DEVELOPMENT OF SAMPLING AND ANALYSIS PROGRAMS

MANAGEMENT SERIES

5

Contaminated Sites Management Series

Development of Sampling and Analysis Programs

(*Guideline for the Assessment of Sites Incorporating Underground Storage Tanks* and *Contaminated Site Assessment Guidelines for the Development of Sampling and Analysis Programs* as amended)

December 2001

Department of **Environmental Protection**
Government of **Western Australia**

PREFACE

This guideline for the *Development of Sampling and Analysis Programs* includes the former draft *Guidelines for the Assessment of Sites Incorporating Underground Storage Tanks* (DEP, 2000) and former draft *Contaminated Site Assessment Guidelines for the Development of Sampling and Analysis Programs* (DEP, 2000) and has been prepared by the Department of Environmental Protection (DEP) to provide consultants, local government authorities, industry and other interested parties in the assessment of contaminated sites in Western Australia (WA).

This guideline provides an indication of the methods and work required when developing a sampling and analysis program (SAP) for the investigation and validation of sites including those incorporating underground storage tanks (USTs). The guideline entitled *Reporting on Site Assessments* (DEP, 2001) provides details, including a checklist of information required by the DEP when reporting on site investigations and remediation validations.

Enquiries about this guideline may be directed to the Contaminated Sites Section as follows:

Contaminated Sites Section
Environmental Regulation Division
Department of Environmental Protection
PO Box K822
PERTH WA 6842
Telephone: (08) 9222 7000
Fax: (08) 9322 1598

ACKNOWLEDGMENTS

The DEP acknowledges the following organisations for assistance in the preparation of this guideline:

- CSIRO Land and Water;
- Water and Rivers Commission (WRC);
- WorkSafe WA;
- EnviroSkill International Pty Ltd;
- PPK Environment and Infrastructure Pty Ltd; and
- URS Australia Pty Ltd.

LIMITATIONS

This guideline applies to persons investigating contaminated sites. The contents herein provide guidance only and do not purport to provide a methodology for the assessment of sites. Competent professionals should be engaged to provide specific advice in relation to the assessment of contaminated sites.

This guideline should be used in conjunction with the texts referenced herein, and any other appropriate references.

This guideline does not contain occupational safety and health procedures and should therefore not be used as a field manual for sampling. WorkSafe Western Australia should be consulted regarding such requirements.

DISCLAIMER

This guideline has been prepared by the DEP in good faith exercising all due care and attention. No representation or warranty, expressed or implied, is made as to the relevance, accuracy, completeness or fitness for purposes of this document in respect of any particular user's circumstances. Users of this guideline should satisfy themselves concerning its application to their situation, and where necessary seek expert advice.

CONTAMINATED SITES MANAGEMENT SERIES

This guideline forms part of the Contaminated Sites Management Series developed by the DEP to address certain key aspects of contaminated site management in Western Australia.

The management series contains the following guidelines:

- Assessment Levels for Soil, Sediment and Water;
- Certificate of Contamination Audit Scheme;
- Community Consultation;
- Contaminated Site Auditor Accreditation Scheme;
- Development of Sampling and Analysis Programs;
- Disclosure Statements;
- Guidance for Planners;
- Potentially Contaminating Activities, Industries, and Landuses;
- Reporting of Known or Suspected Contaminated Sites;
- Reporting on Site Assessments; and
- Site Classification Scheme.

Reference to this guideline should ensure that the general requirements of the DEP are satisfied.

Copies of these guidelines are available on the DEP website, www.environ.wa.gov.au

STAGED APPROACH TO SITE INVESTIGATIONS

The Contaminated Sites Management Series of guidelines has been developed by the DEP to encourage a consistent approach to contaminated site assessment and management. One of the main focuses of the series is the **staged approach to site investigation**.

The purpose of this flow-chart is to highlight to the reader the appropriate reference guideline(s) during each of the stages of site investigation.

Stages of Site Investigation	Contaminated Sites Management Series Guidelines
Stage 1 Preliminary Site Investigation (PSI)	Potentially Contaminating Activities, Industries and Landuses Reporting of Known or Suspected Contaminated Sites Development of Sampling and Analysis Programs Reporting on Site Assessments Community Consultation
Development of a HSEP and SAP*	
Stage 2 Detailed Site Investigation (DSI)	Community Consultation Development of Sampling and Analysis Programs Assessment Levels for Soil, Sediment and Water Reporting on Site Assessments
Development of a HSEP and SAP*	
Stage 3 Site Management Plan (SMP)	Community Consultation Development of Sampling and Analysis Programs Reporting on Site Assessments
Development of a HSEP and SAP*	
Stage 4 Remediation Validation and Ongoing Management	Reporting on Site Assessments Assessment Levels for Soil, Sediment and Water Community Consultation

*Where samples are to be collected a Health, Safety and Environment Plan (HSEP), and Sampling and Analysis Program (SAP) should be prepared.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

Summary

- **The objective of this guideline is to assist practitioners to develop sampling and analysis programs (SAP) as part of the contamination assessment, remediation and validation stages of site assessments.**
- **A SAP is a site-specific document which presents:**
  - **the objective(s) for sampling at a contaminated site;**
  - **a methodology for determining sampling, sample preservation, sample transportation, sample storage, quality assurance and quality control (QA/QC), and analysis; and**
  - **the number, type and locations for sampling to ensure the collection of representative, reproducible data on the nature and extent of *in situ* contamination.**

The development of a SAP is a key factor in conducting a site investigation or remediation program to ensure that representative and reproducible data is obtained, which can be used to assess the nature and extent of *in situ* contamination and any risks posed to the environment and human health.

Prior to the collection of samples at a site, during a Preliminary Site Investigation (PSI), Detailed Site Investigation (DSI) or Remediation Validation, a comprehensive SAP should be developed. Page III presents a flow chart indicating when SAPs and Health and Safety and Environment Plans (HSEPs) should be developed in the site assessment process.

The level of detail within a SAP is determined by both the characteristics of the site and the objectives of the program. There can be no prescribed method for the assessment of site contamination as each site presents a different scenario in terms of contaminants, exposure pathways and desired end uses. The assessment of a contaminated or potentially contaminated site should therefore be undertaken on a site-specific basis.

As such, this guideline is not prescriptive, but presents factors that should be taken into account when developing a SAP. This guideline should be used in conjunction with any other relevant guidelines, standards and information sources as well as professional experience and judgement to develop the most appropriate program for a site. Full justification for the location of sampling points, frequency and analytes used, should be provided in the SAP and any subsequent reports.

The development of a SAP ensures that all persons collecting samples at a site are aware of the objectives of the sampling program, the correct sampling methodologies, sample preservation and analytical program, etc. This information is important as it will provide guidance where field conditions differ from expected conditions, and to ensure reliability of sampling.

Reference to this guideline should ensure that the general requirements of the DEP are satisfied. Specialist advice should be sought on site-specific requirements from competent professionals and the DEP, where appropriate.

1.1 GOAL

The goal of this guideline is to provide practical guidance to assist practitioners in developing a SAP to:

- obtain representative and reproducible data of the nature and extent of *in situ* contamination at a site in order to adequately assess the risk and potential risk that a site poses to both human health and the environment; and
- validate remediation of a site to ensure that no contamination remains on-site which may pose a risk to human health or the environment.

1.2 SCOPE

This guideline has been prepared specifically to assist practitioners to develop a SAP for assessing contaminated sites.

This guideline presents the requirements for the development of a SAP for soil, sediment and groundwater. For each of these media, factors to be considered in determining the sampling design, including the location (spatial and vertical), number and frequency of sampling are provided. This guideline also addresses QA/QC.

This guideline does not cover:

- sampling methodologies and techniques;
- sampling requirements for biota or food chains;
- remediation methodologies and techniques; or
- occupational health and safety issues.

Where information on contaminant concentrations in plant and animal tissues is required, reference should be made to the risk assessment methodologies provided in the *National Environment Protection (Assessment of Site Contamination) Measure* (NEPM) (NEPC, 1999).

This guideline provides factors that should be considered in developing a SAP. The guideline for *Reporting on Site Assessments* (DEP, 2001) should be referenced for a general overview of the stages of site assessment, and the requirements of the DEP with respect to reporting on site assessments.

The *Potentially Contaminating Activities, Industries and Landuses* (DEP, 2001) guideline provides a list of potentially contaminating activities that can be used to assess the possibility for contamination at a site.

Additional information with respect to contamination assessment levels can be obtained from the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) guideline.

1.3 HEALTH & SAFETY

The scope of this guideline does not cover the health and safety aspects of contaminated sites, however some points have been included here to prompt the consideration of health and safety when planning activities on contaminated sites.

Health and Safety Plans (HSEPs) should be considered before each sampling stage.

The *Occupational Safety and Health Act 1984* places a clear obligation on a person to ensure the safety and health of anyone they engage to do work (such as drillers, earthmoving contractors and consultants). It is therefore recommended that HSEPs be produced and the contents adequately communicated to all site personnel prior to their exposure to the site.

Guidance on the contents of HSEPs can be obtained from the *National Environment Protection (Assessment of Site Contamination) Measure (Schedule B(9) Protection of Health and the Environment During the Assessment of Site Contamination)* (NEPC, 1999).

Copies of HSEPs should be forwarded to WorkSafe Western Australia along with notification of any site works prior to the commencement of the site works. WorkSafe Western Australia should be contacted for further information on notification of site works and HSEP requirements.

Any risks to the public such as adjacent landowners/occupants should be identified and measures implemented to minimise them.

It is expected that when conducting site investigations:

- practitioners engage contractors (e.g. drillers, earth moving contractors, surveyors) who have undergone some training associated with operating on contaminated sites, and ensure that all persons on the site are familiar with the relevant health and safety aspects of the site;
- drilling contractors holding an appropriate National Water Well Drillers Licence would be engaged where groundwater bores are to be installed; and
- competent professionals possessing the relevant skills, knowledge, experience and judgement would supervise all intrusive investigations, e.g. geologist, hydrogeologist.

If the site subject to the investigation is on a mine-site as defined under the *Mine Safety and Inspection Act 1994*, then a copy of the HSEP should be submitted to the Department of Mineral and Petroleum Resources (DMPR).

1.4 STAGED APPROACH TO SITE INVESTIGATIONS

In order to obtain the most representative samples and data on a site, a staged approach to contaminated site assessment should be adopted, for example:

- **Stage 1** - Preliminary Site Investigation (PSI);
- **Stage 2** - Detailed Site Investigation (DSI);
- **Stage 3** - Site Management Plan (SMP); and
- **Stage 4** - Remediation, Validation and Ongoing Management.

Reports can be submitted to the DEP for review at any stage of the assessment process or on completion of the entire investigation. The DEP recommends, however, that a staged approach to the submission of contaminated site reports be taken, consistent with the staged approach to site investigations as outlined in the *Reporting on Site Assessments* (DEP, 2001). Submitting reports in a staged manner enables the DEP to provide guidance and advice in the early stages of the investigation, which often reduces delays during the final assessment and clearance of sites. Difficulties associated with the quality of information, sampling parameters and distribution, adopted investigation levels and environmentally sensitive issues can be resolved in the early stages of the investigation. Submission of reports on completion of each of the stages of investigation also enables site investigation and management objectives to be developed in consultation with the DEP prior to commencement of the next stage of investigation. The DEP is not, however to be used as a consultant. Suitable reports should therefore be developed to meet the requirements as outlined in this guideline.

Preliminary Site Investigations (PSIs) identify the site characteristics (location, layout, building construction, hydrogeology) and historical landuses and activities at the site. PSIs are primarily "desk top" studies, although a detailed site inspection (including interviews with site representatives) should be included where possible. PSIs may include the collection of preliminary samples. The findings of a PSI form the basis of all further site investigations, and therefore it is imperative that as much information on the site as possible is obtained and included in this preliminary phase of investigation.

Following a PSI, Detailed Site Investigations (DSIs) may be required to confirm the findings of the PSI, to identify any additional evidence of contamination via sampling and to determine the impact that contamination at a site has, or may have, on human health and the environment.

The purpose of a DSI is to conduct detailed sampling to establish the nature of contamination, the lateral and vertical distribution of contaminants, determine contaminant concentrations, clarify contamination sources and give consideration to potential human health and environmental impacts. DSIs may be completed in a number of stages depending upon the size or complexity of the site.

The development of a Site Management Plan (SMP) involves the selection of an effective management strategy which is practical, achieves the desired outcomes and is socially and environmentally acceptable. The SMP should address:

- specific data gaps identified during the DSI;
- identify the additional information required for the selection and/or design of remedial and/or management options (e.g. active remediation, risk mitigation); and
- identify the required baseline data for sites subject to monitored natural attenuation (passive remediation).

Remediation, validation and ongoing management enable the success of the remediation to be assessed. The remediation and validation report should clearly demonstrate that the land is suitable for its current or intended use, that the beneficial use of environmental receptors including groundwater or surface water is not compromised and that all the objectives of the remediation have been achieved and accounted for.

1.5 RELEVANT REFERENCES

A large amount of literature is available on the assessment of contaminated sites. This guideline has been written to amalgamate the key points of a number of references, but it is by no means exhaustive and more detailed information should be obtained on specific media, contaminants etc. where required prior to design of a program. Some useful references are provided in Section 9.

2. SAMPLING AND ANALYSIS PROGRAM DESIGN

Summary

- **Sampling and analysis programs (SAP) should be developed prior to the collection of any samples on a site.**
- **SAPs should be site-specific.**
- **SAPs should be based upon the findings of PSIs. (Where sampling is to be conducted as part of the PSI, then a SAP should be developed based upon the findings of the desktop study and detailed site inspection conducted as part of the PSI).**
- **The SAP should document, as a minimum:**
  - **the objectives of the sampling program;**
  - **background information on the site (location, activities, known contaminants);**
  - **the number and type of samples to be collected;**
  - **sample collection locations (sample patterns);**
  - **a description of sampling methods including sample containers, sampling devices and equipment, equipment decontamination procedures, sample handling procedures, sample preservation methods and reference to recognised protocols;**
  - **disposal of sampling/remedial waste (soils, sediment, waters, decontamination wastes, etc.);**
  - **sample analysis requirements (analytes and analytical methods); and**
  - **QA/QC methods.**

2.1 INTRODUCTION

Prior to the collection of any samples at a site, a SAP should be developed to determine the most effective and representative sampling strategies and analysis parameters.

A SAP should document, as a minimum:

- the objectives of the sampling program;
- background information on the site (e.g. location, activities, known contaminants);
- the number and type of samples to be collected;
- sample collection (sample patterns);
- a description of sampling methods (including sample containers, sampling devices and equipment, equipment decontamination procedures, sample handling procedures and reference to recognised protocols, etc.), sample collection information (e.g. depth, methodology), sample identification, preservation, handling and storage details and chain of custody details;
- disposal of sampling/remedial waste (soil, sediment, waters, decontamination wastes, etc.);
- sample analysis requirements; and
- QA/QC methods.

