

Schedule B (2)
Guideline on Data Collection,
Sample Design and Reporting

NEPC



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



The following guideline provides general guidance in relation to Data Collection, Sample Design and Reporting in the assessment of site contamination.

This Guideline forms part of the National Environment Protection (Assessment of Site Contamination) Measure 1999 and should be read in conjunction with that document, which includes a Policy Framework and Assessment of Site Contamination flowchart.

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CONTENTS

DATA COLLECTION, SAMPLE DESIGN AND REPORTING

| | <i>Page</i> |
|--|-------------|
| 1. INTRODUCTION | 1 |
| 2. STAGES OF INVESTIGATION | 1 |
| 3. BASIC SITE INFORMATION | 2 |
| 3.1 Property Details | 2 |
| 3.2 Current and Proposed Use | 2 |
| 3.3 Data Quality Objectives | 3 |
| 3.4 Site History | 3 |
| 3.4.1 Site plan | 3 |
| 3.4.2 Zoning | 3 |
| 3.4.3 Present owners, occupiers and current users of the site. | 3 |
| 3.4.4 Previous occupiers | 3 |
| 3.4.5 Previous activities/uses | 3 |
| 3.4.6 Previous and present building and structures | 4 |
| 3.4.7 Industrial processes carried out on site and the products manufactured | 4 |
| 3.4.8 Raw materials used | 4 |
| 3.4.9 Intermediate products | 4 |
| 3.4.10 Wastes produced | 4 |
| 3.4.11 Waste disposal locations | 4 |
| 3.4.12 Discharges to land and water | 5 |
| 3.4.13 Product spills, losses, incidents and accidents (including fire) | 5 |
| 3.4.14 Sewer and underground service plans | 5 |
| 3.4.15 Chemical storage and transfer areas | 5 |
| 3.4.16 Motive power | 5 |
| 3.4.17 History of adjacent land uses | 5 |
| 3.4.18 Interview information | 5 |
| 3.4.19 Source information | 5 |
| 3.4.20 Earth moving activities carried out on the site. | 6 |
| 3.5 Sources of information | 6 |
| 3.6 Local Geology and Hydrogeology | 9 |
| 3.6.1 Geology and Hydrogeology | 9 |
| 3.7 Site Inspection | 10 |
| 4. SOIL INVESTIGATIONS | 11 |
| 4.1 Sampling plans | 11 |
| 4.2 Sampling Patterns for Soils | 12 |
| 4.2.1 Site history-based (judgemental) sampling | 12 |
| 4.2.2 Grid (systematic) sampling | 12 |
| 4.2.3 Stratified sampling | 12 |

| | | |
|-----------|---|-----------|
| 4.3 | Sampling Density | 12 |
| 4.4 | Sampling Depth and Bore Logging | 13 |
| 4.5 | Composite sampling | 14 |
| 4.6 | Choice of Analytes | 15 |
| | 4.6.1 General | 15 |
| | 4.6.2 TPH Analyses | 15 |
| 4.7 | Field Testing | 15 |
| 4.8 | Sample handling, storage and transport | 16 |
| | 4.8.1 Sample Integrity | 16 |
| 4.9 | Chain of custody | 17 |
| 4.10 | Quality assurance of data | 17 |
| | 4.10.1 Quality Assurance (QA) | 17 |
| | 4.10.2 Quality Control | 18 |
| | 4.10.3 Blanks | 18 |
| | 4.10.4 Replicate Analysis (Matrix Duplicate) | 18 |
| | 4.10.5 Recovery Check or Reference Material Analysis | 19 |
| | 4.10.6 Surrogate Spikes and Internal Standards | 19 |
| | 4.10.7 Control charts | 20 |
| 5. | GROUNDWATER INVESTIGATIONS | 20 |
| 5.1 | Groundwater Investigation Approaches | 21 |
| | 5.1.1 In Situ and Ex Situ Technologies | 21 |
| | 5.1.2 Scope of Investigation | 21 |
| | 5.1.3 Site-Specific Conditions | 22 |
| | 5.1.4 Analyte-Specific Characteristics | 22 |
| | 5.1.5 Financial/Logistical Constraints | 23 |
| 5.2 | Monitoring Well Establishment | 24 |
| | 5.2.1 Well Construction | 24 |
| | 5.2.2 Groundwater Sampling | 25 |
| | 5.2.3 Monitoring and Profiling Groundwater Parameters | 27 |
| | 5.2.4 Monitoring Groundwater Levels | 27 |
| | 5.2.5 Monitoring Wells and Aquifer Tests | 28 |
| | 5.2.6 Delineating the Plume | 28 |
| 5.3 | Fate and Transport Modelling | 29 |
| | 5.3.1 Limitations of Fate and Transport Modelling | 29 |
| 6. | ASSESSMENT OF SUMMARY STATISTIC DATA AND DATA PRESENTATION AND REPORTING | 31 |
| 6.1 | Assessment of summary statistic data | 32 |
| | 6.1.1 Summary Statistics | 32 |
| | 6.1.2 Censored data | 33 |
| 6.2 | Data Presentation | 33 |
| | 6.2.1 Some Principles of Graphical Representation | 33 |
| | 6.2.2 Contouring | 34 |
| | 6.2.3 Maps | 34 |
| | 6.2.4 Cost of Graphics | 35 |
| | 6.2.5 General Requirements | 35 |
| | 6.2.6 Site Drawings | 36 |
| | 6.2.7 Presentation of Analytical Results and Borelogs | 37 |
| | 6.2.8 Photography | 46 |

| | | |
|-----------|---|-----------|
| 6.2.9 | Access to Electronic Data | 46 |
| 6.2.10 | Integration of Reports | 46 |
| 6.3 | Assessment of Impacts from Specialised Forms of Contamination | 46 |
| 7. | REFERENCES | 47 |
| | APPENDIX 1 POSSIBLE ANALYTES FOR SOIL CONTAMINATION | 51 |
| | APPENDIX 2 (PART A) A RANGE OF VARIOUS GROUNDWATER FATE AND TRANSPORT MODELS | 57 |
| | USEPA Models | 57 |
| | USGS Models | 58 |
| | Department of Environmental Protection, New Jersey | 58 |
| | Centre for Inland Waters, Canada | 58 |
| | Other Models | 58 |
| | APPENDIX 2 (PART B) US REFERENCES FOR GROUNDWATER MODELLING | 60 |
| | APPENDIX 3 DATA PRESENTATION ON SCALE DRAWINGS AND BOREHOLE LOGS..... | 61 |

1. INTRODUCTION

Adequate data collection is the foundation for acceptable assessment of health and environmental risks associated with site contamination. This guideline provides information on the collection of data, design and implementation of soil and groundwater sampling programs, presentation of data and preparation of site assessment reports. It does not provide information on biological sampling for site specific risk assessment, or on assessing unexploded ordnance.

The data collection phase will be comprised of the following components:

- Setting Data Quality Objectives
- Establishing a site history
- Detailing the proposed use
- Reviewing local geology and hydrogeology
- Conducting a detailed site inspection
- Establishing a sampling strategy and sampling pattern for soil and groundwater contamination
- Ensuring appropriate analysis
- Coherent presentation of the data

2. STAGES OF INVESTIGATION

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

The preliminary investigation will involve the components in Section 1 above to the point where analysis is undertaken when the site history indicates that contamination may be present. Investigations are usually confined to areas where potentially contaminating activities have occurred and involve a site history based sampling plan. The preliminary investigation should be sufficient to indicate that contamination is present or likely to be present. Contamination may not be completely delineated at this stage. Standards Australia AS 4482.1-1997 provides more detail on the scope of preliminary investigations. When detailed preliminary investigation shows a history of non-contaminating activities and there is no other evidence or suspicion of contamination, there may be no need for further investigation.

A detailed investigation is required when the results of preliminary investigation are insufficient to enable site management strategies to be devised. Potential or actual contamination will usually require further definition. Potential contamination may have been indicated by the presence of unexpected underground structures (eg. underground fuel or chemical storage tanks), the presence of imported fill (eg. ash, odorous material or various types of refuse), or staining of soil. Actual contamination may have been detected in the form of contaminants which are not

naturally occurring or as elements or compounds which are above background levels or exceed the investigation levels ([Schedule B\(1\)](#)).

The detailed investigation stage should delineate the lateral and vertical extent of contamination and the sampling plan may incorporate both judgemental and grid based sampling patterns.

Depending on the proposed use and the results of initial site history investigations, the assessment of a site may incorporate the preliminary and detailed investigations. In this event, the site investigation must cover all the components which enable an acceptable assessment of risk and not be limited to a grid based sampling program.

Many site investigations proceed in multiple stages due to the complexity of the site and the discovery of unexpected contamination, or as investigation funds become available. Site investigators should obtain and consider all site information available to minimise the number of site visits and costs associated with the mobilisation of field investigation teams.

3. BASIC SITE INFORMATION

The purpose of the site information is to identify potential contaminants and areas of contamination by site history investigations, review of local geology and hydrogeology, and undertake site inspections to confirm site history and identify additional site information that is required. It is essential that the location of the site and the significant features involved in its contamination history be accurately and clearly identified.

3.1 PROPERTY DETAILS

The current lot on plan (real property) descriptions of all affected parcels and the street number and name and suburb are to be provided.

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

3.2 CURRENT AND PROPOSED USE

The following details should be provided:

- current uses of the site
- map and narrative description of proposed use(s)
- type of use - should be classified according to the categories detailed in [Schedule B\(1\)](#).
- density of residential use

- type of users - residents -(adults + children), flora, fauna
- local government approval for proposed use (and date)

(adapted from El Saadi & Langley, 1991, Taylor and Langley 1998)

3.3 DATA QUALITY OBJECTIVES

The amount, nature and quality of the data will be determined by the Data Quality Objectives (DQO) which will be site-specific. DQO must ensure that the data obtained are sufficient to characterise the contamination on a site and enable appropriate assessment of health and environmental risks for the current or proposed use. A summary of the DQO process is provided in Section 5 of *AS 4482.1 - 1997*. More detail is given in *EPA QA/G 4 Guidance for the data quality objectives process*. Washington: US Environment Protection Agency. EPA 600R96055

3.4 SITE HISTORY

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

3.4.1 Site plan

A current plan of the site, with scale bar, indicating the site orientation (including north) and general contours of the property, local water drainage and other environmentally significant features is essential as well as a locality map and a series of aerial photographs (where relevant) with dates.

3.4.2 Zoning

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

3.4.3 Present owners, occupiers and current users of the site.

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

3.4.4 Previous occupiers

These must be listed chronologically, from the first land title record, including any periods during which ownership or tenancy is unknown or uncertain.

3.4.5 Previous activities/uses

A chronological list of industrial or contaminating activities should be compiled including any periods during which the land use is unknown or uncertain. While "small tannery" may be seen as an imprecise description it nonetheless provides

some information of the nature, severity and distribution of any potential contamination. Precise industrial capacities of properties should be cited if available. The chronology should include times when areas of the site were concrete paved in relation to the occurrence of potentially contaminating activities to prevent unnecessary underslab sampling, although the potential for the migration of contamination underneath paving from adjacent sources will need to be taken into account. Consideration should also be given to uses on adjacent sites that could be a source or receptor of contamination.

3.4.6 Previous and present building and structures

These would be best illustrated by a series of annotated site maps showing the locations of permanent, semi-permanent structures, offices, sheds, reaction vessels, storage tanks, etc. These should be presented as a chronological series to show how the site developed.

3.4.7 Industrial processes carried out on site and the products manufactured

A listing of the products from the industries identified in 3.4.5 above.

3.4.8 Raw materials used

A list of raw materials used in industries listed in 3.4.5 above. Chemicals should be identified by common or systematic names if possible, although trade names should also be provided.

3.4.9 Intermediate products

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

3.4.10 Wastes produced

This requires an understanding of the processes being performed in the industries identified in 3.4.5 above. Wastes may be identified specifically (eg. waste degreasing solvents including carbon tetrachloride) or more generally (eg. acid slurry).

3.4.11 Waste disposal locations

Locations of solid waste disposal areas and liquid waste lagoons, settling tanks and sumps should be identified in the maps and figures in 3.4.6 above.

3.4.12 Discharges to land and water

The quantities and types of waste discharged should be identified.

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

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

3.4.14 Sewer and underground service plans

This may assist in identification of preferential contamination migration pathways.

3.4.15 Chemical storage and transfer areas

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

3.4.16 Motive power

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

3.4.17 History of adjacent land uses

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

3.4.18 Interview information

Documentation of interviews with past property or business owners and employees should be provided.

3.4.19 Source information

Logs of all sources from which site history information was sought should be provided so that the completeness of the assessment may be determined.

3.4.20 Earth moving activities carried out on the site.

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

(adapted from Edwards et al 1994, p 5 and EPA NSW, 1997, p6)

3.5 SOURCES OF INFORMATION

Sources of information for compiling a site history include:

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

Recollections and anecdotal records should be cross-checked where possible and the limitations of the data noted. The source from which all site history information was sought, successfully or otherwise, should be described.

