox conditions, temperature and the chemical composition of aquifer materials and groundwater. Evidence for the occurrence and efficiency of degradation processes should be considered in the development of the CSM. Where modelling is undertaken, care should be taken to ensure that the biodegradation process(s) being modelled is appropriate and that realistic reaction rate constants are used.

Further information on attenuation processes and their effects can be found in UK EA (2000a, 2000b) and ITRC (1999).

7.4 Contaminant fate and transport modelling

Source: UK EA (2000b)

7.4.1 Overview of contaminant fate and transport modelling

Risk assessments undertaken when groundwater or soil vapour contamination is present may involve the use of quantitative contaminant fate and transport models. Specific expertise and experience are required to carry out this type of modelling because of the highly complex nature of most contaminant fate and transport problems.

In the context of this guidance, a model is defined as a mathematical representation of reality in the form of equations or computer code and values of parameters. Output from this type of modelling may include travel times to receptors and concentrations of contaminants likely to reach receptors.

A model should only be used when it is clear how and why it is to be used. In deciding whether a modelling approach is appropriate, some of the questions that need to be considered are:

- What is the objective for modelling and what are its benefits? For example, a model may help in the decision-making process by quantifying the potential impact on a receptor and therefore the need to take action to protect the receptor.
- Can a model provide reliable answers? For example, the hydrogeological system may be too complex to be adequately represented by the available modelling resources, in which case the application of a model would serve no purpose.
- Is the hydrogeological system sufficiently understood to warrant the use of a model? A model should not be used as an alternative to collecting further site-specific information; however, it may be used to guide further data collection.

If the decision is taken to use a model, then the limitations and assumptions of the model selected should be assessed to determine whether it is fit for the selected purpose.

Modelling is unlikely to be appropriate where preferential migration pathways are present. These pathways may be natural features; for example, solution channels associated with karst development in limestones, weathered shear zones, and permeable geological faults, or of anthropogenic in origin; backfill around foundations, backfill in trenching for buried utilities such as sewer, water, gas and electricity lines, and backfill around buried tanks and associated piping.

The key stages in developing a contaminant fate and transport model are:

- scoping study, comprising a review of existing information and consultation with relevant stakeholders to define the objectives of the study and the scope of work
- development of a CSM of the groundwater system and consideration of how the contaminant fate and transport processes can be represented in a model
- selection of an appropriate model based on the objectives of the study, the CSM and data availability
- construction/application of the model and comparison of model results with field data to assess model validity
- sensitivity analysis to determine which parameters have the most significant influences on the model results
- uncertainty analysis to take account of uncertainty in the conceptual model, parameter measurement and natural variability of parameters
- assessment of results and reporting, including assumptions and limitations.

The development of the CSM is a critical step and should identify and consider the relevant aspects of the flow system and the contaminant transport processes likely to be operating. In constructing the CSM, a number of assumptions regarding the system behaviour will need to be made. The assessment should consider whether the assumptions and uncertainties are important, that is, whether it is possible to adopt a relatively simple mathematical model of contaminant transport or, alternatively, whether understanding and definition of the system behaviour is so poor that development/use of a mathematical model is inappropriate, and that the first priority should be to obtain further site-specific information.

A phased approach to using mathematical models is recommended, moving from simple calculations to analytical models and, finally, to numerical models if appropriate. The quality and quantity of the data available should be taken into account when selecting the mathematical model. Where data are limited, complex models are generally not appropriate. In each case the selection of the modelling approach should be justified and appropriate to the available data and understanding of the system behaviour.

Data collection should be an iterative process and linked to the development and refinement of the CSM and the mathematical model. Site-specific data should be obtained wherever possible and, for certain parameters, site-specific data are essential. Literature values may need to be used for some parameters, and the values selected will need to be justified.

Construction/application of a model using parameter data will generally involve a calibration step whereby the model parameters are adjusted within a credible range to achieve the best fit between model results and field data. If an acceptable fit cannot be obtained in this calibration step, the appropriateness of the model, the need for further site-specific data, and the CSM should be reviewed.

When completed, the model should be fully documented, including the objectives of the model, the model code used and its limitations, description of the conceptual model including all parameters used and any assumptions made, how the model was constructed and calibrated, and information on the accuracy of its predictions.

7.4.2 Data requirements

The quality and reliability of contaminant transport model results are dependent on the data that have been used to develop the conceptual model and to construct and refine the mathematical model. If the data are inadequate, the model results will be unreliable.

Data requirements vary at different stages in the modelling process but are dependent on the objectives, the complexity of the problem and the sophistication of the analysis. The assessor will need to determine the key parameters for which site-specific data are required and those parameters for which literature values will be acceptable. The ease of collection and relative cost of obtaining site-specific values for flow and transport parameters are summarised in Table 4.

Table 4. Summary of site-specific data requirements for contaminant fate and transport modelling

Parameter	**Site-specific data essential**	**Site-specific data useful**	**Comments on ease and cost of obtaining site-specific data**
Aquifer depth/geology	√		Easy to obtain but data quality, reliability and cost depends on site-investigation techniques used.
Hydraulic conductivity	√		Relatively easy to obtain but data quality depends on method used. Pump tests provide the best data but can be expensive, particularly where contaminated water needs to be managed.
Hydraulic gradient and direction of groundwater flow (and seasonal variability)	√		Relatively easy to obtain but data quality, reliability and cost depend on number and construction of boreholes and frequency of measurement.
Porosity		√	Intergranular porosity is inexpensive and easy to measure. Generally difficult to measure in fractured aquifers due to factors such as the presence of preferential flow paths e.g.fractures, joints, faults or caverns.
Transport porosity		√	Difficult to measure – requires tracer test.
Bulk density		√	Inexpensive and easy to measure.
Partition coefficient (K_d)	√ (for inorganics)		Generally inexpensive and easy to measure but data quality, reliability and cost will depend on methods used.

Cation exchange capacity (CEC)		√ (for inorganics)	Inexpensive and easy to measure.
Moisture content of unsaturated zone	√		Inexpensive and easy to measure.
Fraction of organic carbon (FOC)		√ (for organics)	Inexpensive and easy to measure. Representative data can be difficult to obtain in low organic carbon aquifers, in which case, reasonable default values should be selected based on geological records.
Infiltration		√	Meteorological data is easy and relatively inexpensive to obtain.
Degradation	√ (not for metals)		Relatively difficult and expensive to measure and requires long-term monitoring but is essential to provide confidence in outcomes.
Contaminant concentrations	√		Cost dependent on analytical suite and number of samples.
Redox conditions	√		Cost dependent on analytical suite and number of samples (DO, pH and redox inexpensive and easy to measure).

In some instances, the collection of site-specific hydrogeological data may not be possible, in which case, reasonable default values should be selected based on geological records.

Rigorous scrutiny should be applied to ensure that input parameters are consistent with the geology, hydrogeology and geochemistry of the site or region modelled. Special care should be taken to ensure that values for hydraulic conductivity, contaminant load and degradation rates (if applicable) are appropriate, and that conclusions drawn on the basis of fate and transport modelling are supported by the available monitoring data.

7.4.3 Limitations of fate and transport modelling

Problems can arise at different stages of a project due to:

- poor sampling and analysis
- inadequate CSM
- inappropriate model selection
- use of inappropriate data sources (literature)
- (mis) interpretation/use of results.

Further information on generic 'good practice' to avoid these problems can be found in UK EA (2000b).

7.4.4 Types of model

The two main types of mathematical model are analytical models and numerical models.

Analytical models use exact solutions to equations which describe the migration of contaminants. In order to produce these exact solutions, the flow/transport equations have to be considerably simplified such that they are typically only applicable to simple flow and contaminant transport systems. Analytical models can be simple formulae, spreadsheets or sequences of calculations packaged up in a piece of software, for example, BIOSCREEN and BIOCHLOR from US EPA.

Numerical models use approximate numerical solutions to the governing equations of groundwater flow and transport. Parameter values are specified at certain points in space and time and provide a more realistic representation of the variation of parameters than is possible with analytical models. Numerical models range from relatively simple one-dimensional steady-state transport models to three-dimensional time-variant models, for example, MODFLOW from the US Geological Survey (USGS), and may consider any or all of advection, dispersion and retardation, biodegradation, multiphase flow and density-driven flow.

When considering using models, advice should be sought from suitably experienced persons in hydrogeology and geochemistry and the application of such models. Comprehensive information and software is available from:

- US EPA Centre for Subsurface Modelling Support

  < www.epa.gov/ada/csmos/index.html#download>
- USGS < water.usgs.gov/software/lists/groundwater/>.

A comprehensive software catalogue of a wide range of models which includes information on the advantages and disadvantages of each type is maintained by the International Groundwater Modelling Centre at the Colorado School of Mines (<www.mines.edu/igwmc/>).

8 Vapour and soil gas investigations

8.1 Introduction

This section provides an assessment framework for vapour intrusion and basic requirements for measurement of volatile organic compounds (VOCs) in soil gas, indoor air and outdoor (ambient) air. Primarily, the methods included are applicable to chronic low levels of vapour concentrations as are typically encountered in contaminated site assessments. This guidance is not targeted at the assessment of ground gases associated with operating or closed landfills ('landfill gas') or buried putrescible wastes.

An overview of vapour fate and behaviour processes relevant to VOCs can be found in Davis et al. (2009a, 2009b). Additional information on assessing vapours is provided in other Schedules to this Measure.

The assessment of vapours and soil gas should be undertaken by appropriately qualified and experienced professionals.

If vapour intrusion is suspected of posing an existing or imminent threat to human health, including from inhalation exposure or risk of explosion, then immediate mitigation or management strategies should be implemented.

8.2 Vapour intrusion assessment framework

Source: ITRC (2007a), Davis et al. (2009a) and ODEQ (2010)

For the vapour intrusion pathway to be complete, there must be three components present – a source of sub-surface vapours (in soil and/or groundwater), occupied buildings or the potential for occupied buildings, and a migration route to connect them. Once the pathway is identified as being complete or potentially complete, a staged approach to assessment informed by the iterative development of a CSM is recommended — see section 4. For smaller sites, a single phase of work may be adequate to determine vapour intrusion potential, while larger sites can require multiple phases of vapour sampling to fully define the area of concern and accurately characterise the risks.

8.2.1 Preliminary screening

As a preliminary screening measure, the potential for a vapour intrusion risk should be considered where the Henry's law constant for a substance is greater than 10^{-5} atm/m^3/mol and its vapour pressure is > 1 mm Hg at room temperature. This includes substances such as petrol, diesel, solvents and certain pesticides and PAHs.

In addition, some sites may be screened out of the assessment by the use of a lateral exclusion distance of 30 m from the sub-surface extent of the vapour source. To apply this criterion to a groundwater source, there should be a high degree of confidence based on field data that the dissolved phase plume is stable or shrinking.

8.2.2 Multiple-lines-of-evidence approach

For the assessor to conclude that the vapour intrusion/emission pathways are unlikely to be active or to present a significant risk, multiple lines of evidence are required. This requires the assessor to present more than one reasoned line of evidence as to why the pathway is considered inactive/unlikely to present a significant risk.

The following are some possible lines of evidence, listed in no particular order:

- soil gas spatial concentrations - sub-slab, near-slab (or crawl space) with some level of vertical profiling if appropriate
- groundwater spatial data with vertical profiling if appropriate
- background outdoor and indoor sources
- building construction and operating conditions
- indoor air data and concurrent ambient air data
- comparison of vapour constituent ratios in soil gas with crawl space/indoor air
- biodegradability of vapours and availability of oxygen.

8.2.3 Conceptual site model

A well-developed CSM of vapour risk is essential for understanding current site conditions, determining potential vapour behaviour and (as part of the DQO process) identifying data gaps and uncertainties and priorities for investigation. Site-specific data needed for vapour intrusion pathway risk assessment may include measurement of:

- VOCs in soil gas within the fill and/or native soils below existing buildings
- VOCs in groundwater beneath or in the vicinity of potentially affected buildings or future buildings
- VOCs in indoor air, outdoor air, or soil
- ambient VOCs that may contribute to VOCs measured at the site
- VOCs in preferential migration pathways such as service trenches for utilities.

Consideration of preferential vapour migration pathways is an essential part of the development of the CSM. These may intersect vapour sources or soil gas migration routes, for example, building sumps, drains, or utility and service connections to any buildings. Natural preferential pathways may also occur, for example, fractured bedrock where the fractures are interconnected and in direct contact (including connection by permeable fill) with the building foundation and vapour source.

8.3 Design of sampling and analysis plans for vapour intrusion assessments

Source: ITRC (2007a), Davis et al. (2009a) and ODEQ (2010)

When designing a SAP, consideration should be given to the following:

- confounding sources of VOCs and SVOCs
- degradability of vapours and potential presence of daughter compounds
- environmental factors including spatial and temporal variability issues
- reliability, representativeness, precision and accuracy of available measurement techniques.

8.3.1 Confounding sources of VOCs and SVOCs

Indoor air sampling is the most direct method of measuring VOC exposures where the CSM has identified that vapour intrusion is a potentially complete pathway. In circumstances where very high levels of contamination are present or the contamination has a unique character, the data can provide relatively quick confirmation of vapour intrusion impacts. However, for most sites, simply detecting VOCs inside a building is not definitive evidence of vapour intrusion.

Outdoor or ambient air commonly has detectable levels of VOCs, sometimes exceeding ambient air guideline values. The largest sources of these contaminants include vehicle emissions, fuel storage facilities and emissions from commercial/industrial activities (including service stations). As outdoor air typically makes up 99% to 99.99% of indoor air, ambient VOC levels tend to represent the minimum concentrations in indoor air. Buildings can also contain interior sources of VOCs which include building materials, paints, dry-cleaned clothes and some commercial and household cleaning products. It is therefore advisable to conduct a survey of the building interior in advance of any indoor sampling to identify potential confounding sources and eliminate them as far as practical prior to sampling and to obtain concurrent ambient air samples.

As it is often not possible to remove all interior sources of VOCs prior to sampling, indoor air results should only be used in the context of a multiple lines of evidence approach. To reduce the frequency of false positives, indoor air sampling is not recommended until other information (lines of evidence) indicates a potential vapour intrusion risk.

Further information including detailed protocols for the collection of indoor air data can be found in ITRC (2007), NYSDOH (2006), and NJDEP (2005).

8.3.2 Biodegradation

The concentration of petroleum hydrocarbon (such as TPH and BTEX) vapours in well-oxygenated, generally near-surface soil can be significantly reduced by biodegradation (Davis et al. 2009a, 2009c). However, this is generally not the case in less well oxygenated soil such as under large areas of hardstanding or building foundations.

The fundamentals of an approach to include an exposure reduction factor due to aerobic biodegradation are included in Schedule B4). The approach requires the recovery of a soil gas sample from a depth of at least 1 m below ground in close proximity to the building (or in a similar nearby soil, soil moisture and soil coverage environment). Where the building slab penetrates the ground by more than 0.3 m, then the additional depth of penetration of the slab below 0.3 m should be added to the depth at which the soil gas sample is recovered for oxygen analysis.

Halogenated hydrocarbons can also be biodegraded, but the process for most halogenated compounds occurs in anaerobic conditions via a number of steps which can be much slower than for the aerobic degradation of petroleum hydrocarbons. The SAP should address potential degradation products as appropriate.

8.3.3 Undeveloped land

Assessing the potential for vapour intrusion in to a future building on vacant land poses unique challenges. Some of the investigative tools of the vapour intrusion pathway (for example, indoor air and sub-slab sampling) are not possible when there is no slab or structure present; however, others (soil, soil gas and groundwater sampling) may be able to be used with appropriate precautions or adjustments.

As for existing buildings, a multiplication factor (x10 or x100 as appropriate) due to biodegradation may be able to be applied to relevant HSLs if the proposed maximum building size can be determined with a high degree of certainty, and the exclusion/inclusion criteria listed in Davis et al. (2009c) can be fulfilled (see Schedule B4).

8.3.4 Environmental factors

VOC concentrations in the environment are highly variable, and collecting sufficient data to thoroughly understand and predict their temporal and spatial distribution can be time-consuming and costly. VOC levels in ambient air can vary greatly over time. Diurnal fluctuations occur due to changes in vehicle traffic (for example, rush-hour effects), commercial activity, and as a result of atmospheric heating and cooling cycles, air pressure changes and wind speed. These fluctuations and their impact on the data analysis can be reduced by collecting time-integrated samples. Additional information on environmental factors and their effects can be found in Davis et al. (2004).

To compensate for these inherent uncertainties, consideration should be given to identifying and characterising the main factors which may lead to a reasonable worst-case exposure scenario. The time period selected for sample collection should be appropriate to characterise the exposure scenario.

Rates of vapour intrusion are affected by both short-term and seasonal changes in weather conditions. Changes in barometric pressure associated with the arrival of weather fronts can move gases into or out of the vadose zone. This phenomenon, known as barometric pumping, increases the rate of vapour emission as low pressure systems arrive and decreases rates when transitioning to higher pressure. This effect is only of importance for soil gas where sampling is shallow (less than 1 m–2 m). Wind can also enhance vapour intrusion rates by depressurising a building relative to the underlying soil, causing more vapours to enter the building from the sub-surface. Similarly, high volume air conditioning systems in buildings may affect vapour intrusion.

To account for wind and barometric pressure effects, consideration should be given to sampling during stable weather conditions and recording local barometric pressure and wind-speed data over the three days before and during the sampling event.

Variations in soil temperature result in the expansion and contraction of soil air, leading to partial exchange with the atmosphere. Hence vapour measurements may change daily and from season to season. However, temperature effects decrease with depth below ground and typically show minimal variation much below 1 m below ground. Temperature variations are not expected to have a large influence on soil gas or indoor air concentrations unless the source is very close to surface.

Soil moisture increases due to rainfall infiltration may inhibit gas exchange processes, and in particular, vapour movement towards the ground surface, and oxygen ingress from the atmosphere. An increase in moisture content decreases the air-filled porosity and results in lower vapour and gas diffusion rates in the vadose zone. This is likely to be particularly the case for heavier textured (clay) soils (Davis et al. 2004).

Sampling of soil gas (particularly from depths shallower than 1 m to 1.5 m) directly after significant rainfall events (greater than 25 mm) should generally be avoided, unless the rainfall is representative of normal conditions. Soil gas samples collected from depths greater than 1.5 m are unlikely to be significantly affected by rainfall events. No specific guidance on how long to wait before sampling shallow soil gas (shallower than 1 m to 1.5 m) after a rainfall event is given as it is dependent on the soil type and other climatic conditions. If uncertainty remains as to the potential for a rainfall event to change the distribution of vapours in the sub-surface, then repeat sampling should be undertaken or measurements of soil moisture may be taken at the time of vapour sampling.

8.4 Soil gas sampling methods

This section provides a summary of commonly used methods for sampling and characterising soil gas at a site and has been adapted from information provided in Davis et al. (2009a). More detailed information can be found in Davis et al. (2009a), Baker et al. (2009), API (2005), NYSDOH (2006), and ITRC (2007a).

Soil gas samples may be taken from probes installed in open ground or recovered via access holes drilled through sealed surfaces (such as a driveway or parking area 'near-slab') or beneath building foundations ('sub-slab'). Sampling installations may be permanent, semi-permanent or temporary depending on access and the need to re-sample.

A field screening assessment of the contaminants present can be carried out by drawing the gas through an online PID, FID or other handheld detector for obtaining readings of parameters such as O_2, CO_2 and methane.

8.4.1 Temporary spear probing

Spear probing (driven soil gas probes) of soil involves driving a spear/rod into the ground to a shallow depth (for example, 1.5 m–2.0 m below ground surface), extracting a soil gas sample for analysis of the vapours of concern and/or major gases (for example, oxygen), and withdrawal of the spear probe. Samples should be recovered below the zone influenced by transient effects, which is likely to extend to 1 m or greater below the surface. The probe should be decontaminated before using at the next location.

Spear probing is generally used as a screening tool (as it permits a large number of locations to be sampled in a cost-effective manner) to inform a more detailed investigation of identified areas of interest.

The method can also be used to collect samples from a vertical profile (from as shallow as 0.3 m) to assist in the identification of various vapour zones and to define the potential aerobic reaction zone.

As a quantitative technique, spear probes can be installed and sampled in the same manner as permanent probes/samplers. Additional considerations associated with the sampling of soil gas are noted in the relevant sections in this Schedule.

8.4.2 Permanent multi-level probes/samplers

The installation of permanent sub-surface soil-gas multi-level probes/samplers permits:

- depth profiling of vapour concentrations through the soil profile from near source to near the ground surface
- repeat sampling and monitoring over time at fixed locations.

Single depth permanent probes can either be installed at depth (close to the source) or in the shallow sub-surface (particularly where the source is shallow). Multiple depth (or multi-level) gas sampling installations may be undertaken by installing multiple sample ports at different depths (separated by a bentonite seal) within the one sampling well (API 2005; Hartman 2002), or installing separate soil gas probes at different depths (separated by at least 0.6 m) (API 2005; NYSDOH 2006).