The development of a SAP should take into consideration the following:

- findings of the PSI;
- objective(s) of the SAP;
- contaminant distribution (known or inferred, point source or diffuse source, handling of contaminated material to avoid spreading the contamination, and prevention of further distribution);

- background sampling locations (to benchmark site contamination and establish any naturally elevated parameters);
- choice of analytes;
- health and safety of site workers, general public and the environment (preparation of a HSEP);
- potential site outcomes (proposed site uses);
- most effective sampling techniques; and
- proposed disposal location for any excavated/abstracted waste during/following sampling and remedial works.

2.2 OBJECTIVES OF SAMPLING AND DATA COLLECTION

Prior to designing a SAP, the objectives of the program should be defined. A SAP can range in detail from a preliminary sample screening exercise to a plan for a DSI, or form part of remediation, validation and ongoing management. The objectives of the program must be clearly defined to enable determination of the most appropriate sample types, sampling locations, analysis parameters, analytical detection limits and review of investigation findings to determine if the objectives have been met.

The objectives of a SAP can include:
- determination of the location of contaminant sources;
- determination of the nature, magnitude and extent of contamination;
- determination of background concentrations;
- determination of contaminant migration and exposure pathways;
- data quality objectives (DQOs) (statements which specify the quality of the data required, guidance can be sought in *AS 4482.1 – 1997 Guide to the Sampling and Investigation of Potentially Contaminated Soil, Part 1: Non-volatile and Semi-Volatile Compounds* (*AS4482.1-1997*));
- provision of meaningful and accurate results on which to base human health and/or ecological risk assessments; and
- provision of validation data to determine successful remediation of a site.

Once determined, the objective(s) of the program will influence:
- what information is required;
- what level of detail of information is required;
- sample methodologies (including the number and type of samples to be collected and sample locations);
- sample preservation requirements; and
- analysis parameters.

During investigation of contaminated sites, the objectives of a SAP may change as more contamination is identified, new sources of contamination are identified, or redevelopment plans for the site change, etc. If the objectives of the project change, then it is important to re-assess the SAP and determine if it will still provide the required information/results.

Documentation of the required works in a SAP, or recording all actions and decisions, allows review of how an investigator has structured the program of sampling and analysis. It also enables comparisons to be made of works planned against the actual field activities and sampling completed in order to identify whether the objectives of the program were adopted during the course of the investigation.

2.3 SAMPLING REQUIREMENTS

In order to adequately assess a contaminated site, a SAP should be designed to include the number and type of samples, and locations of sample collection. Table 1 presents a summary of the sampling requirements for the assessment of contamination at a site and validation of remediation.

Where a UST(s) is, or has been present at a site, reference should be made to Appendix F for the minimum sampling requirements in the vicinity of the tank and any associated infrastructure.

Sampling of groundwater is required unless it can be demonstrated to the satisfaction of the DEP that there is limited potential for groundwater to be contaminated at the site.

More detailed information is presented within the relevant sections of this guideline.

TABLE 1. OVERVIEW OF SAMPLING REQUIREMENTS

	ASSESSMENT OF CONTAMINATION		VALIDATION OF REMEDIATION	
	No. of Samples	**Sample Location**	**No. of Samples**	**Sample Location**
Soil	Dependent upon size of site, geology, hydrogeology, type of contamination, historical landuse, outcomes of previous investigations, etc.	Laterally and vertically spaced to determine the extent of contamination.	Dependent upon extent of contamination and remedial works.	Systematic, evenly spaced samples across walls and bottom of all excavated areas. Sampling in areas of remaining contamination in addition to the grid pattern.
Sediment	Dependent upon the size of the site, the sediment lithology, the type of contamination, historical landuse, outcomes of previous investigations, etc.	Laterally and vertically spaced to determine the extent of contamination.	Dependent upon extent of contamination and remedial works.	Grid pattern across dredge area, and along boundaries of dredge area. Monitoring to ensure that the source is removed, and build up of contaminated sediments does not re-occur.
Groundwater	Dependent upon the size of the site, aquifer properties (including permeability, groundwater levels, presence of confining units/sand lenses, etc.) and groundwater quality.	Within, down-gradient and up-gradient of groundwater contamination plume. Minimum of three bores to allow estimation of groundwater flow direction.	Dependent upon aquifer properties and temporal variations in water quality and levels. Consecutive results should show contaminant concentrations below acceptable guideline criteria.	Dependent upon location of groundwater monitoring bore locations across site.

2.4 CHOICE OF ANALYTES

The choice of analytes for sample analysis should be site-specific and take into consideration:

- the objectives of the program;
- known contamination (e.g. historical leaks and spillages);
- potential contamination sources (identified during the PSI and site inspection);
- proposed landuse for the site;

- potentially applicable comparison levels or guidelines;
- availability of National Association of Testing Authorities (NATA) accredited laboratories to undertake analysis; and
- breakdown products of contaminants (in some cases these can be more toxic, and/or more mobile than the parent contaminant (e.g. TCE)).

The *Potentially Contaminating Activities, Industries and Landuses* (DEP, 2001) guideline provides a list of potential contaminants (analytes) which may be associated with some activities, industries and landuses, and can be used as a general guide when selecting analytes. However site-specific information obtained during a PSI should identify the actual and potential contaminants at a site, based on site activities.

When determining analytes, the detection limits should be considered. The required detection limits may vary based upon the level of contamination at a site and the landuse/beneficial use of the site. Detection limits should be below the relevant assessment levels. Consultation with the laboratory during the development of the SAP maybe required to determine what can be achieved.

Where soils are being assessed, in addition to the type and concentration of contaminants present, determination of the leachability of those contaminants may also be required where groundwater is at a shallow depth, or where disposal to landfill is to occur.

There is a range of testing procedures to assess the leachability of contaminants. In the past, the USEPA Toxicity Characteristic Leaching Procedures (TCLP) has been used but this has now been superseded by the leaching procedures defined in *AS 4439.1-1999 Wastes, Sediments and Contaminated Soils – Preparation of Leachates – Preliminary Assessment* (*AS 4439.1*) (ASLP). Justification for the use of the leachability testing procedure should be provided and used on a case-specific basis.

Where sediments are being assessed, it is recommended that the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ 2000) be referred to in determining the most suitable analytes and analytical methods. Where sediments are being sampled, the quality of pore water within the sediments should be considered, which is also a source of contamination. The ecological impacts of contaminated sediments are influenced by the bioavailability of the contaminants of concern. Therefore when assessing sediments, the total concentrations of contamination, dilute acid-solubility of contaminants, organic content, grain size and speciation of the sediments and pore water concentrations should be considered. Refer to other sections of this guideline for further information about sediment sampling.

Analysis of samples should be completed by laboratories that hold NATA accreditation for the particular analytes and methodologies required. It should be noted that a laboratory may be NATA accredited for some analytes and not others, and therefore a check of the laboratory accreditation for the required analysis should be made prior to consigning the samples.

Laboratory certificates should be NATA endorsed reports.

Schedule B(3) Guideline on Laboratory Analysis of Potentially Contaminated Soils, National Environment Protection (Assessment of Site Contamination) Measure (NEPC, 1999) refers to various laboratory techniques for the analysis of contaminated soils.

2.5 APPROPRIATE SAMPLING METHODS

2.5.1 Factors to be Considered

This guideline does not contain information on sampling techniques or methodologies. Information on sampling techniques can be sourced from other references. However, in selecting the most appropriate sampling method, the following factors should be considered:

- knowledge and experience of field staff in sampling techniques;
- accessibility to the site and/or sections of the site;
- availability of equipment;
- nature of contaminant(s);
- health and safety of site personnel and general public (e.g. exposure to contaminants, potential release of contaminants);
- anticipated extent of contamination (e.g. hand augers can be used to sample shallow contamination in soft soils, whereas deeper contamination and hard soils may require a drilling rig);
- geological conditions (e.g. type of drilling rig required);
- hydrogeological conditions (e.g. depth to watertable, aquifer type, number of aquifers, groundwater flow direction);
- potential for vertical and/or lateral cross contamination during and after the collection of samples;
- sensitivity of samples to potential cross-contamination and degradation in storage;
- type and volume of wastes produced and waste disposal methods;
- disturbance of flora/fauna/heritage sites; and
- potential for release of contamination to the wider environment and surrounding beneficial uses (e.g. dust, odours, and stormwater runoff).

All samples should be collected using appropriate techniques to provide representative and reproducible data.

It should be noted that where underground structures (USTs, pipe-work, bowsers, drainage lines, etc.) remain *in situ* during any investigations, the results are indicative only. In order to determine a more detailed and accurate representation of contamination, collection of samples from beneath infrastructure is required and this is generally not possible where underground infrastructure remains, and particularly where the site remains operational, as access is often limited. Therefore any information obtained from sites where infrastructure remains will require validation following decommissioning of the site.

Where the location of a UST and associated infrastructure is unknown, the use of geophysical methods and field-testing should also be considered.

2.5.2 Composite Sampling

A composite sample is made up of a number of constituent samples (sub-samples), which are collected from a body of material and combined into a single sample, which therefore represents the average conditions of the body of material.

The rationale behind the use of composite sampling is often to reduce analytical costs, and to provide a general indication of the presence/absence of contamination in investigation programs. Although in principle composite samples represent the average concentration of the constituent samples, a major drawback with compositing is that a constituent sample containing a high concentration of contaminant can remain undetected because its concentration was diluted in the compositing process. Conversely, constituent samples may contain lower concentrations than the average, and where the average is above assessment levels, may result in investigation/remediation of areas that are below the assessment levels. Therefore, when interpreting data from composite samples, it is extremely important to be aware that as the data only shows an average concentration, there are likely to be higher or lower concentrations *in situ*.

With this in mind, composite sampling can be used as an initial screening tool only. More detailed information on the exact extent of contamination can only be obtained from individual (or discreet) samples.

In addition, due to the fact that composite samples do not provide an indication of the possible maximum contaminant concentrations, the results from composite sampling cannot be used for health or ecological risk assessments.

Based on the above limitations, composite sampling can be used for PSIs, however the DEP will not accept composite sample results as final results of an investigation unless adequate justification of the use of composites is provided, as well as full delineation of any identified contamination. Compositing for validation purposes is not accepted by the DEP.

Where composite sampling is to be used at a site, the following should be considered:

- all samples are made up from the same number of constituent samples;
- no more than 4 constituent samples should be included in a composite sample;
- constituent samples should be equal in size;
- constituent samples should be obtained from immediately adjacent sampling points;
- constituent samples should only be composited laterally, not vertically;
- constituent samples should be obtained from locations which are evenly spaced;
- composite samples should be composited in a laboratory environment and not in the field. Composites prepared outside the laboratory would be unlikely to provide acceptable results because of the difficulties in controlling homogenising and weighing of samples Compositing in the laboratory should be undertaken in accordance with *AS 4482.1-1997*; and
- composite samples are not satisfactory for semi-volatile and volatile substances e.g. Total Petroleum Hydrocarbons (TPH) and Polycyclic Aromatic Hydrocarbons (PAH).

Where composite samples are to be collected, information on compositing methodology should be detailed and should also be reported in any documents relating to the sampling.

Where composite sampling is undertaken, adjustment of the assessment level is required. Further information on adjusting assessment levels for composite sampling can be obtained from the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) guideline.

2.5.2.1 Soil

In addition to the limitations discussed above, composite sampling of soils is unsuitable for:

- site validation sampling, as it does not provide a definitive indication of concentrations remaining within the soil; and
- soils with a high clay content, as mixing and compositing is difficult.

2.5.2.2 Sediment

As with soils, compositing of sediment samples is not recommended unless more detailed investigations are to be completed. It is recommended that compositing of sediments only occur over small areas of a site otherwise too much information may be lost regarding the nature and distribution of the contamination.

Composite samples should not be made from sediments of a different nature/geology (e.g. organic content/particle size). The nature of the sediment bed should always be visually checked first to ensure that the sediment beds are geologically compatible.

The correct sampling and analytical methodologies for each of the known or expected contaminants should be identified and incorporated into the SAP.

Further information may be obtained from *AS/NZS 5667.12:1999 Water Quality – Sampling, Part 12: Guidance on Sampling of Bottom Sediments* (*AS/NZS 5667.12:1999*).

2.5.2.3 Groundwater

Compositing of groundwater samples, say from a number of monitoring bores at a site, <u>is not accepted</u> due to the limitations of compositing including the:

- inherent variability in groundwater conditions;
- possibility of cross contamination from compositing equipment; and
- possibility of alteration of sample by ambient conditions during compositing e.g. temperature, oxidation, ultra-violet radiation, introduction of dust, etc.

2.6 SAMPLE IDENTIFICATION, PRESERVATION, TRANSPORTATION AND STORAGE

2.6.1 Sample Identification

The SAP should document the sample identification requirements for all types of samples to be collected at the site. Sample identification should be completed as outlined in *AS/NZS 5667.1:1998 Water Quality – Sampling, Part 1: Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples* (*AS/NZS 5667.1:1998*).

2.7 SAMPLE PRESERVATION, TRANSPORTATION AND STORAGE

The SAP should document the sample preservation, transportation and storage requirements of all types of samples to be collected at the site. These parameters are dependent upon the sample media and choice of analytes. Sample preservation, transportation and storage should be completed according to relevant Australian Standards such as *AS 4482.1-1997* and *AS 4482.2-1999 Guide to the Sampling and Investigation of Potentially Contaminated Soil, Part 2: Volatile Substances* (*AS 4482.2*) and *AS/NZS 5667.1:1998* and the analytical methods selected.

It is recommended that sample preservation, transportation and storage requirements be confirmed with the analytical laboratory prior to sample collection.

2.8 UNCERTAINTY OF SAMPLING

In all sampling programs there will be uncertainty as to how representative samples are of *in situ* contamination. This is due to a number of factors, including cross contamination of samples, spatial and temporal variations in soil, sediments and groundwater, and the fact that most contamination is present beneath the ground surface and is therefore unidentified until intrusive investigations are conducted (and even then generally only small areas of the subsurface). A SAP should be designed so as to minimise uncertainty by basing it on a sound understanding of the site and the contaminants of concern.

Sampling uncertainty should be taken into consideration where decisions are being made based on analysis results, where statistical sampling methods of site assessment are applied and where modelling is based on analysis results.

2.9 SAMPLING AND REMEDIAL WASTE DISPOSAL

Where site contamination is known, or where it is determined that there is a high probability of contamination, it is recommended that remediation options (for example, disposal) of any material during sampling and remediation activities (soil/sediment/water) be addressed prior to commencing site works so as to:

- minimise health and safety risks to the public, site personnel and the environment associated with exposure to any contaminated material;
- determine a strategy/method for characterising the waste;
- determine the packaging requirements for waste material to be disposed of so as to reduce the risk of costly and unsafe double handling (refer to the *Australian Dangerous Goods Code* Volume 1 and 2);
- minimise time taken to obtain the appropriate approvals for off-site disposal; and
- determine whether a permit for the transport of contaminated soils or liquid waste is required under the *Environmental Protection (Controlled Waste) Regulations 2001*.

Where the concentration of contaminants in the spoil is below the relevant investigation levels as documented in the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) guideline or DEP approved site-specific criteria, waste may be disposed of on-site at a suitable location following approval from the site operator/owner and any interested parties and authorities.

Where the spoil is contaminated above the relevant assessment or site-specific levels for the current or proposed landuse of the site, treatment (on-site or off-site), or off-site disposal to a suitable location is required.