Table 3-A

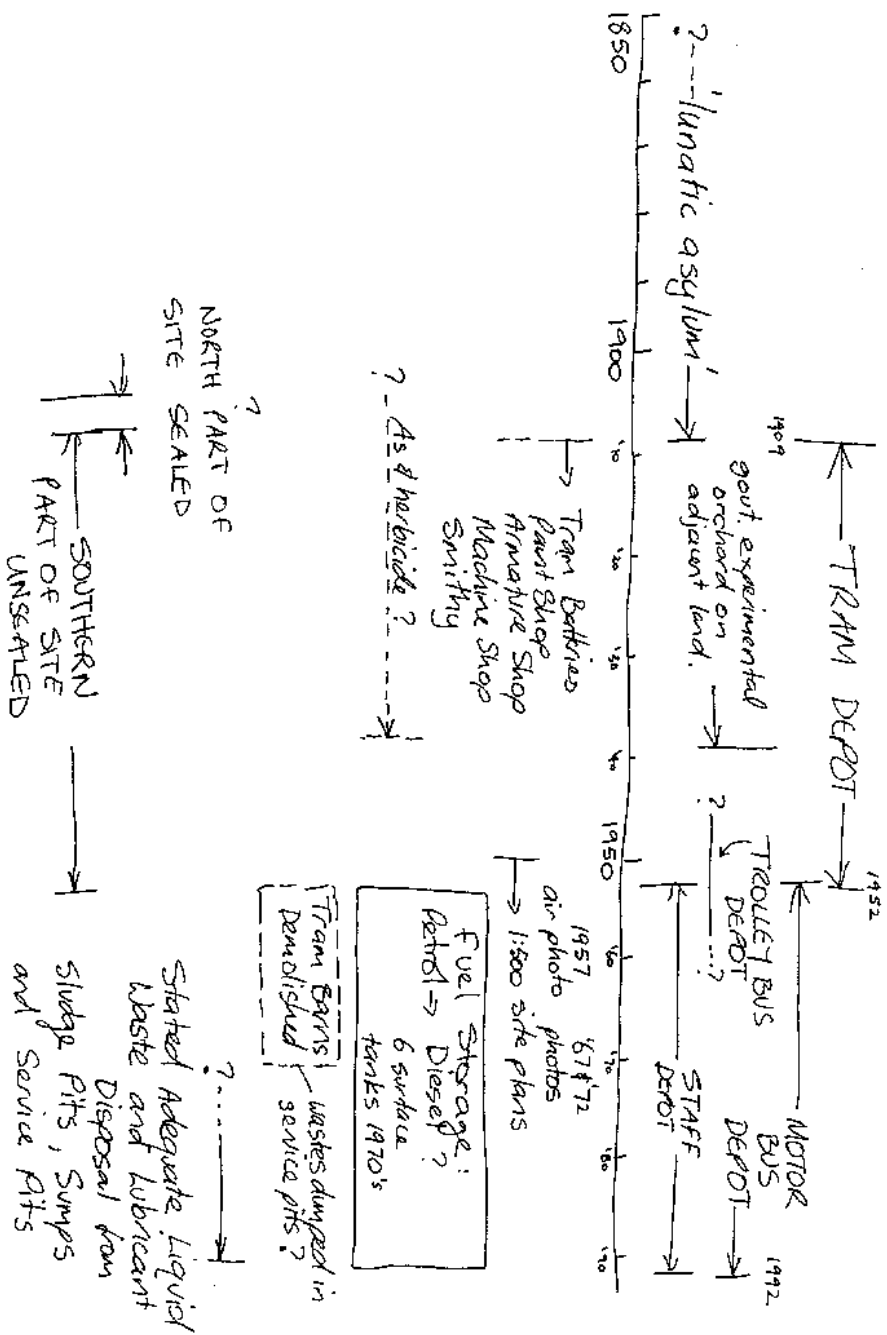
An example of a site chronology table where the gaps in the data and inadequacies of information are readily identified

| Date | Owner | Occupant | Industry or Landuse | Process or Equipment Plant | Chemicals Inputs Byproducts Waste | Buildings Structures and Services | Soil Cover Vegetation Paved Areas | Fill and Excavation | Comments |
|------------------|-------------------------|--------------------------------------|--|---|---------------------------------------|--|--|---------------------|---|
| 1993 (to Mar) | PD Nominees | PD Nominees | Springwater Bottling | Confidential | | | | | |
| 1986 (from Sept) | PD Nominees | PD Nominees | Vinegar Bottling | | Acetic Acid | 20x30 m Warehouse Built Nov 1986 | Site completely covered by a concrete slab | | Soil Logs available from the Warehouse Construction |
| 1979 (11 Jun) | PD Nominees | R McLaren | Motor Vehicle Repair and Car Park | | Oil Solvents Lubricants | No Buildings on Site Unfenced | Half of site covered by 150mm of coarse gravel | Coarse gravel... | Surface oil waste contamination |
| 1979 (10 Jun) | F. Bath | F. Bath | Electrical Workshop | | Solders, capacitors, mercury switches | Workshop destroyed in fire | | | Burning building associated with colourful flames |
| 1978 (5 Nov) | | | | | | | | | |
| 1979 (5 Nov) | R. Bath | | | | | | | | |
| 1972 | | | | | | | | | |
| 1972 | R. Bath | R. Bath and Sons | Process Control and Electrical | Burnt coatings off copper wire for scrap copper | | | | | (some complaints under the Clean Air Act) |
| 1965 | | | | | | | | | |
| 1965 | R. Bath and D Fergusson | R. Bath and D Fergusson | Maintenance Electrical Motor Rewinders | | | Tannery building converted to Workshop (property still fenced) Drying Shed Removed | | Tannery Pits Filled | |
| 1958 (Sept) | | | | | | | | | |
| 1958 (Sept) | D Muldoon | Unoccupied due to closure of Tannery | | | | | | | Cadastral Survey Records Show Ground Level at 0.35 metres lower than in the 1979 survey |

from van Alphen 1993

An example of the representation of site history information on a time line, so as to enable a check of the completeness of available information. This is a translation of 5 pages of site history text in rough draft form.

Figure 3-1



3.6 LOCAL GEOLOGY AND HYDROGEOLOGY

The local and site-specific setting would have an influence on the distribution of potential contaminants (if any) in the vicinity and at the subject site. The setting may be described according to the dominant topographical, geological and hydrological features.

Topography is an expression of the local geology and local hydrological conditions. The hydrological and hydrogeological conditions at a site normally would have a significant affect on the distribution of potential contaminants.

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

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

3.6.1 Geology and Hydrogeology

Information required may include:

- regional and site-specific soil and geological records;
- geophysical data
- drilling logs which clearly identify imported and locally derived fill (including refuse) and natural stratum;
- well logs including strata, casing or construction details and water level, quality and pump/discharge rate information;
- aquifer types (unconfined, semi-confined, confined) and aquitards/aquicludes present;
- direction and rate of groundwater flow;
- values for soil bulk density and porosity;
- storativity or storage;
- soil organic matter content;
- cation exchange capacity;
- soil pH; and redox potential measured in situ;
- regional and site-specific hydrogeologic information, including groundwater quality;
- hydraulic and piezometric heads and hydraulic gradients;

- hydraulic conductivity;
- transmissivity;
- current usage/resource potential;
- existing monitoring wells and records of registered production wells or survey of surrounding landholders to determine the existence of wells where the resource may potentially be used in the vicinity of the site; and
- other parameters as appropriate.

Appendix III of the Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC 1995) gives some helpful advice on hydrogeological desk-top studies.

These data form the basis of an initial appraisal of the potential risk to a receptor. When the likelihood of an unacceptable groundwater impact is identified, [Schedule B\(6\)](#), should be followed.

3.7 SITE INSPECTION

A site inspection should be conducted by a professional, who is suitably qualified and experienced in the assessment of contaminated sites. For further information on suitable qualifications and experience, refer to [Schedule B\(10\)](#).

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

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

- current uses of the site and surrounding uses;
- disturbed coloured or stained soil;
- bare soil patches;
- disturbed or distressed vegetation;
- presence of chemical containers, holding tanks etc.;
- unusual odour;
- quality of surface water;
- site topography and surface water drainage;
- condition of buildings, concrete and bitumen floors and roads etc;
- presence of fill, containment areas, sump, drains and landfill sites - existing and buried
- underground structures that may be associated with sub-surface contamination;
- condition of materials storage and handling facilities and any solid or liquid waste disposal areas; and

- any evidence of off-site migration, on-site spillage of dangerous goods, abnormal colouration of ground or surface waters or sheens on water surfaces.

4. SOIL INVESTIGATIONS

4.1 SAMPLING PLANS

Sampling programs should be designed on the basis of site history and site conditions. Soil contamination is usually heterogeneous and may be present in discontinuous lenses in various fill horizons across a site. Professional experience and judgement should be used to ensure adequate coverage. The sampling plan and decisions regarding the number, type and location of samples need to be developed with an understanding of the potential exposure pathways and routes (EPA (US), 1989). Sampling locations should be referenced to a scaled xy coordinate system and preferably have an elevation referenced to a datum such as AHD.

Resampling of a site with heterogeneous contamination is likely to lead to a different result for the mean values of target analytes. However, if the sampling pattern and density is adequate, the change in values is unlikely to be sufficient to alter the site assessment outcomes.

Sampling will be influenced by, and will influence, site management decisions (Heyworth, 1991). The proposed use for the site will critically affect the nature of the sampling program.

The reasons for sampling include:

- determining the nature of contamination;
- determining the concentration and distribution of contamination both laterally and vertically;
- identifying types and concentrations of contaminants, for assessing potential exposure levels and risks;
- monitoring site conditions to determine if remedial action is required;
- designing and implementing remedial action; and
- determining if clean-up has been achieved.

(Heyworth 1991)

It may be appropriate to use test pits, trenching or remote sensing devices in areas where contamination is suspected and there are insufficient data available from site history investigations. The use of metal detectors, magnetometers and ground penetrating radar should be considered in some instances to locate underground tanks, buried drums, disposal pits, services and other sub-surface structures.

4.2 SAMPLING PATTERNS FOR SOILS

The site investigator must select an appropriate sampling program based on accurate and reliable site specific information as far as practicable. An explanation for the sampling plan should be provided. Specialised professional and jurisdictional advice should be sought in developing sampling plans for rock soil mixtures at waste rock dumps, tailings dams, heap leach pads, and other artificial structures associated with mining site contamination. The following is the preferred order for sampling patterns:

4.2.1 Site history-based (judgemental) sampling

Sampling is localised to known or potentially contaminated areas identified from knowledge of the site. To undertake judgemental sampling there needs to be a high level of confidence in the reliability of information about the site and that the information reflects the current state of the site (ibid). Site-history based sampling may be justifiable for preliminary assessment and for particular features in post-remediation sampling.

4.2.2 Grid (systematic) sampling

This permits the whole of the site to be covered and for sampling points to be more readily identified for further sampling (Heyworth, 1991). Grid Sampling may involve the application of a regular or offset grid or herringbone pattern and the site assessor should select a pattern which is suitable for the site size and topography. Grid sampling is often used to cover the remainder of the site after judgemental sampling has been located, or if there is an inadequate site history.

4.2.3 Stratified sampling

The site is divided and different sampling patterns and densities are used in different sub-areas. It is useful for large and complex sites (Standards Australia 4482.1 - 1997).

4.3 SAMPLING DENSITY

Mathematical formulae for determining sampling density are usually based on the requirements that the results will be normally distributed (ie in a bell-shaped curve) and that a particular concentration is equally likely to occur at any point (eg. Appendix D, AS 4482.1, 1997). There may be a need to be able to estimate, prior to sampling, average results and the standard deviation of results. These requirements can rarely be met during the stages of initial and detailed investigation, as sites are usually heterogeneous with a skewed distribution of results. Tables are available (eg. AS 4482.1, 1997) for determining the size of circular "hot spots" (localised areas of significantly elevated contamination) which may be identified with 95% confidence at given sampling densities but these rely on a normal distribution of results for the site and do not replace site history-based sampling.

Sampling is a screening process and false positive and false negative results will occur. From a health and environmental perspective the aims of sampling are to reduce the likelihood of a false negative that could result ultimately in significant adverse effects, and to enable the identification and adequate remediation of contaminated sites sufficient to protect human health and the environment.

A considerable amount of expert judgement based on site history information is required to determine the density of sampling. The final amount will depend on an integrated appraisal of factors including:

- proposed use(s) and users;
- current use;
- the likely shape(s) of contamination and its distribution;
- the size of contaminated areas to be detected;
- the number of stages of sampling considered feasible;
- the size of the site, and final subdivided sites if the site is to be subdivided;
- the distribution of uses on the site and the disposition of structures;
- the site history;
- potential remediation and management strategies; and
- sampling density may vary across regions of a site based on site history.

If a site is to be subdivided the size of the subdivided sites should be taken into account when planning the sampling density. While predictions may be able to be made on a 'macro' scale, residents or owners may seek information about their particular area of land and the risks associated with a smaller piece of land, especially if the potential contamination on the original site was uneven in magnitude and type. The detection of "hot spots" is an important issue for sites to be used for residential purposes or other sensitive uses where children have regular access to soil or where there is potential groundwater contamination. A greater sampling density is usually required for these sites. The toxicity of the contaminant, and the size and magnitude of the potential "hot spot(s)" need to be considered in determining grid size.

An explanation of, and justification for, the sampling density chosen should be provided.

4.4 SAMPLING DEPTH AND BORE LOGGING

For health and ecological risk assessment, the soil strata to which people and other receptors could feasibly be exposed should be adequately sampled. This will result in a weighting towards near surface sampling unless the history or the nature of the soil (eg. its porosity) and the presence of groundwater suggests it should be otherwise. The depth of sampling will be determined from the site history, the proposed end use, the mobility of the contaminants, the depth of fill and the presence of groundwater on the site. On residential sites, excavations beyond three metres (such as for a swimming pool) are generally unlikely, but much deeper soil disturbance

may occur on a commercial site. Also, if dealing with volatile contaminants such as light fraction petroleum hydrocarbons or chlorinated solvents, then vapour transport from depth and through a shallow soil zone may pose a risk. Deeper sampling to define the nature, longevity etc of the source of the vapours and risk may be required. There may also be other ecological or liability matters which should be assessed by deeper sampling. The risk to groundwater needs to be appraised according to jurisdictional requirements, especially if receptors may be exposed by current or realistic future use of the groundwater resource (refer [Schedule B\(6\)](#)).

