

2

Site sampling procedures

2.1	Introduction	2-3
2.2	Sampling plan design	2-3
2.2.1	Risk-based sampling plan design	2-3
2.2.2	Quality assurance/quality control framework	2-4
2.3	Sampling strategies	2-4
2.3.1	Systematic sampling	2-4
2.3.2	Targeted sampling	2-5
2.3.3	Stratified sampling	2-5
2.4	General sampling requirements	2-5
2.5	Site assessment techniques	2-6
2.5.1	Subsurface techniques	2-6
2.5.1.1	Geophysical surveying	2-6
2.5.1.2	Electromagnetics	2-6
2.5.1.3	Magnetics	2-7
2.5.1.4	Resistivity	2-7
2.6	Typical soil sampling procedures	2-8
2.6.1	Outline of field investigation	2-8
2.6.2	Hand auger sampling	2-9
2.6.2.1	Shallow samples	2-9
2.6.2.2	Deep samples	2-9
2.6.3	Boreholes	2-9
2.6.3.1	Drilling	2-10
2.6.4	Backhoe testpits	2-10
2.7	Typical groundwater sampling procedures	2-11
2.7.1	Outline of field investigations	2-11
2.7.2	Drilling	2-12
2.7.3	Standpipe installation	2-12
2.7.4	Bore development and aquifer testing	2-13
2.7.5	Groundwater sampling	2-14
2.7.6	Water level determination	2-15
2.8	Typical surface water and sediment sampling procedure	2-15
2.8.1	Outline of field investigations	2-16
2.8.2	Stream sampling	2-16
2.8.3	Sediment sampling	2-16

2.9	The use of blank and duplicate samples as quality assurance and quality control measures	2-17
2.9.1	Blank samples used to estimate sampling bias	2-17
2.9.2	Number and frequency of blank samples	2-18
2.9.3	Duplicate sampling to estimate precision	2-19
2.10	Documentation and record keeping	2-19
2.10.1	Documentation	2-19
2.10.2	Record keeping	2-19
2.11	Field cleaning procedures	2-21
2.12	Disposal of sampling wastes	2-21
2.13	References	2-23

Appendices

2A	Quality assurance/quality control approach to site assessment	2-24
2B	Example of the process of developing Data Quality Objectives	2-30
2C	Sampling plan and protocol checklists	2-32
2D	Field quality control samples	2-34
2E	Site specific health and safety plan for investigation of subsurface contamination at gasworks sites	2-35
2F	Field logs	2-36

Site sampling procedures

2.1 Introduction

The section explains the design of sampling plans, sampling strategies that can be used at a gasworks sites, and the level of detail and care required for the collection of samples during the environmental sampling programme at former gasworks sites.

This module covers the following:

- sampling plan design
- sampling strategies
- general sampling requirements
- site assessment techniques
- typical soil sampling procedures
- typical groundwater sampling procedures
- typical surface water and sediment sampling procedures
- the use of blank and duplicate samples as quality assurance and quality control measures
- documentation and record keeping
- field cleaning procedures
- disposal of sampling wastes

Additional information site assessment can be found in Section 3 of the Users Guide, including:

- ▲ the site assessment process (Section 3.2)
- ▲ what media should be sampled for? (Section 3.3)
- ▲ the recommended approach to sampling (Section 3.4)
- ▲ site assessment techniques (Section 3.5)
- ▲ field sampling procedures (Section 3.6)
- ▲ the analytical programme (Section 3.7)
- ▲ the recommended approach to compositing (Section 3.8)
- ▲ reference analytical methods (Section 3.9)
- ▲ site assessment reporting (Section 3.10)
- ▲ health and safety issues (Section 3.11)
- ▲ example of a typical sampling plan (Section 3.12)

2.2 Sampling plan design

The sampling strategy should be developed on a site-specific basis depending on sampling objectives and site characteristics.

2.2.1 Risk-based sampling plan design

Risk-based sampling design focuses the investigation effort on the collection of information aimed to assess risk to human health and the environment. This may be undertaken at a range of levels, with associated degrees of uncertainty.