There are a range of methods available for installing permanent probes. The probe installation method used should be determined based on site-specific factors such as access and environmental conditions (for example, soil texture or moisture conditions which may limit the use of very narrow tubing).

A log of soil types encountered during drilling should be documented. To assist in the assessment, a soil core may also be recovered and sub-sampled to determine organic carbon and soil parameters (for example, bulk density, porosity) at the depths of the sampling ports, and for analysis of the soil for the chemicals of concern.

Correct sealing of the installations is essential, especially in low permeability soils. Separate installations rather than multi-level samplers may be necessary in low permeability soils to ensure a good seal is able to be achieved or where the upper sample is less than 1 m below the surface.

Sampling of permanent probes and multi-level samplers can be carried out using a range of sampling methods. Typically, permanent probes should be left for a minimum of 24 to 48 hours to equilibrate prior to sampling (DTSC 2009; NYSDOH 2006), depending on the installation method and the site conditions.

8.4.3 Online VOC and oxygen probes

Near-continuous measurement of total vapour (or VOCs) and oxygen concentrations is possible using online VOC and oxygen probes (Patterson & Davis 2008; Patterson et al. 1999, 2000). These can be buried at multiple depths to give near-continuous measurements of total vapour and oxygen concentrations for extended periods (months to years). Apart from providing vapour and oxygen depth profiles, the detailed information derived from these probes allows seasonal trends in vapour fluxes and other parameters such as degradation rates to be assessed.

Online VOC probes do not directly monitor individual compounds such as benzene, but can be sub-sampled to obtain a gas sample, which can then be analysed by conventional means for component VOC and major gas concentrations.

8.4.4 Factors for consideration when sampling soil gas

The following factors require consideration in the design of a soil gas sampling program:

- *Location and number of sampling points*— the number of locations sampled depends on the CSM, access and cost. As a minimum, samples should be collected within or adjacent to the site of maximum source concentration near or under a building and at each corner or along each side (if practical).
- *Depths* — the depth of samples should be based on the CSM; in particular, the depth of sub-surface sources and the nature of the contamination. Where shallow sources are present or where deep samples cannot be obtained, the collection of soil gas from shallow depths (<1.0 m) may be appropriate; however, sampling from these depths requires justification. When installing or using data from shallow wells the potential for aerobic degradation and potential transient influences should be considered.

- *Frequency* — a single sampling event may be sufficient in certain circumstances, provided that the data are used as part of a multiple lines of evidence approach and the results are well below the assessment criteria (Baker et al, 2009). Multiple sampling events will be required in the event that (i) the first round of data are close to or above guideline values, (ii) if samples were collected from shallow depths (<1.0 m), and/or (iii) seasonal variations in temperature or soil moisture need to be considered.
- *Probe integrity/seal* — soil gas probes (temporary or permanent) should be installed in a manner that ensures that ambient air is not drawn into the sampling system and that a representative soil gas sample can be collected. This may require an additional seal around the probe, even for temporary installations. An adequate seal is particularly important for shallow probes or sub-slab probes. A number of tracer methods are available to test the seal integrity - see API (2005) and ITRC (2007).
- *Tubing type* — the tubing type should be selected to minimise false positives due to outgassing from the tubing materials.
- *Sample volume* — sample volumes should be minimised as far as practicable to meet the requirements of the sampling/analytical method selected. A review of available studies on sample volumes by Hartman (2006) suggested that the sample volume is less important for coarse grained soil, but in finer grained soils large volumes may be difficult to collect due to the creation of a vacuum during sampling. Large sample volumes increase the likelihood that the sample may originate from different depths and locations, hence, sample volumes collected should be minimised. Near ground surface, recovering large sample volumes may result in ambient air being drawn from outside of the annulus of the shaft of the probe.
- *Purge volumes* — the sample probe, tubing and equipment have an internal volume that must be purged prior to sampling to ensure that only soil gas is sampled and that the data obtained is representative. Generally, three to four system volumes should be purged as long as the purge volume is not large. Whatever calculation is used to estimate the volume purged, this should remain consistent for all locations sampled. As large purge volumes can result in low pressure/vacuum conditions which may cause contaminant partitioning from the soil to soil gas, the purge volume should be minimised as far as practical to ensure that the sample collected is representative.
- *Sample flow rates* — to minimise the potential for desorption of contaminants from soil to soil vapour in the sampling zone; the assessor should select a sample flow rate appropriate for the soil type. A low sample flow rate (<0.2 L/min) is important where soil gas is collected from low permeability soil (McAlary et al. 2009a); however, higher flow rates (<100 L/min) may be used for coarse grained soils [ITRC 2007a]). Low permeable or high-moisture content soils can induce greater suction pressures when sampling which can make samples difficult to recover.

8.5 Flux chamber methods

Source: Davis et al. (2009a)

A flux chamber (or a flux hood) is a device that is placed on a surface to measure vapour/gas flux (or emission rate) discharging through that surface. The surface may be open ground or be part of a building foundation such as a concrete slab.

The technique enables direct measurement of vapour flux from the surface of the ground or building foundation, thus providing a direct estimate of the parameter of interest (rather than calculating it from sub-surface vapour distributions). Flux methods effectively 'integrate' all sub-surface processes (for example, phase partitioning, biodegradation, preferential pathways, advective and diffusive transport) often close to the point of potential exposure.

There are two primary types of flux chamber methods: a static (closed) chamber method, and a dynamic chamber method.

8.5.1 Static chamber

The static chamber method requires the placement of the flux chamber on the surface of the ground or building foundation, excluding passage of air through the chamber. This allows vapours to be trapped and the stagnant chamber vapour concentration to build up over time. Active samples can be collected at discrete intervals through a time period and at the end of a time period.

8.5.2 Dynamic chamber

The dynamic chamber method involves the use of an inert sweep gas which is continually introduced into the chamber with an equivalent amount of gas allowed to escape. The system is allowed to reach steady-state, (assumed to be four or five chamber volumes) before the chamber is sampled. The sample can be a discrete sample or monitored continuously.

8.5.3 Factors for consideration when using flux methods

When designing a sampling program the following should be considered:

- *Coverage of the area of concern* —adequate coverage of possible vapour conduits, areas of maximum source concentrations and consideration of other site-specific building features as required.
- *Deployment period* — this should be adequate to address the issues of concern and, where possible, enable temporal variability to be assessed.
- Basements — flux chambers may not be suitable for dwellings with basements because of additional potential fluxes from the basement walls to the interior of the dwelling.
- *Sub-surface conditions* — flux monitoring provides little information about the processes that may be occurring within the vadose zone such as oxygen penetration and hydrocarbon degradation. Longer-term controls on emissions and hence potential changes in sub-surface conditions may not be detected with such a device, unless long-term near-continuous emission monitoring is undertaken.
- *Buildings* — because of the usually limited surface area of coverage, flux chambers may not measure the actual flux into a built structure especially if there is preferential access to the structure. Also, air-movement conditions within the chamber may not reflect 'natural' room conditions in a structure – leading to overestimation or underestimation of fluxes depending on relative pressure differentials inside and outside a chamber.

More detailed information can be found in Davis et al. (2009a), Baker et al. (2009) and Hartman (2003).

8.6 Passive implant sampling

Source: Davis et al. (2009a)

'Passive' implant sampling refers to the burial or placement of an adsorbent or other material in the ground, which is recovered for analysis after an appropriate period of time (hours to days). It is termed passive because no gas sample is actively recovered from the soil profile. The adsorbed mass cannot be equated to a concentration because the volume of air associated with the adsorbed mass is largely unknown.

The method enables a screening level assessment of the presence of vapours in the vadose zone to identify if the vapour pathway is complete and to identify hot-spot areas for further sampling using more quantitative methods. Passive samplers may be of benefit in areas where soil gas probes cannot be installed, in areas where preferential pathways are suspected (or need to be assessed) or where very low permeability soils limit the practicality and integrity of sampling from soil gas probes (API 2005).

Passive samplers may desorb soil vapours from fine grained layers that are otherwise not mobile thus overestimating the amount of soil vapours that are capable of being transported into overlying zones.

More detailed information can be found in Davis et al. (2009a), Baker et al. (2009) and ITRC (2007).

8.7 Sample collection and analysis

Source: Davis et al. (2009a)

Samples that are collected and sent to a laboratory or field GC/MS for analysis, may be collected using a range of media that include sorbent tubes (charcoal or multisorbent), summa canisters, tedlar bags, glass vials, and syringes.

Commonly used active and passive collection methods are discussed in the following sections, while more detailed information can be found in Davis et al. (2009a).

8.7.1 Active methods

8.7.1.1 Sorbents

Sorbent materials, packed into tubes, typically comprise activated carbon and/or a range of multi-sorbent materials (one or more different sorbent media may be present in each sample tube). Vapour samples are collected by drawing air (using pumps) at a calibrated rate through the tube over a specified period of time. The flow rate and sampling volume are dependent on the sorbent media used, the range of target chemicals and the required limit of reporting. The reporting limit is determined by the volume of air drawn through the sample tube, the adsorbent and analytical method used, and the potential for high concentrations (requiring dilution of the sample during analysis).

8.7.1.2 *Canisters*

Whole air samples can be collected using specially prepared canisters which are sent to the field under vacuum and certified clean and leak free. The canister is fitted with a calibrated regulator that, when opened, allows air to be drawn into the canister over a pre-set time period at a constant flow rate. Initial and final vacuums are recorded for each canister, as well as the vacuum when received at the laboratory.

8.7.1.3 *Other methods*

Whole air samples can also be collected using Tedlar® bags or syringes and glass vials.

8.7.2 Passive methods

Passive methods can involve the use of a wide range of sorbent materials. These materials are available in a range of forms (badges, canisters, tubes, strips) where the collection of compounds is based on the diffusion of the compound to the surface of the sorbent material. Other samplers/systems are also available and can be used depending on the target analytes, required use and reporting limits.

The range of compounds that are commonly analysed with passive sorbents include petroleum hydrocarbons, chlorinated hydrocarbons, ammonia, aldehydes, phenols and creosols, hydrogen chloride, hydrogen fluoride and hydrogen sulphide. Other compounds can be targeted using passive methods depending on the sorbent materials/housings used, the ability to assess uptake (diffusion) rates, and analysis methods. The limit of reporting varies depending on the sampler (sorbent material) used, the analysis method and the sample time.

Passive methods are generally considered to provide a qualitative measure of concentration; however, quantitative results may be obtained under certain conditions. This is dependent on the concentration present in air, the time sampled and, for some samplers, the movement of air past the sampler. The concentration is calculated based on diffusion principles (uptake rates). The reliability of the results should be assessed as part of the DQO process.

The use of a passive sampling system, selection of appropriate sampler (to adequately address the range of compounds required), sampling time and analysis method should be considered in the design of the sampling plan.

8.7.3 Analytical methods

The analytical method(s) selected should be considered with respect to the target compounds, DQOs, the availability of analysis, and the advantages/disadvantages of each method.

Ambient air and soil gas samples are generally analysed using methods sourced from the US EPA's *Compendium of methods for the determination of toxic organic compounds in ambient air* (TO-methods). In some cases, site assessors may wish to use alternative methods in which case the alternative method should be at least as rigorous and reliable as the TO-methods. For further information on reference methods and alternative methods, see Schedule B3.

9 Assessment of specific forms of contamination

9.1 Assessment of asbestos soil contamination

The site-specific assessment of sites contaminated by asbestos in soil should be aimed at describing the nature and quantity of asbestos present in sufficient detail to enable a risk management plan to be developed for the proposed or future land use.

As suggested in the WA Department of Health guidance (DoH 2009a), the assessment process may move from a preliminary site investigation to a more comprehensive detailed site investigation — see Schedule B1. A comprehensive detailed assessment will not be required in many cases, as a management approach will be preferred and qualitative assessment of the lateral extent of soil contamination will be sufficient.

Assessment would normally require a sampling and analysis plan (SAP) to support the investigations and also any validation sampling that occurs. A site management plan may be required to protect the public and workers during the assessment process, as well as long-term users of the site.

Detailed guidance on the assessment procedures can be found in the WA guidelines.

9.1.1 Preliminary site investigation

The presence of asbestos materials, most commonly asbestos cement material (ACM), in soil (including stockpiles and areas of fill) on a site may trigger an initial qualitative assessment on its lateral and vertical distribution in a site. The extent to which this is undertaken should be related to the existing and/or proposed land uses. Fragments must be inspected by an appropriately qualified and experienced assessor. Assessors employed to investigate and manage asbestos contamination should be led and supervised by a consultant with appropriate asbestos credentials. The lead consultant should normally have a minimum of three years' experience with asbestos soil contamination and relevant tertiary qualifications in environmental science, science or engineering. The default assumption should be that the suspect material does contain asbestos and appropriate management action should be initiated. Where confirmation is required regarding the nature of the fibre in the ACM, identification by transmission electron microscopy is the favoured method to determine if the suspect material in the cement matrix is asbestos.

Issues that should be considered during preliminary assessment are described below.

9.1.1.1 Condition of the asbestos materials

Asbestos cement material may be able to be easily broken by hand force and be more readily crumbled when water-saturated or corroded. In a partially crumbled state, ACM may be of greater concern particularly if it is exposed at the surface and is open to abrasion during land use. In particular, roofing material containing asbestos may be heavily weathered which can corrode away the cement matrix and expose fibrous asbestos to the atmosphere. ACM which can be easily crushed by hand should be considered friable and assessed for management actions accordingly. Similarly, unbonded asbestos or fibrous asbestos (FA), including loose material such as insulation products and low density board (up to 70% asbestos in calcium silicate), are considered friable.

9.1.1.2 *Condition of the soil and future uses*

Generally accepted guidance for considerations of site setting and characteristics should be applied. Soil type should be considered. Any potential for exposure of the ACM to an acid-generating environment may be a factor that will increase the potential for release of fibres from the cement matrix. Many Australian soils are weakly acidic but some sites may have potential for exposure to acid sulfate soils or other acidic soil conditions. The clay and moisture content of soils is also a consideration as these factors tend to inhibit the release of fibre by binding and damping mechanisms.

9.1.1.3 *Detailed site assessment*

Detailed site investigation is only applicable to asbestos cement containing material (ACM). Qualitative assessment may be sufficient to determine that the distribution of ACM is limited and that no further action, or limited action such as removal of minor surface material, is all that is required. Where there is a concern (and a need to determine) that the level of ACM may exceed the screening criterion, quantitative assessment using a gravimetric approach may be undertaken to assess the site-specific risk. This more detailed assessment may also be carried out when ongoing management of the site under regulatory controls is a potential requirement.

Detailed site assessment should be undertaken for sensitive land uses where asbestos contamination (using a gravimetric approach) is likely to approach or exceed screening criteria. This may involve a quantitative, thorough, and well-argued risk assessment involving a detailed test pit and trenching program based on site history where it is available, and appraisal of the relevant site-specific risk issues.

9.1.2 Issues in assessment of asbestos site contamination

9.1.2.1 *Distribution of asbestos cement materials*

Surface distribution - ACM fragments are often present as surface deposits on sites from past poor demolition and building practices. While isolated fragments across the surface of a site are usually of low concern, any surface material may present a risk of exposure over time from decay through corrosive weathering or abrasion by vehicle traffic and other activities. There should be no visible ACM fragments greater than 7 mm x 7 mm on the surface or in the top 10 cm of soil, which can be achieved by multidirectional raking or tilling and hand picking. When cohesive soils or a large surface area is involved it may be more practical to skim the top 5–10 cm of soil for disposal in accordance with jurisdictional requirements. The exposed surface of the site can then be further visually assessed by an appropriately qualified and experienced professional on a systematic basis where some localised hand picking or additional earthworks may be required.

ACM through a soil profile - test pits or boreholes may reveal the presence of ACM in fill through a soil profile. This can be quantified on a gravimetric basis and compared to the screening criteria in Schedule B1.

9.1.2.2 *Assessing quantity and distribution – gravimetric approach*

A thorough site history should inform any sampling plan for boreholes, test pits or trenches to enable the estimation of the quantity and distribution of ACM across a site. The sampling density should be sufficient to enable an appropriate management plan to be developed.

Samples of known weight can be taken from a trench wall, the soil inspected and any ACM found removed by hand, sieved through a 7 mm x 7 mm sieve, washed free of soil, dried and weighed to estimate the mass of ACM present. The asbestos ACM % w/w is then calculated based on estimates of the asbestos content of the particular ACM material. Results are compared to the screening criteria in Schedule B1.

If the ACM is friable, or there is a strong likelihood of asbestos free fibres associated with degradation of ACM or small fragments (< 7 mm x 7 mm) in the soil, better quantification can be achieved by sieving and washing to estimate the amount of the lower size fractions. Note that asbestos fines (AF) are defined as ACM fragments that pass through a 7 mm x 7 mm sieve and that a soil screening criteria of 0.001% would normally apply to this form of asbestos contamination.

9.1.2.3 Collating data

Collation and reporting of data should identify the distribution of the ACM or other asbestos contamination to the limits of its lateral and vertical presence. Assessment may reveal an irregular distribution of the ACM that will allow partial removal of material to achieve lower overall asbestos concentration in the soil.

9.1.3 Management

Remediation options which minimise soil disturbance and therefore public risk are preferred.

Management of asbestos in situ is encouraged, which may include covering the contamination with uncontaminated fill (minimum 30cm layer) and/or other protective or warning layers as well as institutional controls such as registering a memorial on the relevant certificate of title. It should be noted that the common alternative of complete removal of asbestos from a site often involves extensive and costly investigative and confirmatory sampling and sometimes is not effective or necessary.

Regulatory authorities may consider management controls to land with substantial ACM contamination to ensure that appropriate management conditions including land use limitations apply to the site. These controls may include notation on title, approved management and listing on public site contamination registers or ongoing controls under audit statements and planning controls, as relevant for the jurisdiction. In situations where no long-term management is able to occur, high levels of buried ACM >0.1% are not acceptable as there is no guarantee that the ACM will not be disturbed over time.

The WA guidelines (WA DoH 2009b) provide a simplified management approach for use by local government in dealing with single residential lots with ACM contamination arising from asbestos dumping or poor demolition practices. This makes use of visual contamination indicators, site knowledge and basic remediation measures for what is usually a low-risk situation.

Strategies for such sites may be summarised as follows:

- *10 ACM fragments or less per m^2* with little associated past soil disturbance – simply remove all visible ACM
- *more than 10 ACM fragments per m^2* or fragments plus significant soil disturbance - consult relevant regulator or consultant, with the expectation of a surface soil skim being necessary down to depth of likely soil penetration
- *many fragments per m^2* and with likely but unknown degree of burial – consult relevant regulator or consultant with the expectation of a more detailed site assessment being required.

9.2 Assessment of dioxins and dioxin-like compounds

It is rarely necessary to undertake analysis for dioxins and dioxin-like compounds (dioxins) at contaminated sites. Analysis should ONLY be undertaken when the site history clearly indicates that dioxins are very likely to be present as a by-product resulting from specific manufacturing and industrial activities, or from waste disposal. Further information on dioxins is provided in Appendix E.

Dioxin contamination may be present following long-term and large-scale use of a site for the following activities:

- manufacture and waste disposal associated with certain chlorinated compounds, for example, PCBs, phenoxy herbicides, organochlorine pesticides, chlorinated benzenes, chlorinated aliphatic compounds, chlorinated catalysts, and halogenated diphenyl ethers
  - bleach pulp and paper mills processes known to produce dioxin
  - incineration of substantial chlorinated compounds
  - former municipal solid waste incinerators
  - hospital waste incinerators
  - extensive use of PCP in timber treatment.

Where dioxins are detected at levels significantly above background, a site-specific assessment may be required to determine the appropriate action.

10 Assessment of summary statistic data and data presentation and reporting

An efficient and accurate appraisal of a site requires that the data be collated in a form, or 'model' that facilitates understanding of the location, extent, trends, and likely 'behaviour' of any contamination.

An adequate understanding of what is occurring on a site is almost impossible to achieve from pages of raw data, especially where there are abnormal results or more than a handful of results. At its worst, sample identification numbers, sampling points, geotechnical logs, and results for each analyte will be on separate pages.

A uniform approach to the location and presentation of data makes for more rapid and accurate assessments of reports.

The major problems that can occur with data sets and assessments are:

- a failure to collate data and to condense it into logical and comprehensible tables
- a failure to provide cluttered data sets, tables and graphs
- treating the sum of the data as somewhat greater than the sum of its parts.

This is exemplified by:

- over-elaborate contour maps (some can be useful) based on a very limited number of data points which are not annotated on the map
- providing fairly definitive conclusions unsupported by the data
- considering the numbers in isolation from other data important to interpretation, for example, site history and soil characteristics.