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

At the surface, samples at 0-100mm or 0-150mm should be taken unless there is evidence of a thin superficial layer of contamination. At greater depths, sample intervals should be less than 300mm to avoid a compositing effect.

In the sampling process all bore holes, groundwater monitoring wells and test pits should be geologically logged and the presence of all natural stratum, moisture, seeps or water bearing zones, elevation of the water level/hydraulic head, imported fill and odorous materials carefully noted. These logs are essential for interpretation of chemical data to establish the extent of contamination and to assist in the design of more detailed investigations (see Figures 7-III, 7-VI, 7-VIII).

4.5 COMPOSITE SAMPLING

Composite sampling is often incompatible with health risk assessment and is generally unsuitable for the definitive assessment of site contamination due to the inherent uncertainties in the resultant data (Lock, 1996). Composite sampling should not be used for site-specific health and ecological risk assessments but may be acceptable to regulatory authorities for the appraisal of stockpiled material with non volatile contaminants.

For example, a soil stockpile of say 100m³ is suspected of arsenic contamination. The contamination may be adequately characterised for the purpose of determining an acceptable disposal location by composite sampling. Four composite samples may be formed by partitioning the stockpile into quarters and taking 5 individual samples at surface and depth from each quarter. The five samples are thoroughly mixed and subsampled to form the final composite. Clustered sampling (where samples from a stratum are taken within a 1 to 5metre diameter area and combined to represent a sampling point) may be acceptable to regulatory authorities. Clustered samples must be thoroughly mixed to ensure a true average test result is obtained.

4.6 CHOICE OF ANALYTES

4.6.1 General

Analyte choice will be principally governed by the site history. Further information is available in Section 7.2.5 of AS 4482.1 - 1997 and Turczynowicz (1991).

The table, Appendix 1, indicates the range of elements and chemicals for each group of contaminants. Analytes selected within groups of contaminants should be based on site history.

Depending on the available history, potentially contaminated fill may require a more extensive series of analytes. The appearance, odour and texture of the soil samples and cores may influence the choice of analytes.

4.6.2 TPH Analyses

In the screening of sites affected by total petroleum hydrocarbons (TPH) the initial analysis usually includes C₆-C₉, C₁₀-C₁₄, C₁₅-C₂₈, C₂₈-C₃₆, fractions and BTEX (benzene, toluene, ethyl benzene and xylenes). The site investigator should also select a number of samples for PAH (polycyclic aromatic hydrocarbon) analysis. The separated fractions are usually determined by an analytical method which measures combined aliphatic and aromatic constituents as well as other recoverable hydrocarbons eg. vegetable oils.

In the event that a site specific quantitative health risk assessment is required (see [Schedule B\(4\)](#)), consideration should be given to an appropriate analytical methodology which separates aliphatic and aromatic fractions. *n*-Pentane is substituted for methylene chloride for this process and the extract is separated by use of SW-846 EPA Method 3611 and SW-846 EPA Method 3630. This approach will facilitate the application of toxicity and fate and transport data which are representative of the fractions present in collected samples.

Investigation criteria for the aliphatic and aromatic fractions is currently under development.

4.7 FIELD TESTING

A variety of field testing devices may be used as a limited contribution to the screening of samples on contaminated sites. These include photoionisation detectors (PIDs), flame ionisation detectors (FIDs), gas detectors and field portable x-ray fluorescence spectrum analysers (FPXRF) and field gas chromatography (Field GC).

The role in providing real-time data needs to be augmented by chemical analysis of soil. Their use as the sole source of analytical data in the assessment of potentially contaminated sites is inappropriate as they may give falsely high or low results.

Prior to use there should be:

- A determination that they are capable of detecting relevant contaminants;
- Adequate understanding of the methods of use for the particular instrument, its limitations and site conditions that may affect the results;
- Appropriate calibration (and recording of the calibration data) for the substances being measured; and
- An appraisal of site conditions that may affect the results eg. high soil moisture may result in artificially high results for benzene.

PID measurements may be useful as a field guide to indicate areas of volatile compounds and may assist in the selection of samples for laboratory analysis. However, the measurements do not correlate well with laboratory results and therefore cannot be used to substitute for validation sampling.

4.8 SAMPLE HANDLING, STORAGE AND TRANSPORT

Important sample handling and transport references include Section 7.4 of AS 4482.1 - 1997 and Section 5 of [Schedule B\(3\)](#).

4.8.1 Sample Integrity

Integrity of all soil samples must be considered, particularly when dealing with volatile and semi-volatile components. Reference should be made to AS 4481.2-1997 and the appropriate Australian Standard on sampling for volatiles.

Weathering and biodegradation by soil micro-organisms will result in a loss of volatile hydrocarbon components from the surface of affected sites. An example of this situation would be an underground fuel storage site where the tanks have been removed and the excavation has been left exposed for several months. In these circumstances, collecting samples from sub-surface layers (approximately 0.5m below the surface of the excavation) may provide a more accurate representation of contamination for non-operational sites. Surface samples from excavations for volatile hydrocarbons are appropriate when characterising operational sites (particularly those with soils of high clay content) or if taken at the time of excavation.

Samples should be placed in appropriate decontaminated sample containers with gastight, non-absorptive seals, allowing no headspace, and kept on ice until arrival at the laboratory. Arrangements should be made to ensure delivery of chilled samples to the laboratory within the holding time of the specified analysis. Samples must remain preserved and be analysed within the time limitations which apply for the analyte and laboratory method. Additional information on sample integrity and appropriate procedures are available from AS 4482.1-1997.

4.9 CHAIN OF CUSTODY

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

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

(EPA NSW, 1997, p12)

AS 4482.1 - 1997 Appendix H provides a Chain of Custody form.

A copy of the receiving laboratories' advice should be provided which describes the following information:

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

4.10 QUALITY ASSURANCE OF DATA

4.10.1 Quality Assurance (QA)

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

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

In the laboratory, QA involves proper receipt documentation, sample control, data transfer, instrument calibration, selection of properly trained staff and suitable equipment, reagents and analytical methods.

For site assessors, Section 8 of AS 4482.1 - 1997 provides a basis for of quality assurance. As many sites are small with limited sampling, the rate of blind replicates and split samples should be adjusted to a level to ensure sufficient quality assurance.

Laboratories should conform to the quality assurance requirements of Section 4 of [Schedule B\(3\)](#).

4.10.2 Quality Control

Quality Control (QC) involves those parts which serve to monitor and measure the effectiveness of QA procedures by comparison with previously decided objectives. In the field, this may include checking of sampling equipment cleanliness by keeping rinses for analysis, cross-checking of sample identities, duplicate sampling of sites and performance of "field blanks" and "field spikes". In the laboratory, QC procedures involve measurement of the quality of reagents, cleanliness of apparatus, accuracy and precision of methods and instrumentation by regular analysis of "blanks", sample replicates, "spiked recoveries" and standard reference materials (SRMs), with proper recording of results for these checks and immediate investigation of observed problems (Good, 1993, p 44).

According to these definitions, adequate QA is achieved when the results of QC demonstrate that agreed objectives such as freedom from contamination, method accuracy and precision can be reliably achieved. An important decision then is the correct level of QC (ibid, p47).

AS 4482.1 - 1997 recommends use of field duplicate samples sent to two laboratories for QC purposes. This includes blind replicate samples and rinsate blanks collected in the field which are sent to the primary laboratory to determine the precision of the field sampling and laboratory analytical program. Split samples collected in the field should be analysed at a secondary laboratory to determine the accuracy of the analytical programs.

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

4.10.3 Blanks

A reagent blank (or preferably two for very low level analysis) is prepared by processing reagents only in exactly the manner used for each sample. The aim of the blank determination is to establish the magnitude of that component of the analytical signal which can be ascribed to contributions from reagents, glassware, etc.

4.10.4 Replicate Analysis (Matrix Duplicate)

Repeat analysis of at least one sample. The variation between replicate analyses should be recorded for each batch to provide an estimate of the precision of the method.

4.10.5 Recovery Check or Reference Material Analysis

4.10.5.1 Recovery Check (Matrix Spike)

Analysis of one or more replicate portions of samples from the batch, after fortifying the additional portion(s) with known quantities of the analyte(s) of interest. Recovery check portions should be fortified at concentrations which are easily quantified but within the range of concentrations expected for real samples. Spiking must occur before the commencement of any analytical process.

4.10.5.2 Reference Material Analysis

Analysis of a sample similar in matrix type to the samples, with accurately known concentration of the analyte(s) of interest. Results of recovery checks and reference material analyses for each batch should be recorded so that the bias of a method may be estimated, and day-to-day method efficiency may be monitored.

4.10.6 Surrogate Spikes and Internal Standards

Wherever appropriate, especially for chromatographic analysis of organics, the use of surrogate spikes and internal standards should be undertaken. Inclusion into methods requires little additional effort and greatly enhances confidence in qualitative and quantitative results obtained.

4.10.6.1 Surrogate Spikes

Surrogate spikes are known additions, to each sample, blank and recovery/reference sample analysis, of known amounts of compounds which are similar to the analytes of interest in terms of:

- extractability;
- recovery through clean-up procedures; and
- response to chromatographic or other measurement,

but which:

- are not expected to be found in real samples;
- will not interfere with quantification of any analyte of interest; and
- may be separately and independently quantified by virtue of, eg. chromatographic separation or production of different mass ions in a GC/MS system.

Surrogate compounds may be alkylated or halogenated analogues or structural isomers of analytes of interest.

The purpose of surrogate spikes, which are added immediately before the sample extraction step, is to provide a check for every analysis that no gross processing errors have occurred which could have led to significant analyte losses or faulty calculation.

4.10.6.2 Internal Standards

Immediately prior to instrumental analysis, each sample, blank and recovery or reference material extract is fortified with a set amount of one or more compounds which:

- are not found in real samples;
- will not interfere with quantification of analytes of interest; and
- may be separately and independently quantified.

The purpose of internal standards in instrumental techniques is to provide independent signals which serve to check the consistency of the analytical step (eg. injection volumes, instrument sensitivity and retention times for chromatographic systems). Analyte concentrations may be determined by measuring the ratio of the analyte response to that of an internal standard, with marked improvements in quantitative precision.

4.10.7 Control charts

Nadkarni (1991) claims that the heart of a QA/QC program is a control chart. This is a numerical picture (a plot) of the variation of measured QC parameter (eg. blank and recovery values). Data are plotted in the sequence in which they were obtained, and reviewed frequently in order to detect any problem with minimal delay. The use of these charts is highly recommended (Good 1993, p 47).

5. GROUNDWATER INVESTIGATIONS

A risk-based approach to the assessment of groundwater contamination is outlined in [Schedule B\(6\)](#). Section 2.2 of that guideline identifies when groundwater contamination is to be investigated in the overall site assessment. The process involves a staged approach to delineation of contamination using the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992) and the Australian Drinking Water Guidelines (NHMRC/ARMCANZ 1996) as investigation and response levels. It applies fate and transport modelling to predict current positions and future movements of contaminants to assess risk to potential receptors. This section deals with the basic requirements for groundwater investigation including installation of monitoring wells, and sampling of groundwater and presentation of data.

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

5.1 GROUNDWATER INVESTIGATION APPROACHES

5.1.1 In Situ and Ex Situ Technologies

There are several methods by which groundwater data may be gathered. In general each method involves the collection of:

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

The various *in situ* and *ex situ* technologies that are available for sub-surface investigations and groundwater sampling each have a unique set of applications, benefits and limitations. The main issues that determine the selection of appropriate method(s) for any *in situ* or *ex situ* groundwater investigation are:

- the scope of the investigation;
- site-specific conditions;
- analyte-specific characteristics; and/or
- financial/logistical constraints.

Careful consideration, and appropriate weighting of each of these inter-related issues, would determine the most appropriate method(s) of groundwater investigation.

5.1.2 Scope of Investigation

The appropriate scope of the investigation would be determined after consideration of the following information most of which is collected at preliminary investigation stage:

- The site history/land use assessment;
- Known and/or potential groundwater contaminants;
- Site geological and hydrogeological conditions;
- Current and future realistic use(s) of the groundwater resource and nearby surface water resources; and
- Known and/or perceived risks to the environment and/or human health.

5.1.3 Site-Specific Conditions

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

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

Any of these conditions may limit the applicability of certain methods of drilling, bore installation and groundwater sampling, for example, and make other methods more practical and cost effective. In any case the drilling program must not aggravate any groundwater contamination by introducing migration pathways from the surface to groundwater or between different aquifers.

5.1.4 Analyte-Specific Characteristics

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

- Solubility;
- Presence of NAPL;
- Relative density (in the case of NAPLs, LNAPL (light NAPL) less dense than water such as oils, DNAPL (dense NAPL) denser than water – some common solvents; for aqueous liquids, relative salinities are important);
- Stability (chemically and microbiologically);
- Partitioning characteristics (eg. sorption, volatility, Henry's Law constant); and
- Presence of degradation products or electron receptors (eg. nitrates, sulfates, ferrous iron, carbon dioxide, methane).

Each of these characteristics will determine if contaminants:

- are capable of leaching through a soil profile and/or are soluble in the groundwater;
- are more or less dense than the groundwater, such that there is a likelihood for them to be present close to the water table (LNAPLs or where low salinity water infiltrates into more saline groundwater) or more extensively throughout the

- aquifer (eg. with DNAPLs or where saline water infiltrates through fresh groundwater); and
- are relatively unstable and susceptible to effects of vaporisation, reaction with other chemicals/substances in the sub-surface, biodegradation, dispersion or other forms of attenuation.