In addition to the usual sampling of soil and groundwater, consideration may be given to:

- increased sampling of surface soils, as these usually govern the risk to human health
- collection of information that allows for more accurate modelling of fate and transport of contaminants (e.g. soil and aquifer properties)
- sampling from adjacent surface water bodies
- sampling of biota (either terrestrial or aquatic) to assess uptake, and the risk to both human consumers and the local ecosystem
- sampling of indoor air or soil gas where emission of volatiles is of concern.

The direct sampling of media to which site users or ecological receptors may be exposed (e.g. ambient air, biota) rather than only soil and groundwater improves the reliability of risk estimates. Similarly, information that assists in fate and transport predictions is useful in refining exposure estimates.

2.2.2 Quality assurance/quality control framework

The quality assurance/quality control (QA/QC) framework for site assessment is designed to ensure that appropriate planning is undertaken before the assessment begins and that the information gathered as part of the assessment answers the correct questions. The essence of the QA/QC framework for site assessment may be summarised as follows:

- determine the objectives of the study, e.g. to determine whether a site is suitable for its intended use, or whether a site is contaminated or not
- identify the questions that need to be answered in addressing the objective of the study. For example, does the risk to human health exceed a nominated threshold?
- determine what information is required to answer the question and the accuracy and reliability required in the information to make reliable decisions regarding the overall study objective
- define the basis on which decisions are to be made.

Once the information has been collected it should be reviewed to make sure it complies with the requirements for quality (e.g. accuracy and reliability) and then used to make the required decisions. See Appendix 2A for more guidance on the quality assurance/quality control approach to site assessment.

2.3 Sampling strategies

The objective of sampling must be clearly identified before a sampling strategy is adopted. Sampling patterns can be:

- targeted or judgemental
- systematic
- stratified

As mentioned in the Users' Guide, a targeted sampling programme is useful where the site history and site features can be clearly identified for targeted sampling. Where site history is limited, the requirement for systematic sampling is increased so unknown areas of contamination can be identified.

2.3.1 Systematic sampling

- sampling points are usually regularly spaced in a square grid pattern (herringbone or triangular grids may also be used)
- where contamination points are known, the sampling pattern can be oriented to avoid over- or under- representation of these points

- systematic sampling should be used when the investigator has limited knowledge about the site
- systematic sampling is easily statistically analysed, increasing the confidence of locating a hot spot of a given size.

2.3.2 Targeted sampling

- sampling points are selected on the basis of the investigator's knowledge of the probable distribution of contaminants at the site
- the quality of the sampling depends on the skill and experience of the investigator and the amount of information available
- can be used for preliminary site investigations, and for detailed investigations in conjunction with the systematic sampling programme.

A targeted sampling strategy is only as good as the review of the site history on which it is based. If an area of potential contamination is not identified as part of the site history review, then it will not be addressed as part of a targeted sampling programme. Therefore, a targeted sampling programme should not be used where there is little or no site history to support the selection of sampling locations.

2.3.3 Stratified sampling

- site is divided into sub-areas based on factors including geological or geographical features, the likely spatial distribution of the contamination, former use patterns and intended future use
- each sub-area is considered as an individual site and sampling strategies for each sub-area are selected as appropriate
- targeted sampling may be used within the areas known to be a contamination source with systematic sampling across the general site area.

Additional information on statistical estimates can be found in the following document:

Draft Australian Standard (1996) Sampling of Soils, Part 1: Guide to the Sampling and Investigation of Potentially Contaminated Soil. (CH/28/96-6). August.

2.4 General sampling requirements

Some general requirements related to preserving the integrity of the samples, irrespective of the media being sampled, include:

- the sampling area should be isolated to minimise potential for cross contamination. An area should be established on which sampling equipment and containers can be placed without risk of contamination
- field personnel must wear clean PVC/latex gloves whilst handling sampling equipment and taking samples. Every member of field staff who will come into direct contact with the medium being sampled must change to a clean pair of gloves for collecting each sample
- care should be taken to avoid excess aeration of samples of soil, water or sediment
- to minimise the degradation of samples between the field and laboratory every effort should be made to keep the sample cool without having to freeze (keep under $<4^{\circ}\text{C}$ if possible) They should be transferred to the analytical laboratory as soon as practicable
- samples which are to be analysed for BTEX, should placed in a sealed head space vial, taking care to minimise the loss of volatiles (e.g. sampling to be

completed quickly, groundwater samples recovered using techniques that limit the aeration of samples)

- all samples should be transported to the laboratories by the field engineer, or a designated courier who must be documented in the chain-of-custody documentation.