There are certain requirements for the transport of soils that are classified as a Controlled Waste as per the *Environmental Protection (Controlled Waste) Regulations 2001*. The collection or transport of controlled waste must be carried out by a licensed transporter as stipulated under Regulation 15 of the *Environmental Protection (Controlled Waste) Regulations 2001*. A licensed transporter is defined as a person who collects and transports a controlled waste for financial reward or more than the notifiable quantity (one tonne in the case of contaminated soil) of controlled waste in a period of one year.

An occupier of premises who wishes to remove a controlled waste from the premises must apply to the Chief Executive Officer of the DEP for a permit to remove the waste.

Disposal of contaminated soil to landfill must be at a licensed waste disposal facility and undertaken in accordance with the *Guidelines for Acceptance of Solid Waste to Landfill* (DEP, 2001).

3. QUALITY ASSURANCE/QUALITY CONTROL

The SAP should include measures to ensure the quality and reproducibility of all sampling methods used at the site. Accurate QA/QC is required to ensure that the samples collected are of the highest quality and integrity, and that analysis is completed with the highest accuracy. Where results are produced with inadequate QA/QC procedures, they cannot be accepted as being accurate or representative of the site conditions. This guideline does not contain details on QA/QC measures as these are covered in *AS 4482.1-1997* and *AS/NZS 5667.1:1998*. Guidance on the QA/QC reporting requirements of the DEP for contaminated site management is provided in the *Reporting on Site Assessments* (DEP, 2001) guideline.

<u>QA/QC measures are required regardless of the number of samples taken.</u>

3.1 FIELD QUALITY ASSURANCE/QUALITY CONTROL

The minimum field QA/QC procedures that should be performed are:

- collection of quality control samples (for sampling and transportation/preservation methods);
- use of standardised field sampling forms and methods; and
- documenting calibration and use of field instruments.

Field QC samples are used to check for:

- processes that may have interfered with the integrity of the samples;
- cross contamination in the sampling procedures;
- cross contamination from bore construction/sampling infrastructure installation;
- interferences from preservatives added to the samples;
- interferences from processes within the analytical laboratory;
- accuracy of the laboratory results; and
- precision of the laboratory results.

3.1.1 Quality Control Samples

The objectives of the SAP should be considered when determining appropriate QC procedures.

AS 4482.1-1997 provides further information on quality control samples which should be included when collecting soil samples, these should also be adopted when sampling sediments. *AS/NZS 5667.1:1998* provides information on the collection of quality control samples when sampling waters. Refer to Table 2 for a summary of some of the quality control samples that need to be considered for soil, sediment and groundwater sampling.

TABLE 2. QUALITY CONTROL SAMPLES

Type of Sample	Why are they used?	How many should be taken?	Field/Laboratory considerations
Background samples[1]	Background samples are generally taken outside of the boundary of the site. They provide a comparison of environmental quality away from the influence of the site.	Dependent upon the nature of contamination and background environment.	-
Blind replicate samples (also known as field duplicates)[1]	Blind replicates may be used to identify the variation in analyte concentration between samples collected from the same sampling point and/or also the repeatability of the laboratory's analysis.	One blind replicate sample should be taken for every 20 investigative samples.	The blind replicate sample and investigative sample from the sample location should be submitted to the laboratory as two individual samples without any indication to the laboratory that they have been duplicated.
Split samples[1]	Split samples are used to provide a check on the analytical proficiency of the laboratories.	For every 20 samples, one set of split samples should be taken.	One sample from each set should be submitted to a different laboratory for analysis. The same analytes should be determined by both laboratories, using the same analytical methods.
Rinsate blanks[1]	Rinsate blanks are used to provide confirmation that there has been no cross-contamination of substances from the sampling equipment used. They are collected where cross-contamination of samples is likely to impact on the validity of the sampling and assessment process.	Dependent upon types of equipment used, contaminants and decontamination procedures.	-
Field blank[2]	Field blanks are used to estimate contamination of a sample during the collection procedure.	At least one field blank should be taken per sampling team per trip per collection apparatus.	-
Transport blank[2]	Transport blanks are used to estimate the amount of contamination introduced during the transport and storage of samples from the time of sampling until the time of analysis.	At least one transport blank should be collected per group of samples.	-
Container blanks[2]	Container blanks estimate contamination from the container and preservation technique during storage of the sample.	At least one container blank should be collected per group of samples.	A cleaned sample container is filled with water of an appropriate quality, any preservative used in the sample is added, and then the blank is stored for the same time and same location as the samples for analysis.
Other QC samples[1]	-	Dependent upon sampling and preservation techniques.	-

Notes:
1. please refer to *AS 4482.1-1997* for further information.
2. please refer to *AS/NZS 5667.1:1998* for further information.

3.2 LABORATORY QUALITY ASSURANCE/QUALITY CONTROL

Analysis of samples should be completed by laboratories that hold NATA accreditation for the particular parameters and methodologies required. Information on QA/QC methods should be obtained from the designated laboratory prior to sampling to ensure that they meet the requirements of the SAP.

The laboratory report should be a NATA endorsed report and include:

- the results of the analysis;
- sample numbers;
- laboratory numbers;
- a statement about the condition of the samples when they were received (e.g. on ice, cold, ambient, etc.);
- date and time of receipt;
- dates and times of extraction and analysis of samples;
- quality control results; and
- a report on sampling and extraction holding times.

3.3 CHAIN OF CUSTODY

Chain of custody is the process that details the links in the transfer of samples between the time of collection and their arrival at the designated laboratory. Several transfers may take place in this process, for instance, from the sampler to the courier, and from the courier to the laboratory.

The minimum information that should be included on the Chain of Custody form is as follows (refer to *AS 4482.1-1997* for further information):

- name of person transferring the samples;
- name of person receiving samples (e.g. laboratory staff);
- time and date the samples were taken;
- time and date the samples are received (e.g. at the laboratory);
- condition of samples (e.g. chilled or ambient temperature);
- name and contact details of the client;
- analytes to be determined;
- the set of samples that are to be composited for analysis, and along with compositing method (further information on compositing is provided Section 2.5.2 of this guideline);
- details of the sample matrix;
- the required sample detection limits;
- other specific instructions in the handling of the samples during the analysis (e.g. special safety precautions, analysis of both solid and liquid phase of sludge/sediment samples, notification of heavy contamination to minimise laboratory staff contact with samples and to ensure analysis equipment is appropriately calibrated.

3.4 DATA REVIEW

Following receipt of field and/or laboratory data, a detailed review of the data should be completed to determine its accuracy and validity, prior to any decisions being made based on it. The data should be checked against the DQOs specified in the SAP (refer to Section 2.2) to ensure that these objectives and the objectives of the overall program have been met. Where inconsistencies are identified, then further investigations and/or remediation may be warranted.

Laboratory data should be checked for any analytical errors, such as contamination identified in rinsate, transport and laboratory blanks, which may indicate cross-contamination of samples. Analytical data should be reviewed against field data and field observations to identify any spurious results inconsistent with field findings. Where inconsistencies are identified, re-sampling or re-analysis may be required.

4. SOIL SAMPLING DESIGN

Summary

- **Soil samples can be collected during PSIs, DSIs, remediation progress evaluations and remediation, validation and ongoing management.**
- **Sampling locations should be determined so as to provide an accurate representation of the lateral and vertical extent of contamination across a site.**
- **Where possible, control points should be identified to act as reference points in determining the levels of contamination against 'background' concentrations. Several locations for control points may be required.**

4.1 INTRODUCTION AND OBJECTIVES

Contaminated soil can arise from a number of sources, including accidental spillage of chemicals, leaching of contaminants from poorly managed landfills and leakage of chemicals from drums, tanks, pipe-work and drains.

Contaminated soils can potentially pose a threat to the environment through contributing to groundwater contamination via the leaching of contaminants through the soil profile and through uptake by plants. Contaminated sites can also potentially pose a threat to human health through the release of hazardous dusts and vapours during any reworking of the soils (such as during redevelopment of a site), through direct contact with the skin, and via ingestion.

Soil investigations generally comprise the installation of soil investigation bores using hand or power driven drilling/excavation equipment to enable the collection of soil samples representative of the soil profile. The soil samples can then be examined and analysed to determine whether adverse impacts have resulted.

Soil sampling at a site can be conducted as part of:

- PSIs to determine if further investigations are necessary;
- DSIs (sometimes staged);
- Site Management Plan, for example, remediation progress evaluations; and
- Remediation, validation and ongoing management.

For any of these, a SAP with multiple stages may be required, especially for large and/or complex sites.

Once analytical results have been received, determination of the level of contamination should be made via comparison of results against site-specific investigation and response levels, or against the DEP assessment levels as presented in the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) guideline.

4.2 SOIL SAMPLING LOCATIONS

4.2.1 Pattern Types

The determination of soil sample locations is dependent upon the characteristics of the site and the contaminants of concern. Soil sampling locations may be based on knowledge of the site (judgemental sampling), or may be determined by a set pattern such as:

- systematic sampling (grid pattern);
- stratified sampling (sampling of sub areas);
- random sampling;
- stratified random sampling (random sampling within sub areas); and
- composite sampling (refer to section 2.5.2 of this document).

Further information on these pattern types is provided in Appendix A and *AS 4482.1-1997*.

For all sampling programs, justification for the sample locations chosen must be documented and reported to enable assessment of the results based on the location of sampling points. Where justification is not considered acceptable, particularly where limited sampling has been completed, the DEP may return the report without assessment.

As a general rule, where detailed information is available for the site in terms of physical characteristics, potential contaminants and potential sources of contamination, judgemental or stratified sampling can be applied. For example, some sites, such as former gas works, have a well-defined process layout of operations and the distribution of contaminants generally relates well to the industrial processes involved and also their particular location on the site. Where little or no information is available on potential contamination sources at a site, such as former landfill sites, then a systematic (grid) pattern of sampling may be more appropriate.

Sampling types may be combined such as a grid pattern with some judgemental sampling at locations where more information is available.

It is recommended that, where possible, control points be identified to act as a reference point in determining the levels of contamination against 'background' concentrations.

It should be emphasised that one of the goals of a SAP is to produce data which is an accurate representation of the *in situ* contamination at a site, therefore a sampling pattern should be applied so as to produce adequate information on the type, location and extent of any contamination.

4.2.2 Number of Samples

In determining the number of samples to be collected, the following should be considered:

- findings of the PSI;
- SAP objectives;
- size of the site, and final subdivided sites (if the site is to be subdivided);
- sampling pattern applied;
- depth of investigations (i.e. metre intervals, lithological changes);
- the number of stages of sampling considered feasible; and
- potential remediation and management options for the site.

4.2.2.1 Hot Spot Detection

When hot spots (areas of contamination/elevated concentration of contaminants) of a specific size need to be detected, the number of sampling points can be determined by the procedures outlined in Appendix B – Number of Sample Locations Required for Hot Spot Detection.

Appendix C – Minimum Sampling Points Required for Site Characterisation Based on Circular Hot Spots Using Systematic Sampling Pattern, should be used as a last resort, and provides the minimum number of samples required for site characterisation based on detection of circular hot spots using a systematic sampling pattern.

Appendix C should only be used where no information on the nature and extent of contamination is available or where broad-scale contamination may be present (e.g. market gardens/landfills). Sample locations should preferably be based on site-specific information in relation to geology/hydrogeology, site operations and layout, contaminant characteristics and migration pathways.

Where the minimum number of samples is collected (in accordance with Appendix C), justification is required as to why more extensive sampling was not undertaken.

The number of samples collected and the choice of sampling locations need to be justified. Where justification is not considered acceptable, the DEP may return the report without assessment.

The number of samples collected should be:
- adequate enough to indicate the lateral and vertical extent of contamination; and
- capable of detecting a 'reasonable' size hot spot in comparison to the size of the site. 'Reasonable' size should be taken to mean the largest area of contamination that could be dealt with if it were not identified during the investigation, but discovered only after development work on the site had started.

Hot spots can sometimes be identified using field monitoring techniques other than direct soil sampling. Soil-vapour analysis (e.g. active: PID for volatile hydrocarbons, and passive: sorbents for contaminants of low volatility) and geophysical techniques (for locating drums containing chemicals, unexploded ordnance, etc.) are two such techniques. Where instruments are used to detect hot spots, all equipment should be calibrated to ensure accuracy of readings. In addition, soil samples will be required to verify the results of the screening instruments.

It is not acceptable that sampling programs contain the minimum number of sampling points to be able to 'comply' with this guideline. Sampling locations should always be chosen based upon knowledge of the site, contaminants and migration pathways. Choice of sampling points should be based upon site knowledge, professional judgement and where applicable, statistical analysis.

Detailed justification of the number and locations of sampling points should be provided in relation to the site layout, areas of potential contamination, contaminant migration characteristics, site geology/hydrogeology, etc.

The sample numbers presented in Appendix C should only be used as a last resort, where little or no information is available upon which to determine sampling locations, or where it is anticipated that broad scale contamination has occurred, such as market gardens, landfills etc.

4.2.3 Sampling Depth

In order to determine the vertical extent of contamination, soil samples should be collected from more than one depth at each sampling location.

Where contamination is identified, the maximum depth (where practicable) to which that contamination extends should be determined.

Where soil contamination extends to the water table, samples of both the soil within the saturated zone and groundwater should be collected (refer to Section 6 for design of groundwater sampling programs) in order to delineate the concentration of contaminants present in both the soil and groundwater. Where soil samples are collected from the saturated zone they should be clearly identified as such in any reports and documentation.

The determination of soil sampling depths should take into consideration:
- findings of the PSI;
- SAP objectives;
- known or potential sources of contamination (e.g. surface spillage or UST(s) and pipelines);
- depth to groundwater;
- nature of aquifers beneath site;
- underlying natural soil/geology (well defined layers or infrastructure trenches/corridors present that would influence contaminant migration);
- presence of fill horizons on-site;
- type and nature of contaminants (mobility, persistence);
- length of time contaminants have been, or may have been, present at a site (which will have a bearing on the lateral and vertical dispersion of contaminants, such as smearing of profiles within a saturated zone, formation of a groundwater contaminant plume, etc.);
- field observations and identification of contaminated soil (staining, odours); and
- human health and ecological risks.

Where groundwater is encountered, drilling should continue to a sufficient depth below the static water level, or to a depth where no impact is suspected based on observation and field headspace screening (where applicable).

It may be necessary to increase the depth interval if the volume of soil recovered is insufficient to undertake the required analysis (often the case where duplicate samples are required). This will be directly dependent on the sampling method utilised.

4.2.4 Field Rankings and Headspace Analysis

Boreholes should be geologically logged by a competent professional (reference can be made to *AS/NZS 4452.1:1997 The Storage and Handling of Toxic Substances* (*AS/NZS 4452:1997*) and *AS 1726-1993 Geotechnical Site Investigations* (*AS 1726*-1993) for the unified classification system for soils), and field classified based on visual and olfactory examination. The soil description should include soil type, consistency, colour, structure, grain size, shape, sorting, particle type and cementation (carbonate soils only), moisture and origin.

Any obvious odours should be recorded, however <u>direct smelling of any samples should be avoided</u>.