10.1 Assessment of summary statistic data

Source: Langley (1993)

10.1.1 Summary statistics

No single summary statistic (for example, an arithmetic mean or the median) fully characterises a site. Instead, a range of summary statistics is needed to develop understanding of the site conditions and likely contaminant behaviour.

Each summary statistic will have a contribution, but will also have certain limitations. For example, the mean is affected by each individual value and is particularly sensitive to extreme values. However, it is less sensitive to sampling variation than the median or mode , that is, it is less affected by repeated series of random samples from a single population. The median is less sensitive than the mean to extreme values and is usually more sensitive to sampling variation (but less so than the mode) (Pagano 1986).

Given that much of the sampling in contaminated site assessments is judgemental rather than random, caution needs to be taken with the use of conventional (parametric) statistical methods. Non-parametric methods can be used for judgemental sampling and for where data are not normally (or lognormally) distributed. Further information can be found in Gilbert (1987) and US EPA (2007).

For multiple analytes, an impression of the typical levels, location of contaminants within strata, total 'burden', and statistical distribution of results can be presented as in Table 5.

The following summary statistics should be provided for each stratum of testing where sample size permits.

Table 5: Summary statistics for multiple analytes and stratum

Chemical name	**XXX**
Number of samples:	
Range:	
Investigation Level:	
Median:	
Arithmetic mean:	
Arithmetic standard deviation:	
Geometric mean:	
Geometric standard deviation:	
95 percentile	

Frequency distribution[a]	**Number**	**%**
Less than investigation level:		
≥ 1 and < 2 times investigation level:		
≥2 and <5 times investigation level:		
≥5 and < 10 times investigation level:		
≥10 times investigation level:		

a:An arbitrary method is used to categorise data.

10.1.2 Censored data

Censored data is that which is below the level of reporting. Summary statistics can be biased according to the values substituted into mathematical formulae to allow calculations of, for example, means. Often the value of the level of reporting is falsely substituted, upwardly biasing the sample statistics. Further information is available in Heyworth (1991) and US EPA (2007).

10.2 Data presentation

10.2.1 Some principles of graphical representation

Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space. Graphical excellence is the well-designed presentation of interesting data - a matter of substance, of statistics, and of design, and consists of complex ideas communicated with clarity, precision, and efficiency (Tufte 1983).

Some basic principles of graphic representation are given in Table 6.

Table 6. Helpful vs unhelpful graphics

Helpful	Unhelpful
No cryptic abbreviations. No elaborate encoding.	Numerous abbreviations requiring searching the text for explanation.
Words run in natural left to right direction.	Words run vertically or in several directions. Letters running vertically may be even worse.
Brief text messages explain data.	Understanding graphic requires repeated sorties into text.
No elaborate shadings, cross hatchings and overpowering colouring.	
Simple labelling of graphic means no legend or key is required.	Elaborate or obscurely coded patterns requiring continual return to legend or key.
Simple, upper-and-lower case font with serifs modestly and consistently used.	Multiple overbearing fonts, in upper case sans serif.
Clearly printed.	Murky and clotted printing.
Enlightens and arouses curiosity.	Graphic repels interest and obscures meaning.

(Source: Langley 1993, adapted from Tufte 1983)

10.2.2 Contouring

Graphical representations of contours can provide useful information about sites such as the distribution and 'trends' of contamination. Very rarely, though, are there sufficient data points or sufficient associations between adjoining points (that is, sites are likely to be very heterogeneous). The methods used, for example, kriging, regression, minimum curvature, etc. can influence the results. For this reason, contours should be interpreted with caution and should include all data points for clarity.

Groundwater pollution plumes are mostly visualised by contouring occasionally by colour variability and should also be interpreted with caution and review of each data point. Uncertainty is usually identified by using broken lines for boundaries. The same could be used for soils.

10.2.3 Maps

Mapping the results can be useful but poor design can cause clutter which obscures important data.

If there is ‘too much’ data available, this may be addressed by displaying only significant results on the map. However, this should be done cautiously as censoring some of the data can obscure trends. Normal results can be important if elevated results were anticipated and may need to be included.

Another way of tackling the problem of excessive data is to remove relatively unimportant analytes such as zinc or copper unless these provide some form of surrogate measure of where contamination may occur on a site. A series of transparent overlays, each with a different analyte, can be very useful in this situation.

10.2.4 Graphics

For all but the most simple of sites, some form of graphical representation is imperative for the assessor and other relevant parties to accurately visualise the site. Without such representations, inaccurate (and probably costly) decisions may be made.

Useful examples of graphical representation of site data can be found in Appendix D.

10.2.5 General requirements

Reports should preferably be printed on A4 size paper, with durable covers and binding which allows for easy opening. Photographs and figures should be of high quality and adequately display the points of interest.

Reports should follow appropriate subject headings and be structured in a logical way.

To support the site history investigation, copies of all current and old site layout plans, diagrams, correspondence, photographs, permits, etc. should be included in appendices.

Where the site history is complicated because of numerous past uses and/or occupiers, information may be effectively presented as a table or time line. Reports should also include the assessor’s opinion and conclusions relating to the environmental condition of the site, as well as recommendations for any further assessment or site work the assessor considers necessary.

A discussion of assumptions made in relation to the assessment, including those related to sampling density, sample locations, choice of analytes, off-site impacts and potential groundwater contamination, should be made.

The following documentation should be included in reports:

- disposal dockets and receipts issued when contaminated soil and fuel tanks or other structures are removed from the site
- validation of any ’clean fill‘ used at the site
- certificates of clearance for asbestos removal or remediation clearance
- QA/QC protocols for field and laboratory work
- calibration reports for all field monitoring equipment
- chain-of-custody documents for all soil, vapour, groundwater and surface water samples and laboratory receipt notices.

10.2.6 Site drawings

10.2.6.1 Displaying site features

Site plans should be drawn to a scale appropriate to the size of the project and the level of detail required. Drawings on A3 or larger paper may be necessary. Drawings should show:

- a north-facing arrow
- scale
- lot boundaries
- location of present and former infrastructure and site activities
- distribution of fill types
- locations of affected vegetation, stains, odours, chemical containers, etc.
- direction of surface run off and drainage
- presence of above and below ground services
- areas covered by an impermeable seal (e.g. concrete, bitumen and buildings).

In some situations, it may be necessary to show previous site layouts as overlays over the current layout and perhaps have another overlay of sample locations or show sample excavation boundaries (see Appendix D).

Figures showing topographical contours in relation to site features and sample locations can assist with the assessment of sites with varied topography/changes of level.

10.2.6.2 Displaying contaminant concentrations

Sample locations, sample identification numbers and depths should be plotted on one or more site layout figures. Sites with a large number of sample locations and numerous elevated results can be difficult to fully comprehend and time-consuming to assess. Therefore, to minimise assessment times and to allow, at a glance, a clear representation of contamination issues associated with the site, site plans should be used to display sample results.

The following techniques to clearly display results should be considered:

- a separate site plan for each elevated analyte, which displays sample locations, sample identification numbers and depths, and shows different concentration ranges in different colours
- a separate site plan (including locations, identification numbers and depths) for each elevated analyte, where the actual data are displayed, any exceedances of the guidelines are highlighted, and the exceedances are colour coded according to concentration ranges.
- a site plan displaying all analytes tested at each depth at each location and highlighting all results above environmental investigation thresholds in one colour and all results above health investigation thresholds in another colour (same colour regardless of analyte)
- a site plan displaying all results at each depth at each location in a specific colour for each analyte
- concentration contours, for each specific sample depth, to show plumes from a point source. Care should be taken when using this technique because inferred areas may be misleading if only a small number of sample locations are used
- cross-sectional drawings for depicting concentrations of contaminants through the soil profile or to display complex local geology.

It may be necessary to provide separate site plans for various depth ranges if plots are cluttered.

A particular technique will not be suitable in every situation. For example, choosing the third point above would not be useful if the majority of sampling results were above investigation levels. In this situation, a technique which showed concentration ranges in different colours would be more applicable.

To assist report assessors to log appraisal of a site, a plain site plan which shows only sample locations, identification numbers and depths should also be provided. Examples of appropriate data presentation on site drawings are shown in Appendix D.

A separate site plan must always be provided which clearly displays locations, depths and results of all samples, including samples from Stage 1 and 2 reports, which are used as validation samples.

10.2.7 Presentation of analytical results and bore logs

Analytical results should be presented as originally received from the laboratory. In addition, results should be presented in tabulated form and transcribed onto site plans where appropriate. Presentation should ensure that the location of each sample can be readily identified.

Summary tables should show at least the essential details of sample locations and depths against the laboratory results. Results exceeding investigation threshold levels should be highlighted. For ease of reference, the addition of information such as date sampled, date received at laboratory, date analysed, and soil profile data to the summary table can expedite assessments by reducing cross-referencing. Examples are shown in Table 8 to Table 12.

Bore logs and test pit logs are necessary to provide accurate descriptions of soil types encountered throughout the profile and should clearly distinguish natural soils from fill. Sample locations and perched water and groundwater levels should be shown. If rubble or rubbish is encountered, the percentages of each type of foreign matter should be estimated. Soil profile information may be presented as an appendix or used to construct cross-sectional drawings of the site. Presentation of the locations of odours, stains and field test measurements on the logs would assist with the site assessment. Bore logs are also to be used to represent the construction of monitoring wells. Examples of bore, monitoring well and test pit logs are shown in Appendix D.

Statistical analysis may be appropriate where a large number of samples have been collected. Whilst reporting of minima, maxima, mean, median, standard deviation, upper confidence limits etc. provide necessary information, such data may not be sufficient to characterise a site. Appropriate graphical displays such as histograms or frequency distributions and box-and-whisker plots should also be considered to illustrate the distribution of results.

Table 7. Example report structure for soil analytical results

Locations 7-12: Chemical Screening Results

Loc 7

Depth (mm)	Pb	As	Cd	Cr	Co	Ni	Zn	Cu	Hg	pH
0~50	200	3	~	100	4	14	210	28	0.25	8.6
150-300	170	3	~	80	6	15	220	100	0.25	8.7
300-450	10	~	~	60	8	20	34	20	<0.05	8.6
Loc 8										
0~50	36	2	~	90	18	75	24	8.0	0.50	8.0
150-300	~	2	~	110	12	28	46	28	0.05	7.6
Loc 9										
0.15-	250	3	~	90	4	15	310	50	0.55	8.8
150-300	160	2	~	85	5	13	240	60	0.40	8.4
750-900	4	~	**95****	11	22	44	26	7.6	<0.05	7.6
Loc 10										
0~50	10	~	~	70	~	8	16	1.0	<0.05	8.3
150-300	24	5	1	85	5	13	34	1.8	0.05	8.1
300-450	12	3	1	90	7	15	30	1.8	<0.05	8.1
750-900	4	~	1	50	6	14	22	1.5	<0.05	8.4
Loc 11										
0~50	290	5	~	80	4	11	540	24	0.10	8.3
150-300	**450***	10	~	85	5	15	760	1750	0.70	8.1
300-450	90	5	~	110	9	17	30	1.9	0.05	7.8
	12	2	~	110	9	17	30	19	0.05	7.8
Loc 12										
0~50	100	3	2	85	6	15	80	28	0.25	8.4
150-300	**940****	5	~	130	7	18	190	60	2.70	8.4
300-450	46	1	~	110	12	24	46	26	0.20	7.8
HIL A	**300**	**100**	**20**	**-**	**100**	**400**	**8000**	**7000**	**200**	

HIL A = Health investigation levels for standard residential use
All units are in mg/kg except where shown
~ indicates < level of reporting (LOR)
* denotes ≥ and <2 x HIL[a]
** denotes ≥2 and <5 x HIL
*** denotes > 5 and < 10 x HIL
**** denotes > 10 x HIL

[a] Arbitrary method of categorising data

Table 8. Stockpile volumes and land farming results

Stockpile number	In-situ volume lxbxd=vol (m^3)	Spoil source	Sample ID	Stockpile depth	Date excavated	Date sampled	Date to lab	Date analysed	Results (mg/kg)														
									C_6-C_9	C_{10}-C_{14}	C_{15}-C_{28}	C_{29}-C_{36}	B	T	E	X	As	Cd	Cr	Cu	Pb	Zn	Ni
SP1	5x2x2.5=25	Bowser island	SP1	0.5m	10/03/97	10/03/97	10/03/97	11/03/97	3400	4500	1200	250	19	12	15	40	1	2	23	35	210	195	40
			SP1a	0.5m		10/05/97	10/05/97	13/05/97	125	1050	595	170	<1	<1	<1	<1	nt	nt	nt	nt	176	nt	nt
			SP1b	0.5m		25/06/97	28/06/97	30/06/97	45	205	295	130	<1	<1	<1	<1	nt	nt	nt	nt	nt	nt	nt
			SP1c	0.5m		2/08/97	2/08/97	3/08/97	<20	63	135	<100	Nt	nt	Nt	nt	nt	nt	nt	nt	nt	nt	nt
SP2	8x5.5x3=132	Tank pit A	SP2,1	0.5m	10/03/97	10/03/97	10/03/97	11/03/97	175	190	145	<100	<1	2	1	3	3	0.5	22	2	101	135	31
			SP2,2	0.5m		10/03/97	10/03/97	11/03/97	210	430	215	<100	<1	3	3	6	4	0.5	12	4	163	88	23
			SP2,3	0.5m		10/03/97	10/03/97	11/03/97	75	95	150	<100	<1	<1	<1	<1	1	<0.5	19	1	76	67	28
			SP2,1a	0.5m		24/04/97	24/04/97	25/04/97	<20	<20	<50	<100	<1	<1	<1	<1	nt	nt	nt	nt	nt	nt	nt
			SP2,2a	0.5m		24/04/97	24/04/97	25/04/97	<20	<20	<50	<100	<1	<1	<1	<1	nt	nt	nt	nt	nt	nt	nt
			SP2,3a	0.5m		24/04/97	24/04/97	25/04/97	<20	<20	<50	<100	<1	<1	<1	<1	nt	nt	nt	nt	nt	nt	nt
SP3	4x3x3=36	Tank pit B	SP3	0.5m	10/03/97	10/03/97	10/03/97	11/03/97	95	490	320	<100	<1	1	2	3	1	<0.5	8	9	30	10	26
			SP3a	0.5m		24/04/97	24/04/97	25/04/97	<20	<20	245	<100	<1	<1	<1	<1	nt	nt	nt	nt	nt	nt	nt
SP4	8x3x2.5=60	Interceptor	SP3,1	0.5m	7/03/97	7/03/97	10/03/97	13/03/97	470	1100	7890	3300	4	7	7	15	6	0.5	75	58	171	175	43
			SP3,2	0.5m		7/03/97	10/03/97	13/03/97	390	670	6350	7340	3	5	6	4	5	1	78	55	256	177	42
			SP3,1a	0.5m		24/06/97	24/06/97	25/06/97	55	240	2400	5330	<1	<1	<1	<1	nt	nt	nt	nt	212	nt	nt
			SP3,2a	0.5m		24/06/97	24/06/97	25/06/97	70	170	1950	3580	<1	<1	<1	<1	nt	nt	nt	nt	160	nt	nt
			SP3,1b	0.5m		10/10/97	10/10/97	13/10/97	<20	<20	235	665	Nt	nt	Nt	nt	nt	nt	nt	nt	nt	nt	nt
			SP3,2b	0.5m		10/10/97	10/10/97	13/10/97	<20	<20	145	680	Nt	nt	Nt	nt	nt	nt	nt	nt	nt	nt	nt

Queensland Department of Environment 1998

- Shaded area indicates contaminant levels which exceed Queensland Government CHEM Unit Draft March 1991 screening levels for TPH
- nt = not analysed

Table 9. Analytical results against geological profiles (useful for showing correlation between contamination and particular fill types)

Bore/ test pit	Depth (m)	Description	Sample depth (m)	Analysis results in mg/kg																	Sample date	Date to lab	Analysis date (organic)	Analysis Date (inorganic)
				C_6-C_9	C_{10}-C_{14}	C_{15}-C_{28}	C_{29}-C_{36}	B	T	E	X	Total PAH	As	Cd	Cr	Cu	Pb	Zn	Ni	Hg				
TP1/1	0.0-0.1	Silty sand, brown, damp, loose, fine sand	0.0-0.2	1500	2240	1200	<100	<1	<1	<1	<1	<5	66	<1	8	312	209	310	97	<0.05	27/05/97	28/05/97	28/05/97	29/05/97
/2	0.1-3.55	Gravelly silt sand, dark grey red, loose, fine to coarse sand, ASH FILL	0.3-0.5	1000	1900	1100	<100	<1	<1	<1	<1	11	45	4	8	269	307	274	85	<0.05	27/05/97	28/05/97	28/05/97	29/05/97
/3		bricks and steel throughout	0.85-1.05	700	59	900	<100	<1	<1	<1	<1	8	32	5	5	211	253	213	69	<0.05	16/09/97	17/09/97	18/09/97	18/09/97
/4	3.55-3.75	Clay, olive grey, moist, soft, plastic	3.55-3.75	50	<20	200	<100	<1	<1	<1	<1	<5	1	<1	1	82	21	20	62	<0.05	16/09/97	17/09/97	18/09/97	18/09/97
TP2/1	0.0-0.3	Sandy silt, brown, dry, loose, soft, non-plastic	0.0-0.2	60	130	1200	1500	9	5	8	11	30	22	<1	64	100	541	450	27	0.05	27/05/97	28/05/97	28/05/97	28/05/97
/2	0.3-0.5	Silty sand, black, dry, loose, fine to coarse sand, ASH FILL	0.3-0.5	<20	110	700	<100	3	2	<1	5	22	34	3	4	184	400	533	22	<0.05	27/05/97	28/05/97	28/05/97	28/05/97
/3	0.5-1.0	Clay, brown, dry, hard, plastic	0.5-1.0	<20	<20	<50	<100	<1	<1	<1	2	7	<1	<1	<5	52	30	142	23	<0.05	27/05/97	28/05/97	28/05/97	28/05/97
TP3/1	0.0-0.3	Gravelly silty sand, black, loose, damp, fine to coarse sand, ASH FILL	0.0-0.3	<20	<20	<50	<100	<1	<1	<1	<1	9	17	6	1	115	218	264	23	<0.05	27/05/97	28/05/97	28/05/97	29/05/97
/2			0.3-0.5	<20	<20	<50	<100	<1	<1	<1	<1	<5	12	2	15	88	123	425	23	<0.05	27/05/97	28/05/97	28/05/97	29/05/97
/3	0.3-1.0	Silty clay, brown, damp, soft, non-plastic clay and silt	0.5-1.0	<20	<20	<50	<100	<1	<1	<1	<1	<5	1	<1	16	35	25	166	19	<0.05	16/09/97	17/09/97	19/09/97	18/09/97
TP4/1	0.0-0.5	Silty sand, brown, dry, loose, fine sand	0.0-0.2	1200	224	1200	1000	27	15	17	25	<5	15	2	12	45	900	540	15	<0.05	16/09/97	17/09/97	19/09/97	22/09/97
/2	0.5-2.2	Gravelly silty sand, grey, dry, loose, fine to coarse sand, ASH FILL	0.2-0.5	600	220	1300	900	19	9	12	19	13	23	<1	75	209	1000	560	13	<0.05	16/09/97	17/09/97	19/09/97	22/09/97
/3			0.5-1.0	300	230	1350	875	11	4	8	13	<5	34	5	92	75	1200	230	14	<0.05	16/09/97	17/09/97	19/09/97	22/09/97
/4	2.3+	Clay, brown, damp, moderately soft, plastic	2.3-2.5	105	127	760	716	<1	<1	<1	2	<5	18	<1	65	38	45	150	11	<0.05	16/09/97	17/09/97	19/09/97	22/09/97
/5			2.5-3.0	<20	<20	<50	<100	<1	<1	<1	2	<5	4	<1	34	19	36	68	5	<0.05	3/11/97	4/11/97	5/11/97	5/11/97
TP5/1	0.0-0.2	Gravelly silty sand, black, dry, loose, fine to coarse sand, ASH FILL	0.0-0.2	110	95	500	1400	2	1	<1	3	26	18	4	75	187	640	150	43	<0.05	27/05/97	28/05/97	29/05/97	29/05/97
/2			0.2-0.5	105	71	<50	400	1	1	1	2	19	1	5	46	95	500	199	29	<0.05	27/05/97	28/05/97	29/05/97	29/05/97
/3	1.2+	Clay brown / reddish brown, damp, soft, plastic IN SITU	1.2-1.5	<20	<20	<50	<100	<1	<1	<1	<1	<5	<1	8	87	25	23	35	35	<0.05	27/05/97	28/05/97	29/05/97	29/05/97
TP6/1	0.0-0.35	Gravelly silty sand, dark reddish brown, loose, fine to coarse sand, FILL	0.0-0.35	<20	<20	<50	<100	<1	<1	<1	<1	<5	2	9	16	82	100	65	32	<0.05	27/05/97	28/05/97	28/05/97	28/05/97
/2	0.35-1.0	Clay, light brown, wet,soft,plastic	0.35-0.5	<20	<20	<50	<100	<1	<1	<1	<1	<5	5	5	12	16	250	31	22	<0.05	27/05/97	28/05/97	28/05/97	28/05/97
/3			0.5-1.0	<20	<20	<50	<100	<1	<1	<1	<1	<5	4	<1	5	9	167	66	19	<0.05	27/05/97	28/05/97	28/05/97	28/05/97
BH1/1	0.0-0.2	Silty sand, brown, damp, loose, fine sand	0.0-0.2	<20	<20	<50	<100	<1	<1	<1	<1	<5	43	2	25	15	125	55	16	<0.05	16/09/97	17/09/97	19/09/97	22/09/97
/2	0.2-0.45	Silty sand, black, dry, loose, fine to coarse sand, ASH FILL	0.2-0.45	<20	<20	<50	<100	<1	<1	<1	<1	<5	25	3	4	62	119	171	89	<0.05	16/09/97	17/09/97	19/09/97	22/09/97
/3	0.45-1.0	Silty clay, brown, damp, soft, non-plastic clay and silt	0.45-1.0	<20	<20	<50	<100	<1	<1	<1	<1	<5	7	<1	8	19	104	25	15	<0.05	16/09/97	17/09/97	19/09/97	22/09/97
/4	1.0-1.3	Clay, brown, dry, hard, plastic	1.0-1.3	<20	<20	<50	<100	<1	<1	<1	<1	<5	6	<1	18	15	31	32	25	<0.05	16/09/97	17/09/97	19/09/97	22/09/97