2.5 Site assessment techniques

Information on soil, groundwater, and surface water and sediment sampling techniques can be found in Section 3.5 of the Users' Guide.

2.5.1 Subsurface techniques

2.5.1.1 Geophysical surveying

Geophysical surveying is a remote sensing tool that is able to provide a cost effective and efficient way of better defining the subsurface conditions at an investigation site. Geophysical methods are, for the most part, non-destructive and non-invasive, which can be extremely important for a site where little is known of past practices or locations of subsurface structures. A preliminary geophysical survey can locate subsurface structures that may otherwise present a health and safety hazard in drilling or trenching programmes designed on random or grid basis.

Advantages	Disadvantages
<ul style="list-style-type: none"> • rapid surveying over wide areas 	<ul style="list-style-type: none"> • strong clay concentrations at or near the ground surface may significantly reduce penetration depth and signal clarity
<ul style="list-style-type: none"> • no ground disturbance, greatly reduces chances of occupational exposure 	
<ul style="list-style-type: none"> • very detailed interpretation possible in the near surface zone generally of interest in gasworks investigations (0 to 10 metres below the surface) 	
<ul style="list-style-type: none"> • ability to define the locations of important subsurface structures such as pits, tanks and pipes 	
<ul style="list-style-type: none"> • direct detection of subsurface contaminants possible 	
<ul style="list-style-type: none"> • initial interpretation possible in the field from continuous subsurface profiles, allowing modification of the survey to provide more detail on areas of interest 	
<ul style="list-style-type: none"> • reprocessing of data may improve the location and interpretation of subsurface features 	
<ul style="list-style-type: none"> • areas of interest can be located for targeted drilling thereby improving drilling efficiency and allowing for precautions to be taken when possible tanks/pits are to be drilled 	

2.5.1.2 Electromagnetics

Electromagnetic (EM) fields generated above the ground are used to induce currents in the ground that, in turn, set up secondary EM fields that are detected at the surface. The strength of these secondary fields is dependent on the conductive properties of the subsurface materials and therefore allow the detection and mapping of lateral variations in subsurface conditions.

Advantages	Disadvantages
<ul style="list-style-type: none"> relatively fast surveying over wide areas 	<ul style="list-style-type: none"> limited depth sounding ability
<ul style="list-style-type: none"> relatively inexpensive 	<ul style="list-style-type: none"> instrument alignment during field surveys may be critical to interpretation
<ul style="list-style-type: none"> no ground disturbance, greatly reduces chances of occupational exposure 	<ul style="list-style-type: none"> poor response in low conductivity ground
<ul style="list-style-type: none"> targets near surface zone generally of interest in gasworks investigations (0.75 to 1.5m for EM38 and 3 to 6m for EM31) 	<ul style="list-style-type: none"> plotting and contouring of data required for full interpretation
<ul style="list-style-type: none"> ability to locate important subsurface structures such as pits, tanks and pipes 	<ul style="list-style-type: none"> may be reflected by cultural noise¹
<ul style="list-style-type: none"> direct detection of subsurface contaminants possible 	
<ul style="list-style-type: none"> initial interpretation possible in the field from continuous subsurface profiles, allowing modification of the survey to provide more detail on areas of interest 	
<ul style="list-style-type: none"> reprocessing of data may improve the location and interpretation of subsurface features 	
<ul style="list-style-type: none"> areas of interest can be located for targeted drilling thereby improving drilling efficiency and allowing for precautions to be taken when possible tanks/pits are to be drilled 	

2.5.1.3 Magnetics

Magnetic surveying measures variations in the magnetic field at or above the ground surface which is affected by lateral variations in the concentrations of the magnetic minerals or man-made materials (pipes and tanks).

Advantages	Disadvantages
<ul style="list-style-type: none"> good detection of ferro-magnetic (e.g. metallic) objects 	<ul style="list-style-type: none"> no depth sounding ability
<ul style="list-style-type: none"> may detect lateral changes relating to varying amounts of magnetic minerals in the subsurface (i.e. differences from natural ground) 	<ul style="list-style-type: none"> data quality may be badly affected by natural magnetic storms
<ul style="list-style-type: none"> no ground disturbance, greatly reduces chances of occupational exposure 	
<ul style="list-style-type: none"> may be used in conjunction with other methods to clarify nature of subsurface features 	

2.5.1.4 Resistivity

Resistivity surveying relies on the injection of electrical current into the ground and the measurement of the induced potential differences between points at the surface.