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

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

5.1.5 Financial/Logistical Constraints

The aim of any groundwater investigation would be determined according to current, intended or realistic future uses of the groundwater resource that is subject to investigation and to regulatory requirements on groundwater contamination which apply in each jurisdiction. In practice it is typical that investigations are scoped to the satisfaction of the appropriate regulatory authority and local communities and/or legitimate interest groups.

However, there will always be situations where the cost of conducting an investigation to the satisfaction of all applicable stakeholders cannot reasonably be covered. Under these circumstances it would be necessary to prioritise certain aspects of the investigation according to the use(s) of the groundwater resource and known risks to human health and/or the environment. It may be feasible and acceptable to conduct a staged investigation as:

- additional funds/resources become available;
- logistical issues are resolved; and/or
- additional information with regard to risks to human health and/or the environment becomes available.

Where there is a risk to the integrity of the aquifer, or any potential to cross-contaminate between aquifers, the appropriate investigation method must be used. An example of this includes situations where a superficial aquifer contains DNAPL or more saline liquids (with specific gravity exceeding the specific gravity of the groundwater) and overlies an uncontaminated aquifer. Any drilling or well construction method that is insensitive to lithological changes has the potential to

cause a vertical conduit for the dense contaminants to migrate directly into the lower aquifer.

Certain groundwater investigation methods may be relatively insensitive to the occurrence of contaminants associated with LNAPLs or aqueous liquids which are less dense than groundwater, and should be designed so that the part, or parts, of the aquifer most likely to be affected are targeted for the investigation. It is often possible that contaminants that are less dense than the groundwater, are located further below the groundwater surface with increasing distance from the source. This is due to the effects of recharge away from the source and investigation methods should be designed/selected to address these situations.

5.2 MONITORING WELL ESTABLISHMENT

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

- Groundwater sampling for *ex situ* analysis;
- Monitoring and/or profiling *in situ* groundwater parameters;
- Monitoring of groundwater level fluctuations; and
- Aquifer testing.

Monitoring wells may also be used to obtain geophysical logs to determine lithological differences, and to validate certain observations that may be recorded on drilling logs.

Depending on the purpose of the monitoring wells they may require specific construction details. These should be determined prior to drilling and, where applicable, they should be based on the relevant standards (see Section 5.2.1).

5.2.1 Well Construction

A decision on the appropriate means of constructing sampling wells involves consideration of a number of factors including the hydrology, geology and geochemistry of the formation, the nature of the contamination, risk and cost and the necessity to maintain the integrity of samples.

There are several standard well construction methods available which apply in different settings. The appropriate method of well construction for a site should always be determined in the field based on observations of geological, hydrogeological and contaminant characteristics. The site investigator is to ensure that the well construction materials are compatible with the target analyte. Well construction methodologies are discussed in detail in many reference documents (Aller *et al*, 1989, Driscoll, 1986) and WRC No.4 and USEPA 1995, EPA/540/530.

An appropriate drilling method is one which adequately allows for the description of the sub-surface geology, provides for suitable mechanisms for sampling and does not contribute material to the aquifer. Drilling methods should be chosen to satisfy the objectives of the investigation; one type of drilling will not be appropriate in all situations. Useful references are *The Manual of Methods, Applications and Management* produced by the Australian Drilling Industry Training Committee Limited 1997 and *Minimum Construction Requirements for Water Bores in Australia* (ARMCANZ, 1997).

Incorrect installation of wells can result in costly contamination of aquifers. It is common for an annulus to be constructed incorrectly so that it acts as a conduit for contamination and for a “bentonite seal” to be constructed using only bentonite pellets set in the vadose zone. If this occurs, the bentonite pellets can set dry and crack, resulting in an ineffective seal between the aquifer and contamination near the ground surface.

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

5.2.2 Groundwater Sampling

The *Murray-Darling Basin Groundwater Quality Sampling Guidelines* are recommended as a useful reference on sampling. They contain information on the following:

- sampling objectives and principles;
- indicator selection;
- location and frequency;
- sampling devices;
- decontamination;
- bore purging;
- field measurements;
- filtration;
- containers, preservation, holding and transport;
- chain of custody records; and
- quality assurance/quality control.

It is essential that groundwater sampling methods result in the collection of samples that are representative of aquifer conditions. Management decisions, that may involve considerable expenditure and potential inconvenience to the public, will be based on these results. In many circumstances, budgeting for additional sampling and analysis costs for site characterisation for definition of groundwater pollution problems could save further assessment expenditure and costly delays to development approaches and property sales. Other published information on the sampling of groundwater wells can be found in Barcelona *et al*, 1985; Barber *et al*,

1987 and 1994; Scalf *et al*, 1992; EPA, 1991 and Weaver, 1992. The general reference for the analysis of groundwater used by accredited laboratories is American Public Health Association (APHA), 19th edition 1995, Standard Methods for the Examination of Water and Wastewater.

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

- Submersible pumps;
- Non-submersible pumps;
- Bladder and inertial pumps;
- Bailers;
- Air compressor equipment; and
- Field filtration devices.

Each of the above types of equipment, and their correct operation, are not described in any detail in this document. For specific information and capabilities of the above equipment it is recommended that operating manuals or specific product information be consulted where applicable. The selection of the appropriate equipment for a groundwater investigation should be based on the following:

5.2.2.1 Target analytes.

Certain analytes are prone to effects of aeration and agitation and, where applicable, sampling equipment should account for minimal agitation and aeration of the sample. Sampling equipment should also have negligible capacity for sorption, precipitation and oxidation of analytes of interest.

5.2.2.2 Contaminant distribution.

Due to a range of chemical and/or physical characteristics, contaminants may be concentrated in certain parts of the aquifer under investigation. The sampling equipment should be capable of targeting the depth interval most likely to contain the target analytes.

5.2.2.3 Cost and logistical issues.

Cost and logistical issues may limit the availability of certain equipment. Where compromises in equipment selection are necessary for these reasons efforts should be made to quantify and minimise the possible inaccuracies associated with the sampling equipment

5.2.2.4 Decontamination requirements.

Depending on the potential for cross-contamination between wells or within the profile of a single well certain equipment may be relatively difficult to decontaminate and it would be necessary to opt for more simple sampling systems or to dedicate sampling equipment to a particular well or interval.

5.2.2.5 Field Filtration.

Depending on the use of the aquifer and the distribution of certain analytes it may be a requirement to use a sample filtration device in the field. Field filtration should be undertaken when there is interest in the concentration of dissolved contaminants and where contaminants may sorb to the aquifer materials. Some field filtration methods have the potential to introduce airborne contaminants, encourage aeration of samples and are normally unable to fully filter a sample, particularly those containing colloidal fractions. Disposable syringes combined with 0.45 µm filters are preferred and ensure that the sample has minimum air exposure. Depending on the nature of the particulate matter present, it may be necessary to use a 0.22µm filter. In very turbid waters a glass fibre filter is placed in series with the membrane filter.

In general, groundwater samples should be filtered (using disposable syringes in filters) unless validated otherwise for that particular site. Sample filtration devices should be decontaminated between use or discarded to prevent cross-contamination and ensure continued effect.

5.2.3 Monitoring and Profiling Groundwater Parameters

Groundwater parameters that may be measured *in situ* include pH, electrical conductivity, redox potential and unusual physical characteristics, eg. depth of floating hydrocarbon layers.

There is a wide range of equipment available for the measurement and logging of these parameters. Information on the correct and accurate operation of the equipment is normally available as manufacturer's instructions. Sampling should not be undertaken until the bore has stabilised (typically 24 hours).

5.2.4 Monitoring Groundwater Levels

The groundwater elevation in a monitoring well is an expression of the hydraulic head of the aquifer(s) in which a well has been slotted. Groundwater elevations may be measured with calibrated pressure transducers and/or measuring tapes.

Where floating hydrocarbon product is present it will affect the groundwater elevation inside a cased well. Corrections for this should be based on the measured thickness and density of the product.

Relative groundwater elevations within the same aquifer indicate the hydraulic gradient between wells and, given at least 3 wells, spaced roughly equilaterally, a groundwater flow direction may be calculated. Water level measurements should be

taken on the same day or at shorter intervals if tidal effects are involved. Saline and hot groundwater conditions also require that measured groundwater elevations are corrected for density effects. Groundwater flows may vary significantly at a site so it is recommended that a groundwater contour map be generated based on several bores to determine groundwater flow directions and variability across a site.

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

5.2.5 Monitoring Wells and Aquifer Tests

In general, aquifer testing involves the determination of a range of hydraulic properties within an aquifer. This is accomplished by stressing the aquifer at a test well, either by the addition or removal of water (or an equivalent volume of water) and measurement of the hydraulic response at observation wells within the test area. Depending on the type of aquifer testing required it is possible that groundwater monitoring wells could be used either as test wells and/or observation wells. However, most aquifer test methods would require specific well construction details. For additional information on aquifer testing it is recommended that AS 2368-1990 (Australian Standard Test Pumping of Water Wells) be referred to.

Results of aquifer tests play an important part in:

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

5.2.6 Delineating the Plume

Monitoring wells should be installed to enable delineation of the plume following selection of appropriate target analytes. However, delineation does not necessarily mean that the outer contour of the plume should be delineated as this is often impractical. Depending on the objectives of the site assessment, delineation can be achieved in different ways. For example, delineation may be suitably obtained at a site if all down gradient results are 'not detectable', even if the upgradient wells show higher concentrations (if you are confident of flow directions, which are often difficult to define locally, or if flow directions don't change seasonally, etc which can and does occur). In this situation it is not possible to determine exactly where the plume ends but what is known is that the plume does not reach the down gradient wells. This type of delineation may not be useful if the purpose of the investigation is to design a remediation system, but it can be used to demonstrate no current impact on receptors below the down gradient wells at the time of assessment. Another example of a different type of delineation is where down gradient wells are at or below the Investigation Level or the Response Level but the full extent of the plume is not known, but it is known that the plume exceeds the relevant criterion. This type

of delineation may be of use if demonstrating whether receptors are at risk due to exceeded criteria, demonstrating natural attenuation or designing remediation systems.

The delineation process also needs to consider variations with time and the need to assess variations as a whole within the monitoring well network not simply at specific points. Vertical variability is also critical (to target remediation). Reliance on too few monitoring points (spatially in 3-D) can lead to inaccurate estimation of pollutant distribution. Assessors should be aware that different contaminants may move at different rates not only as a result of physical processes, but also because of chemical interactions with soil components. Consideration also needs to be given to variations resulting from sampling procedures and laboratory analyses.

5.3 FATE AND TRANSPORT MODELLING

As a relatively simple and cheap alternative to directly investigating all data gaps, it may be beneficial to develop an appropriate numerical model for the site. Modelling is the primary method of receptor identification when groundwater or soil vapour contamination is present. An effective model could be used to predict and graphically display contaminant concentrations throughout the site at any given time and should describe the contaminant distribution in the sub-surface migration pathways, the mass and timeframes for migration and the likely plume conditions in the future. In these circumstances, a model would be acceptable provided:

- the model is operating on an accurate and complete set of physical and chemical input data for the site;
- site-specific spatial and temporal data are used to develop and/or calibrate the model;
- the modelled outputs are subject to routine validation with real data obtained from the site; and
- the model is adaptable to changing site conditions.

When completed the model should be fully documented, including the objectives of the model, the model code used and its limitations, description of the conceptual model including all parameters used and any assumptions made, how the model was constructed and calibrated and information on the accuracy of its predictions. The data output from any model will be a reflection of the quality of the input data.

5.3.1 Limitations of Fate and Transport Modelling

A source of groundwater contamination in the sub-surface does not necessarily mean that downgradient impacts will occur. Often the rate of groundwater movement is very low, and the chemical properties of contaminants may be such that they move through the sub-surface at a slower rate than groundwater. Some chemical contaminants are denser than water and sink to the bottom of the affected aquifer, which causes greater uncertainties when modelling. Their flow direction is influenced more by the topographical characteristics of the base of the aquifer than

by groundwater flow direction. In addition, the movement of volatile components through the unsaturated zone can contaminate soil and groundwater. These factors, coupled with natural processes, mean that an assessment of the likelihood of the contamination reaching a receptor should be made before any remedial action is undertaken.

To address these issues, a number of mathematical fate and transport models have been developed to allow estimation of concentrations in the sub-surface downgradient of contaminant sources. These models are generally conservative in their assumptions and the limitations of these models should be understood before use.

Rigorous scrutiny should be applied to the input parameters to ensure they are consistent with the geology, hydrogeology and geochemistry of the site or region modelled. Modelling all possible natural sub-surface pathway scenarios is impossible. Every contaminated site is unique in this regard, having a set of geological and hydrological conditions that may not be duplicated elsewhere due to the natural variations in geological deposits. In areas where bedrock is exposed at land surface, pathways may consist of solution channels dissolved out of limestone, weathered-out shear zones in granite, porous reef zones in limestone, and permeable geologic faults. In addition, anthropogenic sub-surface pathways should be investigated because these pathways play a major role in both complicating the interpretation of natural sub-surface pathways and providing highly permeable conduits for contaminant transport. Examples of anthropogenic pathways include backfill around foundations, backfill in trenching for buried utilities such as sewer, water, gas and electricity lines, and backfill around buried tanks and associated piping.

In addition, consideration must be given to the fate of the contaminant as it moves along the pathway requiring the need for chemical, physical and biological interactions between sources and the sub-surface materials to be taken into account. Contaminated plumes may be subjected to biodegradation by microbes, volatilization, water washing, and adsorption. These plume attenuation mechanisms are specific to the composition of the contaminant plume, the composition of materials comprising the pathway and the microbial activity along the pathway. Where the model assumes that biodegradation of particular contaminants occurs, care should be taken to ensure that an appropriate biodegradation process is modelled and reaction rate constants are used.