Table 10. Field observations against soil profiles

Bore / test pit	Location	Depth (m)	Description	Remarks	PID Readings	Sample depth (m)
TP1/1	Bowser	0.0-0.1	Silty sand, brown, damp, loose, fine sand	surface staining	100	0.0-0.2
/2		0.1-0.65	Gravelly silt sand, dark grey red, loose, fine to coarse sand, FILL	no odour	<5	0.2-0.5
/3		0.65-1.0	Clay, medium brown, soft, plastic	slight odour	10	0.5-0.7
TP2/1	TIT	0.0-0.3	Gravelly silty sand, black, loose, damp, fine to coarse sand, FILL	surface staining	30	0.0-0.3
/2		0.3-1.0	Silty clay, brown, damp, soft, non-plastic	no odour	25	0.3-0.5
/3					10	0.5-1.0
TP3/1	Tank pit east	0.0-0.5	Silty sand, brown, dry, loose, fine sand	surface staining	250	0.0-0.2
/2		0.5-2.8	Gravelly silty sand, grey, dry, loose, fine to coarse sand, FILL	no odour	50	1.8-2.0
/3		2.9	Clay, brown, damp, moderately soft, plastic	no odour	25	2.9-3.2
TP4/1	Tank pit west	0.0-0.2	Gravelly silty sand, black, dry, loose, fine to coarse sand, FILL	surface staining	10	0.0-0.2
/2		0.2-3.2	Sandy silt, red brown, loose, coarse FILL	no odour	10	1.8-2.3
/3		3.3	Clay brown / reddish brown, damp, soft, plastic	no odour	5	3.3-3.5
TP5/1	Tank pit south	0.0-0.35	Gravelly silty sand, dark reddish brown, loose, fine to coarse sand, FILL	surface staining	10	0.0-0.35
/2		0.35-2.5	Gravelly silty sand, brown, loose, fine to coarse, FILL	slight odour	40	0.35-0.5
/3				moderate odour	135	2.0-2.5
/4		2.5-3.3	Clay, medium brown, wet, soft, plastic	slight odour & heavy stains	800	2.5-3.0
/5		3.4	Clay, brown, dry, hard, plastic	faint HC odour	65	3.4-3.7
BH1/1	Tank pit south-east	0.0-0.2	Silty sand, brown, damp, loose, fine sand	surface staining	80	0.0-0.2
/2		0.2-0.45	Silty sand, black, dry, loose, fine to coarse sand, FILL	faint HC odour	60	0.2-0.45
/3		0.5-2.9	Gravelly sand, brown, loose, coarse, FILL	faint HC odour	25	1.5-2.0
/4				moderate odour	100	2.5-2.8
/5		3.0-3.5	Clay, brown ,dry, hard, plastic	strong HC odour & heavy stains	420	3.0-3.5
/6		3.5-4.0	Clay, brown, dry, hard, plastic	strong HC odour	230	3.5-4.0

Queensland Department of Environment, 1998

Table 11. Frequency distributions are useful for illustrating results (Table 10 data were used)

Concentration range (ppm)	*Frequency*	*Cumulative %*
0-60	20	30%
60-200	16	54%
200-400	11	70%
400-600	8	82%
600-800	5	90%
800-1000	2	93%
1000-1200	2	96%
1200-1400	3	100%

Queensland Department of Environment 1998

Table 12. Statistical analysis of results for a particular sampling event

Sample no.	Arsenic	Cadmium	Cobalt	Chromium	Copper	Nickel	Lead	Zinc
A1	12	1	27	256	51	69	116	398
A2	9	3	12	316	131	36	47	105
A3	8	1	26	294	236	82	25	73
A4	7	1	5	15	1290	19	154	1660
A5	8	1	34	132	403	166	99	105
A6	4	1	20	39	333	130	11	64
A7	12	1	43	300	546	84	58	128
A8	10	2	11	231	766	45	117	159
A9	6	1	52	304	642	62	57	131
A10	36	1	7	254	836	34	95	571
A11	8	1	22	255	33	92	19	46
A12	7	5	27	225	541	63	140	1380
A13	4	1	24	365	321	87	42	150
A14	3	0.5	83	257	453	71	22	30
A15	4	4	57	235	678	84	111	261
A16	3	1	22	223	165	59	385	584
A17	5	2	58	277	207	92	840	1740
A18	7	2	45	330	105	86	1870	649
A19	5	0.5	62	503	26	65	80	94
A20	6	1	46	400	345	65	217	4310
A21	12	1	30	273	16	81	180	458
A22	12	1	27	256	789	69	116	398
A23	15	1	15	254	345	44	117	218
A24	9	3	12	316	16	36	47	105
A25	34	1	29	169	342	100	43	135
A26	8	1	26	294	132	82	25	73
A27	12	1	32	215	107	104	272	360
A28	7	1	5	15	1290	19	154	1660
A29	14	2	51	266	119	112	383	852
A30	6	1	77	365	74	91	23	64
A31	14	1	53	205	33	101	34	39
A32	8	1	34	132	40	166	99	105
A33	17	1	43	291	32	74	58	112
A34	4	1	20	39	357	130	11	64
A35	12	1	31	285	1260	79	66	139
A36	12	1	43	300	345	84	58	128
A37	8	2	121	236	156	148	32	94
A38	9	2	53	454	435	79	10	19
A39	6	1	32	207	534	81	15	37
A40	8	1	46	240	39	102	84	165
A41	8	1	15	269	30	48	59	88
A42	10	2	11	231	66	45	117	159
A43	9	2	44	250	42	88	92	155
A44	6	1	52	304	42	62	57	131
A45	5	2	35	412	615	62	25	982
A46	36	1	7	254	55	34	95	571
A47	6	1	39	221	453	59	11	30
A48	8	1	22	255	65	92	19	46
A49	7	1	55	278	34	87	28	64
A50	5	1	34	239	66	87	21	67
A51	9	1	79	300	75	103	57	142
A52	8	2	29	188	67	83	312	643

Sample no.	Arsenic	Cadmium	Cobalt	Chromium	Copper	Nickel	Lead	Zinc
A53	9	2	34	227	34	72	86	164
A54	4	1	57	153	42	204	33	80
A55	7	1	48	259	50	101	204	251
A56	16	4	24	143	169	79	1310	10900
A57	8	1	45	207	36	191	30	122
A58	5	1	34	239	1185	87	21	67
A59	8	2	29	188	1034	83	312	643
A60	4	1	57	153	442	204	33	80
A61	16	4	24	143	116	79	1310	10900
A62	5	1	40	147	47	199	10	100
A63	6	1	28	177	231	106	54	110
A64	2	1	16	107	184	35	79	366
A65	9	1	48	206	395	98	33	166
A66	11	1	26	156	845	54	216	251
A67	6	1	13	287	25	70	46	71
Arithmetic mean	9	1	36	239	314	86	164	675
Standard deviation	7	1	21	92	346	41	322	1913
Geometric mean	8	1	30	210	158	77	70	193
Minimum	2	0.5	5	15	16	19	10	19
Maximum	36	5	121	503	1290	204	1870	10900
Median	8	1	32	250	165	82	58	135
90 percentile	14	2	57	322	808	137	312	1141
95 percentile	17	4	72	390	1140	184	703	1716
N	67	67	67	67	67	67	67	67

Source: Queensland Department of Environment 1998

Note that the statistical analysis carried out will depend on whether the data are normally or non-normally distributed and the DQO requirements (see Appendix B).

10.2.8 Photography

A photographic record that is well labelled for date, location and orientation is a valuable reference for such things as the site inspection (for example, topography, soil staining, state of underground storage tanks when removed, visual signs of plant toxicity), and the strata demonstrated in test pits and soil cores.

10.2.9 Access to electronic data

Consultants, assessors and government agencies should have access to electronic data as it avoids a further source of transcription error and facilitates the further analysis of data using other software packages. Users of data should be aware of copyright, data protection and data integrity issues.

10.2.9.1 Integration of reports

Where there is a series of reports, each succeeding report should summarise the important and relevant portions from the preceding reports. This will assist in the rapid comprehension of new material by all parties involved.

11 Protection of the environment during site assessment

11.1 General considerations

Assessment of site contamination, or potential contamination, presents risks to the environment as well as to site personnel and local residents. This guidance provides the minimum measures that should be adopted to ensure protection of the environment during site assessment. Site-specific environmental management measures must ensure compliance with environmental management and protection legislation applying in each jurisdiction.

All states and territories have legislated occupational health and safety requirements for work sites. Plans developed under such legislation should address all exposure pathways for site-specific contaminants of concern. This guidance does not deal with occupational health and safety matters, so all site assessment activities should comply with guidance and legislation applying in each jurisdiction.

11.1.1 Core environmental protection elements

Environmental protection plans should address the following issues:

- management of dust emissions and on-site and off-site odours
- protection of groundwater resources
- prevention of migration of contamination to adjacent sites or uncontaminated areas within the site
- prevention of contaminated run-off water reaching stormwater systems or local surface water environments
- prevention of initiation or spread of fire, either underground or above ground
- collection and disposal of excavation spoil
- collection and disposal of contaminated groundwater.

11.1.2 Less obvious concerns

Less obvious assessment issues that risk being overlooked include:

- extending contamination or assisting contaminant migration during site investigation works by, for example, drilling through a contaminated aquifer into an uncontaminated lower aquifer thereby creating a conduit through which contamination may migrate
- introducing contamination to an otherwise clean soil stratum by backfilling a test pit found to be contaminated at surface level but clean at depth using the contaminated soil. It is always preferable to temporarily stockpile test pit spoil in excavation sequence so that it may be returned to the pit to roughly the same depth from which it was excavated
- initiating or extending underground fire by the introduction of oxygen
- enhancing acid run-off by enabling oxidation of in-situ materials through exposure to atmosphere
- destabilising an otherwise stable embankment by introducing water.

11.2 Addressing environmental protection issues

The following elements of environmental protection should be considered prior to site assessment and be incorporated into the site assessment plan for each site. In particular, site contamination that is likely to cause public concern by the scale of operations, the nature of the site contamination or the potential for emission of noxious or offensive odours should indicate the commencement of public consultation and community engagement (refer Schedule B8) well before the commencement of site assessment works.

11.2.1 Management of dust and offensive and noxious odours

Environmental concerns regularly encountered on site assessments are dust and odour emissions which may be wind-blown and aggravated by the actions of trucks or other plant on the site. When warranted by the scale of site assessment and specific site conditions, area/boundary monitoring for dust deposition, inspirable and respirable dust and respective contaminants should be undertaken. Protection measures are important to ensure that dust inhalation or noxious or offensive odours do not pose a health risk for site operatives, nor a health risk or nuisance to local residents or passers-by and that concentrations of chemical substances do not exceed any relevant state or territory guidelines.

The traditional methods of dust and odour control include:

- application of a water spray with the objective to dampen the soil and not to saturate it, as potentially contaminated run off from saturated soils entering adjacent sites, stormwater systems, or local waterways must be avoided (note: care should be taken when applying water onto soil that has recently been contaminated with volatiles or semi-volatiles as this can result in a large increase in contaminant emissions from the soil)
- covering exposed faces with barriers (e.g. synthetic barriers, mulch) to prevent the emission of odours and dust
- minimising traffic and its speed on exposed contaminated soils
- the use of ground covers
- installation of screens to act as windbreaks.

Many sites, particularly those with TPH, organic contamination or putrescible wastes, may generate offensive odours or noxious vapours. In such cases, intensive odour control measures should be considered including minimising the exposed surface of the odorous materials at all times, timing excavation activities to minimise off-site nuisance, and by re-covering exposed faces overnight or during periods of low excavation activity. Such odorous materials should not be stockpiled unless closely contained or covered.

When dealing with volatile pollutants an assessment should be made of the need for the regular analysis of atmospheric levels of pollutants on site and at site boundaries to ensure that workers and residents are not being exposed to unacceptable levels of substances (for example, benzene) that may give rise to adverse health effects.

In addition, site boundary and competent community monitoring of offensive odours should be regularly undertaken during assessment of problematic sites. Site work practices relating to odour generating activities should be promptly amended or stopped and reassessed in response to the results of boundary and community monitoring. The social impact from the excavation of odorous or noxious materials can often be mitigated by excavating only when the wind direction is such that there will be the minimum possible effect upon neighbouring populations.

Where excavation of odorous or noxious material is expected or planned as part of an assessment process, the local population and other stakeholders should:

- be advised of the expected duration of the operation
- be advised that the operation will last for a limited time only
- be advised whether or not the odours may pose any potential health risk
- be given reassurance with regard to mitigation measures being undertaken.

An effective community consultation program is an essential consideration for sites that pose a risk of offensive or noxious odours. Information on development and implementation of community consultation and risk communication programs is provided in Schedule B8.

11.2.2 Preservation of groundwater resources

Before commencement of any drilling work, sufficient research should be undertaken to establish how much information is available regarding the geology and hydrogeology of the area to be investigated. If groundwater contamination is suspected there should be an audit of local bores. If more than one aquifer is expected, care should be taken to ensure that the potential for cross contamination is minimised. Bores should be constructed so that different aquifers are isolated.

Licensing of monitoring bores may be a statutory requirement in some states and territories. There may also be state or territory guidelines that apply to minimum bore requirements and their decommissioning.

11.2.3 Site run off, drainage and sedimentation

Care must be taken to avoid surface run off from assessment activity impacting on adjacent sites, wetlands, water courses or stormwater drainage systems. The site assessor should be aware of the topography and geology of the site under assessment, and the possibility of migration of contaminants within the site or to adjacent sites, whether wind-blown, adhering to vehicles, plant and equipment, as free-flowing liquids, as surface run off, or in groundwater flow. Stockpiled, pre-excavated materials awaiting removal from site may create a particular risk to the environment.

Mitigation measures may include the use of temporary rain-proof covers, excavation of drainage or run-off water diversion trenches, collection or absorption pits, or installation of temporary barriers in the form of hay bales, geofabrics, or similar materials. Temporary bunding around stockpiles, or location of stockpiles on waterproof surfaces such as asphalt or concrete, or under cover where available, should be considered. Designation of an area within which all run-off and infiltration is to be controlled in accordance with strict performance objectives (for example, zero uncontrolled run off) should also be considered. Disposal of any run-off should be carried out in accordance with relevant state or territory legislation.

Following rainfall it may be necessary to retrieve any sediment which has been carried in run-off or drainage water and manage this material appropriately. Respraying contaminated water onto stockpiles of contaminated soil as a means of effectively managing the water is also a possibility.

Treatment and disposal of collected contaminated run-off water should be appropriate to the contamination expected. If water treatment facilities are not immediately available, following consultation with local waste water authorities, diversion to sewer should be considered.

Removal to landfill (not permitted in certain states) or treatment facility by means of road tanker is an expensive final option.

11.2.4 Contamination carry-over to public roads and highways

Potential carry-over of contamination to public roads and highways is an issue where excavation plant is operating on a site. Care must be taken to ensure that potentially contaminated material is not transported off site. Vehicle washing systems with facilities for handling the wash water and the installation of 'rumble strips' to help dislodge dust and mud, should be considered for installation at exits from sites where potential carry-over is perceived to be a problem. Procedures should be set in place for the handling and disposal of potentially contaminated water arising from wheel-wash operations.

11.2.5 Collection and disposal of contaminated water

Sample pits should be backfilled soon after sampling and sampling should not take place during rain. Contaminated water may be encountered where sample pits have been left open, and in boreholes. Care should be taken in disposing of contaminated flush water from borehole purging to ensure that contamination is not spread on the site. Gross contamination from borehole purging should be collected for approved off-site disposal.

After excavation test pits may fill with rain or groundwater. Care should be taken to ensure that backfilling of the test pit does not rapidly displace this water, causing it to flow over the site. If necessary, the test pit should be part-backfilled and then baled out to a suitable storage to enable full backfilling with spoil. Contaminated water should be disposed as appropriate.

11.2.6 Collection and disposal of excavation spoil

It is normal practice to return excavation spoil from test pits to the excavation from which it came. Drilling cuttings are seldom returned to the bore. However, care should be taken to ensure that contaminated materials are not returned to a pit or bore where they could contaminate unaffected strata or groundwater. Due to practical difficulties in compaction of excavation spoil there will inevitably be excess spoil after backfilling of a test pit. Care should be taken to ensure that contaminated spoil does not become spread across an otherwise uncontaminated surface.

Excess spoil should be stored in a lined skip or lined drums brought to site or placed on an impervious surface such as concrete, asphalt, polyethylene sheeting or similar until analytical results can be assessed to enable cost-effective and safe methods of disposal. Where excess spoil is stored on site, and is not stored within a container, bunding should occur around the area to contain potential run off. If contaminated materials are to be drummed for disposal or for treatment, the contents should be analysed, and management decisions made, based on the analytical results.

Allowances should be made within site assessment budgets for any necessary safe removal of a quantity of soil/fill from the site to an appropriate waste disposal or treatment facility. Transport and disposal of contaminated soil should be carried out in accordance with relevant state or territory legislation.

11.2.7 Noise and vibration

Noise can be a health risk to workers and is often a nuisance to those in the vicinity of a site. The potential for noise arising from site assessment activities should be evaluated and appropriate control measures put in place to reduce unacceptable noise (for example, by installing screens or noise baffles). Noise should not be a nuisance to people living or working around the site. Activities with potential for noise generation should be carried out in accordance with relevant state or territory legislation.

Similarly, vibration from excavation and drilling, from plant, or from the movement of heavily laden trucks can sometimes result in damage to foundations of adjacent structures or to underground services or utilities. This possibility should be addressed and any risks assessed prior to choice of excavation or drilling method.

11.2.8 Acid sulfate soil

A significant hazard may arise from earthworks when soils containing acid sulfate are exposed. This can lead to the generation of acidic run off. In some instances, there may be more environmental risk associated with acid generation from digging up anthropogenic contamination during the site assessment than would be caused from leaving the contamination in situ. In these instances, discussions should be held with the relevant regulatory authorities prior to excavation and the appropriate control measures applied.

11.2.9 Underground fire

Underground fire may be encountered in coal mining areas or in former landfill sites. In the event of discovery of underground fire all assessment work should cease in that area until full assessment of the situation has been completed. Avoid any action which might enable or encourage the propagation or spread of the fire.

11.2.10 Heritage sites

Special care should be taken to ensure any assessment works activities of or adjacent to sites of cultural or natural heritage significance will not have an adverse impact. Heritage places may include buildings, structures, archaeological remains, or landscaped or natural areas of aesthetic, historic, scientific or social value. Where appropriate, advice should be sought from the local representatives of the National Congress of Australia’s First Peoples, the Australian Heritage Council, and state or territory heritage bodies and local councils.

11.2.11 Rare habitats or endangered species

Special care should be taken to ensure that any assessment activities will not impact upon rare natural habitats or any endangered species. Advice may be sought from the relevant jurisdiction to ensure that site environmental protection plans are sufficiently protective.