The four methods outlined above are generally employed in conjunction with a well designed drilling or trenching programme to provide ground truth for the geophysical observations. An advantage in carrying out a geophysical survey is that the need for invasive testing can be greatly reduced by targeting anomalous features. Geophysical surveys also allow more confidence in the interpolation of drilling and trenching results across an entire site and reduce the possibility of missing discrete features such as buried tanks or pits.

¹ Geophysical noise caused by anthropogenic sources (e.g. car and pumps) as well as wind and moving trees

Advantages	Disadvantages
<ul style="list-style-type: none"> • very limited disturbance, greatly reduces changes of occupational exposure 	<ul style="list-style-type: none"> • relatively slow and labour intensive surveying
<ul style="list-style-type: none"> • may be used in either profiling or sounding modes to detect lateral variations or depth structure respectively 	<ul style="list-style-type: none"> • ground contact required by electrodes, necessitating some site disturbance
<ul style="list-style-type: none"> • ability to locate important subsurface structures such as pits or tanks 	<ul style="list-style-type: none"> • processing of data required for interpretation
<ul style="list-style-type: none"> • direct detection of subsurface soil and water contamination possible 	<ul style="list-style-type: none"> • may be affected by cultural noise

2.6 Typical soil sampling procedures

The number of samples required as part of any site investigation must be determined for each site, reflecting the objectives underlying the information collection (e.g. assessment of risk, or estimation of volumes). Notwithstanding this, in some cases it may be appropriate to design the investigations with a view to collecting information that may be of use in answering questions that may follow on from the current work.

The following points should be noted:

- the objective of the soil sampling should be to provide an estimate of the mean contaminant concentration in soil to which site users will be exposed. The programme should be designed taking into account the area in which site users may spend their time. (Averaging contaminant concentration across the entire site may over- or under-estimate the risk depending on whether site users spend more or less time in the contaminated areas)
- an estimate of the contaminant concentrations in surface soil is also needed to determine the risk associated with erosion and off-site transport of contaminated soil. Although sampling at a range of depths is required, greater attention should be paid to the surface and near surface soils.²
- the risk to site users is governed by contaminant concentrations in the near-surface soils and therefore attention may be focussed on assessing the average contaminant concentrations in these. Less information is needed on contaminant concentrations at depth, but sufficient information must be available to determine whether deep contaminated soil will continue to be an ongoing source of groundwater contamination, and what the risk will be if more highly contaminated material is excavated
- the soil sampling programme should also identify contaminant hot spots which have the potential to cause adverse health effects in the short term (e.g. acute health effects).

2.6.1 Outline of field investigation

- soil samples should be collected in accordance with a documented field sampling plan, and a health and safety plan
- drilling or excavation using a backhoe may be necessary if ground conditions make hand augering difficult, or where deep sampling is required
- the analytical programme must be developed to suit the site and should be documented in the field sampling plan. Many of these compounds may be present in trace quantities which require very sensitive laboratory analytical procedures. Consequently it is important that soil sampling procedures assume the quality of the samples

² Historically many soil sampling programs recover the first sample at a depth of 0.5 to 1.0 m which does not necessarily reflect the conditions to which site users are exposed. However in the context of site redevelopment, the surface soils are frequently removed or replaced or overlain with clean material.

- samples should not be composited in the field
- logs of soil conditions should be prepared on standard log sheets. The soil will be recorded using the Unified Method of Classification, using standard abbreviations. Particular note will be taken of the appearance, discolouration and odour. If contamination by volatile organic compounds is suspected, field screening of samples using an organic vapour analyser (e.g. photoionisation detector (PID)) may be warranted.

2.6.2 Hand auger sampling

The following procedures should be used when collecting shallow samples. If samples are collected from several positions within a given test location for later compositing by the laboratory, the same sampling tool and tray can be used, provided all loose dirt is removed from the tools. This does, however, reduce the integrity of individual samples, and limit the extent to which the sub-samples can be used as independent samples.