Contaminant properties which may play an important role in the fate and transport of contaminants in the sub-surface include:

- water solubility;
- density;
- chemical reactivity;
- vapour pressure - the extent to which a compound will volatilise;
- melting point - indicates the physical state of a compound at site temperatures;

- viscosity - an indication of the ease with which a contaminant will flow or percolate through the sub-surface;
- Henry's Law constant - the extent to which a compound will volatilise from an aqueous solution; and
- biodegradability potential.

Fate and transport models should be run using data collected during assessment. The data needs for each model are specific to that model. In some instances, the collection of site-specific hydrogeological data may not be possible. In such instances, conservative default values should be used, based on geological records. Special care should be taken to ensure that values for hydraulic conductivity, contaminant load and degradation rates (if applicable) are appropriate, and that conclusions drawn on the basis of fate and transport modelling are supported with monitoring data. It should be recognised that modelling can only give an indication of the likely behaviour of contaminants in groundwater.

When considering the use of models, advice should be sought from persons experienced in hydrogeology and geochemistry and the application of such models. Appendix 2 (Part A) provides some examples of commercially available fate and transport models and a short statement on their applicability. A comprehensive software catalogue of a wide range of models which includes information on the advantages and disadvantages of each type is maintained by the International Groundwater Modelling Centre, Colorado School of Mines (<http://www.mines.edu/igwmc/>).

A number of useful US ASTM guidelines exist for groundwater modelling which are listed in Appendix 2 (Part B)

6. ASSESSMENT OF SUMMARY STATISTIC DATA AND DATA PRESENTATION AND REPORTING

Vast amounts of data can be generated about a single site under investigation. To enable an efficient and accurate appraisal of a site requires that the data be collated in a form, or 'model' that allows an understanding of the location, extent, trends, and likely 'behaviour' of any contamination.

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

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

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

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

This is exemplified by:

- over-elaborate contour maps (some can be useful) based on a very limited number of data points;
- providing fairly definitive conclusions insufficiently underpinned by supporting data; and
- considering the numbers in isolation from other data important to interpretation eg. history and soil characteristics.

6.1 ASSESSMENT OF SUMMARY STATISTIC DATA

(from Langley 1993, pp23-28)

6.1.1 Summary Statistics

No single summary statistic (eg. an arithmetic mean or the median) fully characterises a site. Instead a range of summary statistics is needed to build up a picture of a site.

Each summary statistic will have a contribution, but will also have certain limitations. For example, the mean is affected by each individual score and is particularly sensitive to extreme scores. However it is less sensitive to sampling variation than the median or mode ie. it is less affected by repeated series of random samples from the one population. The median is less sensitive than the mean to extreme scores and usually more sensitive to sampling variation (but less so than the mode) (Pagano, 1986). Given that much of our sampling is judgmental rather than random, caution needs to be taken with the use of conventional statistical methods.

For multiple analytes, an impression of the typical levels, location of contaminants within strata, total 'burden', and statistical distribution of results can be presented as in Table 6-A.

The following summary statistics should be provided for each stratum of testing where there is a large enough sample size.

Table 6-A

Summary Statistics for Multiple Analytes and Stratum

| Chemical name | XXX | |
|---|------------|----------|
| Number of samples: | | |
| Range: | | |
| Investigation Level: | | |
| Median: | | |
| Arithmetic mean: | | |
| Arithmetic s.d.: | | |
| Geometric mean: | | |
| Geometric s.d.: | | |
| Frequency Distribution^a | | |
| less than Investigation Level: | n | % |
| ≥ 1 and < 2 times Investigation Level: | | |
| ≥2 and <5 times Investigation Level: | | |
| ≥5 and < 10 times Investigation Level: | | |
| ≥10 times Investigation Level: | | |

a: An arbitrary method is used to categorise data.

6.1.2 Censored data

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

6.2 DATA PRESENTATION

6.2.1 Some Principles of Graphical Representation

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

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

Table 6-B

Useful vs unuseful graphics

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

(Langley 1993, adapted from Tufte, 1983)

6.2.2 Contouring

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

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

6.2.3 Maps

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

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

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

6.2.4 Cost of Graphics

Graphic work is usually time consuming and the cost of this may be significant. However, for large and complex sites, some form of graphic representation may be imperative for the assessor and other relevant parties to accurately visualise site. Without such representations inaccurate (and probably costly) decisions will be made.

Figure 7-III and Figure 7-V provide useful examples of graphical representation of site data.

6.2.5 General Requirements

Reports should preferably be printed on A4 size paper, with durable covers and binding which allows for easy opening. Photographs should be presented as original prints or superior quality colour copies that adequately display the points of interest.

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

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

Where the site history is complicated because of numerous past uses and/or occupiers, information may be effectively presented as a table or timeline (see Table 3-A and Figure 3-I). Reports should also include the assessor's opinion and conclusions relating to the environmental condition of the site, as well as recommendations for any further assessment or site work the assessor considers necessary.

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

The following documentation should be included in reports:

- Disposal dockets and receipts issued when contaminated soil and fuel tanks or other structures are removed from the site;
- certificates of clearance for asbestos removal or remediation clearance;
- QA/QC protocols for field and laboratory work; and

- chain of custody documents for all soil, groundwater and surface water samples and laboratory receipt notices.

6.2.6 Site Drawings

6.2.6.1 Displaying Site Features

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

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

In some situations it may be necessary to show previous site layouts as overlays over the current layout and perhaps have another overlay of sample locations or show sample excavation boundaries (see Appendix 3, Figure 7-I).

Drawings showing topographical contours in relation to site features and sample locations would assist with the assessment of undulating sites.

6.2.6.2 Displaying Contaminant Concentrations

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

The following techniques should be considered to clearly display results:

- a separate site plan for each elevated analyte, which displays sample locations, sample identification numbers and depths and shows different concentration ranges in different colours;
- a separate site plan (including locations, identification numbers and depths) for each elevated analyte, which displays the actual results for the analyte and then highlights over each result in a colour appropriate to the concentration range in which the result falls;

- a site plan may display all analytes tested at each depth at each location and highlight all results above environmental investigation thresholds in one colour and all results above health investigation thresholds in another colour (same colour regardless of analyte);
- a site plan may display all results at each depth at each location in a specific colour for each analyte;
- concentration contours, for each specific sample depth, may be useful to show plumes from a point source. Care should be taken when using this technique because inferred areas may be misleading if only a small number of sample locations are used; and
- cross-sectional drawings are very useful for depicting concentrations of contaminants through the soil profile or to display complex local geology.

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

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

To assist report assessors to log appraisal of a site, a plain site plan which shows only sample locations, identification numbers and depths should also be provided. Examples of appropriate data presentation on site drawings are shown in Appendix 3 to Figure 7-V.

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

6.2.7 Presentation of Analytical Results and Borelogs

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

Summary tables should show at least the essential details of sample locations and depths against the laboratory results. Results exceeding investigation threshold levels should be highlighted. For ease of reference, the addition of information such as date sampled, date received at laboratory, date analysed, and soil profile data to the summary table would expedite assessments by reducing cross-referencing. Examples are shown in Table 6-D to Table 6-H.

Bore-logs and test pit logs are necessary to provide accurate descriptions of soil types encountered throughout the profile and should clearly distinguish natural soils from fill. Sample locations and perched water and groundwater levels should be shown. If

rubble or rubbish is encountered, the percentages of each type of foreign matter should be estimated. Soil profile information may be presented as an appendix or used to construct cross-sectional drawings of the site. Presentation of the locations of odours, stains and field test measurements on the logs would assist with the site assessment. Bore-logs are also to be used to represent the construction of monitoring wells. Examples of bore, monitoring well and test pit logs are shown in Appendix 3 Figure 7-VI to Figure 7-VIII.

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

Table 6-C

Example report structure for soil analytical results

Locations 7-12: Chemical Screening Results

Loc 7

| Depth (mm) | Pb | As | Cd | Cr | Co | Ni | Zn | Cu | Hg | pH |
|------------|-----|----|----|-----|----|----|-----|-----|-------|-----|
| 0~50 | 200 | 3 | ~ | 100 | 4 | 14 | 210 | 28 | 0.25 | 8.6 |
| 150-300 | 170 | 3 | ~ | 80 | 6 | 15 | 220 | 100 | 0.25 | 8.7 |
| 300-450 | 10 | ~ | ~ | 60 | 8 | 20 | 34 | 20 | <0.05 | 8.6 |

Loc 8

| | | | | | | | | | | |
|---------|----|---|---|-----|----|----|----|-----|------|-----|
| 0~50 | 36 | 2 | ~ | 90 | 18 | 75 | 24 | 8.0 | 0.50 | 8.0 |
| 150-300 | ~ | 2 | ~ | 110 | 12 | 28 | 46 | 28 | 0.05 | 7.6 |

Loc 9

| | | | | | | | | | | |
|---------|-----|---|----|----|----|----|-----|-----|-------|-----|
| 0.15- | 250 | 3 | ~ | 90 | 4 | 15 | 310 | 50 | 0.55 | 8.8 |
| 150-300 | 160 | 2 | ~ | 85 | 5 | 13 | 240 | 60 | 0.40 | 8.4 |
| 750-900 | 4 | ~ | 95 | 11 | 22 | 44 | 26 | 7.6 | <0.05 | 7.6 |

Loc 10

| | | | | | | | | | | |
|---------|----|---|----|----|----|----|----|-----|-------|-----|
| 0~50 | 10 | ~ | -1 | 70 | -1 | 8 | 16 | 1.0 | <0.05 | 8.3 |
| 150-300 | 24 | 5 | 1 | 85 | 5 | 13 | 34 | 1.8 | 0.05 | 8.1 |
| 300-450 | 12 | 3 | 1 | 90 | 7 | 15 | 30 | 1.8 | <0.05 | 8.1 |
| 750-900 | 4 | - | 1 | 50 | 6 | 14 | 22 | 1.5 | <0.05 | 8.4 |

Loc 11

| | | | | | | | | | | |
|---------|------|----|---|-----|---|----|-----|-------|------|-----|
| 0~50 | 290 | 5 | ~ | 80 | 4 | 11 | 540 | 24 | 0.10 | 8.3 |
| 150-300 | 450* | 10 | ~ | 85 | 5 | 15 | 760 | 1750* | 0.70 | 8.1 |
| 300-450 | 90 | 5 | ~ | 110 | 9 | 17 | 30 | 1.9 | 0.05 | 7.8 |
| | 12 | 2 | ~ | 110 | 9 | 17 | 30 | 19 | 0.05 | 7.8 |

Loc 12

| | | | | | | | | | | |
|---------|-------|---|---|-----|----|----|-----|----|------|-----|
| 0~50 | 100 | 3 | 2 | 85 | 6 | 15 | 80 | 28 | 0.25 | 8.4 |
| 150-300 | 940** | 5 | ~ | 130 | 7 | 18 | 190 | 60 | 2.70 | 8.4 |
| 300-450 | 46 | 1 | ~ | 110 | 12 | 24 | 46 | 26 | 0.20 | 7.8 |

| | | | | | | | | | | |
|------|-----|-----|----|-----|-----|-----|------|------|----|----------|
| HIL. | 300 | 100 | 20 | 12% | 100 | 600 | 7000 | 1000 | 15 | <5 or >9 |
|------|-----|-----|----|-----|-----|-----|------|------|----|----------|

HIL = Health-based Investigation Levels

All units are in mg/kg except where shown

~ indicates < Level of Reporting (LOR)

* denotes \geq and $<2 \times$ HIL^b

** denotes ≥ 2 and $<5 \times$ HIL

*** denotes > 5 and $<10 \times$ HIL.

**** denotes $> 10 \times$ HIL

a. Health Investigation Level

b. Arbitrary method of categorising data

(adapted from South Australian Housing Trust/South Australian Health Commission format)

Table 6-D

Stockpile volumes and land farming results

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

Queensland Department of Environment, 1998

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

Table 6-F

Field observations against soil profiles

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

Queensland Department of Environment, 1998

Table 6-G

Frequency distribution are useful for illustrating results (Table 6-F data were used)

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

Queensland Department of Environment, 1998

Table 6-H
Statistical analysis of results for a particular sampling

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

| Sample No | Arsenic | Cadmium | Cobalt | Chromium | Copper | Nickel | Lead | Zinc |
|--------------------|---------|---------|--------|----------|--------|--------|------|-------|
| A51 | 9 | 1 | 79 | 300 | 75 | 103 | 57 | 142 |
| A52 | 8 | 2 | 29 | 188 | 67 | 83 | 312 | 643 |
| A53 | 9 | 2 | 34 | 227 | 34 | 72 | 86 | 164 |
| A54 | 4 | 1 | 57 | 153 | 42 | 204 | 33 | 80 |
| A55 | 7 | 1 | 48 | 259 | 50 | 101 | 204 | 251 |
| A56 | 16 | 4 | 24 | 143 | 169 | 79 | 1310 | 10900 |
| A57 | 8 | 1 | 45 | 207 | 36 | 191 | 30 | 122 |
| A58 | 5 | 1 | 34 | 239 | 1185 | 87 | 21 | 67 |
| A59 | 8 | 2 | 29 | 188 | 1034 | 83 | 312 | 643 |
| A60 | 4 | 1 | 57 | 153 | 442 | 204 | 33 | 80 |
| A61 | 16 | 4 | 24 | 143 | 116 | 79 | 1310 | 10900 |
| A62 | 5 | 1 | 40 | 147 | 47 | 199 | 10 | 100 |
| A63 | 6 | 1 | 28 | 177 | 231 | 106 | 54 | 110 |
| A64 | 2 | 1 | 16 | 107 | 184 | 35 | 79 | 366 |
| A65 | 9 | 1 | 48 | 206 | 395 | 98 | 33 | 166 |
| A66 | 11 | 1 | 26 | 156 | 845 | 54 | 216 | 251 |
| A67 | 6 | 1 | 13 | 287 | 25 | 70 | 46 | 71 |
| Arithmetic Mean | 9 | 1 | 36 | 239 | 314 | 86 | 164 | 675 |
| Standard Deviation | 7 | 1 | 21 | 92 | 346 | 41 | 322 | 1913 |
| Geometric Mean | 8 | 1 | 30 | 210 | 158 | 77 | 70 | 193 |
| Minimum | 2 | 0.5 | 5 | 15 | 16 | 19 | 10 | 19 |
| Maximum | 36 | 5 | 121 | 503 | 1290 | 204 | 1870 | 10900 |
| Median | 8 | 1 | 32 | 250 | 165 | 82 | 58 | 135 |
| 90 Percentile | 14 | 2 | 57 | 322 | 808 | 137 | 312 | 1141 |
| 95 Percentile | 17 | 4 | 72 | 390 | 1140 | 184 | 703 | 1716 |
| N | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 |

Queensland Department of Environment, 1998

6.2.8 Photography

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

6.2.9 Access to Electronic Data

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

6.2.10 Integration of Reports

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

6.3 ASSESSMENT OF IMPACTS FROM SPECIALISED FORMS OF CONTAMINATION

Guidelines for the assessment of contamination in the following areas are beyond the current scope of the Measure:

- c. Unexploded ordnance;
- d. Radioactive substances;
- e. Biologically pathogenic materials and waste; and
- f. Contaminated sediments.