Where the contaminants of concern are volatile organic compounds (VOCs), headspace screening may be a useful field-screening tool. Headspace screening should be undertaken using a PID, flame ionisation detector (FID) or other appropriate instrument. Information on the capabilities and limitations of these instruments is presented in *AS 4482.2-1999*. Where possible, all instruments should be calibrated on-site. Calibration documentation should be incorporated into any reports produced.

The ambient air and soil at background locations adjacent to the site should also be screened. All background concentration results should be fully documented and incorporated into any reports produced.

A number of factors affect the relationship between the overall concentration of a given contaminant in the soil and its concentration in the vapour phase. These include soil porosity, soil water content, organic carbon content, soil temperature and weathering of the contaminant. Hence the composition of volatile substances in the vapour phase may not accurately reflect their occurrence in soils. In addition, instruments used to obtain headspace results are not designed or capable of detecting individual volatile contaminants that may be present at a site. <u>Sample analysis results are therefore required to confirm any field observations and field tests</u>.

4.2.5 Sampling from Stockpiles and Clean Fill

Sampling from stockpiled material to be taken to landfill should be conducted according to the *Guidelines for Acceptance of Solid Waste to Landfill* (DEP, 2001), which provide guidance on the number of samples to be collected depending on the volume of material.

Clean fill that is to be imported onto the site should be also sampled in accordance with the *Guidelines for Acceptance of Solid Waste to Landfill* (DEP, 2001). The fill should be assessed against Ecological Investigation Levels (EILs) as per the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) unless it can be demonstrated that the material is from a clean source (e.g. borrow pit, quarry) via a letter/certificate from the source.

4.3 SAMPLING OF SOILS IN VICINITY OF USTS

When investigating a site containing USTs, the soil investigation program should initially concentrate on:

- locations selected on the basis of the infrastructure on the site, such as USTs and associated infrastructure, bowsers and oil/water interceptor traps; and
- areas of known spillage and/or leakage.

If the details of infrastructure on the site are not available it may be necessary to establish a grid of soil investigation locations over the site.

4.3.1 Factors to be Considered for Soil Sampling for the Investigation of USTs

4.3.1.1 Sample Location

Where a UST remains on-site, the following should be considered:

- samples should be collected from as close to the UST as is feasible;
- where secondary containment is present, samples should be collected from the fill material within the secondary containment to provide an indication of any leakage from the UST;
- where contamination is identified within the secondary containment, further sampling outside the secondary containment is required to confirm whether there has been leakage of contaminants from the secondary containment to the natural soils;
- where the UST is surrounded by fill material, the fill may comprise soils which are more susceptible to through-flow than the natural soils, therefore the contamination concentrations within the fill material may be lower than in the surrounding natural soils. It is therefore important to sample both the fill material and the natural soils;
- the proximity of the soil sampling location may be affected by the presence of pipe-work or by a concrete anchor over the top of the UST, especially in areas of shallow groundwater.

Where a UST has been removed, samples should be collected from immediately beneath and immediately surrounding the area where the UST was located.

It should be noted that it is not sufficient to determine the extent of adversely affected soils on the basis of site observations and field measurements. Laboratory analysis of soil samples is required for verification.

All site bore logs and field observations should be provided to the DEP as part of any investigation report.

4.3.2 Soil Sampling for the Investigation of UST Associated Infrastructure

Soil samples to determine whether the infrastructure associated with the UST(s), such as bowsers and pipe-work, have had adverse impacts may initially be limited to sampling from immediately below the potential contaminant source.

If fill material is located beneath the infrastructure it is recommended that the fill material is removed and that a sample is collected from the natural soil profile. Where contamination extends below, then additional investigations are required to determine the maximum depth of contamination.

Typical UST infrastructure and groundwater monitoring bore locations are provided in Appendix D.

4.3.3 Sample Depth for Sites Incorporating USTs

The following should be considered when determining the depth of sampling in the vicinity of USTs:

- samples should be collected from a depth greater than the base of the UST(s) and associated infrastructure to ensure that the condition of the soil below the UST(s) and infrastructure is established.
- if contamination is detected during drilling, the soil investigation bore should be continued to a sufficient depth below the base of the contamination or until groundwater is intersected.
- the sampling depth will vary on the basis of:
  - information on the UST construction and installation obtained during the PSI;
  - vertical distribution of contaminated soils encountered during drilling;
  - depth to groundwater;
  - nature of aquifers beneath the site;
  - underlying natural soil/geology (e.g. well defined layers or infrastructure trenches/corridors that would influence contaminant migration);
  - presence of fill horizons on-site;
  - nature of contaminants (i.e. if dealing with volatile contaminants such as light fraction petroleum hydrocarbons or chlorinated solvents, the vapour transport from depth through a shallow soil zone may pose a health risk);
  - field observations and identification of contaminated soil (e.g. staining and odours); and
  - human health and ecological risks.
- it is recommended that soil sampling be extended to a sufficient depth below the static water level or to a depth where no impact is suspected based on observations and field headspace screening (where appropriate), whichever is deeper, when there are:
  - indications of significant seasonal fluctuations in the depth of the groundwater table;
  - the UST has contained dense non-aqueous phase liquids (DNAPLs) (e.g. solvents);
  - where there is a history of dewatering; and
  - USTs that may have been present at the site and have been removed, but may not have been investigated.
- where soils samples are collected from below the watertable, groundwater samples should also be collected at that location in order to delineate the extent of contamination in the soil and the groundwater, and these samples should be clearly identified as such in any field documentation and reports.

It should be noted that even where no contaminated soils are detected surrounding the UST(s), the possibility for a leak from the UST(s) or the associated infrastructure remains. The presence of preferential pathways beneath a tank or the associated infrastructure means that significant impacts to underlying soil and groundwater aquifers may have occurred even though no adversely affected materials were detected by the soil investigation program. Soil and/or soil gas sampling should therefore be undertaken at other locations around the site such as site boundaries, drainage channels, infrastructure trenches, etc.

TABLE 3. SUMMARY OF MINIMUM SOIL SAMPLING REQUIREMENTS FOR SITES CONTAINING, OR PREVIOUSLY CONTAINING UST(s)

LOCATION	MINIMUM NO. OF SAMPLES FOR LABORATORY ANALYSIS	ACTION
UST (*in situ*) (natural and fill material where relevant)	Two per tank (from separate locations).	Samples should be collected from as close to the tank as is feasible and should extend to a depth below the base of the tank. Where secondary containment is present, samples should be collected from inside the containment. Where contamination is identified within the secondary containment, then samples from the material outside the containment are also required. Where fill material is present around the UST/infrastructure, samples should be collected from both the fill material and the surrounding natural soils.
UST Pit	Five per pit plus three for each additional UST in the same pit.	One sample required from the base and one from each wall of the tank pit (following the removal of backfill material). Samples should extend into natural soils.
Bowsers	One (where natural soils) Two (where fill material and natural soils).	One sample required from any fill material beneath the fuel lines and one sample representative of the surrounding natural soils.
Fuel Lines	One (where natural soils) Two (where fill material and natural soils).	One sample required from any fill material beneath the fuel lines and one sample representative of the surrounding natural soils.
Imported fill	As per stockpile sampling requirements presented in the *Guidelines for Acceptance of Solid Waste to Landfill* (DEP, 2001).	Where fill is imported onto a site it should be 'clean fill' comprising undisturbed, natural materials. Where fill other than clean fill is used, samples of the fill material should be sampled to ensure that the fill material would not result in recontamination of the site and meet EILs.
Stockpiled Material (for disposal to landfill)	As per stockpile sampling requirements presented in the *Guidelines for Acceptance of Solid Waste to Landfill* (DEP, 2001).	Samples should be as representative as possible and should not be collected from the surface of the stockpile (composite samples should not be collected when investigating volatiles or semi-volatiles).

5. SEDIMENT SAMPLING DESIGN

Summary

- **When undertaking sediment sampling, control points should be identified to act as a reference point in determining the levels of contamination against 'background'.**
- **Where contaminated sediments are located along a stream or riverbed, the depth and downstream extent of contamination should be identified.**
- **Where contaminated sediments are located in a marine environment, the number of samples and location of sampling is dependent upon the geographic nature of the site and the proximity of the site to pollution sources.**
- **Following remediation of contaminated sediments, ongoing monitoring may be required to ensure that re-contamination of the sediments is not occurring.**

5.1 INTRODUCTION AND OBJECTIVES

Contaminated sediments are soils, sand, organic matter, or minerals that accumulate on the bottom of a water body and contain toxic or hazardous materials that may adversely affect human health or the environment. Sediments may represent either a source or a sink of dissolved contaminants, influence surface water quality, and/or represent a source of bio-available contaminants to benthic biota (and hence potentially to the aquatic food chain). Contaminated sediments can therefore degrade ecological integrity, and pose a threat to human health when pollutants bio-accumulate in edible aquatic organisms.

Sampling of sediments as part of contaminated site assessment/remediation is required where:

- wetlands/rivers/streams form part of, or are located in the vicinity of, a contaminated site;
- a contaminated site is an aquatic environment such as a harbour, estuary, river bed, etc.;
- sediment is required to be dredged as part of port/harbour construction/expansion works or development in a riverine or marine environment.

The assessment of sediments at a contaminated site should:

- identify where contaminant concentrations are likely to result in adverse impacts on sediment ecological health;
- enable a decision to be made about the potential remobilisation of contaminants into the water column and/or into aquatic food chains; and
- identify and enable protection of uncontaminated sediments.

In addition to the sampling of sediments, pore waters within the sediments are also a source of contamination and should therefore be considered when assessing the contamination status of sediments.

Further detailed information on the assessment of sediment quality is provided in the *Draft Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000). Where sediments are being assessed for dredging and ocean disposal, then reference should be made to the *Interim Ocean Disposal Guidelines* (ANZECC 1998). It is recommended that these documents be referred to where sampling of sediments at a site is required, and that expert advice be sought from competent professionals to ensure that the correct methodologies are employed.

Once analytical results have been received, identification of the severity of contamination should be made via comparison of site-specific investigation and response levels, or against the DEP adopted assessment levels as presented in the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) guideline.

5.2 SEDIMENT SAMPLING LOCATIONS

5.2.1 Pattern Types

When determining a sampling pattern the following should be taken into consideration:

- findings of the PSI;
- objectives of the SAP;
- current and historical usage of the site;
- known and potential contaminants (and their distribution);
- nature of contaminants;
- beneficial uses of the site and adjacent sites;
- potential/proposed site use(s);
- climatological conditions;
  - tidal influence (may inhibit ongoing access to the sampling location); and
  - seasonal variability of temperature, wind direction and wind force (e.g. wave movements may restrict sampling location access, storm conditions may disturb sediments to be sampled);
- hydrographical conditions;
  - mobility of sediments (dynamic zones can result in sediment mobilisation enhancing contaminant release, and sediment deposition and sorting of grain sizes);
  - tidal areas (e.g. variations in water depth, current speeds and directions);
  - rivers (e.g. flow rates, geophysical condition of bed areas i.e. riffles versus pools);
  - standing bodies (e.g. lakes and harbour areas may have negligible current to cause sediment disturbance);
  - sediment conditions (e.g. nature and composition of sediment layer, sorting of sediments, sediment depth);
  - influence of stream mixing; and
  - mixing through the profile from wave action;
- nautical conditions (the influence of marine traffic (e.g. some sample points may need to be avoided due to traffic));
- sampling constraints;
  - physical constraints (e.g. boat size, water depth); and
  - safety of sample collection (e.g. presence of soft mud, quicksand, deep holes, swift currents and dangerous marine life);
- contaminant characteristics;
  - solubility, density, persistence and type of contaminants; and
  - proximity of sampling location to outfalls and sources of contamination;
- ecological considerations;
  - plant growth (e.g. disturbance of plant growth and restrictions on access to plant growth (algae on surface of water body, and riverbank vegetation)); and

  - possible impacts on aquatic organisms (e.g. dispersion of contaminated sediments, disturbance of breeding grounds (timing of site access)); and
- potential risks to human health and the environment.

As with soils, where detailed information is available for the site in terms of physical characteristics, potential contaminants and potential sources of contamination, then judgemental sampling can be used to investigate contamination. Where there is little or no data in relation to the potential contamination of the site, then a systematic (grid) sampling pattern should be adopted. Sampling types may be combined such as a systematic (grid) pattern, with judgemental sampling at locations where more information is available. Refer to Appendix A for further information on various sampling patterns.

It is emphasised that a goal of a SAP is to produce data which <u>is an accurate representation of the *in situ* contamination at a site</u>; therefore a sampling pattern should be applied so as to produce adequate information on the type, location and extent of any contamination.

Where large sites are being assessed, such as bays, harbours and marinas, where little information on contamination is available, it is recommended that:
- the site be divided into sub-areas and then random samples collected from within each block. Sub-area size can be varied to increase sampling density in locations with greatest probability of high contamination levels, and areas can be large if evidence indicates contaminant concentrations are unlikely to vary much across the site; or
- a pilot study should be completed comprising 10-20% of the locations anticipated for the full-scale study. Pilot samples should be analysed for the full range of chemical parameters anticipated to be present.

5.2.2 Sampling Depth

Determination of the depth of sampling should take into consideration:
- findings of the PSI;
- objectives of the SAP;
- site history and possible depth of contamination through deposition;
- sediment geology (natural confining layers, preferential pathways);
- nature of contaminants (mobility, persistence);
- known or assumed maximum depth of contamination;
- field observations and identification of contamination (e.g. stained sediments);
- diffuse or point source contamination sources (diffuse contamination within a harbour, or point source contamination at depth from a pipe discharge);
- potential for mixing down the sediment profile; and
- human health and ecological risks.

5.2.3 Number of Samples

Determination of the number of samples to be collected should take into consideration:

- findings of the PSI;
- SAP objectives;
- size of the area to be sampled;
- sampling pattern applied;
- nature, complexity and distribution of known contaminants;
- sediment lithology and variability;
- potential remediation and management options; and
- small-scale variability in contaminant concentration.

Control points should be set up/identified to act as a reference point in determining the levels of contamination against 'background'.

5.2.3.1 Inland Sediments

As with soil sampling programs, the number of samples is dependent upon the site history, distribution of contaminant sources and migration pathways of contamination. Where contaminated sediments are located along a stream or riverbed, the depth and downstream extent of contamination should be identified. Where water flow may have carried contamination downstream, samples should be collected progressively downstream, at regular intervals, from the contamination source and in areas where sediments are likely to settle (e.g. deep pools) until the extent of contamination is determined.

5.2.3.2 Marine Sediments

Where sampling of marine sediments is being undertaken such as in a harbour, marina, port or estuary, the number of samples will be dependent upon the geography of the sampling location:

- where sediments are located at a site which is relatively uniform (e.g. in the centre of a large, flat-bottomed or gently sloping bay) and the site is distant from pollution sources (e.g. the centre of a large bay), then a minimum number of samples can be collected to adequately characterise the contamination status; whereas
- where sediments are near the shore in a geographically complex embayment, with significant changes in depth, shoreline configuration and many potential pollution point sources (e.g. Cockburn Sound), then a larger number of samples will be required.

Justification as to the number of samples required must be documented and incorporated into any reports. Where justification is not considered acceptable, the DEP may return the report without assessment.