The following is an indicative procedure for recovery of soil samples by hand augering.

2.6.2.1 *Shallow samples*

- remove grass and other material from the area to be sampled by hand or with a clean trowel. Always rest the trowel on its wrapping
- remove soil from the sampling area with a trowel to a depth specified in the field sampling plan and place it directly in pre-cleaned glass sample jar
- depending on the analytical requirements, it may be appropriate to recover samples in more than one sample container, particularly where the analyses are to be completed by different laboratories
- if no further samples are to be taken at the location, replace any surface soil removed from the hole.

2.6.2.2 *Deep samples*

- unwrap a pre-cleaned auger or a pre-cleaned shovel or crowbar. Always rest the equipment on the wrapping whilst sampling
- remove the deeper samples by hand auger, taking care to minimise the possibility for cross-contamination. In order to minimise the likelihood of smearing or cross-contamination between sampling depths, recover the initial sample using a sampling spoon or auger. Advance the hole using the auger, then use a smaller diameter auger to recover the second sample
- backfill the hole. If the hand auger hole approaches the water table or passes through an aquitard (a soil horizon with low permeability) the hole should be sealed (e.g. using bentonite pellets) to minimise contaminant migration.

Recovery of samples by hand auger is difficult below a depth of approximately 2m, depending on soil type. The risk of cross-contamination also increases with sample depth when using a hand auger.

2.6.3 Boreholes

Boreholes may be drilled to sample soil and groundwater where hand auger techniques are not appropriate. The hollow auger drilling technique, with sample recovery using a split barrel sampler, is commonly used for sampling unconsolidated formations. Other drilling techniques include cable tool, solid auger, air rotary and air hammer. With the exception of cable tool, each of the techniques relies on the use of a separate sampling device (e.g. split spoon sampler) for recovery of the sample.

Techniques that involve the use of drilling fluids, or other substances that may contaminate the bore are not suitable for soil sampling. Care should be taken to reduce cross contamination from the oil often present as a mist in compressed air supplies.

Solid auger drilling may be acceptable where ground conditions are stable, but the risk of cross contamination is greater than with hollow auger drilling.

2.6.3.1 Drilling

- the drilling rig to be used must be in sound working order and free of oil leaks
- the drill string should be steam cleaned prior to commencing each borehole
- samples of sub-surface material are usually taken from the following depths (although samples may be recovered from other depths as required):
 - 0.5 metres
 - 1.0 metres
 - 2.0 metres or as listed in the sampling schedule
- samples of sub-surface material are recovered by driving a split barrel sampler or other similar sampling device into undisturbed material
- samples collected from air circulation or auger returns must be selected carefully to minimise the possibility of cross contamination. Results from such samples must be treated as indicative only, but it may be necessary to use them where other sampling methods are not possible (for example, in gravelly soils)
- where boreholes intersect the water table they must be sealed with cement grout or bentonite at the completion of drilling, unless they are used to establish a groundwater monitoring well
- a cleaning pad should be established on the site, where the drilling rig and other large equipment can be cleaned without risk of contamination to sampling locations. Power and water will need to be located nearby to enable use of a steam-cleaning unit
- the drilling rig should be decontaminated by steam cleaning on or, preferably, before arrival at the site. This should include all drilling equipment which will go into or be used near the borehole. The drilling rig and all drilling equipment will also be cleaned between boreholes according to the procedure outlined in Section 2.11.

2.6.4 Backhoe testpits

A backhoe may be used to recover soil samples where ground conditions make the use of a hand auger impractical. The following precautions will apply:

- the backhoe bucket and boom must be steam cleaned before each test pit and at the end of each day's work. All grease, oil and liquid tar must be removed
- the backhoe must be in good condition and free of oil or hydraulic fluid leaks
- all loose dirt will be removed from the backhoe bucket, following excavation to the target depth, and a sample representative of the material at the target depth will be recovered using the backhoe. Field staff must not enter a test pit greater than approximately 1.0 m deep under any circumstances, unless it has been made safe in accordance with relevant occupational health and safety regulations
- samples should be recovered at depths as specified in the sampling plan. Additional samples may be recovered at the discretion of the field engineer
- a sample should be recovered from the backhoe bucket using a cleaned sample spoon or trowel, taking care to select material that has not contacted the sides of the bucket. The sample should be placed in a cleaned glass jar with a Teflon lined cap where required. In some circumstances samples may be recovered directly, using a scoop rather than from the backhoe bucket

- all holes should be backfilled and reinstated near possible to original condition.