The presence of such special forms of contamination may become apparent during the Data Collection phase.

Section 3.4, [Schedule B\(1\)](#), includes a brief discussion of the use of Investigation Levels for the assessment of contamination of sediments. Responsibility for the assessment and management of site contamination in these specialist areas involves a range of agencies in each jurisdiction.

Where the site history and/or other investigations indicate the potential for contamination in one or more of the specialist areas, the site assessor should contact the contaminated sites unit within the relevant jurisdictional environment agency for further information.

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APPENDIX 1 POSSIBLE ANALYTES FOR SOIL CONTAMINATION

It should be noted that investigation levels are available for only some of these substances. Analytes selected within groups of contaminants should be based on site history.

Inorganic contaminants

| Analysis name | | | | | | | | | | |
|---------------|--|----------|--------|---------|----------|---------------------|---------|---------|-----------|----------|
| Metals | <p>Where a general purpose screen for metal contamination in soils is indicated it may include:</p> <p>Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Mercury, Nickel and Zinc</p> <p>If more detailed investigation is indicated, soil may be examined for:</p> <p>Aluminium Antimony Barium Beryllium Boron Calcium Cobalt Iron Magnesium Molybdenum Potassium Selenium Silver Strontium Thallium Tin Vanadium</p> | | | | | | | | | |
| Anions | <p>Where a general purpose screen for anion contamination in soils is undertaken it may include:</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 33%;">Bromide</td> <td style="width: 33%;">Iodide</td> <td style="width: 33%;">Sulfate</td> </tr> <tr> <td>Chloride</td> <td>Nitrate and Nitrite</td> <td>Sulfide</td> </tr> <tr> <td>Cyanide</td> <td>Phosphate</td> <td>Fluoride</td> </tr> </table> | Bromide | Iodide | Sulfate | Chloride | Nitrate and Nitrite | Sulfide | Cyanide | Phosphate | Fluoride |
| Bromide | Iodide | Sulfate | | | | | | | | |
| Chloride | Nitrate and Nitrite | Sulfide | | | | | | | | |
| Cyanide | Phosphate | Fluoride | | | | | | | | |

Organic contaminants

| Analysis name | |
|---|--|
| Monocyclic Aromatic Hydrocarbons (MAHs) | <p>Where a general purpose screen for MAH contamination in soils is undertaken it may include:</p> <p>Benzene</p> <p>Toluene</p> <p>ortho-Xylene</p> <p>meta- Xylene (para- Xylene)</p> <p>Ethyl benzene</p> <p>Styrene (vinyl benzene)</p> <p>Cumene (isopropylbenzene)</p> <p>Mesitylene (1,3,5 Trimethylbenzene)</p> <p>p-Cymene (1-methyl-4-isopropylbenzene)</p> <p>n-Propylbenzene</p> <p>n-Butylbenzene</p> <p>iso-Butylbenzene</p> <p>tert-Butylbenzene</p> <p>sec-Butylbenzene</p> <p>If more detailed investigation is indicated, soil should be examined for:</p> <p>Chlorobenzene</p> <p>1,2-Dichlorobenzene</p> <p>1,3-Dichlorobenzene</p> <p>1,4-Dichlorobenzene</p> <p>Nitrobenzene</p> <p>Dinitrobenzenes</p> <p>Nitrotoluene</p> <p>Dinitrotoluenes</p> <p>Trinitrotoluenes</p> |
| Polynuclear aromatic hydrocarbons | <p>Where a general purpose screen for PAH contamination in soils is undertaken it may include:</p> <p>Naphthalene Benzo(a) anthracene</p> <p>Acenaphthylene Chrysene</p> <p>Acenaphthene Benzo(b) fluoranthene</p> <p>Fluorene Benzo(k) fluoranthene</p> <p>Phenanthrene Benzo(a) pyrene</p> <p>Anthracene Dibenz (a,h)anthracene</p> <p>Fluoranthene Benzo(ghi) perylene</p> <p>Pyrene Indeno(123-cd) pyrene</p> |

| Analysis name | |
|----------------------|--|
| Phenols | <p>Where a general purpose screen for phenols contamination in soils is undertaken it may include:</p> <ul style="list-style-type: none"> Phenol o-Cresol p-Cresol 2,3-Dimethylphenol 2,4-Dimethylphenol 2,5-Dimethylphenol 2,6-Dimethylphenol 3,4-Dimethylphenol 3,5-Dimethylphenol 2,3,5-Trimethylphenol 2,3,6-Trimethylphenol 2,4,6-Trimethylphenol <p>If more detailed investigation is indicated, soil should be examined for</p> <ul style="list-style-type: none"> 2-Nitrophenol 4-Nitrophenol 2,4-Dinitrophenol |
| Chlorinated phenols | <p>Where a general purpose screen for chlorinated phenols contamination in soils is undertaken it should always include:</p> <ul style="list-style-type: none"> 2-Chlorophenol 3-Chlorophenol 4-Chlorophenol 2,4 -Dichlorophenol 2,6 -Dichlorophenol 2,4,5 -Trichlorophenol 2,4,6 -Trichlorophenol 2,3,4,5-Tetrachlorophenol 2,3,4,6-Tetrachlorophenol 2,3,5,6 -Tetrachlorophenol Pentachlorophenol (PCP) |
| Chlorinated benzenes | <p>Where a general purpose screen for chlorinated benzenes contamination in soils is undertaken it may include:</p> <ul style="list-style-type: none"> Chlorobenzene 1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene 1,2,3-Trichlorobenzene 1,2,4-Trichlorobenzene 1,2,4,5 Tetrachlorobenzene Pentachlorobenzene Hexachlorobenzene |

| Analysis name | |
|-------------------------------------|--|
| Organochlorine (OCs) | <p>Where a general purpose screen for OCs contamination in soils is undertaken it may include:</p> <ul style="list-style-type: none"> Aldrin HCB alpha-HCH, beta-HCH gamma-HCH (lindane), delta-HCH Chlordane DDD, DDE, DDT Dieldrin Endrin Endosulfan (alpha-, beta- and sulfate) Heptachlor, Heptachlor epoxide Methoxychlor <p>Where site history indicates possible PCB contamination, soil should be examined for:</p> <p>PCB (Aroclors 1016, 1221, 1232, 1242, 1248, 1254 and 1260)</p> <ul style="list-style-type: none"> Toxaphene (chlorcam, campheclor) <p>A halogen-selective detector should be used (electron capture or Hall electrolytic conductivity detector) is preferable to Mass spectrometry in SIM mode.</p> |
| Organophosphorus insecticides (OPs) | <p>Where a general purpose screen for OP contamination in soils is undertaken it may include:</p> <ul style="list-style-type: none"> Chlorpyrifos Coumaphos Diazinon Dichlorvos Dimethoate Ethion Fenthion Malathion Parathion methyl Parathion ethyl <p>If more detailed investigation is indicated, soil should be examined for:</p> <ul style="list-style-type: none"> Azinphos methyl Sulprofos Demeton-s-methyl Disulfoton Ethoprophos Mevinphos Monocrotophos Naled Phorate |

| Analysis name | |
|-------------------------|--|
| | <p>Prothiophos Tetrachlorvinphos</p> <p>A Nitrogen/Phosphorus detector (NPD) or Flame Photometric detector (FPD) or GC/MS should be employed for screening purposes.</p> |
| Acid/phenoxy herbicides | <p>Where a general purpose screen for acid herbicides contamination in soils is undertaken it may include:</p> <p>2,4-D 2,4-DB 2,4,5-T 2,4,5-TP (Silvex) Dicamba and 5-Hydroxydicamba MCPA MCPP 4-Nitrophenol</p> <p>If more detailed investigation is indicated, soil should be examined for:</p> <p>Acifluoren Bentazon Dichlorprop Dalapon Picloram</p> |
| Triazine herbicides | <p>Where a general purpose screen for triazine herbicide contamination in soils is undertaken it may include:</p> <p>Atrazine Ametryn Prometryn Simazine Hexazinone</p> |
| Phthalate esters | <p>Where a general purpose screen for phthalate contamination in soils is undertaken it may:</p> <p>Bis (2-ethylhexyl) phthalate Butyl benzyl phthalate Di-n-butyl phthalate Dicyclohexyl phthalate Diethyl phthalate Dihexyl phthalate Diisobutyl phthalate Dimethyl phthalate Dinonyl phthalate Di-n-octyl phthalate</p> <p>If more detailed investigation is indicated, soil should be examined for:</p> <p>Bis (2-n-butoxyethyl) phthalate Bis (2-ethoxyethyl) phthalate</p> |

| Analysis name | |
|---------------|---|
| | Bis (2-methoxyethyl) phthalate Bis (4-methyl-2-pentyl) phthalate Diamyl phthalate Hexyl 2-ethylhexyl phthalate |

EPA Victoria, 1998

APPENDIX 2 (PART A)

A RANGE OF VARIOUS GROUNDWATER FATE AND TRANSPORT MODELS

The following are examples of types of models which are available and a brief description of their applicability. There are numerous models available and the selection and use of models should be undertaken by a specialised groundwater professional. This appendix should not be taken as an endorsement of any of these models.

USEPA Models

Bioplume III Ver 1.0 - Two-dimensional contaminant transport under influence of oxygen, nitrate, iron, sulfate and methanogenic biodegradation.

HSSM VER 1.20A (WINDOWS)

Hydrocarbon Spill Screening Model which simulates flow of Light Non-Aqueous Phase Liquid (LNAPL).

Bioscreen Ver 1.4 - Three-dimensional contaminant transport for dissolved phase hydrocarbons in the saturated zone under the influences of oxygen, nitrate, iron, sulfate, and methane limited biodegradation.

NAPL Simulator - Simulation of the contamination of soils and aquifers from the release of non-aqueous Phase Liquids (NAPL).

VLEACH Ver 2.2A - Simulation of 1-D water and chemical movement in unsaturated zone.

UNSODA - Data on hydraulic properties for over 100 sites.

CHEMFLO - Simulation of 1-D water and chemical movement in unsaturated zone.

MOFAT - Two-dimensional flow and transport of three fluid phases.

PESTAN - Unsaturated zone modelling of the transport of organic (pesticide) contamination.

RITZ - Unsaturated zone modelling of the transport of contaminants associated with oily wastes.

STF - Database of organic and inorganic chemicals in the soil environment.

RETC - Estimates soil-water retention curve, unsaturated hydraulic conductivity or soil model parameters.

WHPA - Simulates capture zones for pumping wells.

WHAEM - Delineates capture zones and isochrones of groundwater residence time for the purpose of wellhead protection.

USGS Models

MOC - 2-D method-of-characteristics groundwater flow and transport model.

MOC-3D Ver 1.2 - 3-D method-of-characteristics groundwater flow and transport model.

PHREEQC Ver 1.6 - Aqueous geochemical calculations.

Department of Environmental Protection, New Jersey

MOC - 2-D method-of-characteristics groundwater flow and transport model.

Centre for Inland Waters, Canada

BTEX - Multivariate plots of hydrocarbon analyses of groundwater samples.

DPCT - Deterministic-probabilistic Contaminant Transport code simulates contaminant transport in a vertical cross-section.

PC-PHREEQEP - Accurate calculations of mass transfer among aqueous and solid phases in very saline waters and brines.

PIRS - Database containing environmental and classification information for approximately 175 pesticides.

TRILOT - Trilinear plots of the relative abundance of the major ions of groundwater analyses.

Other Models

ASM - Aquifer simulation model for 2-D flow and transport simulations.

HST2D/3D - A finite difference model for the simulation of heat and solute transport in saturated porous media.

HELP - A model for hydrologic evaluation of landfill performance.

MOTRANS - A finite element model to simulate the flow of water, dense or light non-aqueous phase liquid (NAPL) and air, and transport of up to five partitionable species.

SWANFLOW - A 3D finite difference code for simulating the flow of water and an immiscible non-aqueous phase under saturated and unsaturated near-surface conditions.