12 Bibliography

Aller, L, Bennett, TW, Hackett, G, Petty, RJ, Lehr, JH, Sedoris, H, Nielsen, DM & Denne, JE 1989, *Handbook of suggested practices for the design and installation of groundwater monitoring wells*, Report EPA 600/4-89/034, 398, United States Environmental Protection Agency.

ANZECC & ARMCANZ 2000, *National water quality management strategy. Australian and New Zealand guidelines for fresh and marine water quality*, Australian and New Zealand Conservation Council & Agriculture, and Resource Management Council of Australia and New Zealand.

APHA, AWWA & WEF 2005, *Standard methods for examination of water and wastewater,* 21st edn, American Public Health Association, the American Water Works Association, & the Water Environment Federation Washington DC. (Available online at < http://www.standardmethods.org>)

API 2005, 'Collecting and interpreting soil gas samples from the vadose zone. A practical strategy for assessing the subsurface vapour-to-indoor air migration pathway at petroleum hydrocarbon sites', *Regulatory Analysis and Scientific Affairs,* publication no. 4741, American Petroleum Institute.

API 2006, *Downward solute plume migration: assessment, significance, and implications for characterisation and monitoring of 'diving plumes'*, API Bulletin 24.

ARMCANZ & ANZECC 1995, *Guidelines for groundwater protection in Australia*, Agriculture and Resource Management Council of Australia and New Zealand & Australian and New Zealand Environment and Conservation Council, Canberra.

ADITC 1997, *The manual of methods, applications and management,* Australian Drilling Industry Training Committee Ltd, CRC Press, Florida.

AS 1726-1993, *Geotechnical site investigations*, Standards Australia.

AS 2368-1990, *Test pumping of water wells*, Standards Australia.

AS 4482.1-2005, *Guide to the investigation and sampling of sites with potentially contaminated soil, part 1: non-volatile and semi-volatile compounds*, Standards Australia.

AS 4482.2-1999, *Guide to the sampling and investigation of potentially contaminated soil, part 2: volatile substances*, Standards Australia.

AS/NZS 5667.11-1998, *Water quality – sampling, part 11: Guidance on sampling of groundwater*, Standards Australia.

ASTM D5092 (2004e1), Standard practice for design and installation of groundwater monitoring wells, ASTM International.

ASTM D6429–99 (2006), Standard guide for selecting surface geophysical methods, ASTM International.

ASTM D6432-99 (2005) Standard guide for the surface ground penetrating radar method, ASTM International.

ASTM D6771–02 Standard practice for low-flow purging and sampling for wells and devices used for groundwater quality investigations, ASTM International.

ASTM E1689–95(2008) Standard guide for developing conceptual site models for contaminated sites, ASTM International.

ASTM E2531 (2006), Guide for development of conceptual site models and remediation strategies for light non-aqueous-phase liquids released to the subsurface, ASTM International.

Baker, K, Hayward, H, Potter, L, Bradley, D & MacLeod, C 2009, The VOCs handbook. Investigating, assessing and managing risks from inhalation of volatile organic compounds (VOCs) at land affected by contamination, CIRIA C682, CIRIA, London.

Barber, C & Briegel, D 1987, 'A method for the in-situ determination of dissolved methane and other volatiles in groundwater in shallow aquifers', Journal of Contaminant Geology, vol. 12, pp. 51-60.

Barber, C & Davis, GB 1987, 'Representative sampling of groundwater from short-screened boreholes', Ground Water vol. 25, no. 5, pp. 581-587.

Barber, C & Davis, GB 1994, 'Representative sampling of groundwater from boreholes.', in DC Adriano, AK Iskandar & IP Murarka (eds), Advances in Environmental Science: Contamination of Groundwaters - Methodology and Modelling, Science Reviews, UK, pp. 141-160.

Barcelona, MJ, Gibb, JP, Helfrich, JA & Garske, EE 1985, Practical guide for groundwater sampling, Illinois State Water Survey Report 374, US National Groundwater Association, p.94.

Clements, L, Palaiai, T & Davis, J 2009, Characterisation of sites impacted by petroleum hydrocarbons: guideline document, CRC CARE Technical report no. 11, CRC Contamination Assessment and Remediation of the Environment, Adelaide.

Cook, RG 2003, A guide to regional groundwater flow in fractured rock aquifers, CSIRO Land and Water, Glen Osmond, SA.

Davis, GB, Merrick, NP & McLaughlan, RG 2006, Protocols and techniques for characterising sites with subsurface petroleum hydrocarbons – a review, CRC CARE Technical report no. 2, CRC for Contamination Assessment and Remediation of the Environment, Adelaide.

Davis, GB, Wright, J & Patterson, BM 2009a, Field assessment of vapours, CRC CARE Technical Report no.13, CRC Contamination Assessment and Remediation of the Environment, Adelaide.

Davis, GB, Trefry, MG & Patterson, BM 2009b, Petroleum vapour model comparison, CRC CARE Technical Report no. 9, CRC Contamination Assessment and Remediation of the Environment, Adelaide.

Davis, GB, Patterson, BM & Trefry, MG 2009c, Biodegradation of petroleum hydrocarbon vapours, CRC CARE Technical Report no. 12, CRC Contamination Assessment and Remediation of the Environment, Adelaide.

Driscoll, FG 1986, Groundwater and wells, 2nd edn, Johnsons Filtration Systems Inc, St Paul, Minnesota.

DTSC 2009, Vapour intrusion mitigation advisory, Department of Toxic Substances Control, California Environmental Protection Agency, April.

Edwards, JW, van Alphen, M & Langley, A 1994, Identification and assessment of contaminated land. Improving site history appraisal, Contaminated sites monograph series, no. 3, South Australian Health Commission, Adelaide.

EPA NSW 1997 Contaminated sites. Guidelines for consultants reporting on contaminated sites, Environment Protection Authority, Sydney.

EPA Victoria 1991, Guidelines for a site assessment report. Guidelines for Environmental Auditors, Environment Protection Authority, Melbourne.

EPA Victoria 2000, Groundwater sampling guidelines, Publication 669, Environment Protection Authority, Melbourne.

EPA Victoria 2006, Hydrogeological assessment (groundwater quality) guidelines, Publication 668, Environment Protection Authority, Melbourne.

EPA Victoria 2010, Industrial Waste Resource Guidelines (7), Sampling and Analysis: Soil Sampling, Environment Protection Authority, Melbourne.

Ferguson, CC 1992, 'The statistical basis for spatial sampling of contaminated land', Ground Engineering, June, pp. 34-38.

Fetter, CW 2001, Applied hydrogeology, 4th edn, Prentice Hall Inc.

Gilbert, RO 1987, Statistical methods for environmental pollution monitoring, Van Nostrand Reinhold Company, New York.

Hartman, B 2002, ‘How to collect reliable soil-gas data for upward risk assessments, part 1: active soil-gas method’, LUSTLine Bulletin, no. 42, pp. 17-22.

Hartman, B 2003, ‘How to collect reliable soil-gas data for upward risk assessments, part 2: surface flux-chamber method’, LUSTLine Bulletin, no. 44, pp. 14-18; 34.

Hartman, B 2006, ‘How to collect reliable soil-gas data for risk-based applications — specifically vapor intrusion, part 4: updates on soil-gas collection and analytical procedures’, LUSTLine Bulletin, no. 53, pp. 14-19.

Helsel, DR 1990, 'Less than obvious, statistical treatment of data below the detection limit', Environmental Science and Technology, vol. 24, no. 12, pp. 1767-1774.

Heyworth, J 1991, 'Sampling and statistical analysis for assessing contaminated sites', in O El Saadi & AJ Langley (eds), The health risk assessment and management of contaminated sites, South Australian Health Commission, Adelaide.

IGMC 2010, Software catalogue, International Groundwater Modelling Centre, Colorado School of Mines, USA, available online at < http://www.mines.edu/igwmc/>.

Isbell, RF 2002, The Australian Soil Classification, Australian soil and land survey handbook series, rev. ed. CSIRO, Australia.

ITRC 1999, Natural attenuation of chlorinated solvents in groundwater: principles and practices, ISB-3, In-situ Bioremediation Team, Interstate Technology & Regulatory Council, Washington, DC. Also see <www.itrcweb.org>.

ITRC 2005, Technology overview of passive sampler technologies, DSP-4, Interstate Technology & Regulatory Council, Washington, DC.

ITRC 2007a, Vapor intrusion pathway: a practical guideline, VI-1, Vapor intrusion team, Interstate Technology & Regulatory Council, Washington, DC.

ITRC 2007b, 'Vapor intrusion pathway: investigative approaches for typical scenarios', a supplement to Vapor intrusion pathway: a practical guideline, Technical and regulatory guidance supplement prepared by the ITRC vapour intrusion team, Interstate Technology & Regulatory Council, Washington, DC.

Keuper, BH & Davies, KL 2009, Assessment and delineation of DNAPL source zones at hazardous waste sites, EPA/600/R-09/119, US EPA National Risk Management Research Laboratory, Cincinnati, Ohio.

Kruseman, G P & de Ridder, NA 1994, Analysis and evaluation of pumping test data, International Institute for Land Reclamation and Improvement, Wageningen, The, Netherlands.

Langley, AJ 1993, 'The representation of data and the appraisal of contaminated land', in The health risk assessment and management of contaminated sites, proceedings of the second national workshop, by AJ Langley & M van Alphen, South Australian Health Commission, Adelaide.

Lock, WH 1996, Composite sampling, National environmental health monographs, Soil series no. 3, South Australian Health Commission, Adelaide.

McDonald, RC, Isabell, RF, Speight, JG & Walker, J 1990, Australian soil and land survey field handbook, 2nd edn, CSIRO Publishing, Australia.

MDBC 1997, Murray-Darling Basin groundwater quality sampling guidelines, Technical report no. 3, Murray-Darling Basin Commission, Australia.

NHMRC & NRMMC 2004, National water quality management strategy. Australian drinking water guidelines, National Health and Medical Research Council & Natural Resource Management Ministerial Council, Australia.

NHMRC 2008, National water quality management strategy. Guidelines for managing risk in recreational water, National Health and Medical Research Council, Australia.

NJDEP 2005, Vapor intrusion guidance, New Jersey Department of Environmental Protection. (Available online at <www.nj.gov/dep/srp/guidance/vaporintrusion/vig.htm>)

NSW DECC 2006, Guidelines for the NSW site auditor system, 2nd edn, NSW Department of Environment & Climate Change, Sydney.

NYSDOH 2006, Guidance for evaluating soil vapor intrusion in the State of New York, New York State Department of Health.

ODEQ 2010, Guidance for assessing and remediating vapor intrusion in buildings, Report no. 10-LQ-007, Oregon Department of Environmental Quality, Portland.

Pagano, RR 1986, Understanding statistics in the behavioural sciences, West Publishing House, St Paul, Minnesota.

Patterson, BM & Davis, GB 2008, ‘An in situ device to measure oxygen in the vadose zone and in groundwater: laboratory testing and field evaluation’, Ground Water Monitoring & Remediation, vol. 28, no. 2, pp. 68-74.

Patterson, BM & Davis, GB 2009, ‘Quantification of vapour intrusion pathways into a slab-on-ground building under varying environmental conditions’, Environmental Science and Technology, vol. 43, no. 3, pp.650-656.

Patterson, BM, Davis, GB & Johnston, CD 1999, ‘Automated in situ devices for monitoring of VOCs and oxygen in water and soil environments’, in CD Johnston (ed.), Contaminated site remediation: challenges posed by urban and industrial contaminants; proceedings of the Contaminated site remediation conference, Fremantle, Western Australia, pp. 227-234.

Patterson, BM, Davis, GB & McKinley, AJ 2000, ‘Volatile organic compounds in groundwater, probes for the analysis of.’ In RA Mayers (ed.), Encyclopedia of analytical chemistry: instrumentation and application, John Wiley and Sons Ltd, pp. 3515-3526.

Puls, RW & Barcelona, MJ 1996, Low-flow (minimal drawdown) ground-water sampling procedure, Report EPA/540/S-95/504, US Environmental Protection Agency, pp. 12.

Scalf, MR, McNabb, JF, Dunlap, WJ, Cosby, RL & Fryberger, J 1992, 'Manual of groundwater sampling procedures', Joint report of the US National Groundwater Association and the US EPA, Robert S. Kerr Laboratory.

SA EPA 2005, Composite soil sampling in site contamination assessment and management, Environment Protection Agency, Adelaide, South Australia.

SA EPA 2007, Guidelines: regulatory monitoring and testing groundwater sampling, Environment Protection Agency, Adelaide, South Australia.

SA EPA 2009, Site contamination: guidelines for the assessment and remediation of groundwater contamination, Environment Protection Agency, Adelaide, South Australia.

Sundaram, B, Feitz, A, Caritat, P, de, Plazinska, A, Brodie, R, Coram, J & Ransley, T 2009, Groundwater sampling and analysis – a field guide, Record 2009/27 95, Geoscience Australia.

Tufte, ER 1983, The visual display of quantitative information, Graphics Press, Cheshire, Connecticut.

Turczynowicz, L 1991, 'Approaches to analyte selection', in O El Saadi & AJ Langley (eds), The health risk assessment and management of contaminated sites, South Australian Health Commission, Adelaide.

UK EA 2000a, Guidance on the assessment and monitoring of natural attenuation of contaminants in groundwater, R&D publication 95, prepared by Aspinwall & Company/NGC, UK Environment Agency.

UK EA 2000b, Guide to good practice for the development of conceptual models and the selection and application of mathematical models of contaminant transport processes in the subsurface, NC/99/38/3, UK Environment Agency.

UK EA 2003, An illustrated handbook of DNAPL transport and fate in the subsurface, R&D publication 133, UK Environment Agency.

UK EA 2006, Guidance on the design and installation of groundwater quality monitoring points, Science Report SC-020093, UK Environment Agency.

US EPA 1990, Sub-surface contamination reference guide, EPA/540/2-90/011, US Environmental Protection Agency, Washington DC.

US EPA 2000a, Guidance for the data quality objective process, EPA/QA/G-4, US Environmental Protection Agency, Washington DC.

US EPA 2000b, Data quality objectives process for hazardous waste site investigations, EPA/QA/G-4HW, US Environmental Protection Agency, Washington DC.

US EPA 2006, Data quality assessment: statistical methods for practitioners, EPA QA/G-9S, US Environmental Protection Agency, Washington DC.

US EPA 2007a, SW-846, Method 6200, Field Portable X-Ray Fluorescence Spectrometry for the determination of elemental concentrations in soil and sediment, Revision 0 February 2007.

US EPA 2007b, ProUCL version 4.00.04 user guide, EPA/600/R-07/038, US Environmental Protection Agency, Washington DC. (also see <http://www.epa.gov/OSP/hstl/tsc/proucl-4-0-02-user.pdf>.

US EPA 2009, DNAPL remediation: selected projects where regulatory closure goals have been achieved, EPA/542/R-09/008, US Environmental Protection Agency, Washington DC.

van Alphen, M 1993, 'A format for site history reports' in *The health risk assessment and management of* contaminated *sites*; *proceedings of the second national workshop,* by AJ Langley & M van Alphen, South Australian Health Commission, Adelaide.

Van den Berg, M, Birnbaum, LS, Denison, M, De Vito, M, Farland, W, Feeley, M, Fiedler, H, Hakansson, H, Hanberg, A, Haws, L, Rose, M, Safe, S, Schrenk, D, Tohyama, C, Tritscher, A, Tuomisto, J, Tysklind, M, Walker, N & Peterson, RE 2006, 'The 2005 World Health Organisation re-evaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds', Toxicological Sciences, vol. 93, pp.223-241.

WA DoE 2004, Potentially contaminating activities, industries and land uses, Contaminated sites management series, WA Department of Environment.

WA DoH 2009a, Guidelines for the assessment, remediation and management of asbestos-contaminated sites in Western Australia, WA Department of Health, Perth, Australia.

WA DoH 2009b, Management of small-scale low-risk soil asbestos contamination, WA Department of Health, Perth, Australia.

WHO 1989, Polychlorinated dibenzo-p-dioxins and dibenzofurans, Environmental Health Criteria #88, International Program on Chemical Safety. World Health Organisation.

Weaver, J 1992, Groundwater sampling: a comprehensive guide for sampling methods, Report 339, South African Water Research Commission.

13 Appendices

13.1 Appendix A: Possible analytes for soil contamination

It should be noted that investigation or screening levels are available for only some of these substances. Analytes selected for analysis should be based on site history.

Inorganic contaminants

Analysis name	
Metals	Where a general purpose screen for metal contamination in soils is indicated it may include: Arsenic, cadmium ,chromium, copper, lead, manganese, mercury, nickel and zinc If more detailed investigation is indicated, soil may be examined for: Aluminium Antimony Barium Beryllium Boron Calcium Cobalt Iron Magnesium Molybdenum Potassium Selenium Silver Strontium Thallium Tin Vanadium
Anions	Where a general purpose screen for anion contamination in soils is undertaken it may include: Bromide Chloride Cyanide Iodide Nitrate and Nitrite Phosphate Sulfate Sulfide Fluoride

Organic contaminants

Analysis name	
Monocyclic aromatic hydrocarbons (MAHs)	Where a general purpose screen for MAH contamination in soils is undertaken it may include: Benzene Toluene ortho-Xylene meta- Xylene (para- Xylene) Ethyl benzene Styrene (vinyl benzene) Cumene (isopropylbenzene) 1,3,5 Trimethylbenzene 1,2,4-trimethylbenzene 1-methyl-4-isopropylbenzene n-Propylbenzene n-Butylbenzene iso-Butylbenzene tert-Butylbenzene sec-Butylbenzene If more detailed investigation is indicated, soil should be examined for: Chlorobenzene 1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene Nitrobenzene Dinitrobenzenes Nitrotoluene Dinitrotoluenes Trinitrotoluenes
Polynuclear aromatic hydrocarbons (PAHs)	Where a general purpose screen for PAH contamination in soils is undertaken it may include: Naphthalene Acenaphthylene Acenaphthene Fluorene Phenanthrene Benzo(a) anthracene Chrysene Benzo(b) fluoranthene Benzo(k) fluoranthene Benzo(a) pyrene

Analysis name	
	Anthracene Dibenz (a,h)anthracene Fluoranthene Benzo(ghi) perylene Pyrene Indeno(123-cd) pyrene
Phenols	Where a general purpose screen for phenols contamination in soils is undertaken it may include: Phenol o-Cresol p-Cresol 2,3-Dimethylphenol 2,4-Dimethylphenol 2,5-Dimethylphenol 2,6-Dimethylphenol 3,4-Dimethylphenol 3,5-Dimethylphenol 2,3,5-Trimethylphenol 2,3,6-Trimethylphenol 2,4,6-Trimethylphenol If more detailed investigation is indicated, soil should be examined for 2-Nitrophenol 4-Nitrophenol 2,4-Dinitrophenol
Chlorinated phenols	Where a general purpose screen for chlorinated phenols contamination in soils is undertaken it may always include: 2-Chlorophenol 3-Chlorophenol 4-Chlorophenol 2,4 –Dichlorophenol 2,6 –Dichlorophenol 2,4,5 –Trichlorphenol 2,4,6 –Trichlorphenol 2,3,4,5-Tetrachlororphenol 2,3,4,6-Tetrachlororphenol 2,3,5,6 –Tetrachlororphenol Pentachlorophenol (PCP)
Chlorinated benzenes	Where a general purpose screen for chlorinated benzenes contamination in soils is undertaken it may include:

Analysis name	
	Chlorobenzene 1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene 1,2,3-Trichlorobenzene 1,2,4-Trichlorobenzene 1,2,4,5 Tetrachlorobenzene Pentachlorobenzene Hexachlorobenzene
Organochlorine (OCs)	Where a general purpose screen for OCs contamination in soils is undertaken it may include: Aldrin HCB alpha-HCH, beta-HCH gamma-HCH (lindane), delta-HCH Chlordane DDD, DDE, DDT Dieldrin Endrin Endosulfan (alpha-, beta- and sulfate) Heptachlor, Heptachlor epoxide Methoxychlor Where site history indicates possible PCB contamination, soil should be examined for: PCB (Aroclors 1016, 1221, 1232, 1242, 1248, 1254 and 1260) Toxaphene (chlorcam, campheclor)
Organophosphorus insecticides (OPs)	Where a general purpose screen for OP contamination in soils is undertaken it may include: Chlorpyrifos Coumaphos Diazinon Dichlorvos Dimethoate Ethion Fenthion Malathion Parathion methyl

Analysis name	
	Parathion ethyl If more detailed investigation is indicated, soil should be examined for: Azinphos methyl Sulprofos Demeton-s-methyl Disulfoton Ethoprophos Mevinphos Monocrotophos Naled Phorate Prothiophos Tetrachlorvinphos A Nitrogen/Phosporus detector (NPD) or flame photometric detector (FPD) or GC/MS should be employed for screening purposes.
Acid/phenoxyl herbicides	Where a general purpose screen for acid herbicides contamination in soils is undertaken it may include: 2,4-D 2,4-DB 2,4,5-T 2,4,5-TP (Silvex) Dicamba and 5-Hydroxydicamba MCPA MCPP 4-Nitrophenol If more detailed investigation is indicated, soil should be examined for: Acifluoren Bentazon Dichlorprop Dalapon Picloram
Triazine herbicides	Where a general purpose screen for triazine herbicide contamination in soils is undertaken it may include: Atrazine Ametryn Prometryn Simazine Hexazinone

Analysis name	
Phthalate esters	Where a general purpose screen for phthalate contamination in soils is undertaken it may include: Bis (2-ethylhexyl) phthalate Butyl benzyl phthalate Di-n-butyl phthalate Dicyclohexyl phthalate Diethyl phthalate Dihexyl phthalate Diisobutyl phthalate Dimethyl phthalate Dinonyl phthalate Di-n-octyl phthalate If more detailed investigation is indicated, soil should be examined for: Bis (2-n-butoxyethyl) phthalate Bis (2-ethoxyethyl) phthalate Bis (2-methoxyethyl) phthalate Bis (4-methyl-2-pentyl) phthalate Diamyl phthalate Hexyl 2-ethylhexyl phthalate

EPA Victoria, 1998

13.2 Appendix B: Data quality objectives (DQO) process

The DQO process is a seven-step iterative planning approach that is used to define the type, quantity and quality of data needed to support decisions relating to the environmental condition of a site. It has been summarised in guidelines produced by the NSW Department of Environment and Conservation (NSW DEC 2006). The seven steps are described below. Additional information can be found in US EPA (2000a, 2000b) and US EPA (2006). An example of the DQO process applied to a benzene and TCE spill can be found in ODEQ (2010).