2.7 Typical groundwater sampling procedures

Particular consideration should be given to the specific hydrogeological conditions at the site when designing the groundwater investigation programme. The possibility of contaminant migration along preferential flow paths and the need to use techniques other than conventional groundwater monitoring bores should be considered for each site.

The potential for DNAPLs to be present at gasworks means there is need for:

- care in developing a conceptual model for the fate and transport of contamination. The model must take into account features such as confining layers and higher permeability lenses in the unsaturated and saturated zones which may influence the direction and rate of migration of DNAPLs
- care in undertaking field investigations to ensure that confining layers retarding the movement of DNAPL are not damaged during drilling, allowing contamination to migrate into previously uncontaminated zones
- monitoring of contaminant concentrations at various depths in the saturated zone, using a system of nested monitoring bores.

The presence of DNAPLs greatly complicates the assessment of groundwater contamination at gasworks sites, emphasising the need to develop a detailed understanding of the groundwater systems, and to avoid creating preferential pathways for transport of the contaminant through confining layers.

2.7.1 Outline of field investigations

The field investigations are designed to obtain representative groundwater information for the site in order to:

- define the geological profile and aquifer characteristics at the site
- assess the current nature and level of soil and groundwater contamination
- identify principal sources of contamination
- estimate rate and direction of contaminant flow, on and off site
- evaluate remediation requirements for the site
- identify likely zones of discharge
- identify vertical contaminant distribution/stratification.

The field investigations may involve the following:

- installing groundwater monitoring bores as indicated in the site-specific sampling plan
- recovering groundwater samples and measuring the depth to groundwater and separate phase hydrocarbons (if present) in all groundwater monitoring bores. If a separate phase is detected in a bore, groundwater samples are unlikely to be representative of the aquifer conditions, and therefore groundwater samples should not be taken
- measuring rising head permeability at the groundwater bores
- recovering soil samples from selected depths during drilling (refer soil sampling requirements).

Where dense non-aqueous phase liquids (DNAPLs) may be present, it may be necessary to measure the vertical migration of contaminants. Nested bores or several bores installed at the same location but screened across different aquifer intervals may be used to assess the

vertical extent and/or vertical stratification due to hydraulic characteristics of the aquifer as well as density effects.

2.7.2 Drilling

Material handling and quality control measures must be implemented to ensure clean drilling conditions and minimise down-hole contamination. Specific measures include:

- a cleaning pad should be established on the site, where the drilling rig and other large equipment can be cleaned without risk of contamination to sampling locations. Power and water will need to be located nearby to enable use of a steam-cleaning unit
- the drilling rig should be decontaminated by steam-cleaning on or, preferably, before arrival at the site. This should include all drilling equipment which will go into or be used near the borehole. The drilling rig and all drilling equipment will also be cleaned between boreholes according to the procedure outlined in Section 2.11.

Logs of the soil encountered must be prepared on standard borehole log sheets. The soil should be logged using the Unified Method of Classification and standard abbreviations.

Note the nature of possible soil contamination, including an assessment of appearance, discolouration and odour. Where contamination by volatile organic compounds is suspected, field screening of samples using an organic vapour analyser (e.g. PID) may be warranted. All information is to be recorded on log sheets.

All drill cuttings should be placed in sealable containers or a covered waste disposal skip on site for subsequent storage or disposal.

Preference should be given to techniques that do not introduce drilling fluids (including air). Although hollow auger drilling techniques are frequently employed, the selection of a technique should be based on the expected ground conditions and the requirements for bore construction. On those sites covered by concrete paving, drilling will be preceded by concrete coring of a size to accommodate both drilling activities and subsequent borehole completion, including installation of borehead protectors.

Accumulated drill cuttings should be removed from the borehead area as drilling progresses in order to prevent fallback.

The background monitoring bore(s) should be drilled first where possible.