5.2.4 Frequency of Sampling

There is often some form of mobility of sediments, and therefore more than one sampling event may be required to build up a picture of temporal changes in sediment quality. Determination of sampling frequency should take into consideration:

- objectives of the SAP;
- seasonal and diurnal changes in sediments due to tidal influences, etc.;
- sediment geology and stratification; and
- characteristics of particular contaminants (e.g. mobility, partitioning, etc.).

Following remediation of contaminated sediments, ongoing monitoring may be required to ensure that re-contamination of the sediments in the area is not occurring (e.g. through contaminated water flowing over the site, or discharges from unknown or remote contamination sources).

6. GROUNDWATER SAMPLING DESIGN

Summary

- **Assessment of groundwater is required during contaminated site investigations unless it can be demonstrated to the DEP that there is no potential for groundwater to be contaminated.**
- **A minimum of three groundwater monitoring bores should be installed on a site to enable triangulation of water levels and provide an indication of groundwater flow direction beneath the site.**
- **A SAP should include the location, depth, construction, sampling details (methodologies and frequency) and analytical methods for groundwater monitoring at a site.**
- **The construction of groundwater monitoring bores should take into account the nature and characteristics of the contaminants of concern and the local geology.**
- **Accurate monitoring bore installation is required to ensure that contamination is not dispersed through breaching of aquitards into adjacent aquifers.**
- **The use of existing monitoring bores or boreholes should not be considered unless they can be shown to be suitable for the purpose of the sampling program (e.g. bore construction within correct aquifer, adequate construction, suitable sampling points, etc.).**

6.1 INTRODUCTION AND OBJECTIVES

Due to the often shallow and vulnerable nature of groundwater resources in Western Australia, the potential for groundwater impact should be determined for each site. Where groundwater is identified as being present at a site, particularly at shallow depths, it may provide a pathway for migration of contamination both within and across site boundaries.

Groundwater investigations are required at a site unless it can be demonstrated to the satisfaction of the DEP that there is no potential for groundwater at the site to be contaminated.

Groundwater investigations generally comprise the installation of monitoring bores to obtain information on the depth to groundwater beneath the site, determine groundwater flow direction and facilitate the collection of samples which reflect the spatial and temporal variation of the chemical composition of groundwater at the site.

Generally a minimum of three monitoring bores should be installed on a site to enable triangulation of water levels. This provides information on groundwater flow direction beneath the site. Normally, however, it is advisable to define the watertable surface in more detail, as this can be locally complex. It is recommended that specialist hydrogeological advice be sought in the selection of the most appropriate sampling locations. Table 4 provides a summary of the minimum requirements for groundwater sampling.

Grab samples of groundwater collected from the base of test pits or excavations are not acceptable due to the possibility of alteration of the sample by ambient conditions (e.g. temperature, oxygenation, ultraviolet light and presence of dust and particles).

Prior to installing groundwater monitoring bores at a site, any existing bores on, or in the immediate vicinity of, the site should be identified to assist in determining the beneficial use of groundwater in the vicinity of the site (e.g. public supply abstraction wells, domestic irrigation or other monitoring bores). The beneficial use of groundwater and/or bore locations may need to be determined by a door-knock survey of surrounding properties/residences.

The use of existing bores for sampling points should not be considered unless they can be shown to be suitable for the purpose of the sampling program (i.e. that they are constructed so as to intercept the contaminants of concern).

Where UST(s) and associated infrastructure have been installed according to the Australian Institute of Petroleum (AIP) Codes of Practice CP-4-1001 *The Design, Installation and Operation of Underground Petroleum Storage Systems* and Australian Standards, monitoring bores may already have been installed at the site and can be used as an initial indication of contamination.

Enquiries regarding groundwater can be made to the WRC. The WRC maintains a database of groundwater bores throughout the state. However, this information is often limited in coverage and the integrity of the data cannot be guaranteed. The *Perth Groundwater Atlas* (WRC, 1997)[1] provides some indication of the depth and flow direction of the local groundwater aquifer in the Perth area. It is recommended that this publication be used as a guide only, as the information is heavily based on regional groundwater bore data, and is not appropriate, or intended to be used, for site-specific contamination investigations. When determining whether groundwater sampling and analysis is required, the following should be taken into consideration:

- findings of the PSI;
- objectives of the SAP;
- on-site and off-site sources of contamination;
- permeability of the strata on the site;
- known or expected depth to the local groundwater;
- groundwater flow direction and discharge location;
- ambient groundwater chemistry;
- where soil contamination indicates the potential for groundwater contamination;
- quantity of contaminant and its mobility characteristics (persistence, solubility, density, stability, partitioning characteristics);
- soil structures which indicate possible conduits;
- potential receptors (abstraction bores e.g. drinking water supply, domestic irrigation and the aquatic environment - freshwater or marine); and
- whether the site is located within a wetland Environmental Management Area, Underground Water Pollution Control Area (UWPCA), or Public Drinking Water Source Area (PDWSA).

Once analytical results have been received, identification of the severity of contamination should be made via comparison to site-specific investigation and response levels, or against the DEP adopted assessment levels as presented in the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) guideline.

[1] The updated version of the *Perth Groundwater Atlas* (WRC, 1997) and the *Hydrogeological Atlas of Western Australia* is available on the Water and Rivers Commission (WRC) website, www.wrc.wa.gov.au.

6.2 GROUNDWATER SAMPLING PROGRAM

6.2.1 Factors to be Considered

The objectives of a groundwater SAP should generally be to determine:

- the source of contamination (may have been determined by soil sampling program);
- piezometric (water table) contours and local direction(s) of groundwater flow;
- nature and severity of groundwater contamination;
- vertical and lateral extent of contamination;
- potential impacts of groundwater contamination on each of the existing, likely future, and possible uses of groundwater; and
- the discharge location for groundwater.

Determination of groundwater sampling locations should take into consideration:

- findings of the PSI;
- objectives of the SAP;
- depth to groundwater (and seasonal variations in depth);
- characteristics of the aquifer/saturated zone that is being sampled (unconfined or confined aquifer type, vertical and horizontal in-homogeneities, etc.);
- hydraulic gradient;
- direction of groundwater flow (and seasonal variations in flow direction - net flow versus seasonal flow);
- presence of any groundwater bores at, or in the vicinity, of the site (monitoring bores, extraction bores);
- expected contaminant migration pathways;
- potential risks to uncontaminated aquifers and/or surface water resources; and
- risk to human health or the environment (through disturbance of contamination, extraction of contaminated water).

6.3 INSTALLATION OF GROUNDWATER MONITORING BORES

Drilling, construction and development of bores can affect groundwater sample quality through the introduction of physical or chemical effects or unwanted residues.

The key factors that need to be considered for the installation of groundwater monitoring bores are listed below. For further information reference can be made to Water Quality Protection Note *Monitoring Bores (Slotted Casing)* (WRC, 1999).

6.3.1 Selection of Bore Locations

The location of the monitoring bores should be selected so as to:

- be beneath or immediately down-gradient of the most likely source of contamination (UST, fuel lines, bowsers, spill locations, drum storage areas, etc.);
- provide information on the background water quality at the site (up-hydraulic gradient boundary); and

- provide information on the quality of the groundwater leaving the site (down-hydraulic gradient boundary).

Table 4 provides a summary of minimum groundwater sampling requirements.

TABLE 4. SUMMARY OF MINIMUM GROUNDWATER SAMPLING REQUIREMENTS

LOCATION	MINIMUM NUMBER OF BORES	ACTION
Beneath or immediately down-gradient of any contamination sources.	One per contaminant source. Further bores may be required to determine the lateral extent of contamination if identified.	Soil samples should be collected, logged and analysed during the installation of the groundwater monitoring bores. The construction of the bores, particularly the location of the screened interval, is dependent on the hydrogeological properties of the site and the contaminants of concern (DNAPLs/LNAPLs, etc.).
Site Boundary – hydraulically down-gradient.	One per site* Further bores may need to be installed off-site to determine the extent of any contamination migrating off-site.	
Site Boundary – hydraulically up-gradient.	One per site*.	

* A minimum of three groundwater monitoring bores per site is required to enable the local groundwater flow direction to be determined.

6.3.1.1 Investigation of Diffuse Groundwater Contamination

Sampling of diffuse source groundwater contamination should take into account the groundwater flow-field and landuse distribution variability. The impact of regional diffuse sources tends to increase the average concentrations of contaminants within an impacted flow field in comparison to contaminant concentrations up-hydraulic gradient. When investigating diffuse groundwater contamination, the following should be considered:

- in the case of known groundwater contamination, purpose-drilled bores should be completed and screened over different depth intervals of the aquifer depending on the likely migration pathways of the contaminants (e.g. contaminant density and estimated hydrogeological parameters);
- the use of existing sampling points (e.g. abstraction/pumping bores) can provide integrated samples from a large volume of the aquifer. However, where there is low-intensity pollution, this may not be appropriate due to potentially diluting contamination levels, and in these circumstances smaller-capacity bores should be used;
- sampling bores should be located throughout the area of interest. The sites should be chosen to represent the different hydrogeological and landuse conditions, and areas considered to be particularly vulnerable to diffuse pollution; and
- sampling bores should be located up-hydraulic gradient and down-hydraulic gradient of any identified contamination to obtain information on the extent of contamination. A minimum of three bores should be constructed at a site to determine groundwater flow direction.

6.3.1.2 Investigation of Point-Source Groundwater Contamination

When specifying sampling points to monitor point-source pollution (e.g. from a large chemical spill location or leaking tank), it is necessary to consider the location of the point source in relation to both the regional and seasonal groundwater flow direction(s). Where practical, sampling bores should be installed at the following locations:

- directly beneath the pollution source;
- progressively at distances down-hydraulic gradient from the contaminant source, and perpendicular to the groundwater flow direction, at a range of depth intervals based on contaminant density and estimated hydrogeological parameters; and
- up-hydraulic gradient from the source of contamination, so the areal extent of the pollution plume can be identified. These bores may also provide information on the background groundwater quality.

Where groundwater contamination is identified, the extent of contamination should be determined in order to identify:

- if the contamination is migrating off-site and impacting adjacent properties (i.e. bores at site boundary, bores at down-gradient off-site locations);
- if contamination is migrating on-site from up-gradient sources (i.e. bores at up-gradient site boundary); and
- whether contaminants are at concentrations high enough to warrant active remediation.

6.3.2 Drilling

A drilling technique should be chosen which is the least disruptive to the zone to be monitored as it is preferable that the physical conditions of the aquifer are maintained as close to pre-drilling as possible.

Drilling techniques can cause smearing (e.g. rotary auger) and compaction (e.g. cable tool) of borehole walls and may cause transport of geological formation materials and drilling fluids into different zones. This can result in groundwater and contaminant pathway blockage, thereby excluding contamination from the monitored material.

It is essential that hydrogeological conditions be researched prior to drilling to minimise the risk of penetrating aquitards that can result in further vertical dispersion of contaminants.

Where monitoring bores are required to be drilled through a contaminated upper zone into a potentially uncontaminated lower zone, isolation casing must be installed in the contaminated zone, and the aquitards sealed (reinstated) to prevent migration of contamination between zones during drilling. A qualified and experienced driller must complete these works under the direction of a competent professional, using correct construction materials.

A competent professional should log the bores (reference can be made to *AS/NZS 4452.1997* and *AS 1726-1993* for the unified classification system for soils). Geological data collected during drilling and sampling activities should enable the determination of the specific method of groundwater sample collection and completion intervals for the installation of monitoring bores.

6.3.2.1 Drilling Fluids

Drilling fluids are used during the drilling process to remove cuttings from the borehole, to clean and cool the bit, to reduce friction between the drill string and the sides of the borehole, and to hold the borehole open during the drilling operation.

Drilling fluids used include air, water and specific drilling mud formulations or native clay slurries. They can have a range of effects on groundwater quality:

- air may cause oxidation and precipitation of analytes of interest, such as dissolved metals or, if contaminated with lubricants necessary for compressor operation, may introduce hydrocarbons into groundwater;
- air may also cause severe disturbance of hydrochemical profiles in highly permeable formations;
- water may dilute or flush groundwater near the bore, changing the chemistry of the groundwater;
- water may also cause precipitation of minerals, thereby blocking contaminant and groundwater pathways (i.e. pores and fractures);
- mud may enter the formation and seal preferential groundwater pathways, or clay particles within mud may absorb some electrically charged contaminants (e.g. dissolved metals); and
- the use of additives in mud (e.g. surfactants and drilling detergents) to overcome drilling difficulties increases the potential for introduction of physical and chemical changes.

Since these effects are frequently permanent, it is important to record the drilling method, the fluids used and details of bore development before sampling.

6.3.3 Bore Construction

6.3.3.1 Casing and Screening

The construction of groundwater bores is dependent upon the contaminants of concern.

Casing and screen materials should be chemically compatible with the contaminants of concern and the immediate groundwater environment. If incompatible, either leaching or sorption of analytes may result, while desorption of analytes may occur should water quality change. Diffusion of organics may also occur through polymeric casing materials.

In extreme cases, acidic environments may cause corrosion of metal casing while solvents may dissolve PVC casings. This may cause immediate effects on water quality in the bore and the potential for water from different depths to migrate along the borehole.

Casing and screen materials should be washed on-site with an organic based detergent or obtained washed and sealed. If casing joints are inappropriately constructed, they may cause leakage. Solvent-bonded casing joints, which are prone to solvation, should not be used when sampling for organics. Hydrocarbon-based glues should be avoided for the joining of casing as they are likely to affect sampling results. Threaded casing is preferable.

6.3.3.2 Annular Fill and Gravel Pack

The annular space is the space between the borehole walls and casing or screen. The materials used in the annular space include filter pack materials, such as gravels and fine sand and seal materials, such as bentonite, bentonite/cement mixtures and cement. Any of these materials, when inappropriately used or installed, may alter the chemistry of groundwater entering the bore and need to be considered during bore installation. Cement, for example, may cause a change in pH, while bentonite may sorb dissolved metals.

6.3.3.3 *Location of Sampling Point (Screen Depth and Length)*

The location and length of the screened interval in groundwater monitoring bores can be vital. Due to the generally laminar flow of groundwater, contaminated groundwater usually flows in discrete zones. Poorly placed screens may fail to intercept these zones. Long screens in monitoring bores are known to result in dilution of groundwater samples due to mixing with uncontaminated groundwater, resulting in the collection of unrepresentative samples. Ideally, screened intervals should be short and located specifically within the zone of interest. In some investigations, bores may need to be installed at more than one depth in an aquifer to assess the extent of vertical groundwater flow and the distribution of contaminants at depth.

Correct location of the screened interval is especially critical when dealing with aquifers polluted with non-aqueous phase liquids (NAPLs).

6.3.3.4 *Light Non-Aqueous Phase Liquids (LNAPLs)*

LNAPLs have an average density less than water (specific gravity of less than one) and therefore generally float on water (e.g. petrol, diesel and other petroleum products).

Where LNAPLs are present or potentially present, monitoring bores should be constructed with vertical, overlapping, slotted intervals with a continuous screen or with a spiral screen to ensure accurate measurement of phase separated product.

Bores should be constructed to ensure that the watertable on the site is at a depth within the slotted interval of the groundwater monitoring bore (often one metre of screen above the watertable and at least two metres below).