The DQO process should commence before any investigative work starts, with the timing for various stages of the project being clearly understood by all parties.

13.2.1 Step 1: State the problem

The first step involves summarising the contamination problem that will require new environmental data, identifying the resources available to resolve the problem, and developing a CSM.

13.2.1.1 Some of the matters to consider at this stage include:

- the objective of the proposed investigation, noting that the ability to meet objectives may be limited by constraints such as time, resources, climatic conditions and access restrictions
- the possible content of a problem statement that gives a brief summary of the contamination issue(s) at the site that is to be addressed in the project
- the reason the project is being undertaken
- identifying the project team and technical support experts, such as field manager/site supervisor, field personnel, toxicologists, risk assessors, and statisticians
- budget and community concern issues which may also be factors in designing and carrying out the environmental assessment
- identifying the regulatory authority(ies) and the local government area.

Step 1 of the DQO process should assist in developing the following:

- a concise description of the problem
- a list of the planning team members and identification of decision-maker
- a summary of available resources and relevant deadlines for the study
- a conceptual model of the site, based on available information prior to the commencement of the site investigation, covering:
  - previous investigations
  - present and historical use(s) of the site and adjacent sites
  - geology, hydrogeology
  - potential contaminants of concern
  - potential contaminant migration pathways both to and from the site (such as waterways, drains, service conduits)
  - areas of environmental concern (drawings showing chemical storage, use, disposal)
  - media in which potential contaminants of concern may be present and through which they may migrate (habitat(s) of contamination, lateral, depth extent, temporal, climatic variability)

  - potential exposure pathways to human and/or environmental receptors
  - future land uses.

The conceptual model of contamination of the site that is produced at this early point can be progressively refined through all stages of the assessment.

13.2.2 Step 2: Identify the Decisions

The second step involves identifying the decisions that need to be made about the contamination problem and the new environmental data required to make them.

The objective(s) of the data collection part of the investigation may be identified by:

- referring to the history of use of the site, chemicals of concern and likely concentration range(s), media that may be impacted and likely migration routes, such as groundwater, surface water flow, wind, and service trenches
- considering relevant site criteria for each medium (fill, soil, sediment, groundwater, surface water, air)
- making a series of decision statements that need to be addressed (e.g. a decision statement could consider whether parts of the site would be suitable for a proposed use if the 95% upper confidence limit on the mean concentrations for all chemicals of potential concern were less than the appropriate site criteria).

Step 2 of the DQO process should assist in developing a decision statement linking the principal study question to possible actions that will solve the problem.

The existing conceptual model can then be reviewed to determine whether existing data are satisfactory for the investigation or whether data gaps or an unacceptable level of uncertainty exists.

13.2.3 Step 3: Identify inputs to the decision

The third step involves identifying the information needed to support any decision and whether new environmental measurements will be needed.

Decisions made during this step are of a 'draft' or preliminary nature and are reviewed in Step 7 to develop the sampling analytical and quality plan (SAQP).

Step 3 of the DQO process should assist decision makers to resolve decision statements and make informed, defensible decisions by identifying:

- the media that needs to be collected, such as fill, soil, groundwater, sediments, surface water and air
- the environmental parameters that will be measured for each media
- site criteria for each medium of concern
- analytical methods that are required for chemicals of potential concern so that assessment can be made relative to the site criteria
- the basis for any decisions that are to be made from field screening, such as from PID data, and what action is to be taken if a defined concentration is attained
- any additional information required to make the required decisions.

13.2.4 Step 4: Define the study boundaries

The fourth step involves specifying the spatial and temporal aspects of the environmental media that the data must represent to support decision(s).

13.2.4.1 Some of the matters to consider at this stage include:

- the geographical extent of the proposed investigation
- time and budget constraints
- spatial boundaries (property boundaries, accessibility constraints to parts of the site, potential exposure areas)
- temporal boundaries (the time frame of the investigation, taking into account seasonal conditions, presence of near-surface groundwater or surface water and discharges, access restrictions, availability of key personnel)
- for large sites, the boundaries of each segment to be investigated (based on proposed use of each area of the site which will influence the required sample density, appropriate regulatory guidance)
- the lateral and vertical intervals in which contamination distribution is believed to be uniformly distributed
- the scale of decisions required: site-wide, each residential lot, etc.
- the presence of any heterogeneous materials that may require specific sampling methods
- potential constraints to carrying out the investigation, such as access, presence of infrastructure, health and safety issues.

Step 4 of the DQO process should assist in developing:

- a detailed description of the spatial and temporal boundaries of the problem
- an understanding of any practical constraints that may interfere with the assessment.

13.2.5 Step 5: Develop a decision rule

The fifth step involves defining the parameter of interest, specifying the action level, and integrating information from Steps 1–4 into a single statement that gives a logical basis for choosing from alternative actions.

13.2.5.1 Acceptable limits should be defined for the following:

- chemicals of concern detected in field blanks, rinsate blanks, volatile-spiked trip samples, laboratory method blanks
- recovery of matrix spike additions, surrogate spike additions, laboratory control samples
- relative percent differences (RPDs) of matrix spike and matrix spike duplicates.

Step 5 of the DQO process should assist in producing:

- the statistical parameter (the parameter of interest) that characterises the population
- confirmation that the action level exceeds measurement detection limits
- an 'if . . ., then . . .' statement that defines the conditions that would cause a decision-maker to choose from alternative actions.

13.2.6 Step 6: Specify limits on decision errors

The sixth step involves specifying the decision-maker's acceptable limits on decision errors, which are used to establish performance goals for limiting uncertainties in the data. (For more information about decision errors and decision making, see notes at the end of this Appendix)

13.2.6.1 Some of the matters to consider at this stage include:

- determination of the possible range of the parameter of interest
- identification of decision errors and formulation of the null hypothesis
- specification of a range of possible parameter values where the consequences of decision errors are relatively minor (grey region)
- assignation of probability values to points above and below the action level that reflect the tolerable probability for the occurrence of decision errors.

Step 6 of the DQO process should assist in calculating the decision-maker's tolerable decision error rates based on a consideration of the consequences of making an incorrect decision.

13.2.7 Step 7: Optimise the design for obtaining data

The seventh step involves identifying the most resource-effective sampling and analysis design for generating the data that are required to satisfy the DQOs.

Step 7 of the DQO process should assist in developing:

- the most resource-effective design for the study that is expected to achieve the DQOs
- the optimum manner in which to collect the data required to meet the objectives for the assessment and which will meet the project DQOs
- the SAP.

13.2.8 Notes about decision errors and decision making

Decision errors are incorrect decisions caused by using data that are not representative of site conditions due to sampling or analytical error. As a result, a decision may be made that site clean-up is not needed when really it is, or vice versa.

There are two types of decision error:

- sampling errors occur when the sampling program does not adequately detect the variability of a contaminant from point to point across the site. That is, the samples collected are not representative of the site conditions (e.g. an appropriate number of representative samples have not been collected from each stratum to account for estimated variability)
- measurement errors occur during sample collection, handling, preparation, analysis and data reduction.

The combination of the above errors is referred to as 'total study error'. This directly affects the probability of making decision errors. Study error is managed through the correct choice of sample design and measurement systems. Note that the attainment of a nominated probability generally requires use of a statistically based sampling plan.

The possibility of making a decision error, although small, is undesirable because of the adverse consequences arising from that incorrect decision. Decision error can be controlled through the use of hypothesis testing. This test can be used to show either that the baseline condition is false (and therefore the alternative condition is true) or that there is insufficient evidence to indicate that the baseline condition is false (and therefore the site assessor decides by default that the baseline condition is true).

The burden of proof is placed on rejecting the baseline condition, because the test hypothesis structure maintains the baseline condition as being true until overwhelming evidence is presented to indicate that the baseline condition is not true.

The null hypothesis is an assumption assumed to be true in the absence of contrary evidence, for example, that the site is contaminated unless proved to be clean.

If we reject a hypothesis when it should be accepted, we say that a type I error has been made. If, on the other hand, we accept a hypothesis when it should be rejected, we say that a type II error has been made. In either case, a wrong decision or error in judgment has occurred:

- type I error (false positive decision error) — rejecting the hypothesis as false when it is really true
- type II error (false negative decision error) — accepting the hypothesis as true when it is really false.

In order for decision rules (or tests of hypotheses) to be sound, they must be designed to minimise decision errors. This is not always simple, as for any given sample size, an attempt to decrease one type of error is generally accompanied by an increase in the other type of error. The only way to reduce both types of error is to increase the sample size, which may or may not be always possible.

In testing a given hypothesis, the maximum probability with which we would be willing to accept a type I error is referred to as the ‘level of significance’ or significance level of the test. A significance level of 0.05 or 0.01 is commonly adopted, although other values are used. If for example the 0.05 (or 5%) significance level is selected for a decision rule, then we are accepting that there is a 1 in 20 (that is, 5 chances in 100) chance that we would reject the hypothesis when it should be accepted; that is, we are about 95% confident that we have made the right decision. In this case we say that the hypothesis has been rejected at the 0.05 significance level, which means that the hypothesis has a 0.05 probability of being wrong.

In general, a 95% confidence level is considered acceptable for sensitive land use, whereas 90% may be acceptable for non-sensitive land uses.

13.3 Appendix C: Part 1. Quality assurance and quality control

13.3.1 Assessment of reliability of field procedures and laboratory results

Contaminated site practitioners should undertake an assessment of the reliability of field procedures and analytical results using the data quality indicators (DQI) of precision, accuracy, representativeness, completeness and comparability. The following information has been adapted from NSW DEC guidance for site auditors (NSW DEC, 2006).

DQI are used to document and quantify compliance, or otherwise, with the requirements of the project SAP.

13.3.1.1 QA/QC analytical methods

The DQI for chemical data will differ depending on which analytical methods have been used in a site assessment. These fall into three main categories:

- field methods
- laboratory screening methods
- methods specific for contaminants that are known or expected to be present at a site.

13.3.1.2 Field methods

The following issues should be documented and discussed in assessment reports:

- the applicability and limitations of field methodologies where used
- instrument calibration and validation of field measurements, and comparison with laboratory results
- the significance of the results of field screening methods compared with the results of laboratory analyses, for example, that the results reported for field screening using a photo-ionisation detector are compatible with the results reported by the laboratory for volatile organic compounds. Where not compatible, an adequate explanation should be provided.

13.3.1.3 Laboratory screening methods

Laboratory screening methods are used to determine the type of contamination present and the constituents of a sample that might cause interferences in specific methods. Assessment reports should include appropriate discussion of the applicability and limitations of any screening methodologies used.

DQI for screening methods may be less rigorous than for specific analytical methods. Nevertheless, screening method performance should be known and should be expressed as a multiple of specific analytical method performance.

13.3.1.4 Methods specific for contaminants

Site assessors should ensure that appropriate discussion and documentation about the following issues is included in the assessment report:

- that the analytical methods used for site validation are of appropriate precision and accuracy, and that the sensitivity and selectivity of the analytical methods are appropriate for the assessment of the risk
- that the precision and accuracy criteria set out in the QA/QC plan, for a given method and matrix, meet the performance expected of the reference method
- that the quality of data supplied by the analytical laboratory meets the objectives of the testing laboratory's quality plan for at least 95% of test results. (Note that these DQOs do not refer to field duplicate reproducibility or other measures of sampling variance. Sampling variance should be addressed in the choice of sampling method.)

13.3.1.5 Data quality indicators (DQIs)

Contaminated site practitioners should undertake an assessment of the following DQIs which relate to both field and laboratory procedures, and provide appropriate documentation in the assessment report:

Completeness A measure of the amount of useable data (expressed as %) from a data collection activity		
Field considerations	**Laboratory considerations**	**Comments**
All critical locations sampled All samples collected (from grid and at depth) Standard operating practices (SOPs) appropriate and complied with Experienced sampler Documentation correct	All critical samples analysed according to SAP All analytes analysed according to SAP Appropriate methods and PQLs Sample documentation complete Sample holding times complied with	The required percentage completeness should be specified in the SAP All required data must be obtained for critical samples and chemicals of concern Incompleteness is influenced by: • field performance problems (access problems, difficulties on site, damage, …) • laboratory performance problems (matrix interference, invalid holding times, …) • matrix problems

<table>
<tr><td colspan="3">Comparability
The confidence (expressed qualitatively) that data may be considered to be equivalent for each sampling and analytical event</td></tr>
<tr><td>Field considerations</td><td>Laboratory considerations</td><td>Comments</td></tr>
<tr><td>Same SOPs used on each occasion
Experienced sampler
Climatic conditions (temperature, rainfall, wind…)
Same types of samples collected (filtered, size fractions, ...)</td><td>Sample analytical methods used (including clean-up)
Sample PQLs (justify/quantify if different)
Same laboratories (justify/quantify if different)
Same units (justify/quantify if different)</td><td>Same approach to sampling (SOPs, holding times…)
Quantify influence from climatic or physical conditions
Samples collected, preserved, handled in same manner (filtered, same containers)</td></tr>
<tr><td colspan="3">Representativeness
The confidence (expressed qualitatively) that data are representative of each media present on the site</td></tr>
<tr><td>Field considerations</td><td>Laboratory considerations</td><td>Comments</td></tr>
<tr><td>Appropriate media sampled according to SAP
All media identified in SAP sampled</td><td>All samples analysed according to SAP</td><td>Samples must be collected to reflect the characteristics of each media
Sample analyses must reflect properties of field samples
Homogeneity of the samples
Appropriate collection, handling, storage and preservation
Detection of laboratory artefacts, e.g. contamination blanks</td></tr>
<tr><td colspan="3">Precision
A quantitative measure of the variability (or reproducibility) of data</td></tr>
<tr><td>Field considerations</td><td>Laboratory considerations</td><td>Comments</td></tr>
<tr><td>SOPs appropriate and complied with</td><td>Analysis of:
• laboratory and inter-laboratory duplicates
• field duplicates
• laboratory-prepared volatile trip spikes</td><td>Measured by the coefficient of variance or standard deviation of the mean or by RPDs
Field duplicates measure field and laboratory precision
Laboratory duplicates measure analytical precision</td></tr>
</table>

Accuracy (bias) A quantitative measure of the closeness of reported data to the true value		
Field considerations	**Laboratory considerations**	**Comments**
SOP appropriate and complied with	Analysis of: • field blanks • rinsate blank • reagent blank • method blank • matrix spike • matrix spike duplicate • surrogate spike • reference material • laboratory control sample • laboratory-prepared spikes	Bias introduced: • by chemicals during handling or transport • from contaminated equipment • from contaminated reagent • during laboratory analysis • during laboratory preparation and analysis (may be high or low) • precision of preparation and analytical method • during laboratory analysis • during collection/ transport (may be high or low)

13.3.2 Field QA/QC

Contaminated site practitioners should ensure that the following issues are addressed in the field QA/QC program and that appropriate documentation is included in the assessment report:

- replicate samples are split in the field and submitted to two separate laboratories in accordance with the requirements of Schedule B3
- the sampling program includes assessment of all relevant environmental media, including soil, dust, surface water, groundwater, air, sediments and biota as appropriate
- the sampling strategy is appropriate for the conditions at the site and the nature of the contamination with the rationale for the strategy described in the assessment report and the sampling locations shown on a scaled site sampling plan
- sample collection, handling and transportation procedures are documented and appropriate to meet the project DQOs
- sampling is representative of site conditions, based on the selection of appropriate number of sampling points and of samples from each relevant strata and material types stated in a site sampling plan to meet the project DQOs
- the field QA/QC plan includes details of:
    - the sampling team
    - sampling method(s), including the actual methods employed for obtaining samples, type(s) of sample containers, order and degree of filling, preservation, labelling, logging, custody
    - evidence of appropriate decontamination procedures carried out between sampling events

  - logs for each sample collected are completed showing time, location, initials of sampler, duplicate locations, duplicate type, chemical analyses to be performed, site observations and weather conditions
  - chain-of-custody documentation is completed fully, identifying for each sample the name of the sampler, the nature of the sample, collection date, analyses to be performed, sample preservation method, departure time from the site and dispatch courier(s) and condition of samples at dispatch
    - sample splitting techniques
    - a statement of duplicate frequency for intra-laboratory and inter-laboratory duplicate samples and duplicate sample results
    - field blank results
    - background sample results
    - rinsate sample results
    - laboratory-prepared trip spike results for volatile analytes
    - trip blank results
    - field instrument calibration for instruments used on site.

13.3.2.1 Laboratory QA/QC

Contaminated site practitioners should ensure that the following issues are addressed in the laboratory QA/QC program and that appropriate documentation is included in the assessment report:

- sample analyses use appropriate methodologies for each potential contaminant in the matrix in laboratories accredited for those analyses by the National Association of Testing Authorities (NATA) or an equivalent (government-endorsed provider of accreditation for laboratories)
- appropriate practical quantitation limits (PQLs) for the chemicals of concern for use in the assessment of risk
- a laboratory QA/QC plan with the following information:
  - a copy of signed chain-of-custody forms acknowledging receipt date and time, conditions of samples on receipt and identity of samples included in shipments
  - record of holding times and a comparison with method specifications
  - analytical methods used
  - laboratory accreditation for analytical methods used
  - laboratory performance in inter-laboratory trials for the analytical methods used, where available
  - the results for blind duplicate samples collected from the field.

13.3.3 QA/QC documentation

The site assessment reports should include documentation of QA/QC procedures including all information relevant to the site assessment:

- the QA/QC checklist items, as seen in Appendix C: Part 2, related to field quality assurance and quality control, laboratory QA/QC and data evaluation QA/QC
- the names of the accredited laboratories used and relevant details of their accreditation for each analytical method
- the limits of reporting (ensuring that appropriate assessment can be made according to site criteria as stated in the DQOs for relevant media)

- the acceptance limit(s) for each QC test, such as duplicate relative percentage differences (RPDs) and recoveries for laboratory quality control analyses
- where used, the origin of certified reference material (CRM), its batch number and the concentrations of the chemicals of potential concern
- the QC results relevant to the sample analysis
- for each sample, the highest measurement result wherever replicate measurements are taken (or all measurement results for each sample)
- results for all data tabulated separately according to each type of soil, fill materials, groundwaters, surface waters and sediments, with appropriate statistical analysis
- the laboratory specifying compliance with the requirements of the National Environmental Protection (Assessment of Site Contamination) Measure 2011 and equivalence with the reference method or non-standard methods.