2.7.3 Standpipe installation

- records should be kept on the standard record sheets. These should include all procedures used, materials used and the timing of the various stages of bore construction. Well completion reports may be used, containing information on borehole configuration, piezometer configuration (e.g. screen location, casing length, diameter etc.), placement of screen filter pack and borehole seals, and bore development and completion details. All data will be recorded directly in the field
- all materials placed in the hole must be free of any of the target contaminants
- before installation, standpipe materials should be steam cleaned with phosphate-free detergent, followed by a rinse in potable quality water and a final rinse with deionised water. After this the standpipe materials should be handled only by field personnel wearing clean PVC/latex gloves
- conventional solvent glues must not be used. Instead, mechanical screw fittings should be used on all casing and screen joints
- the length and placement of the screened section should be as documented in the field sampling plan. Excessively long (i.e. >3m) screens should not be used so the averaging affect of vertical groundwater quality entering the bore is minimised. If

significantly stratified groundwater quality is suspected or known to be present, nests of multiple short screened piezometers or piezometer bundles should be used

- groundwater monitoring bores are generally screened across the water table, allowing detection of floating product. The screen placement should account for anticipated fluctuations in the water table. Monitoring bores may be screened at discrete intervals beneath the water table where DNAPLs are suspected, or where the investigation objectives include the assessment of vertical migration of contamination
- following screen and casing installation, graded sand or gravel sized to match the aquifer materials, should be placed around the screen and to a height of approximately 200 mm above the uppermost screen slots. The bentonite seal should be placed directly above the filter pack and extend for a thickness of 1.0 m or more where possible. Where multiple (nested) piezometers are installed in the one hole, bentonite, or other low permeability seals, should be installed between each screened interval
- the filter material should be pre-washed and screened to eliminate foreign material and should be appropriately graded to the aquifer material wherever possible. Sand or gravel should be brought on site in bags and transferred directly from bag to hole
- holes should be backfilled above the bentonite seals to approximately 0.25 m below ground level. At the surface a concrete collar seal and steel protective covers will provide well-head security and prevent accidental damage. In most cases these covers will comprise cylindrical steel upstands fitted with lockable lids
- where vehicular traffic poses a problem, the installation should be fitted flush with the ground surface using a Gatic cover for protection. In this event, a sump should be provided around the top of the casing with subsurface drainage to prevent build up of drainage water around the borehead. All loose material should be removed from the borehead working area before the standpipe is installed to avoid it being dislodged into the open hole
- final levels of both screen filter packs and bentonite seals should be verified by lowering a probe down the space between borehole wall and casing
- monitoring bore basin and screens would typically be constructed from PVC pressure pipe of a nominal 50 mm diameter, but the size and material for the standpipe should suit the site conditions and the investigation objectives. Note that volatile organics are readily absorbed by polymeric material
- screen lengths should be determined on site after drilling has established preferred screen zones. Typically, slot sizes should be nominal 0.5 mm width with at least two rows of slots per screen length and average spacing of 1 cm between slots. Approximately 0.5 m of unslotted casing may be provided below each screen, to act as a sump to collect any fines that may pass through the screens. Monitoring bores should be terminated with a fitted end cap at the lower end and with a cap at the surface
- the precise diameter, material and configuration of monitoring bores should be adjusted to suit the site by a qualified professional. The above guidance is an indication of a typical installation.

2.7.4 Bore development and aquifer testing

- compressed air pumping, mechanical surging or other pumping should be used to develop the bore, depending on the aquifer characteristics. A gentle surging will help removal of any residual fines. Development pumping should continue until water clears of residual sediment and yields stabilise. Adequate development will

be verified by the stabilisation of water chemistry parameters including electrical conductivity and temperature. Records of the above should be maintained

- the selection of an appropriate pumping system for bore development depends on the nature of the aquifer. Care should be exercised, however, to ensure the aquifer is not aerated. Some alternative pumping systems include compressed air with 'U' tube system to avoid aeration, foot valve or ball valve pumps, bladder pumps, air driven displacement pumps, submersible pumps or similar mechanical pumping systems
- pumping systems that avoid aeration of the samples are preferred. Most mechanical systems will not aerate samples. Compressed air systems should be avoided, although some gas displacement systems are available which cause no gas/liquid contact
- when development pumping is completed, water levels will be depressed in the borehole. The groundwater recovery should be monitored by recording the rate of water level rise when pumping stops, and empirical analysis may be used to estimate permeability
- all items inserted into the bore should be decontaminated using high pressure hot water with phosphate-free detergent, followed by final rinse in potable quality water and distilled water.