If multiple aquifers exist at the site nested or multi-port monitoring bores may need to be installed to facilitate sampling over several aquifer intervals.

It is desirable that the screen for the detection of LNAPLs is constructed as close to vertically continuous as is possible.

Where a bore has been installed to monitor for LNAPLs, prior to purging, the bore should be monitored for the presence of separate phase product using appropriate equipment, such as an oil/water interface probe.

6.3.3.5 *Dense Non-Aqueous Phase Liquids (DNAPLs)*

DNAPLs have an average density greater than water (specific gravity greater than one) and will generally sink in groundwater. It should be noted that a mixture of compounds might contain DNAPL compounds but behave as an LNAPL if the average density is less than that of water (e.g. a trace of TCE in oil).

The construction of groundwater monitoring bores will be dependent upon the total depth of the aquifer beneath the site and the presence and locations of any impermeable horizons.

Groundwater monitoring bores for the detection of DNAPLs should be constructed such that the screened interval extends over the full depth of the aquifer or is located immediately above any impermeable horizons that are identified. Depending upon the site characteristics it may be beneficial to construct a nest of groundwater monitoring bores with screened intervals at varying depths throughout the aquifer to enable a vertical profile of the DNAPL contaminant concentrations to be developed.

6.3.4 Bore Development

This is the process of removing fines such as sand, silt and clay from the aquifer around the bore screen and breaking down drilling mud on the borehole wall. Development maximises the hydraulic connection between the bore and the formation.

In most formations, the application of development techniques will result in 'virtually particulate-free' water returns from bores. However, development techniques are limited for small-diameter monitoring bores (i.e. 50 millimetres in diameter or less) and in low yielding geological formations. In such conditions, bore development may not result in samples with low turbidity.

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.

All bores used for groundwater monitoring should be developed prior to sampling where grouting has been used in the construction processes, bores should be developed after the grout has had sufficient time to cure and it can be demonstrated that bore field chemistry has stabilised.

6.3.5 Bore Completion

Groundwater monitoring bores should be labelled as such and have a lockable cap to avoid tampering and contamination.

The elevation of the top of well casing and ground level should be surveyed to the Australian Height Datum (AHD) or to a local height datum. All monitoring bores should be accurately surveyed (suggest a one millimetre elevation accuracy between-bore elevation) to allow for presentation of accurate watertable contours. Combining the bore elevation with the depth to groundwater data enables a groundwater contour diagram for the site to be developed and the direction of the local groundwater flow to be determined.

6.3.6 Documentation

Documentation and reporting of bore construction details is vital, and should include date drilled, drilling method used (e.g. mud rotary, direct push, etc.), time started, time completed, drilling company, name of drilling supervisor, construction depth, tagged depth, screen interval, depth to water, details of bore development (method of development, time to develop, yield, etc.). A typical bore construction log is presented in Appendix E.

Although at this stage there is no requirement for the licensing or registering of groundwater monitoring bores with the WRC, the provision of bore logs and groundwater information to the WRC improves the database and consequently the information obtainable from this source.

6.4 GROUNDWATER SAMPLING

Groundwater samples should only be collected from appropriately constructed groundwater monitoring bores. Samples of groundwater collected from test pits, trenches or similar are not acceptable, as they are not considered representative of groundwater at a site.

Sampling of monitoring bores is not discussed in detail in this document, however the following factors should be noted:

- accurate water level measurements are required from all bores to provide an indication of groundwater flow direction beneath the site and any temporal variations in groundwater level or flow direction.
- where a bore has been installed to monitor for LNAPLs, prior to purging, the bore should be monitored for the presence of phase separated product using appropriate equipment, such as an oil/water interface probe.
- if phase separated product is detected in the groundwater monitoring bore, consideration should be given to correcting the groundwater elevation to allow for the difference in density of the product and groundwater.
- all instruments used on a site should be accurately calibrated. Water level probes can stretch over time and should be regularly calibrated. Where a number of instruments are being used on a site (e.g. different water level probes or an oil/water interface probe), then calibration between instruments is required to ensure accuracy and consistency of results.

6.4.1 Groundwater Level Measurement

Groundwater level measurements are required to determine groundwater and contaminant flow directions and rates.

Some important factors to consider when collection of measurement data should include:

- groundwater levels should always be measured and recorded on the same day (date and time) to the Australian height datum before bore disturbance;
- groundwater levels in new bores may take some time to stabilise after installation and development;
- in some environments, irrigation, pumping or tidal influences may cause rapid groundwater level fluctuations;
- in some situations water can accumulate in bores so consideration of groundwater level measurements before and after purging of the bore may be necessary; and
- methods and instruments used to collect and record changes in the level of groundwater can vary depending on the design and need to be considered.

6.4.2 Purging

Purging is the process of removing stagnant water from a bore before sampling, therefore may not be representative of the aquifer conditions. Boreholes should therefore be purged before sampling, by pumping to waste a volume of water equivalent to at least four to six times the internal volume of the borehole itself.

Purging also involves pumping the water out of the bore until *in situ* measurements such as pH, turbidity, electrical conductivity (EC), temperature, etc. are in equilibrium. The purging process for monitoring bores should not introduce air, water or other materials into the aquifer.

Further information can be obtained from *AS/NZS 5667.11:1998 Water Quality – Sampling, Part 11: Guidance on Sampling of Groundwaters* (*AS/NZS 5667.11:1998*).

6.4.3 Frequency of Sampling

Groundwater quality may vary temporally and spatially due to seasonal fluctuations in groundwater level and groundwater flow directions. Groundwater beneath a site may therefore need to be sampled on more than one occasion. Determination of the frequency of groundwater sampling events should take into consideration:

- objectives of the SAP;
- variation in quality of the groundwater under investigation (temporal and spatial);
- nature and type of contaminants (mobility, dispersion, specific gravity); and
- analysis results and/or continuous monitoring results, which indicate that groundwater contaminant concentration(s) exceeds acceptable concentrations or appears to be changing.

6.4.3.1 Disposal of Extracted Waters

Extracted groundwater, resulting from development and purging of bores and sampling activities should be stored on-site in lined drums on an impervious surface until the analysis results are available to determine the most appropriate disposal option. This is of particular importance where separate phase product is present in the groundwater.

Where site contamination is known, or where it is determined that there is a high probability of contamination, it is recommended that the disposal options for any material requiring removal from a site during sampling activities be addressed prior to commencing works so as to:

- minimise health and safety risks to public, site personnel and the environment associated with exposure to any contaminated material;
- determine a strategy/method for characterising the waste;
- determine the packaging requirements for waste material to be disposed so as to reduce the risk of costly and unsafe double handing; and
- minimise time taken to obtain the appropriate approvals for off-site disposal.

Where the concentration of contaminants in the wastewaters is below the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) guideline or DEP approved site-specific criteria, then they may be disposed of on-site at a suitable location following approval from the site operator/owner, any interested party or authority. Disposal should not be to any surface water bodies, stormwater drains or to sewer (unless prior approval has been obtained from the relevant authority).

Where the concentrations of contaminants are such that they are unable to be disposed of at the site, then off-site disposal at an appropriate location, such as a liquid waste disposal facility is required. Such facilities require a licence under the *Environmental Protection Act 1986*. Any waste considered a controlled waste must be appropriately transported in accordance with the *Environmental Protection (Controlled Waste) Regulations 2001*. For further advice about licence and permit requirements, please contact the DEP.

7. REMEDIATION, VALIDATION AND ONGOING MANAGEMENT

Summary

- **The objective of conducting remediation, validation and ongoing management sampling is to assess whether contaminant concentrations in the material remaining on-site pose a risk to human health or the environment and are acceptable for the intended or current landuse.**
- **Validation of soil remediation should be completed by systematic sampling across the walls and base of all excavations.**
- **Practitioners should confirm that the history of any backfill material indicates that it is not contaminated.**
- **Validation of sediment remediation should be completed by systematic sampling of the remediated area. Re-dispersion of sediments to and from the area should be considered when determining sampling locations and sample depth.**
- **Validation of the acceptability of groundwater should be completed by conducting an ongoing monitoring program until consecutive/seasonal results show either a decrease or stability in contaminant concentrations below the relevant assessment levels.**

7.1 INTRODUCTION AND OBJECTIVES

The objective of conducting remediation, validation and ongoing management sampling is to assess whether contaminant concentrations in the materials remaining on-site (i.e. soil/sediment/groundwater, backfill material, *in situ* and *ex situ* remediated material, etc.) pose a risk to human health or the environment and are acceptable for the intended or current landuse.

Where contamination above acceptable levels is identified during a validation program then the following should be completed:

- review of sampling, analytical and QA/QC results to determine if any errors in sampling/analysis have occurred;
- further investigations to determine the extent of the remaining contamination;
- further remediation to ensure that contamination is not present above acceptable levels;
- validation of the further remediation; and/or
- site based ecological and/or human health risk assessment to determine the impacts of the contamination remaining on-site (which should address all exposure pathways).

The use of PID and other similar field/visual/olfactory methods are not acceptable methods of validation.

UNDERGROUND STORAGE TANK (UST) AND INFRASTRUCTURE REMOVAL

It should be noted that where UST(s) have contained petroleum products, the removal, disposal and *in situ* abandonment of those tanks should be undertaken in accordance with the *Guidance Note S321 Removal and Disposal of Underground Petroleum Storage Tanks* (DME, 1999).

The following factors should be considered when removing tanks and infrastructure:

- **All product lines should be flushed and any residual products removed by an appropriate contractor prior to the commencement of works for the removal of the USTs.**
- **The integrity of the pipe-work (especially where connections occur) should be established by an approved person (refer to *Guidance Note S321*) prior to the removal of the UST. Upon removal, the UST should be examined for evidence of corrosion, pitting, splitting (especially at seams) and any evidence of leakage from fittings noted.**
- **Photographic evidence of the condition of the UST, upon removal, should be obtained. It is also beneficial to provide photographic evidence of the condition of the tank pit following removal of the UST.**

A disused UST may be left in the ground only in exceptional circumstances and subject to approval by the DMPR. The following will be considered when application for *in situ* abandonment of USTs is undertaken:

- **The removal of the tank would bring significant risk to the structural integrity of the nearby buildings or structures.**
- **A competent professional can demonstrate to the satisfaction of the DEP that the risks of contamination of the surrounding soil and groundwater are acceptable. The DEP may require the implementation of a monitoring program.**

7.2 VALIDATION SAMPLING PATTERN SELECTION

7.2.1 Remaining *In Situ* Soil

Where contaminated soil is removed from an area, the soil remaining in the excavation should be validated as being acceptable prior to backfilling. A systematic sampling pattern should be used with sampling points spaced evenly across the walls and the bottom of all excavated areas. The grid spacing should correspond to the number of samples required as discussed in Section 4.

Validation samples should be collected:

- from the walls of the excavation pit at depth intervals dependent upon the location of contamination; and
- from the bottom of the excavated pit.

7.2.1.1 Validation of USTs and Associated Infrastructure

Where a UST has been removed, validation of remaining *in situ* soil should take into consideration:

- imported material located in the tank pit surrounding a UST should be sampled. It is preferable that the imported fill be removed, so that the natural soil profile is exposed for validation;
- validation sampling following the removal of a single UST should consist of a minimum of one soil sample from the base of the tank pit and one sample from each wall of the tank pit. Validation samples should also be collected from beneath the locations of each bowser and beneath each fuel feed line;
- to validate a multiple tank pit the number of soil samples should be increased such that a similar sampling density is obtained to that used for the validation of a single tank pit (see Appendix F);
- in most instances it is recommended that samples are representative of the natural soil profile, whether this is the sidewall, base of the tank pit or beneath bowsers or fuel lines;
- if groundwater is evident in the base of the tank pit, the wall soil samples should be collected from within the capillary fringe of the groundwater aquifer to maximise the probability of detecting any contaminated soils (in addition, groundwater monitoring bores should be installed and groundwater samples collected and analysed – collection of grab samples from within test pits, trenches or similar is not acceptable (refer to Section 6)).

Where a UST has been removed, Appendix F provides suggested sampling locations to validate a tank pit following UST removal.

Refer to Section 4 'Soil Sampling Design' for further information.

7.2.2 Remaining *In Situ* Sediment

Validation of sediment remediation should be completed by systematic sampling of the remediated area (i.e. a grid pattern including collection of samples along the perimeter of the remediated area and immediately beyond the remediated area), to check that no dispersion of contaminated sediments has occurred.

The number of samples required will be dependent upon the size of the area remediated, any dispersion of sediment which occurred during remediation activities, any movement of sediment into the remediated area, and the nature of the contaminants.

The depth of sample collection will depend upon the depth of initial contamination, the remediation depth and the presence of any sediment which has moved onto the site following remediation.

In high sediment movement areas, the remediation area may become in-filled with clean sediments, and it is therefore important to select the most appropriate methodology to ensure that sediment from the zone of contamination is collected rather than clean sediments.

Where the source of contamination is unknown, ongoing monitoring should be undertaken to ensure that re-contamination of sediments does not occur (e.g. by contaminated water flowing over the sediments, or by contaminated sediments settling in an area distant from their source).

Refer to Section 5 'Sediment Sampling Design' for further information.

7.2.3 Groundwater

Accurate validation of contaminated groundwater or of the improvement in groundwater quality is difficult due to inherent variability in groundwater quality, and sampling and analysis error. One set of groundwater monitoring results is not enough to confirm validation of a site.

In order to adequately validate groundwater:

- seasonal trends must be identified, and information provided to demonstrate that the groundwater is of acceptable quality the whole year round, as concentrations of contaminants may change due to seasonal variations in groundwater level; and
- all results must show a consistent trend such as a decrease or stabilisation below the relevant assessment levels. A sudden drop in contaminant concentrations is not considered an adequate validation of reduced contamination, as it may be a result of sampling/analysis error as opposed to actual groundwater conditions. In addition there may be "rebounding" towards original contaminant levels following groundwater remediation (e.g. by residual non-aqueous phase liquid (NAPL)), sorbed or otherwise immobilised contaminants being redissolved in groundwater. Although some indication of rebound may be seen following monitoring for a full year, in some cases it may take considerably longer.

Where active remediation is being undertaken, and analytical results show contaminant concentrations are within acceptable limits, then an adequate monitoring trial should be undertaken prior to cessation of remediation activities to ensure that when active remediation ceases, contaminant concentrations do not return to above acceptable limits when the groundwater returns to equilibrium. Also a period of monitoring after active remediation ceases to confirm successful remediation.

Refer to Section 6 'Groundwater Sampling Design' for further information.

7.2.3.1 Monitored Natural Attenuation (MNA)

Natural attenuation is often presented as a remedial method for groundwater. Although it is recognised that natural attenuation is an effective, inexpensive clean-up option and in some cases the most appropriate way to remediate a site, it is not the DEP's preferred method of management or remediation of groundwater (more active measures such as sparging or dosing are preferred). As with any remedial option, natural attenuation should be evaluated for its appropriateness based on the risks, the site characteristics, and the potential to achieve remediation at a site. The capacity for the aquifer to attenuate contaminants needs to be demonstrated (e.g. dissolved oxygen measurements, pH, sulphate, nitrate, ferrous iron, contaminant-utilising bacteria, and heterotrophic bacteria).