APPENDIX 2 (PART B)

US REFERENCES FOR GROUNDWATER MODELLING

ASTM E1689 Standard Guide for Conceptual Site Models for Contaminated Sites

ASTM D5447 Standard Guide for Application of a Groundwater Flow Model to a Site-Specific Problem

ASTM D5490 Standard Guide for Comparing Groundwater Flow Model to a Site-Specific Problem

ASTM D5880 Standard Guide for Standard Guide for Flow and Transport Modelling

ASTM D5609 Standard Guide for Defining Boundary Conditions in Groundwater Flow Modelling

ASTM D5610 Standard Guide for Defining Initial Conditions in Groundwater Flow Modelling

ASTM D5611 Standard Guide for Conducting a Sensitivity Analysis for a Groundwater Flow Model Application

ASTM D5490 Standard Guide for Comparing Groundwater Flow Model Simulations to Site-Specific Information

ASTM D5981 Standard Guide for Calibrating a Groundwater Flow Model Application

ASTM D5718 Standard Guide for Documenting a Groundwater Flow Model Application

APPENDIX 3 DATA PRESENTATION ON SCALE DRAWINGS AND BOREHOLE LOGS

Figure 7-I: Site layout overlay

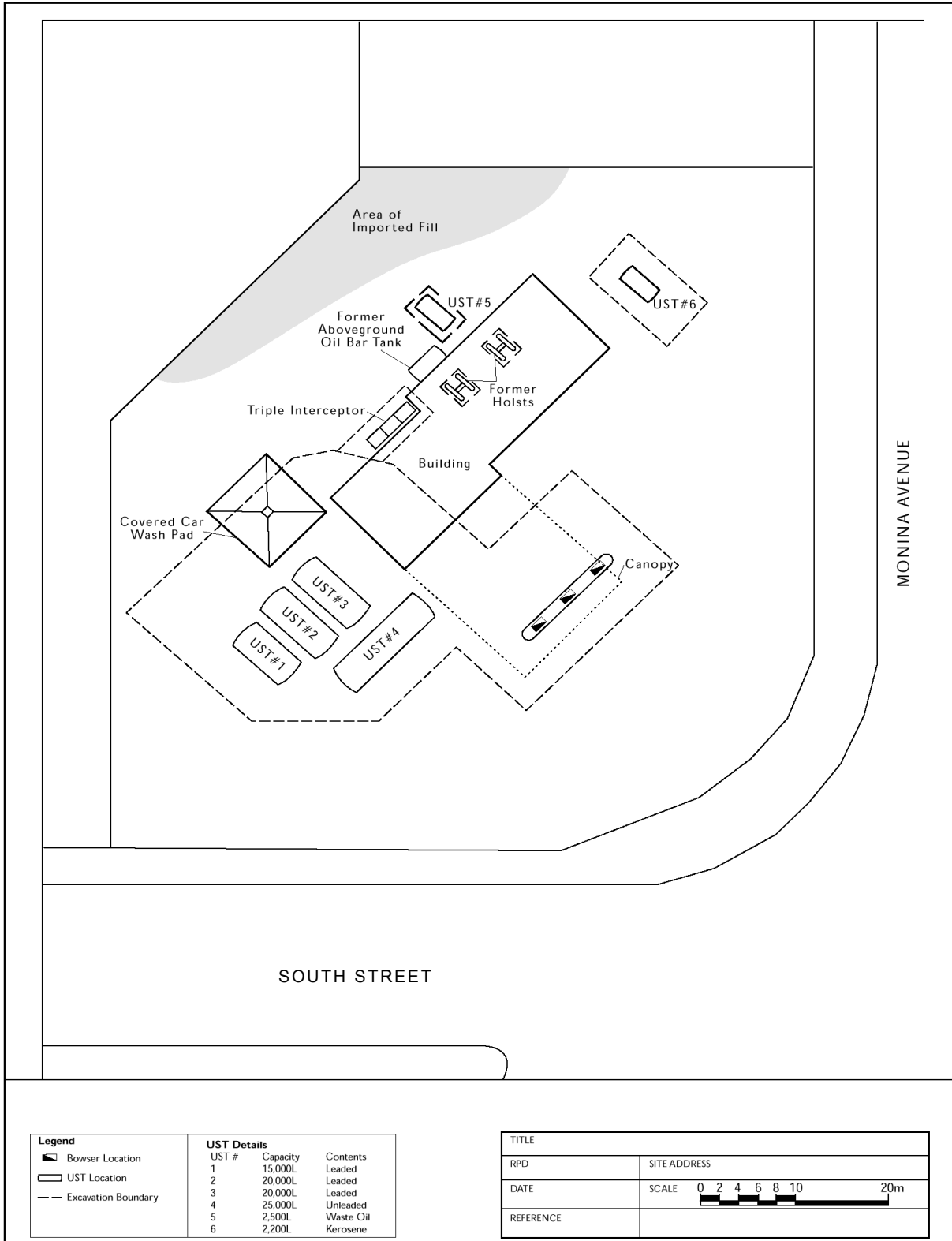


Figure 7-II
Results - v - Site Features

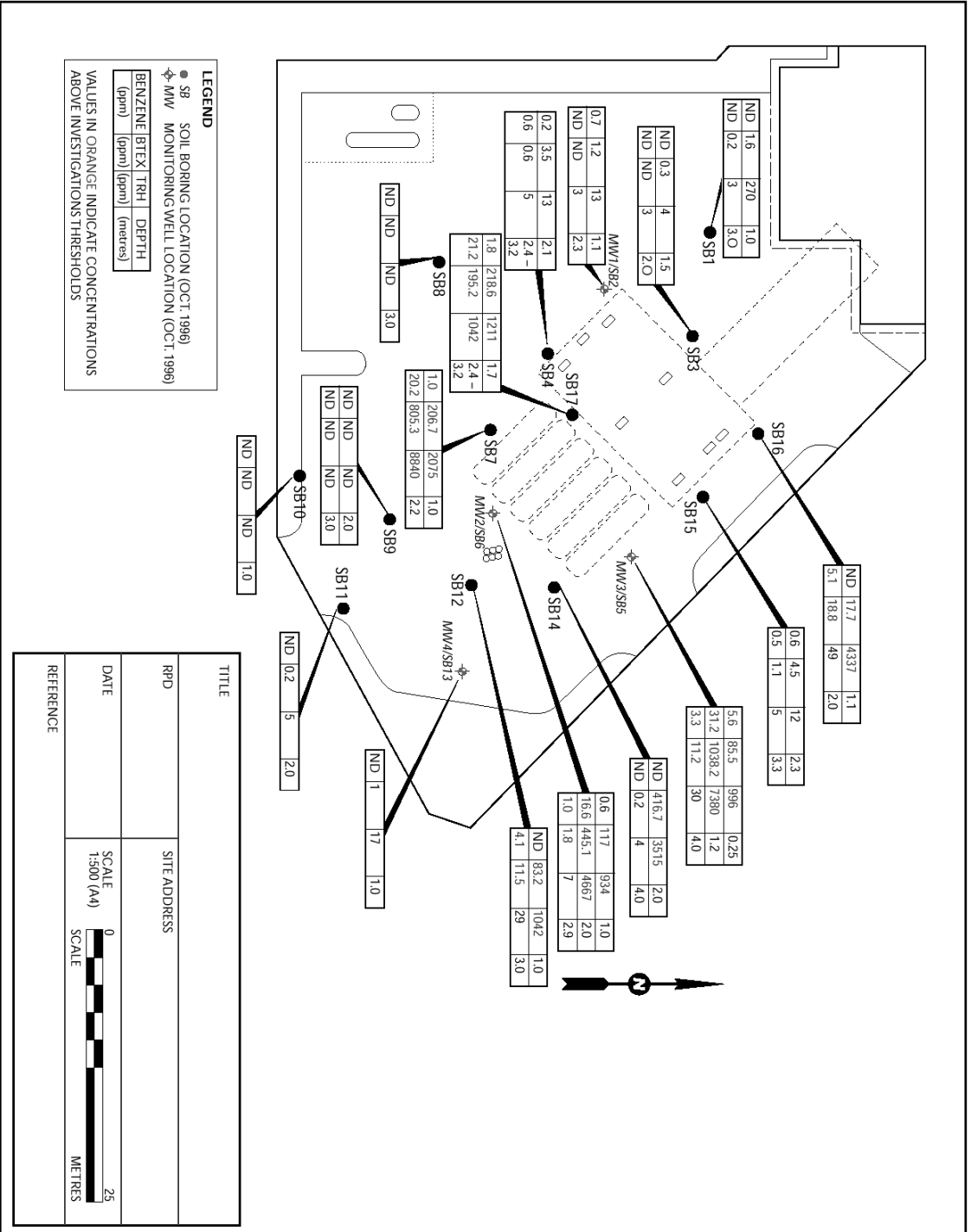
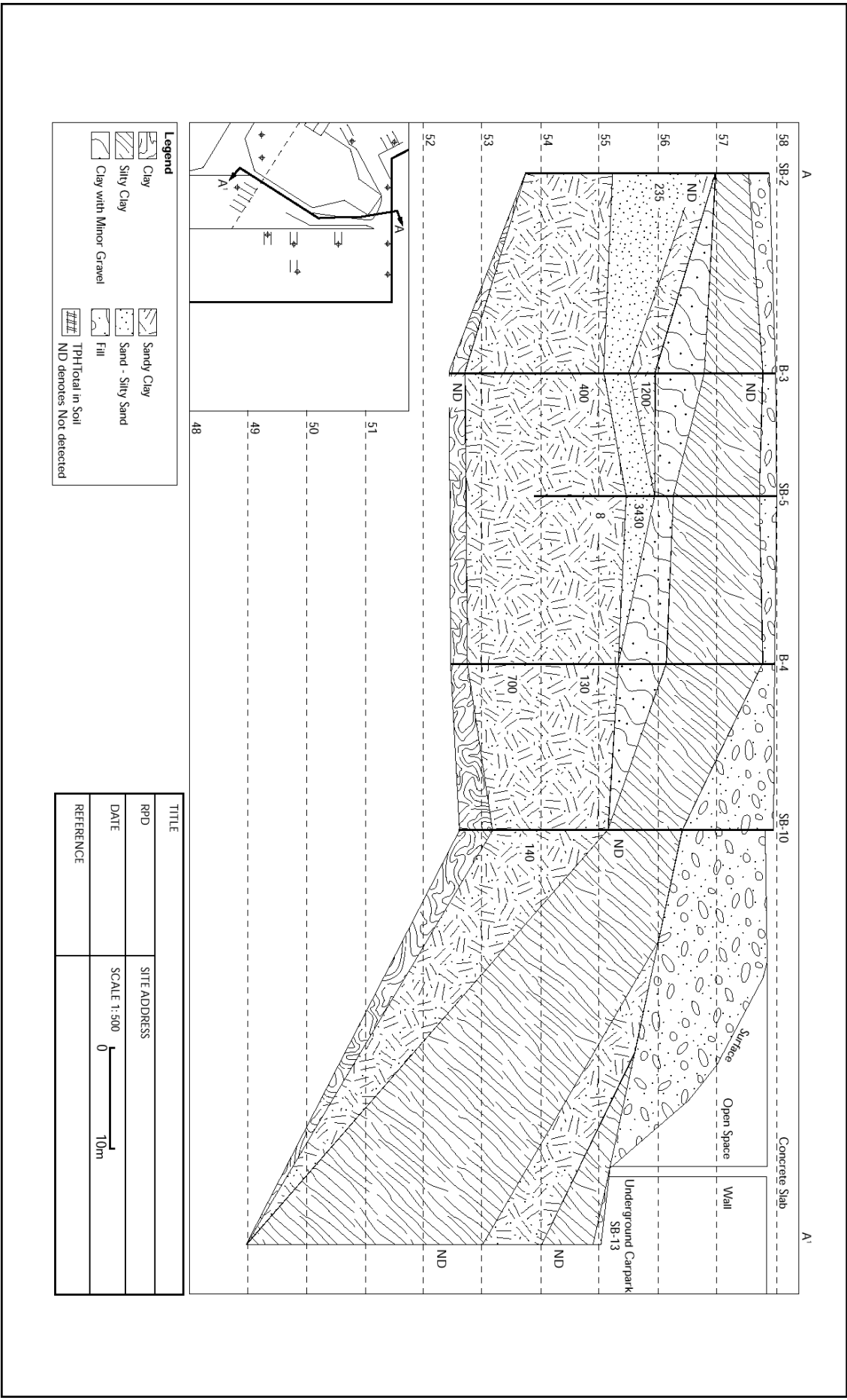