13.4 Appendix C: Part 2. Quality assurance and quality control checklist

Field quality assurance and quality control

- ☐ details of sampling team
- ☐ decontamination procedures carried out between sampling events
- ☐ field logs for samples collected — including time, location, initials of sampler, duplicate locations, duplicate type, chemical analyses to be performed, site observations and weather conditions
- ☐ chain of custody fully identifying — for each sample — the sampler, nature of the sample, collection date, analyses to be performed, sample preservation method, departure time from the site and dispatch courier(s)
- ☐ sample splitting techniques
- ☐ statement of duplicate frequency
- ☐ field blank results
- ☐ background sample results
- ☐ rinsate sample results
- ☐ laboratory-prepared trip spike results for volatile analytes
- ☐ trip blank results
- ☐ field instrument calibrations (when used)

Laboratory QA/QC

- ☐ a copy of the signed chain-of-custody forms acknowledging receipt date and time, and identity of samples included in shipments
- ☐ record of holding times and a comparison with method specifications
- ☐ analytical methods used
- ☐ laboratory accreditation for analytical methods used
- ☐ laboratory performance in inter-laboratory trials for the analytical methods used, where available
- ☐ description of surrogates and spikes used
- ☐ percent recoveries of spikes and surrogates

☐ instrument detection limit

☐ method detection limits

☐ matrix or practical quantification limits

☐ standard solution results

☐ reference sample results

☐ reference check sample results

☐ daily check sample results

☐ laboratory duplicate results

☐ laboratory blank results

☐ laboratory standard charts

QA/QC data evaluation

☐ evaluation of all QA/QC information listed above against the stated DQOs including a discussion of:

- documentation completeness
- data completeness
- data comparability
- data representativeness
- precision and accuracy for both sampling and analysis for each analyte in each environmental matrix informing data users of the level of reliability or qualitative value of the data

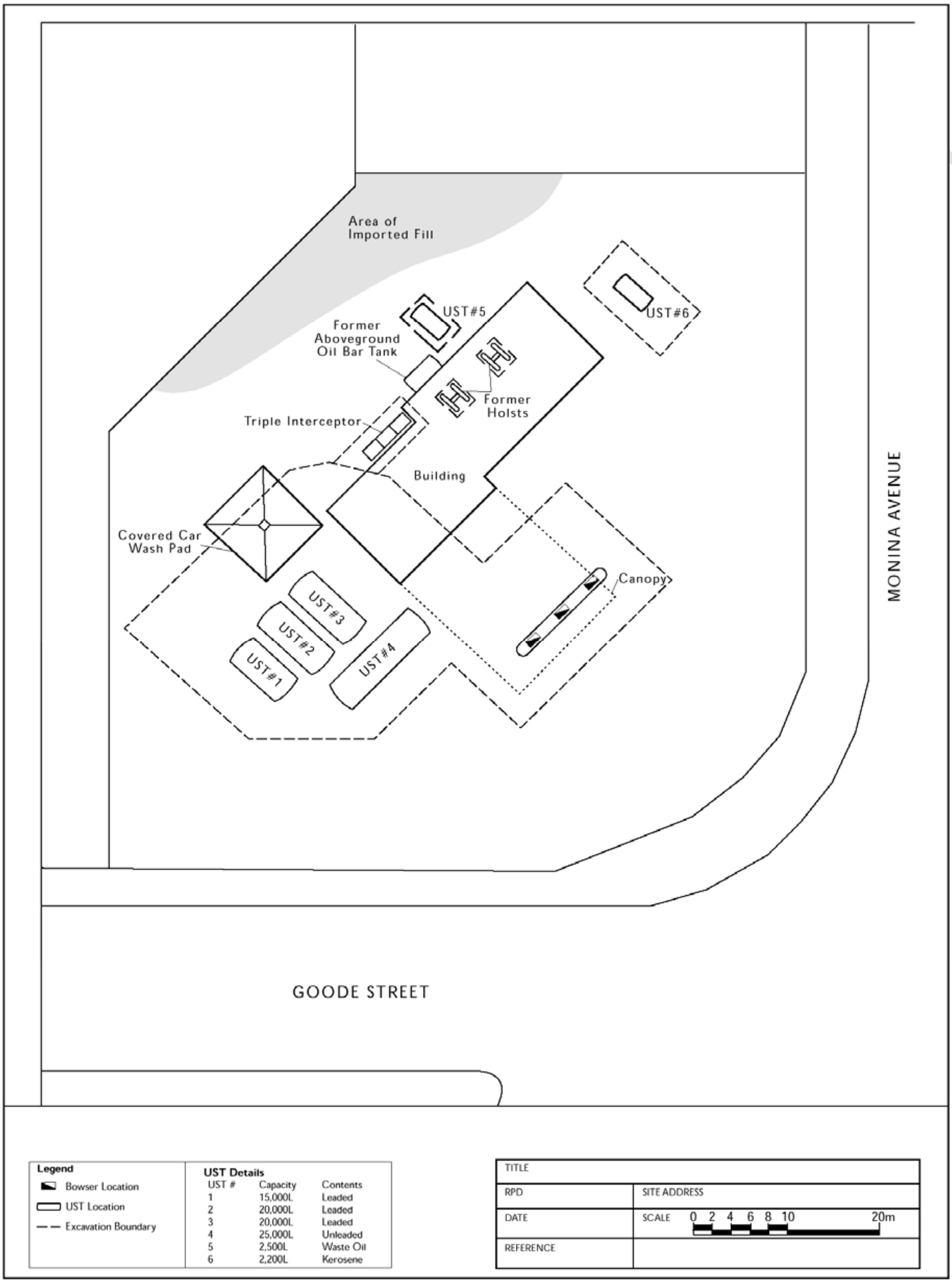
☐ results of data comparability checks to assess bias which may arise from various sources, including:

- collection and analysis of samples by different personnel
- use of different methodologies
- collection and analysis by the same personnel using the same methods but at different times
- spatial and temporal changes (because of environmental dynamics)

☐ relative percent differences for intra- and inter-laboratory duplicates.

13.5 Appendix D: Data presentation on scale drawings and borehole logs

Figure 2. Site layout overlay



UST Details

UST #	Capacity	Contents
1	15,000L	Leaded
2	20,000L	Leaded
3	20,000L	Leaded
4	25,000L	Unleaded
5	2,500L	Waste Oil
6	2,200L	Kerosene

Figure 3. Results – v – Site Features

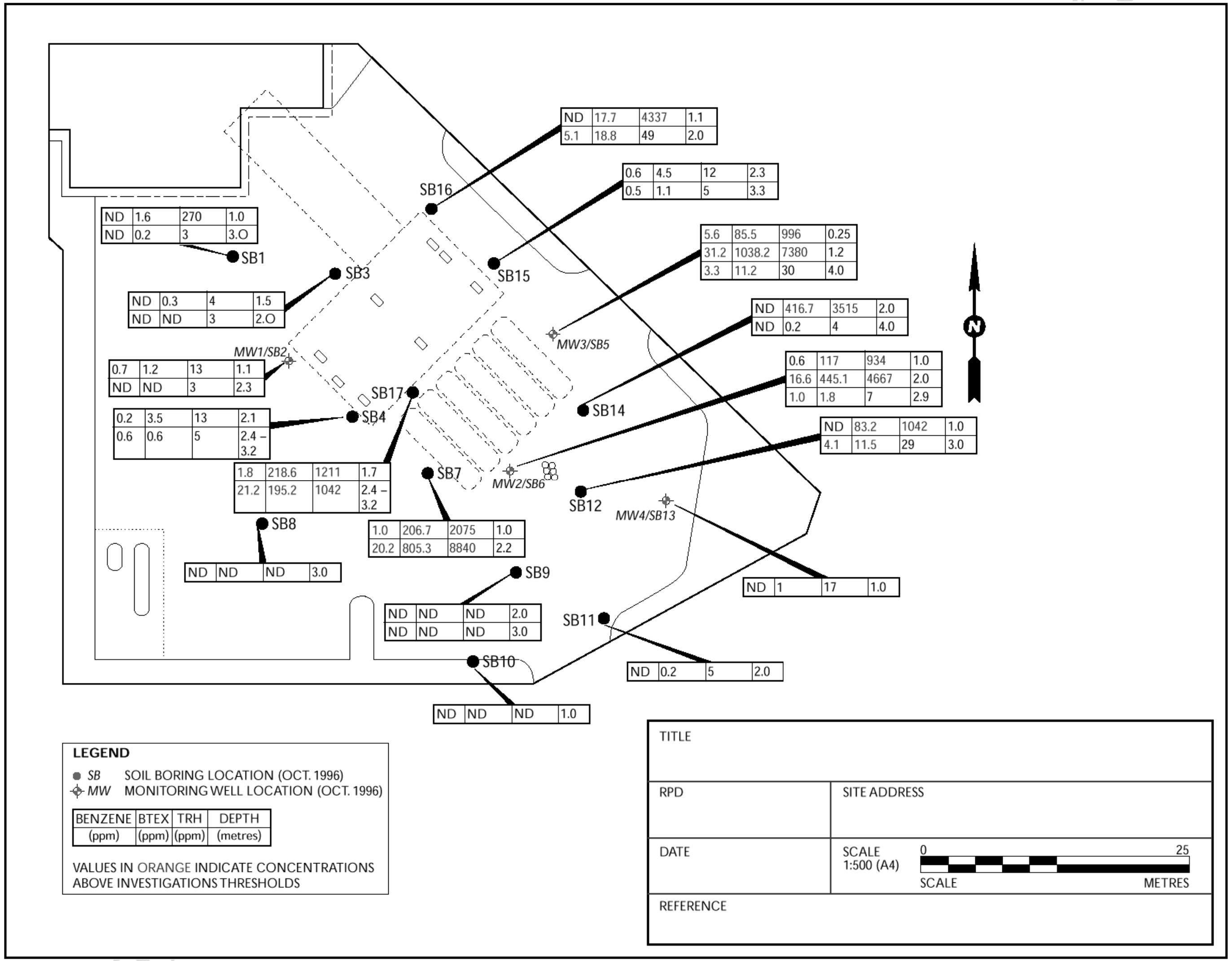


Figure 4. Cross-section – contaminant concentrations through soil profile

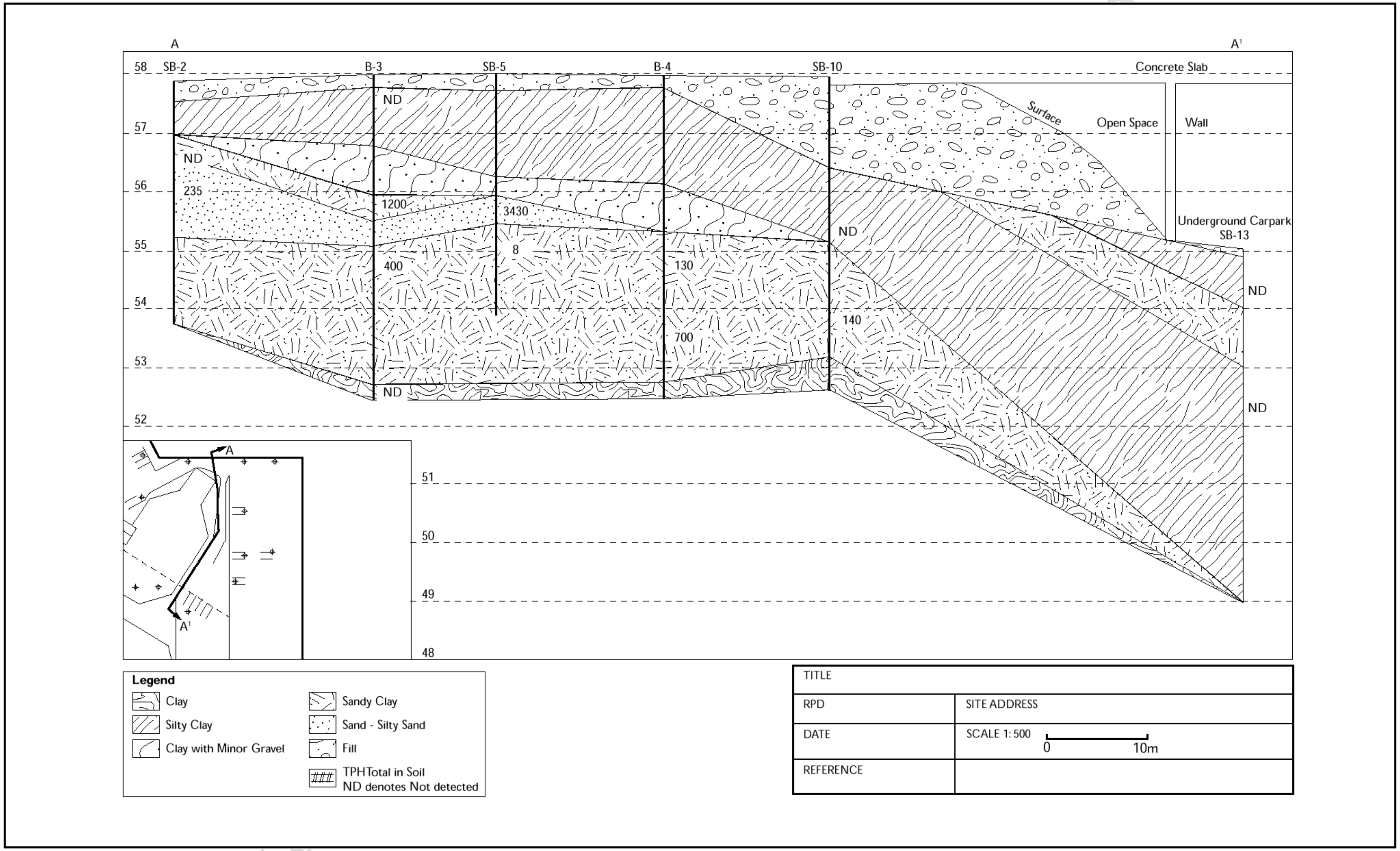


Figure 5. Results from excavation assessment

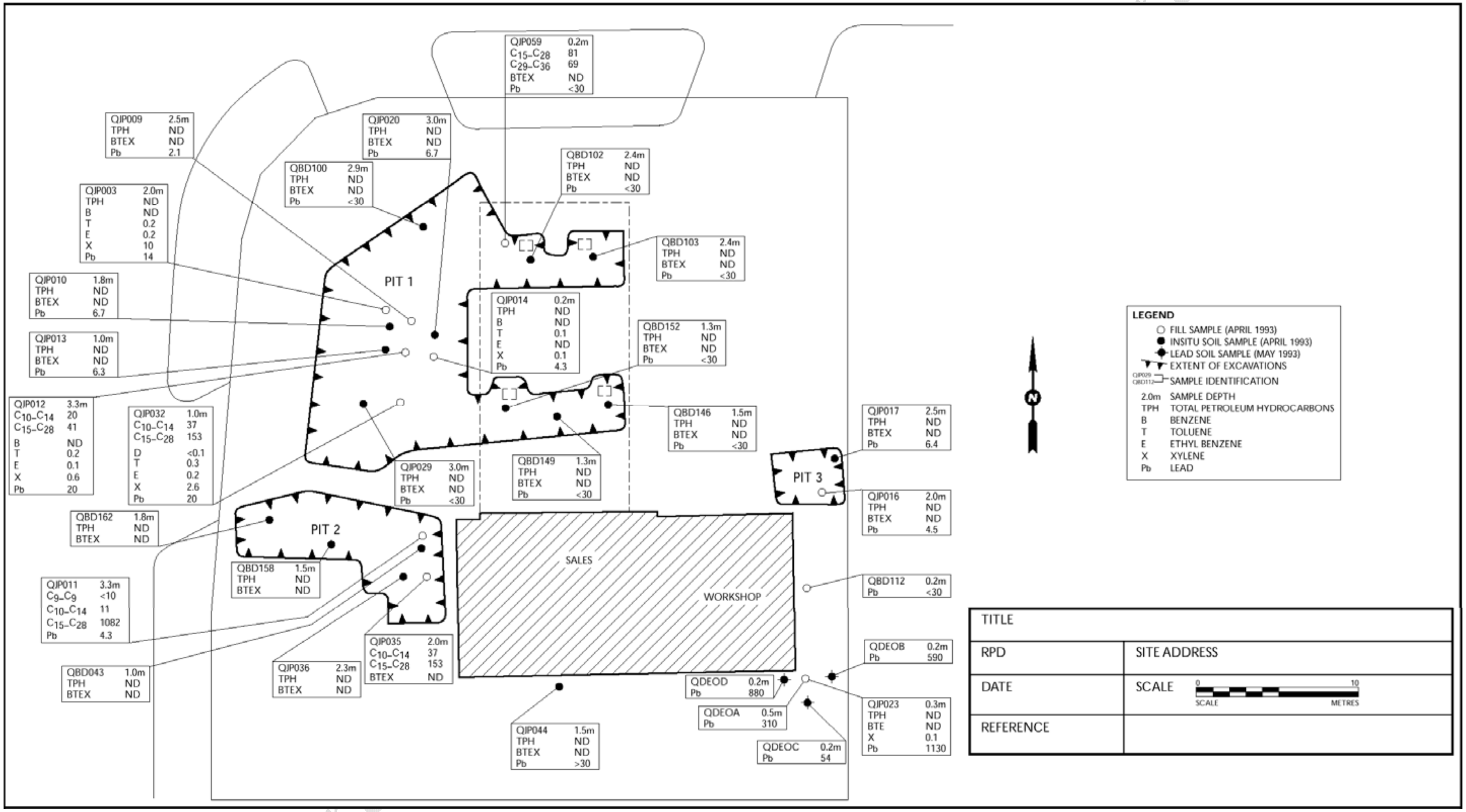
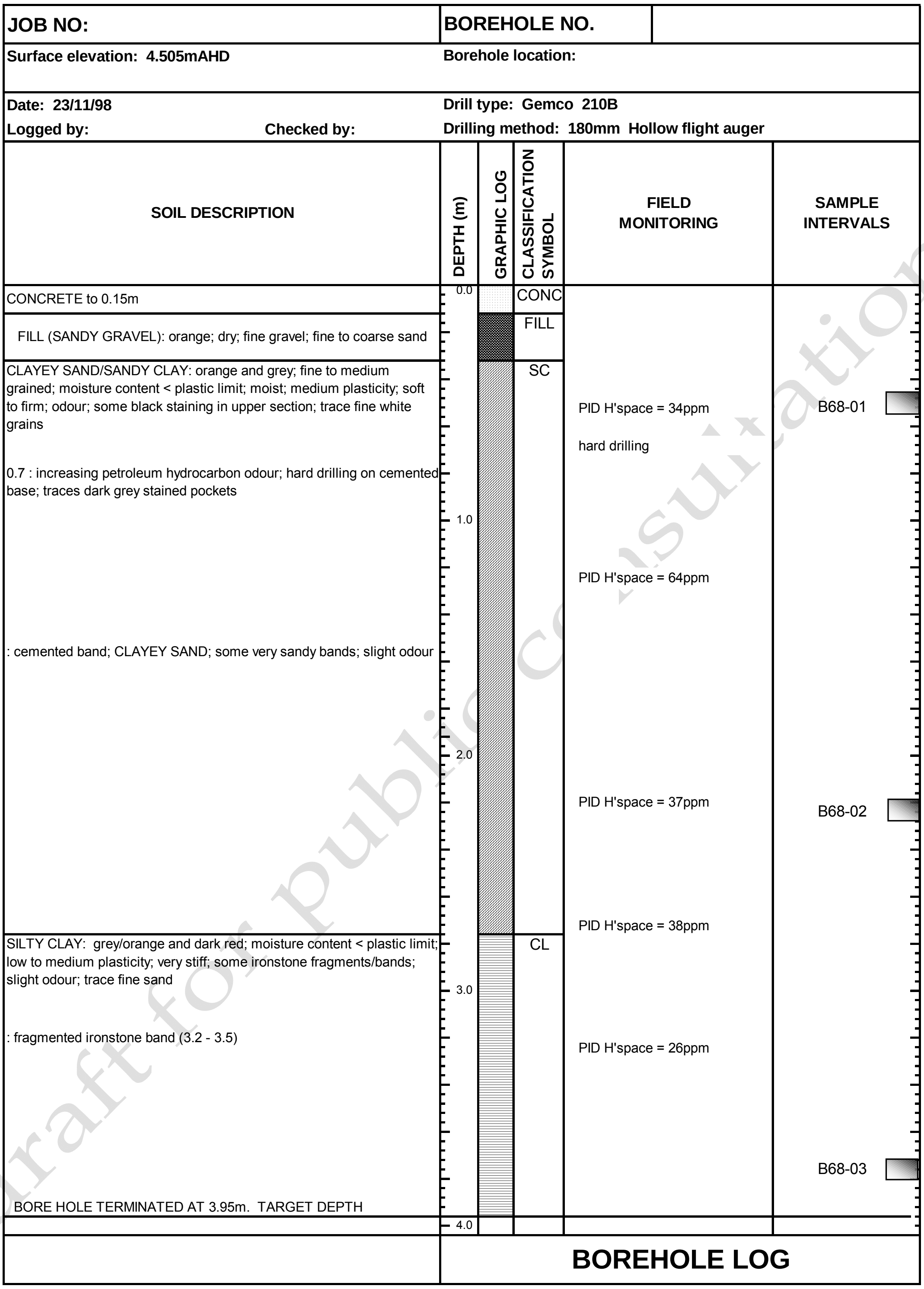