To be accepted as a viable remedy, natural attenuation needs to be used in the context of a carefully controlled and monitored site clean-up approach, including source removal. Because the rates of natural degradation processes are typically slow, long term monitoring is necessary to demonstrate that contaminant concentrations are decreasing at a rate sufficient to ensure that they will not become a threat to human health or the environment, and that transport through the subsurface is as predicted. Continuation of groundwater monitoring is required until such time as the contaminants of concern have decreased to below the relevant acceptance level.

7.2.4 Backfill Material

Backfill material may be imported from either on-site or off-site sources.). The fill should be assessed against Ecological Investigation Levels (EILs) as per the *Assessment Levels for Soil, Sediment and Water* (DEP, 2001) unless it can be demonstrated that the material is from a clean source (e.g. borrow pit, quarry) via a letter/certificate from the source..

The number of samples required is dependent upon the volume of fill material. Sampling should be completed in accordance with the stockpile sampling guidelines provided in the *Guidelines for Acceptance of Solid Waste to Landfill* (DEP, 2001) and the results assessed against EILs as per *Assessment Levels for Soil, Sediment and Water* (DEP 2001).

Indication of the quality of <u>all</u> backfill material at a site is required. Where fill is sourced from a number of locations documented evidence and/or analysis results for each fill source is required, along with a list of the volumes obtained from each source. Where fill is imported, it generally becomes the surface material of the site, therefore confirmation of its quality is required to ensure minimal risk to human health and the environment.

7.2.5 Remediated Material

Excavated material should be sampled to determine appropriate disposal or remediation options.

The material can be sampled *in situ* using a systematic (grid) sampling pattern to demonstrate that the material excavated/dredged is not likely to pose an unacceptable risk to human health or the environment. Judgemental sampling, based on previous investigation results, can be used to validate areas considered most likely to have remained contaminated.

Where material is stockpiled, the number of samples depends upon the volume of material. As with backfill material, the guidelines provided in the *Guidelines for Acceptance of Solid Waste to Landfill* (DEP, 2001) can be utilised in determining the number of samples required.

8. GLOSSARY

Analyte	Refers to any chemical compound, element or other parameter as a subject for analysis.
ANZECC	Australian and New Zealand Environment and Conservation Council.
Aquifer	Rock or sediment in a geological formation, or group of formations, or part of a formation which is capable of being permeated permanently or intermittently and can thereby transmit water.
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand.
Assessment	Study of a site to determine possible and actual contaminants. May involve a desktop review of the site and may also include the collection and analysis of soil, groundwater or sediment samples.
Assessment Levels	Guideline concentrations of contaminants adopted by the DEP to use as a comparison against which to assess the presence and severity of contamination at a site.
Background Concentrations	Naturally occurring ambient concentrations in the local areas of a site.
Beneficial Use	The use of the environment, or of any portion thereof, which is – (a) conducive to public benefit, public amenity, public safety, public health or aesthetic enjoyment; or (b) identified and declared under Section 35(2) of the Environmental Protection Act 1986 (as amended) to be a beneficial use to be protected under an approved policy.
Bioavailability	Availability of contaminants in a form in which organisms or biota can assimilate contaminants e.g. contaminants being in a dissolved state or capable of being solubilised once ingested.
Bore	A hole drilled into an aquifer for the purpose of monitoring or extracting groundwater. Another common term is ‘well’.
BTEX	Benzene, Toluene, Ethylbenzene, Xylene.

Clean Fill	Material that will have no harmful effects on the environment and which consists of rocks or soil arising from the excavation of undisturbed material. For material not from a "clean excavation", it must be validated to have contaminants below Ecological Investigation Levels.
Competent Professional	Possessing the skills, knowledge, experience, and judgement to perform the assigned tasks or activities satisfactorily.
Composite Sample	The bulking and thorough mixing of equal quantities of soil samples collected from more than one sample location to form a single soil sample for chemical analysis.
Contaminant	A substance which has the potential to present a risk of harm to human health or any environmental value.
Contaminant Rebound	Occurs when residual non-aqueous phase liquid (NAPL), sorbed or otherwise, immobilised contaminants, are re-dissolved into the groundwater.
Contaminated	In relation to land or underground water, means that a substance is present in, on or under that land or in that underground water, at a concentration that presents, or has the potential to present, a risk of harm to human health or any environmental value.
Data Quality Objective (DQO)	Qualitative and quantitative statements which specify the quality of the data required.
Dense Non-Aqueous Phase Liquid (DNAPL)	Non-aqueous substances which have an average density greater than water (specific gravity greater than 1) and therefore generally sink in water.
DEP	Department of Environmental Protection.
Detailed Site Investigation (DSI)	An investigation which confirms and delineates potential or actual contamination through a comprehensive sampling program.
Development (of bores)	The removal of fines (including drilling mud) from the aquifer immediately surrounding the bore and creating a filter zone around the bore that prevents further movement of aquifer particles into the bore.
Diffuse Source	Widespread sources of contamination such as the contents of landfill sites, residential areas or large industrial complexes containing a number of point sources.

DMPR	Department of Mineral and Petroleam Resources
Ecosystem	Unit including a community of organisms, the physical and chemical environment of that community, and all the interactions among those organisms and between the organisms and their environment.
EIL_{soil}	Ecological Investigation Level. EILs for soil is the concentration of a contaminant below which adverse impacts upon site-specific ecological values are unlikely to occur.
Environmental Value	(a) beneficial use; or (b) an ecosystem health condition. Which requires protection from activities which may degrade, impair or destroy it.
FID	Flame Ionisation Detector.
GROUNDWATER (ALSO UNDERGROUND WATER)	All waters occurring below the land surface.
HIL_{soil}	Health Investigation Levels. HILs are utilised to assess contamination where: (a) there is no adverse impact, or little potential for any adverse impact, to the environment, or the environmental value or beneficial use of an environmental receptor; and therefore (b) the adverse impacts arising from contamination at a site are to human health only.
Hydraulic Gradient	The change in the static head (of groundwater) per unit of distance in a given direction.
Hydrogeology	The study of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
Interim Sediment Quality Guidelines-Low (ISQG-Low)	Probable-effects concentrations below which biological effects would rarely occur.
Interim Sediment Quality Guidelines-High (ISQG-High)	Probable-effects concentrations below which biological effects would possibly occur. Concentrations at or above the ISQG-High represent a probable-effects range within which effects would be expected to frequently occur.
Investigation Levels	The concentration of a contaminant above which further investigation, evaluation and possibly remediation will be required.

Landfill	In relation to the legal disposal of contaminated material, landfill means a site used for disposal of solid material by burial in the ground that is licensed as a landfill under the *Environmental Protection Act 1986*.
Light Non-Aqueous Phase Liquid (LNAPL)	Non-aqueous substances which have an average density less than water (specific gravity of less than 1) and therefore generally float on water, e.g. petrol.
NATA	National Association of Testing Authorities.
Natural Attenuation	Reliance on natural processes, including various physical, chemical, or biological processes, that, under favourable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil, sediment or groundwater. These *in situ* processes include biodegradation, dispersion, dilution, sorption, volatilisation, chemical or biological stabilisation, transformation, or destruction of contaminants.
NEPC	National Environment Protection Council.
NEPM	National Environment Protection Measure.
NHMRC	National Health and Medical Research Council.
PID	Photoionisation Detector.
Point Source	Localised source of contamination such as storage tanks, pumps and drums.
Practitioners	Suitably qualified professionals with experience in environmental investigations and management.
Preliminary Site Investigation (PSI)	An investigation consisting of a desktop study, a detailed site inspection and, where appropriate, limited sampling. The preliminary site investigation should be of such scope as to be sufficient to indicate whether contamination is present or likely to be present and to determine whether a detailed site investigation should be conducted. Also to provide information for designing a DSI.
Public Drinking Water Source Area (PDWSA)	An area allocated for the collection/abstraction of water for public drinking water supply.

Receptor	The entity that may be adversely affected by contact with or exposure to a contaminant of concern.
Remediation	Action taken to eliminate, limit, correct, counteract, mitigate or remove any contaminant or the negative effects on the environment or human health of any contaminant.
Residual/Remaining Soil/Groundwater	Soil/groundwater remaining after contaminated soil/groundwater has been removed.
Response Level	Concentration of a contaminant at a specific site based on a site assessment for which some form of response is required, to provide an adequate margin of safety to protect public health and/or the environment.
Risk Assessment	Process of estimating the potential impact of a chemical, biological or physical agent on humans, plants, animals and the ecology.
Sample Pattern	The location of sampling points within a sampling area.
SAP	Sampling and Analysis Program.
Saturated Zone	The zone within an aquifer in which all the pores and rock fractures are filled with water.
Sediment	Loose particles of sand, clay, silt and other substances that settle at the bottom of a body of water. Sediment can derive from the erosion of soil or from the decomposition of plants and animals.
Separate Phase Hydrocarbons (also referred to as Phase-Separated Hydrocarbons)	Differences in the physical and chemical properties of water and Non-Aqueous Phase Liquids (NAPLs) results in a physical interface between the liquids, which prevents the liquids from mixing.
Site	An area of land or underground water.

Underground Storage Tank (UST)	A tank that: a) is currently, or has historically been used for the storage of environmentally hazardous substances such as, but not limited to, petroleum products, acids and alkalis; and b) is fully or partially buried.
Underground Water Pollution Control Area (UWPCA)	An area gazetted under the *Metropolitan Water Supply and Drainage Act 1909* to protect groundwater resources used for public drinking water supply. Within these areas restrictions apply to activities which may pollute the groundwater.
Validation	The process of demonstrating that a site has been remediated successfully. Involves the collection and analysis of samples to demonstrate that contaminant concentrations are below acceptable limits and do not pose a risk to human health or the environment.
Watertable	The surface of an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing groundwater bores into the zone of saturation and measuring the water level in those bores.
Water Reserve	An area gazetted under the *Country Areas Water Supply Act 1947* to protect groundwater resources used for public drinking water supply. Within these areas restrictions apply to activities which may pollute the groundwater.
Well	Refer to Bore.
WRC	Water and Rivers Commission.

9. REFERENCES

9.1 CITED REFERENCES

Australian Institute of Petroleum (AIP) Codes of Practice CP-4-1001 *The Design, Installation and Operation of Underground Petroleum Storage Systems.*

Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) *Draft Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.

Australian and New Zealand Environment and Conservation Council (ANZECC) and National Health and Medial Research Council (NHMRC) (1992) *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites.*

Australian and New Zealand Environment and Conservation Council (ANZECC) (1998) *Interim Ocean Disposal Guidelines.*

Department of Environmental Protection (DEP) (2001) *Potentially Contaminating Activities, Industries and Landuses.*

Department of Environmental Protection (DEP) (2001) *Assessment Levels for Soil, Sediment and Water*.

Department of Environmental Protection (DEP) (2001) *Reporting on Site Assessments.*

Department of Environmental Protection (DEP) (2001) *Guidelines for the Assessment of Solid Waste to Landfill.*

Department of Environmental Protection (DEP) (2001) *Community Consultation*.

Department of Minerals and Energy (DME) (1998) *Guidance Note S308 Rev 3 Tank Installations for the Storage of Flammable and Combustible Liquids*.

Department of Minerals and Energy (DME) (1999) *Guidance Note S321 Removal and Disposal of Underground Petroleum Storage Tanks.*

National Environment Protection Council (NEPC) (1999) *Assessment of Site Contamination – National Environment Protection Measure and Impact Statement.*

National Environment Protection Council (NEPC) (1999) *National Environment Protection (Assessment of Site Contamination) Measure.*

New South Wales Environment Protection Authority (NSWEPA) (1995) *Contaminated Sites. Sampling Design Guidelines*.

Standards Australia:

AS 1726-1993	*Geotechnical Site Investigations*.
AS 2368-1990	*Test Pumping of Water Wells.*
AS 4439.1-1999	*Wastes, Sediments and Contaminated Soils – Preparation of Leachates – Preliminary Assessment*.
AS/NZS 4452:1997	*The Storage and Handling of Toxic Substances*.
AS 4482-1997	*Guide to the Sampling and Investigation of Potentially Contaminated Soil (Parts 1 – 3).*
AS/NZS 5667:1998	*Water Quality – Sampling (Parts 1 – 12).*

Water and Rivers Commission (WRC) (1997) *Perth Groundwater Atlas.*

9.2 OTHER USEFUL REFERENCES

American Public Health Association, American Water Works Association, Water Pollution Control Federation (1989) *Standard Methods for the Examination of Water and Wastewater*, 17th edition.

Aller L, Bennet T.W, Hack G, Petty R.J, Lehr J.H, Nielson D.M & Deme J.E, (1989) *Handbook of Suggested Practices for the Design and Installation of Groundwater Monitoring Wells*.

Assink, J.W and van den Brink, W.M, (1986) *Contaminated Soils, First International TNO Conference on Contaminated Soil 11-15 November 1985*.

Australian and New Zealand Environment and Conservation Council (ANZECC) (1992) *Australian Water Quality Guidelines for Fresh and Marine Waters.*

Australian and New Zealand Environment and Conservation Council (ANZECC) (1998) *Interim Ocean Disposal Guidelines.*

Australia and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2001) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.*

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

Department of Environmental Protection (DEP) (1997) *Contaminated Sites. Public Position Paper. Assessment and Management of Contaminated Land and Groundwater in Western Australia.*

Gilbert, R.O, (1987) *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Rienhold, N.Y.

Heyworth, J, (1991) *Sampling and Statistical Analysis for Assessing Contaminated Sites*. (Reproduced in the *Health Risk Assessment and Management of Contaminated Sites. Proceedings of the First National Workshop*. Adelaide: South Australian Health Commission).

Hirschberg, K-J. R, (1993) *Geological and Hydrogeological Guidelines for Landfill Site Selection*. Geological Survey of Western Australia, Department of Minerals and Energy.

Langley, A, and El Saadi, O, (1991) The Health Risk Assessment and Management of Contaminated Sites, *Proceedings of a National Workshop*, South Australian Health Commission, Adelaide.

Lock, W.H, (1996) *Composite Sampling*. National Environmental Health Monographs. Soil Series No. 3. South Australian Health Commission. (Referenced to in NEPM, 1999).

Netherlands Ministry of Housing, Environment etc. (1994) *Environmental Quality Objectives in the Netherlands – A Review of Environmental Quality Objectives and Their Policy Framework in the Netherlands*. Risk Assessment and Environmental Quality Division, Directorate for Chemicals, External Safety and Radiation Protection, Ministry of Housing, Spatial Planning and the Environment, Netherlands.

NSW Environment Protection Authority (NSWEPA) (1994) *Guidelines for Assessment Service Station Sites*.

NSW Department of Planning (1991) *Contaminated Land – Circular C20*.

NSW Water Resources Council (WRC) (1992) *Draft Groundwater Quality Protection Policy for New South Wales*.

SA Health Commission (1991) (1993) *The Health Risk Assessment and Management of Contaminated Sites*. Proceedings of the First and Second National Workshops on the Health Risk Assessment and Management of Contaminated Sites. South Australian Health Commission, 1991 and 1993 respectively.

Turczynowicz, L, (1991) Approaches to Analyte Selection. (Reproduced in the Health Risk Assessment and Management of Contaminated Sites. *Proceedings of the First National Workshop*. Adelaide: South Australian Health Commission).