Figure 7-III
Cross-section – contaminant concentrations through soil profile



**Figure 7-IV
Results from excavation assessment**

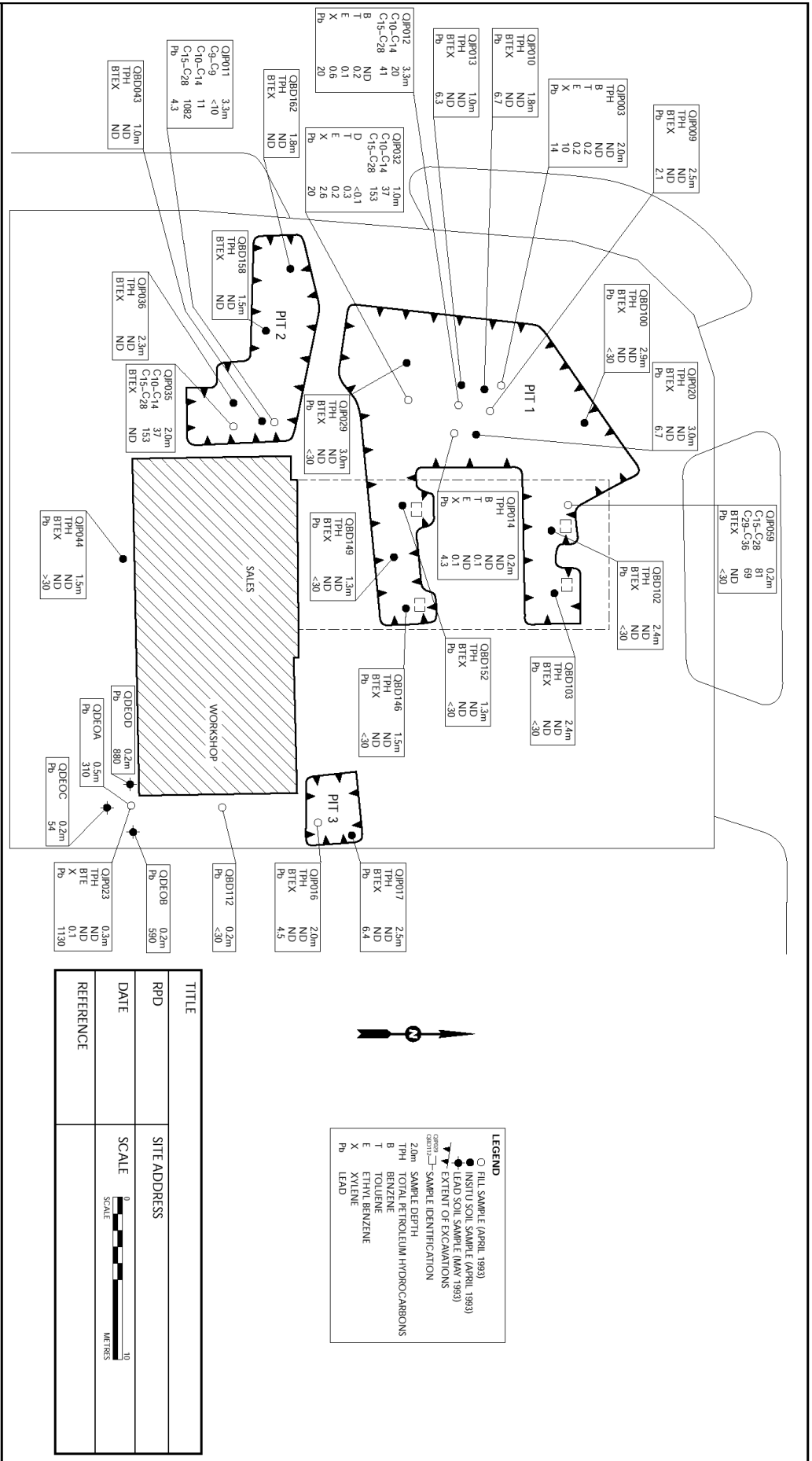
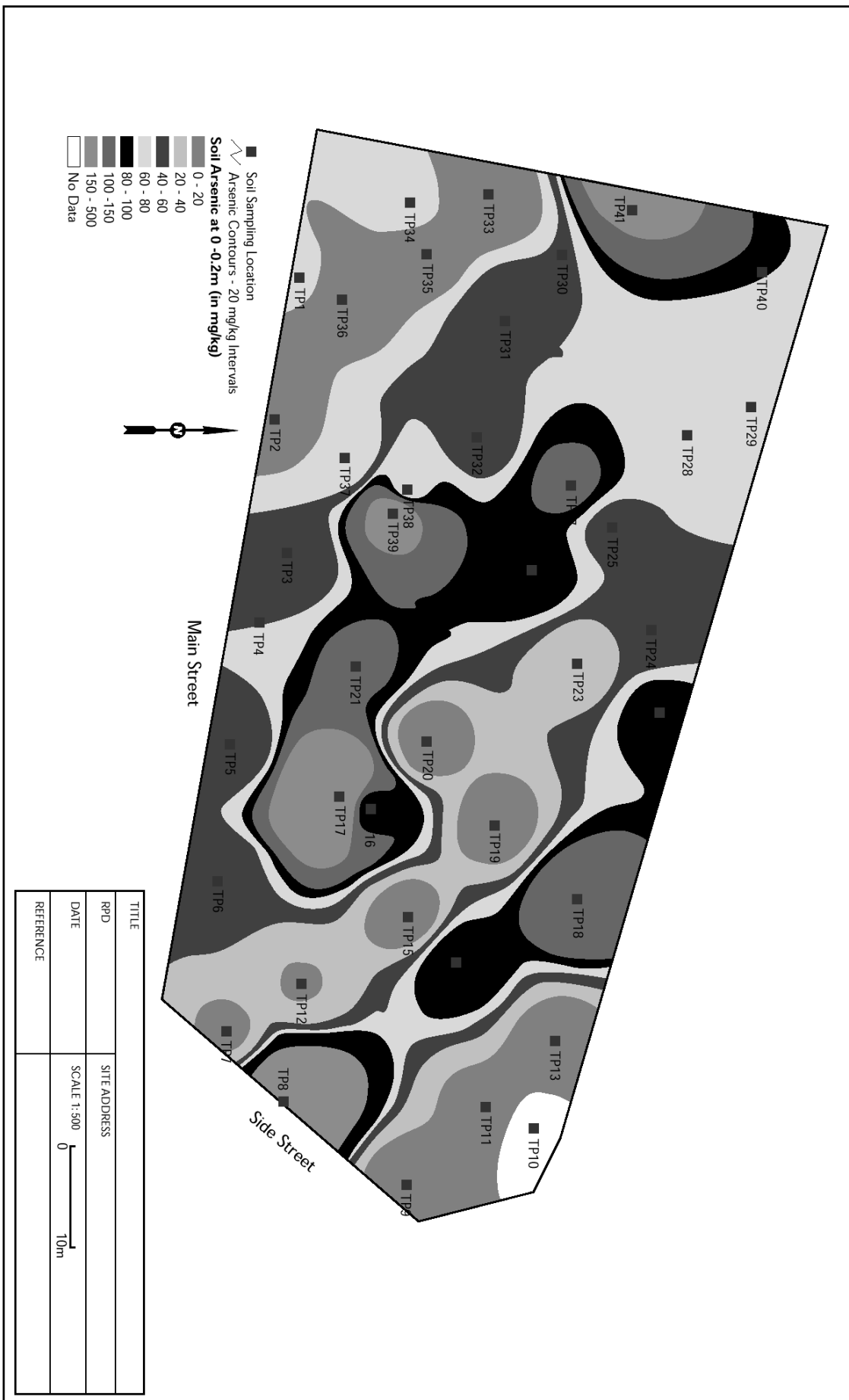


Figure 7-V
Site plan – analyte concentration contours



**Figure 7-VI
Borehole Log - B68**





| JOB NO: | | BOREHOLE NO. | | |
|---|-----------|--|--------------------------------------|------------------|
| Surface elevation: 4.505mAHD | | Borehole location: | | |
| Date: 23/11/98 | | Drill type: Gemco 210B | | |
| Logged by: | | Checked by: | | |
| | | Drilling method: 180mm Hollow flight auger | | |
| SOIL DESCRIPTION | DEPTH (m) | GRAPHIC LOG CLASSIFICATION SYMBOL | FIELD MONITORING | SAMPLE INTERVALS |
| CONCRETE to 0.15m | 0.0 | CONC | | |
| FILL (SANDY GRAVEL): orange; dry; fine gravel; fine to coarse sand | | FILL | | |
| CLAYEY SAND/SANDY CLAY: orange and grey; fine to medium grained; moisture content < plastic limit; moist; medium plasticity; soft to firm; odour; some black staining in upper section; trace fine white grains | | SC | PID H'space = 34ppm hard drilling | B68-01 |
| 0.7 : increasing petroleum hydrocarbon odour; hard drilling on cemented base; traces dark grey stained pockets | 1.0 | | PID H'space = 64ppm | |
| : cemented band; CLAYEY SAND; some very sandy bands; slight odour | 2.0 | | PID H'space = 37ppm | B68-02 |
| | | | PID H'space = 38ppm | |
| SILTY CLAY: grey/orange and dark red; moisture content < plastic limit; low to medium plasticity; very stiff; some ironstone fragments/bands; slight odour; trace fine sand | 3.0 | CL | PID H'space = 26ppm | B68-03 |
| : fragmented ironstone band (3.2 - 3.5) | | | | |
| BORE HOLE TERMINATED AT 3.95m. TARGET DEPTH | 4.0 | | | |
| BOREHOLE LOG | | | | |

**Figure 7-VII
Borehole Log - B69**

| PROJECT: | | BOREHOLE: B69 | | SHEET 1 of 1 | |
|--|-----------|------------------------|-----------------------|--|------------------|
| Surface elevation: 4.508mAHD | | | Borehole location: | | |
| Date: 23/11/98 | | Drill type: Gemco 210B | | | |
| Logged by: | | Checked by: | | Drilling method: 180mm Hollow flight auger | |
| SOIL DESCRIPTION | DEPTH (m) | GRAPHIC LOG | CLASSIFICATION SYMBOL | FIELD MONITORING | SAMPLE INTERVALS |
| CONCRETE to 0.14m | 0.0 | | CONC | | |
| FILL (SANDY GRAVEL): orange; dry; fine gravel; fine to medium sand; no odour | | | FILL | | |
| SILTY CLAY: grey and orange/brown; moisture content < plastic limit; medium to high plasticity; soft to firm; trace fine white grains; no odour | | | CH | PID H'space = 4ppm | |
| CLAYEY SAND: grey and orange; fine to medium grained; moist; trace fine white grains; slight petroleum hydrocarbon odour; some hard, slightly cemented bands | 1.0 | | SC | PID H'space = 10ppm | B69-01 |
| | 2.0 | | | PID H'space = 16ppm | |
| | | | | PID H'space = 25ppm | |
| SANDY SILTY CLAY: grey, orange and dark red; moisture content < plastic limit; stiff; medium plasticity; fine sand; petroleum hydrocarbon odour; some ironstone : large amount ironstone fragmented bands | 3.0 | | CL | PID H'space = 25ppm | B69-02 |
| BORE HOLE TERMINATED AT 3.7m. TARGET DEPTH | 4.0 | | | | |
| BOREHOLE LOG | | | | | |

**Figure 7-VIII
Borehole Log - W60**

| PROJECT: | | BOREHOLE: W60 | | SHEET 1 of 2 | |
|--|-----------|-----------------------------------|---|--|------------------|
| Surface elevation: 3.509mAHD | | Borehole location: | | | |
| Well Head elevation: 3.444mAHD | | | | | |
| Date: 19/11/98 | | Drill type: Gemco 210B | | | |
| Logged by: | | Checked by: | | Drilling method: 180mm Hollow flight auger | |
| SOIL DESCRIPTION | DEPTH (m) | GRAPHIC LOG CLASSIFICATION SYMBOL | WELL CONSTRUCTION | FIELD MONITORING | SAMPLE INTERVALS |
| FILL (SANDY CLAYEY GRAVEL): orange; moist; sand medium grained; gravel fine to medium grained; : becoming brown; some wire; coarse gravel | 0.0 | FILL | | ← Concrete grout | |
| SANDY CLAY: brown with trace grey; moisture content < plastic limit; medium plasticity; firm; sand fine to medium grained; some pockets of black organic matter; trace gravel; trace ironstone; no odour : very moist; soft | 1.0 | CL | | | |
| SILT: grey/black; moisture content < plastic limit; low to medium plasticity; soft to firm | | OL | | | |
| SANDY SILTY CLAY: grey with trace orange mottling; moisture content > plastic limit; medium plasticity; soft; sand fine to medium grained; trace angular coarse gravel (blue metal?) in surface; fine shell fragments/quartz sand; occasional very sandy moist bands : becoming | 2.0 | CL | ← Bentonite granules | | |
| CLAYEY SAND: grey with orange mottling; moist to wet; sand medium grained; trace fine shell fragments : trace subrounded fine to medium quartz gravel; increasing shell fragments | 3.0 | SC | ← 2mm Clean Graded Quartz sand Water level at 3.0m (3/2/99) ← Class 18 50mm UPVC screen 0.4mm slotted | | |
| WELL CONSTRUCTION LOG | | | | | |
| REVISION 0 | | | | | |

| PROJECT: | | BOREHOLE: W60 | | SHEET 2 of 2 | | |
|---|-----------|---|-----------------------|--|---|------------------|
| Surface elevation: 3.509mAHD | | Borehole location: | | | | |
| Well Head elevation: 3.444mAHD | | Date: 19/11/98 | | | | |
| Logged by: | | Checked by: | | Drill type: Gemco 210B | | |
| | | | | Drilling method: 180mm Hollow flight auger | | |
| SOIL DESCRIPTION | DEPTH (m) | GRAPHIC LOG | CLASSIFICATION SYMBOL | WELL CONSTRUCTION | FIELD MONITORING | SAMPLE INTERVALS |
| : becoming GRAVELLY CLAYEY SAND: sand medium to coarse grained; subrounded gravel; gravel fine to course grained; occasional hard; slightly cemented, very clayey bands | 4.0 |  | SC |  | Sampler Wet ← 2mm Clean Graded Quartz sand | |
| CLAYEY SAND: grey & orange; medium to coarse; wet | 5.0 |  | SC |  | ← Class 18 50mm UPVC screen 0.4mm slotted | |
| BOREHOLE TERMINATED AT 5.9m. TARGET DEPTH. WELL INSTALLED. | 6.0 | | | | | |
| | 7.0 | | | | | |
| | 8.0 | | | | | |
| WELL CONSTRUCTION LOG | | | | | | |
| | | | | | | REVISION 0 |