Figure 6. Site plan – analyte concentration contours

Figure 7. Borehole Log – B68

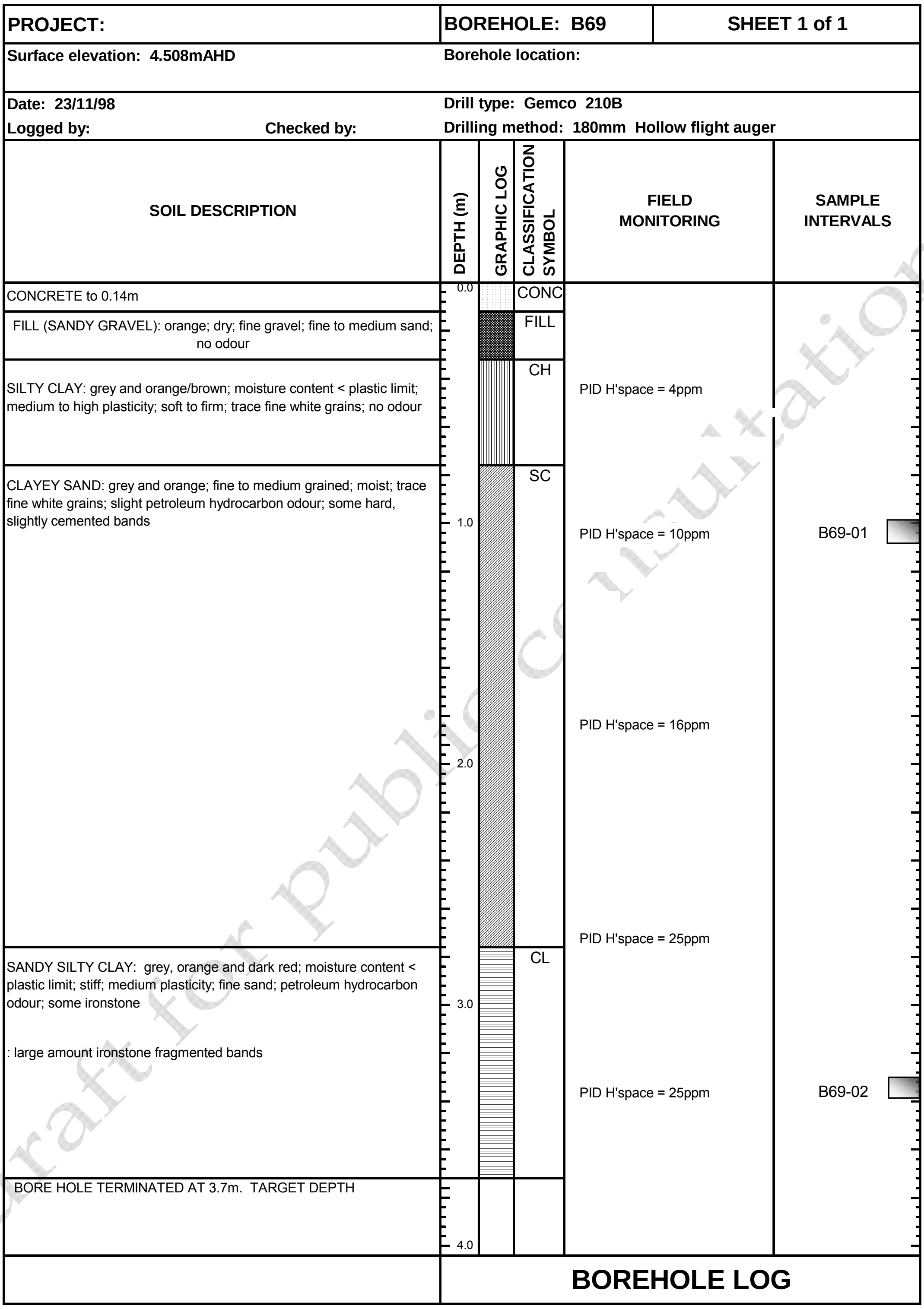


JOB NO:	**BOREHOLE NO.**	
Surface elevation: 4.505mAHD	**Borehole location:**	
Date: 23/11/98 **Logged by:** **Checked by:**	**Drill type: Gemco 210B** **Drilling method: 180mm Hollow flight auger**	

SOIL DESCRIPTION	**DEPTH (m)**	**GRAPHIC LOG**	**CLASSIFICATION SYMBOL**	**FIELD MONITORING**	**SAMPLE INTERVALS**
CONCRETE to 0.15m	0.0		CONC		
FILL (SANDY GRAVEL): orange; dry; fine gravel; fine to coarse sand			FILL		
CLAYEY SAND/SANDY CLAY: orange and grey; fine to medium grained; moisture content < plastic limit; moist; medium plasticity; soft to firm; odour; some black staining in upper section; trace fine white grains			SC	PID H'space = 34ppm	B68-01
				hard drilling	
0.7 : increasing petroleum hydrocarbon odour; hard drilling on cemented base; traces dark grey stained pockets					
	1.0				
				PID H'space = 64ppm	
: cemented band; CLAYEY SAND; some very sandy bands; slight odour					
	2.0				
				PID H'space = 37ppm	B68-02
				PID H'space = 38ppm	
SILTY CLAY: grey/orange and dark red; moisture content < plastic limit; low to medium plasticity; very stiff; some ironstone fragments/bands; slight odour; trace fine sand			CL		
	3.0				
: fragmented ironstone band (3.2 - 3.5)				PID H'space = 26ppm	
					B68-03
BORE HOLE TERMINATED AT 3.95m. TARGET DEPTH					
	4.0				

BOREHOLE LOG

Figure 8. Borehole Log – B69



PROJECT:

BOREHOLE: B69

SHEET 1 of 1

Surface elevation: 4.508mAHD

Borehole location:

Date: 23/11/98

Logged by:

Checked by:

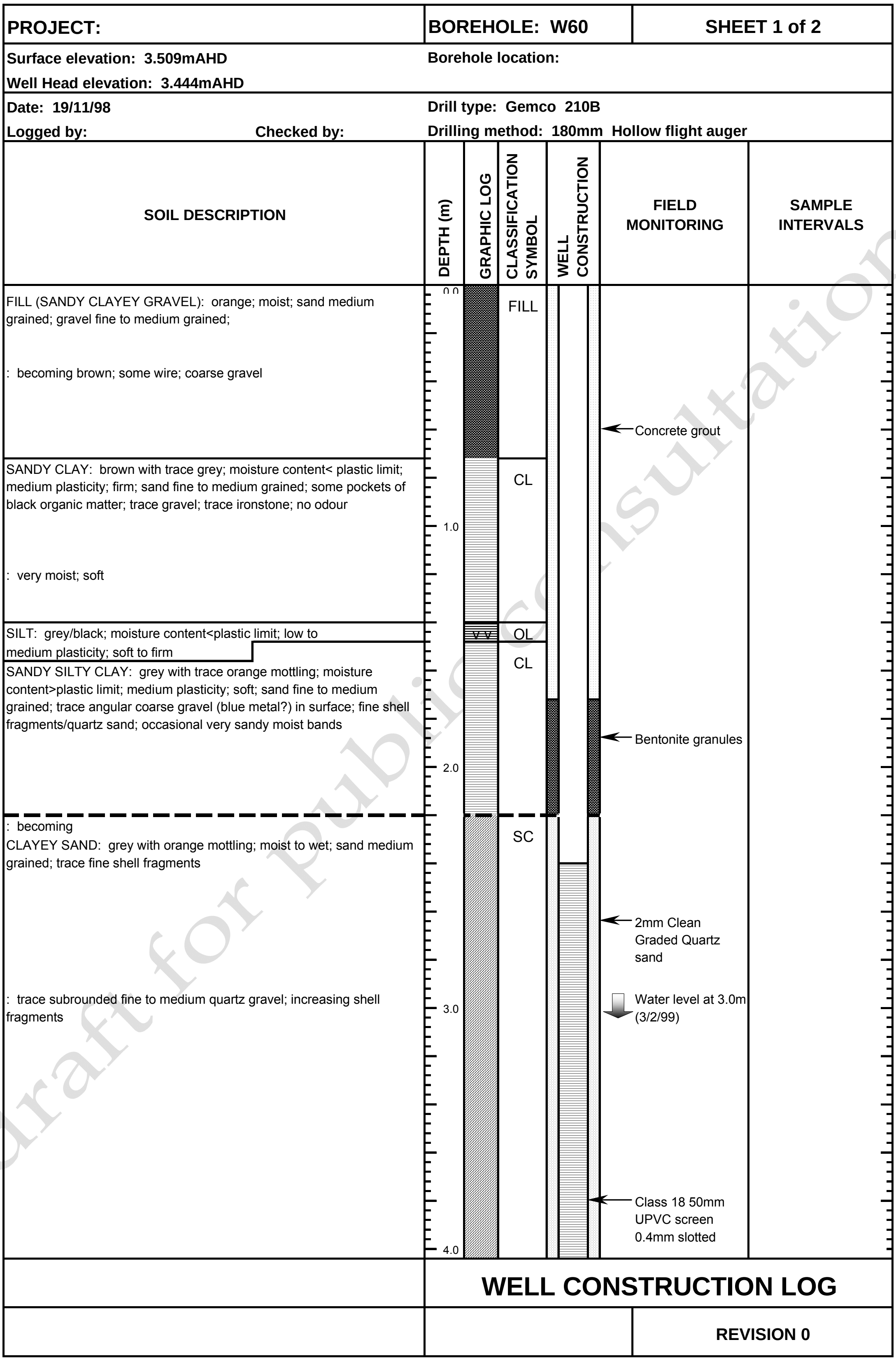
Drill type: Gemco 210B

Drilling method: 180mm Hollow flight auger

SOIL DESCRIPTION	DEPTH (m)	CLASSIFICATION SYMBOL	FIELD MONITORING	SAMPLE INTERVALS
CONCRETE to 0.14m	0.0	CONC		
FILL (SANDY GRAVEL): orange; dry; fine gravel; fine to medium sand; no odour		FILL		
SILTY CLAY: grey and orange/brown; moisture content < plastic limit; medium to high plasticity; soft to firm; trace fine white grains; no odour		CH	PID H'space = 4ppm	
CLAYEY SAND: grey and orange; fine to medium grained; moist; trace fine white grains; slight petroleum hydrocarbon odour; some hard, slightly cemented bands	1.0 2.0	SC	PID H'space = 10ppm PID H'space = 16ppm PID H'space = 25ppm	B69-01
SANDY SILTY CLAY: grey, orange and dark red; moisture content < plastic limit; stiff; medium plasticity; fine sand; petroleum hydrocarbon odour; some ironstone : large amount ironstone fragmented bands	3.0	CL	PID H'space = 25ppm	B69-02
BORE HOLE TERMINATED AT 3.7m. TARGET DEPTH	4.0			

BOREHOLE LOG

Figure 9. Borehole Log – W60 (sheet 1 of 2)



PROJECT:
BOREHOLE: W60
SHEET 1 of 2

Surface elevation: 3.509mAHD
Well Head elevation: 3.444mAHD
Borehole location:

Date: 19/11/98
Logged by:
Checked by:
Drill type: Gemco 210B
Drilling method: 180mm Hollow flight auger

SOIL DESCRIPTION

FILL (SANDY CLAYEY GRAVEL): orange; moist; sand medium grained; gravel fine to medium grained;

: becoming brown; some wire; coarse gravel

SANDY CLAY: brown with trace grey; moisture content< plastic limit; medium plasticity; firm; sand fine to medium grained; some pockets of black organic matter; trace gravel; trace ironstone; no odour

: very moist; soft

SILT: grey/black; moisture content<plastic limit; low to medium plasticity; soft to firm

SANDY SILTY CLAY: grey with trace orange mottling; moisture content>plastic limit; medium plasticity; soft; sand fine to medium grained; trace angular coarse gravel (blue metal?) in surface; fine shell fragments/quartz sand; occasional very sandy moist bands

: becoming
CLAYEY SAND: grey with orange mottling; moist to wet; sand medium grained; trace fine shell fragments

: trace subrounded fine to medium quartz gravel; increasing shell fragments

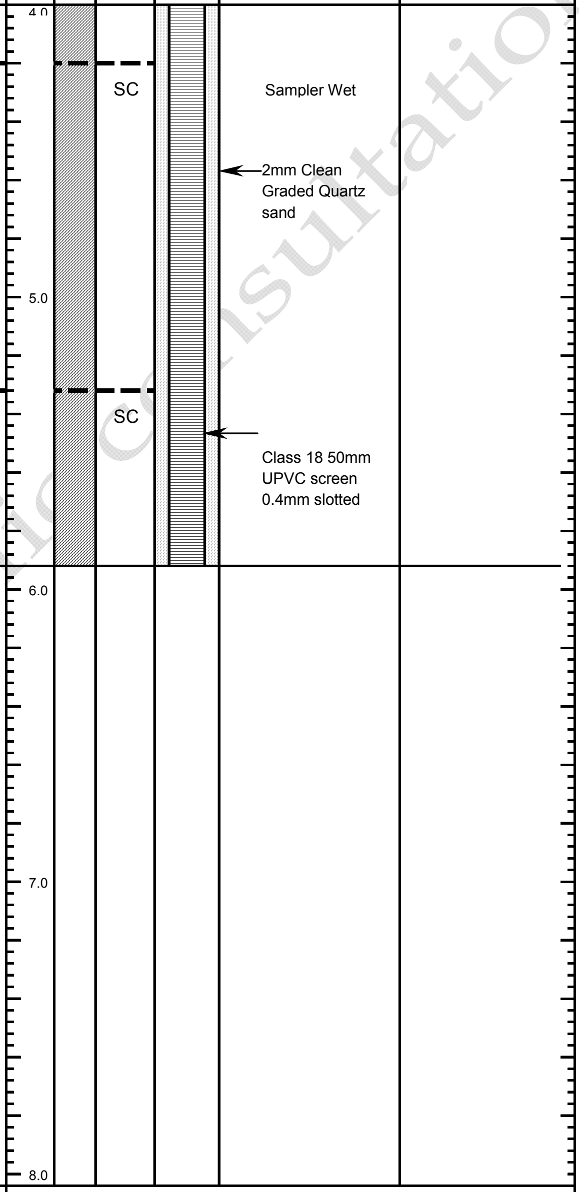
WELL CONSTRUCTION LOG

REVISION 0

Figure 10. Borehole Log – W60 (sheet 2 of 2)

PROJECT:	**BOREHOLE: W60**	**SHEET 2 of 2**
Surface elevation: 3.509mAHD **Well Head elevation: 3.444mAHD**	**Borehole location:**	
Date: 19/11/98 **Logged by:** **Checked by:**	**Drill type: Gemco 210B** **Drilling method: 180mm Hollow flight auger**	

SOIL DESCRIPTION	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	WELL CONSTRUCTION	FIELD MONITORING	SAMPLE INTERVALS
: becoming GRAVELLY CLAYEY SAND: sand medium to coarse grained; subrounded gravel; gravel fine to course grained; occasional hard; slightly cemented, very clayey bands			SC		Sampler Wet 2mm Clean Graded Quartz sand	
CLAYEY SAND: grey & orange; medium to coarse; wet			SC		Class 18 50mm UPVC screen 0.4mm slotted	
BOREHOLE TERMINATED AT 5.9m. TARGET DEPTH. WELL INSTALLED.						



WELL CONSTRUCTION LOG

REVISION 0

13.6 Appendix E: Dioxins and dioxin-like compounds

13.6.1 Background

Dioxins and dioxin-like compounds are chlorinated organic pollutants formed as trace amounts of undesired impurities or by-products in the manufacture of other chemicals such as chlorinated phenols and their derivatives, chlorinated diphenyl ethers, and PCBs (WHO 1989) and combustion of chlorine containing materials under some conditions. These compounds are one class of persistent organic pollutants (POPs).

The dioxins group comprises 75 polychlorinated dibenzo-p-dioxin (PCDD) congeners and 135 polychlorinated dibenzofuran (PCDF) congeners. There are no known technical uses for PCDD and PCDF (WHO 1988).

Some PCBs also have dioxin-like properties and are included as part of dioxin and dioxin-like compounds. PCBs are a class of organic compounds with 1 to 10 chlorine atoms attached to the biphenyl molecule. There are 209 possible PCB congeners although only 130 were found in commercial PCB mixtures.

The World Health Organisation (Van den Berg et al. 2006) identified 29 dioxins and dioxin-like compounds of environmental concern based on similar toxicological profiles. These include 7 PCDD, 10 PCDF and 12 co-planar 'dioxin like' PCB. Whilst these substances have similar toxicological profiles, they have differing toxicological potencies. Thus, their concentrations in environmental and biological media are reported using toxicity equivalence (TEQ) relative to a reference compound, which in this case is 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). The relative toxicity of each compound is expressed as a toxicity equivalency factor (TEF) and the product of the concentration and the TEF for each substance in the mixture results in a TEQ concentration relative to 2,3,7,8-TCDD. The sum of the resultant TEQ for each substance yields a single concentration for the TEQ of the mixture.

The history of TEQ systems is as follows:

- the international TEQ (I-TEQ) was developed largely by the United States Environmental Protection Agency (US EPA) in 1990
- the WHO modified the I-TEQ in 1998 by incorporating 'dioxin-like' PCBs; this was known as the WHO98 TEQ
- in 2005 the WHO98 TEQ system was updated to WHO05 TEQ (Van den Berg et al. 2006).

13.6.2 Occurrence of dioxins and dioxin-like compounds

The major causes of soil contamination by dioxin and dioxin-like compounds are from accidental or incidental spillages in the manufacture, transport, storage and use of various chlorinated compounds and past disposal of these compounds. Land uses associated with waste disposal, pulp and paper mills and chemical manufacturing may have resulted in soil contamination by these compounds.

Other industrial sources of dioxin and dioxin-like compounds such as thermal or combustion sources and reservoir sources such as sludges may be less significant as contaminant sources for soil.

Dioxins and dioxin-like compounds also occur naturally and are released into the atmosphere from creation or entrainment during bush fires and from volcanic activity.

13.6.3 Results from the national dioxins program

As part of the National Dioxins Program (NDP), soils from around Australia were collected and analysed for dioxins. Dioxin-like chemicals were found in all but one of the 114 Australian soils sampled, with concentrations ranging from the limit of detection (0.05 pg TEQ g-1 dwt) to 43 pg TEQ g-1 dwt.

The greatest concentrations of dioxin-like chemicals were found in soils collected near centres of population within the south-east coastal area of Australia, whereas concentrations were consistently low in soils collected from locations in Western Australia and inland areas. Data from the study showed that levels of dioxin-like chemicals in soils from urban and industrial locations were substantially higher relative to agricultural land use and remote locations. This pattern was consistent regardless of whether levels were expressed as toxic equivalents or as concentrations.

Homologue and congener profiles for the PCDD/Fs were strongly dominated by OCDD. Similarly, the tetra-heptachlorinated 2,3,7,8-chlorine substituted profiles are dominated by the highest chlorinated PCDD, 1,2,3,4,6,7,8-heptachloro dibenzodioxin. The source or formation processes by which dominance of higher chlorinated congeners could occur remains unresolved despite intensive studies. With regards to the TEQs, on average, more than 80% of the toxic equivalency across soil samples was attributed to 2,3,7,8-PCDD/Fs.

There is no Australian guideline threshold for dioxin-like chemicals in soils. Comparison of concentrations of dioxin-like chemicals in the NDP soil samples against a categorisation derived from German thresholds showed that only 15% of the Australian samples (all but one of which were from urban or industrial locations) exceeded the German derived target value of < 5 pg TEQ g-1 dwt and only one sample exceeded the guideline threshold of acceptability for specific agricultural uses of soil. Australian jurisdictions do not have a generic action or response level for dioxin-like compounds, but may adopt a site-specific investigation and/or response level for dioxins following a site-specific risk assessment.

The concentrations of dioxin-like chemicals in urban and industrial locations sampled as part of the NDP were similar to those reported in previous Australian studies and in the New Zealand Organochlorine Program. On the basis of toxic equivalents, concentrations of dioxin-like chemicals are on average much lower than those reported from many industrial sites internationally and, globally, can be considered among the lowest background concentrations reported in soil from any industrialised nation.

14 Shortened forms

ACM	asbestos cement materials
CPT	Cone penetrometer testing
CSM	conceptual site model
DNAPL	dense non-aqueous-phase liquid
DQO	Data quality objectives
DSI	detailed site investigation
FID	flame ionisation detector
GC	gas chromatography
LIF	Laser-induced fluorescence
LNAPL	light non-aqueous-phase-liquid
MIP	membrane interface probe
NAPL	Non-aqueous-phase liquid
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PID	photo-ionisation detector
PSI	preliminary site investigation
QA	quality assurance
QC	quality control
SAP	sampling and analysis plan
SOP	standard operating procedure
SVOC	semi-volatile organic compounds
TPH	Total petroleum hydrocarbon
VOC	volatile organic compound