US Environmental Protection Agency (USEPA) (1986) *Test Methods for Evaluating Solid Waste – Physical/Chemical Methods SW-846 – 3rd edition* (revised July 1992). Office of Solid Waste and Emergency Response.

US Environmental Protection Agency (USEPA) (1989) *Methods for Evaluating the Attainment of Cleanup Standards (EPA 230/02-89-042)*. Office of Policy, Planning and Evaluation, United States.

US Environmental Protection Agency (USEPA) (1998) *EPA's Contaminated Sediment Management Strategy*. Office of Water EPA-823-R-98-001.

US Environmental Protection Agency (EPA). Website http://www.epa.gov

Van de Plassche, E.J, & G.J.M, Bockting (1993) *Towards Integrated Environmental Quality Objectives for Several Volatile Compounds*. National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, Report No 679101 011, 1993.

Van de Plassche, E.J. & M.D. Polder & J.H. Canton (1993) *Derivation of Maximum Permissible Concentrations for Several Volatile Compounds for Water and Soil.* National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, Report No 679101 008, 1993.

Van Merwyk, A.M, (1999) *Legal and Regulatory Environment Driving the Remediation of Contaminated Land*. Conference Proceedings "Contaminated Site Remediation: Challenges Posed by Urban and Industrial Contaminants", Centre for Groundwater Studies 1999.

Victorian Environment Protection Authority (Vic EPA) (2000) *Groundwater Sampling Guidelines*, Publication 669.

Water and Rivers Commission (WRC) (1999) Draft Guideline - *The Assessment of Subsurface Contamination*.

APPENDIX A

SAMPLING PATTERNS

APPENDIX A. SAMPLING PATTERNS

Judgemental Sampling

Sampling is localised based on knowledge of known or probable distribution, or location of contamination at a site. A high level of confidence in the reliability of information about the site is required and the information needs to reflect the current state of the site.

Stratified Sampling

The site is divided into sub-areas according to one or more of the following:

(i) geological or geographical features;
(ii) spatial distribution of the contamination;
(iii) former usage pattern of the site;
(iv) intended future use of the sub-area; and
(v) any other common factor not listed.

Once divided, each sub-area should be considered as an individual site and different sampling patterns and sampling densities can be applied to each sub-area.

This pattern is the most appropriate approach for investigating large sites with complex contaminant distributions.

Systematic Sampling

Sampling points are regularly spaced using a grid pattern. This method is statistically unbiased, provided the coordinates of the initial sampling point are determined randomly.

Random Sampling

Sampling points are generated using a random number generator (as available on most scientific calculators). This method is statistically unbiased, however sampling points can cluster together, hence it is not the most effective method for evaluating areas of concern. Where this method is used, a surveyed reference point should be established from which all sample points should have a measured bearing and distance. In general, this method has limited use in contaminated site investigations.

Stratified Random Sampling

Involves dividing the site into areas and randomly sampling within each area. This method allows large areas of land to sampled at lower sample densities.

APPENDIX B

NUMBER OF SAMPLE LOCATIONS REQUIRED FOR HOT SPOT DETECTION

APPENDIX B. NUMBER OF SAMPLING LOCATIONS REQUIRED FOR HOT SPOT DETECTION

This Appendix has been modified from *AS 4482.1-1997*.

B1. SCOPE

The method presented here is based on detecting circular hot spots with 95% confidence using a square grid sampling pattern. To detect hot spots of other shapes, at other confidence levels or by using other sampling patterns, the following references should be consulted:

(a) GILBERT, R.O (1987) *Statistical methods for environmental pollution monitoring,* Chapter 10. Van Nostrand Reinhold: New York.

(b) FERGUSON, C.C. (1992) The statistical basis for spatial sampling of contaminated land. *Ground Engineering,* pp 25, 34-38.

(c) NSW EPA, *Contaminated Sites Sampling Design Guidelines,* September 1995.

B2. CALCULATIONS

B2.1 GRID SIZE

The grid size, *G*, should be calculated using Equation B1:

$$\mathbf{G = R / 0.59} \qquad \dots \text{(B1)}$$

where: *G* = grid size of the sampling plan, in metres
R = radius of the smallest hot spot that the sampling intends to detect, in metres
0.59 = factor derived from 95% detection probability, assuming circular hot spots.

B2.2 NUMBER OF SAMPLING POINTS

The number of sampling points *n* should then be calculated from Equation B2:

$$\mathbf{n = A / G^2} \qquad \dots \text{(B2)}$$

where: *A* = area to be sampled, in square metres
G = grid size of the sampling pattern, from Step B2.1, in metres

B3. PROCEDURE

The procedure should be as follows:

(a) Determine the radius of the hot spot, *R*, that needs to be detected.

(b) Calculate the grid size, *G*, from Equation B1.

(c) Determine the number of sampling points required, *n*, from Equation B2.

APPENDIX C

MINIMUM SAMPLING POINTS REQUIRED FOR SITE CHARACTERISATION BASED ON DETECTION OF CIRCULAR HOT SPOTS USING SYSTEMATIC SAMPLING PATTERN

APPENDIX C. MINIMUM SAMPLING POINTS REQUIRED FOR SITE CHARACTERISATION BASED ON DETECTION OF CIRCULAR HOT SPOTS USING SYSTEMATIC GRID SAMPLING PATTERN

This table has been modified from *Contaminated Sites Sampling Design Guidelines* (NSW EPA, 1995)

AREA OF THE SITE AND/OR EXCAVATIONS ha (m^2)	NUMBER OF SAMPLING POINTS RECOMMENDED	EQUIVALENT SAMPLING DENSITY (POINTS/ha)	DIAMETER OF THE HOTSPOT THAT CAN BE DETECTED WITH 95% CONFIDENCE (m)	GRID SIZE (m)
0.05 (500)	5	100.0	11.8	9.5
0.1 (1000)	6	60.0	15.2	12.9
0.2 (2000)	7	35.0	19.9	16.9
0.3 (3000)	9	30.0	21.5	18.2
0.4 (4000)	11	27.5	22.5	19.1
0.5 (5000)	13	26.0	23.1	19.6
0.6 (6000)	15	25.0	23.6	20
0.7 (7000)	17	24.3	23.9	20.3
0.8 (8000)	19	23.8	24.2	20.5
0.9 (9000)	20	22.2	25.0	21.2
1.0 (10 000)	21	21.0	25.7	21.8
1.5 (15 000)	25	16.7	28.9	24.5
2.0 (20 000)	30	15.0	30.5	25.4
2.5 (25 000)	35	14.0	31.5	26.7
3.0 (30 000)	40	13.3	32.4	27.4
3.5 (35 000)	45	12.9	32.9	27.9
4.0 (40 000)	50	12.5	33.4	28.3
4.5 (45 000)	52	11.6	34.6	29.3
5.0 (50 000)	55	11.0	35.6	30.1

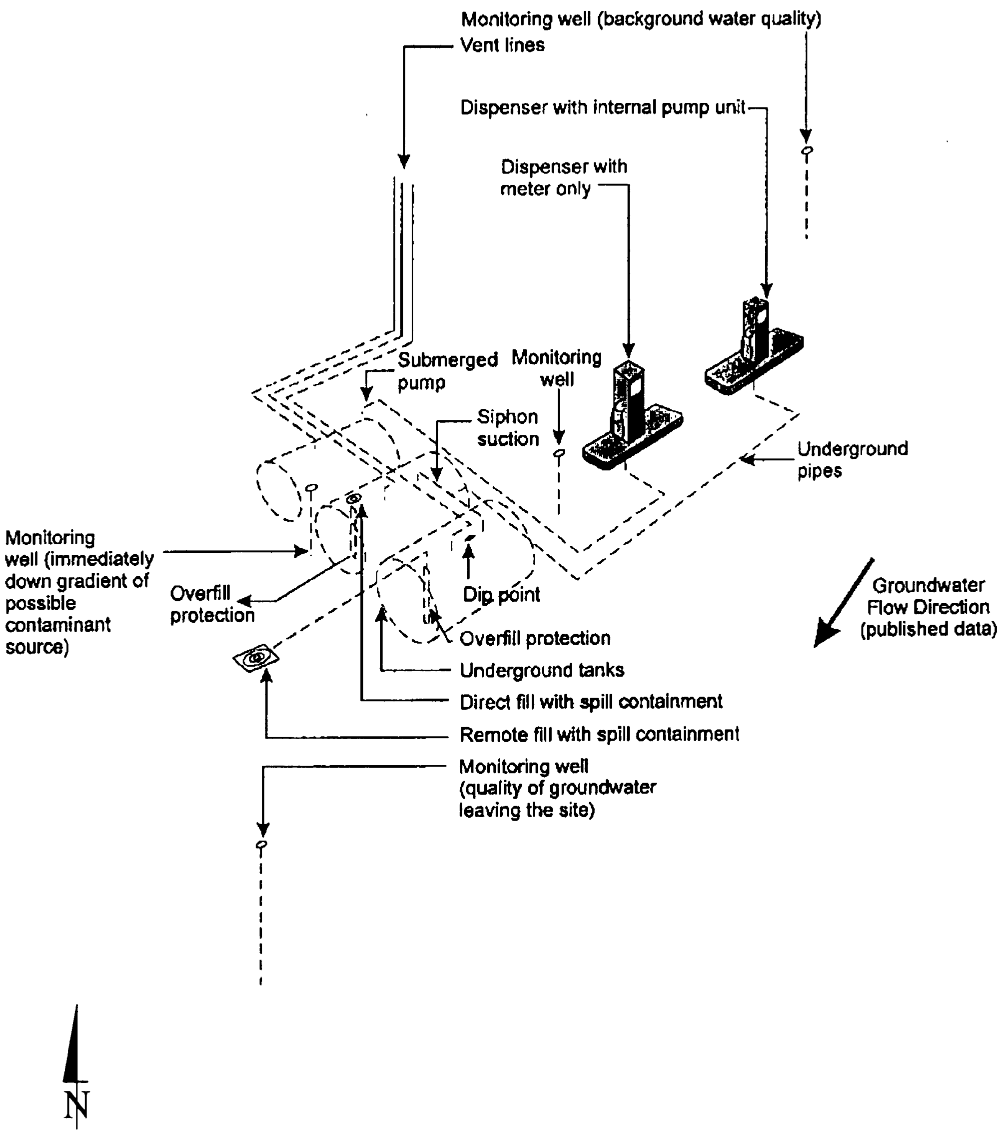
Notes:

1. **The provision in this table of the number of sampling points does not imply that minimum sampling is good practice for a given site. The investigator should be prepared to justify the appropriateness of applying this table or any other sampling rationale.**
2. No guidance is provided for sites larger than five hectares (50 000 m^2). Such sites are usually subdivided into smaller areas for more effective sampling.

APPENDIX D

TYPICAL UNDERGROUND STORAGE TANK (UST) INFRASTRUCTURE AND GROUNDWATER MONITORING BORE LOCATIONS

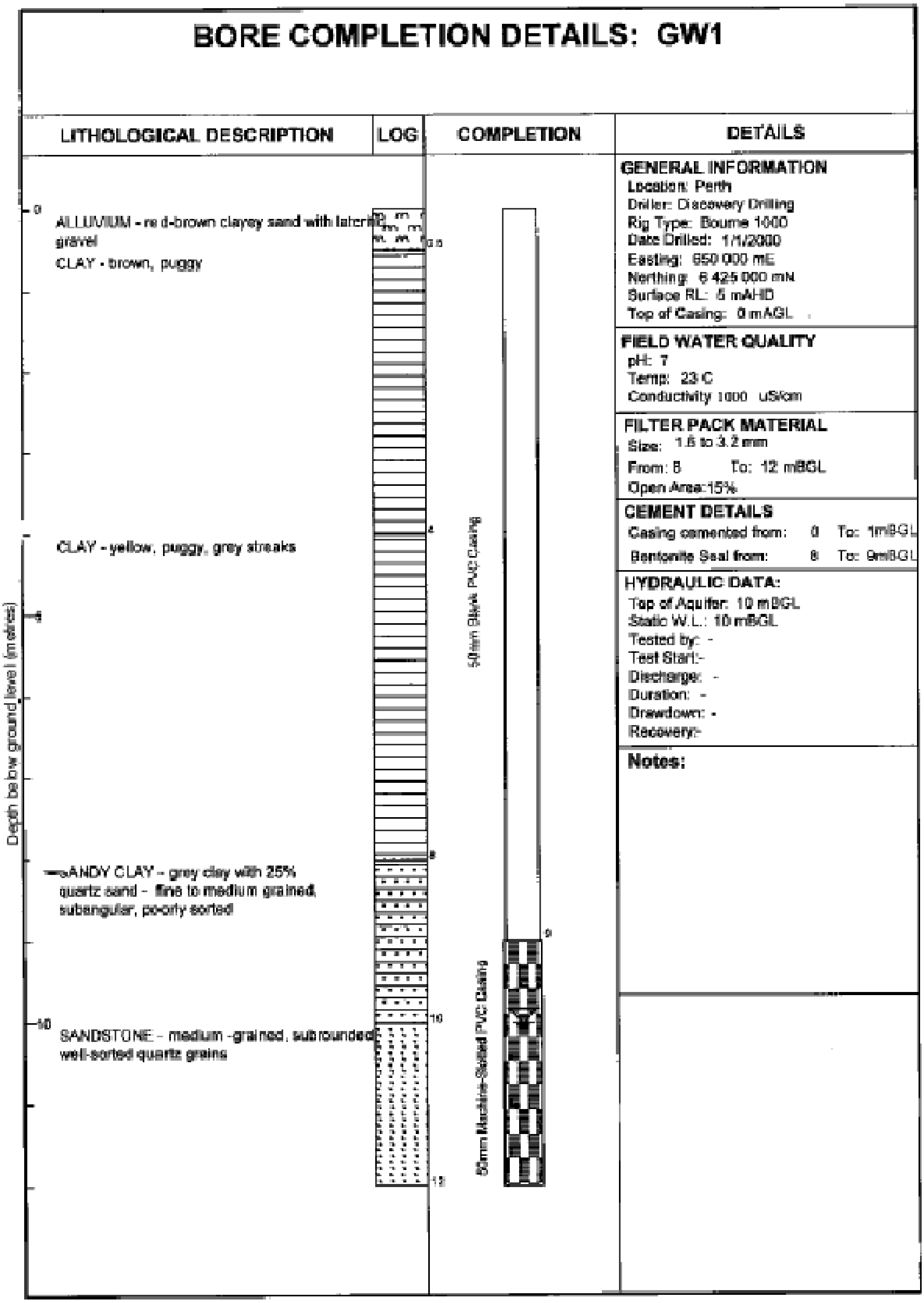
APPENDIX D. TYPICAL UST SITE INFRASTRUCTURE & GROUNDWATER MONITORING BORE LOCATIONS.



APPENDIX E

BORE CONSTRUCTION DETAILS

APPENDIX E. BORE CONSTRUCTION DETAILS



APPENDIX F

TANK PIT VALIDATION: TYPICAL SOIL SAMPLING LOCATIONS

APPENDIX F.

TANK PIT VALIDATION: TYPICAL SOIL SAMPLING LOCATIONS.