Data recording should include:

- daily record of progress sheets, which should include details of all activities, equipment installed, times and durations
- pumping schedule, detailing pump operating periods and measurements or estimates of discharge volumes
- water level recovery data, detailing time, elapsed period since pumping ceased and water level. Water levels should also be recorded before starting pumping.

2.7.5 Groundwater sampling

- groundwater samples must be collected several days after the development pumping and recovery test phase. The borehole should be purged before taking any samples for analysis. During the purging process, check temperature, pH and electrical conductivity and continue pumping until these parameters stabilise. Parameters will be considered to have stabilised when the difference between three consecutive monitoring periods is less than 10%
- a minimum of three bore volumes should always be purged from each bore, however stabilisation of field monitored parameters should be the primary factor determining when the sample shall be taken. Records of temperature, pH and electrical conductivity measurements shall be maintained. Where the potential for intrinsic biodegradation is to be evaluated, dissolved oxygen should also be measured
- samples should be collected in a stainless steel or Teflon downhole bailer, or with an appropriate sampling pump (where disturbance of suspended solids must be minimised). The sampling pump should be decontaminated between sampling sites by cleaning as set out in Section 2.11
- hoses and other fittings that come into contact with the bore fluid need to be of the correct type to ensure adsorption is minimised. If these are not the correct type, residual contamination in sampling hoses may lead to false positive results. Alternatively, a disposable bailer may be used for each sample, provided the bailer material is compatible with the suspected contaminants

- care should be taken when sampling to avoid any opportunity for excess aeration of the sample.

Additional requirements are as follows:

- if a bailer is used, it should be lowered gently to avoid disturbance of any sediment that may still be in the bore and to avoid damage to the bailer or the rope. Samples should be recovered from beside the slotted section of the standpipe
- during sampling, measures should be taken to avoid contamination of sampling equipment. For example, before the commencement of sampling, a clean piece of plastic should be placed on the ground beside the well. All equipment should be placed on this sheet when not in use, and all cleaning should be carried out on the plastic sheet. As the bailer is removed from the well, take care to place the rope on the plastic sheet.
- water samples should be placed in screw capped containers which will be supplied by the laboratory. Bottles supplied should be polythene for metals and inorganics, and glass for organics
- water samples to be analysed for heavy metals may require filtration on site to remove particles that could affect the metal concentration. Water samples should be filtered before they are added to the container with the preservative. Take care to minimise aeration of the sample during filtration. Alternatively, if relatively clear and low turbidity samples can be collected, the sample may be recovered without filtration and preservation, provided it is recovered without aeration (e.g. place outlet of pump directly into the base of the sample container and fill, allowing the container to overflow for several volume changes before sealing).

2.7.6 Water level determination

Following well development, the standing water level should be measured. Allow sufficient time for stabilisation of water levels following development or other disturbance of the bore. The time required for stabilisation depends on the aquifer characteristics, and may range from hours to days.

A cleaned dipper should be lowered down the well to ascertain the water level. The depth to the top of separate phase hydrocarbon can be determined using either a mechanical or electrical measuring device. The depth to top of groundwater can be measured with a cleaned electrical dipper. The difference between the two is the thickness of a separate phase hydrocarbon. This thickness will be verified by bailing with a transparent bailer.

These instruments should be washed copiously with tap water and then rinsed with deionised water. If oil or grease is picked up on the bailer, additional washing with phosphate-free detergent will be required. The bailer may be rinsed with acetone to assist in removal of oil or grease, followed by rigorous rinsing with potable, then deionised water. Alternatively, a disposable bailer may be used.

Water levels should be referenced to ground surface and recorded to the nearest centimetre.

2.8 Typical surface water and sediment procedure

The surface water and sediment sampling programme should provide an estimate of contaminants leaving the site via drains, surface water run-off and groundwater discharge to surface water bodies.

2.8.1 Outline of field investigations

The field investigations are designed to obtain representative samples of water from waters receiving contaminants (receiving waters) in the vicinity of the site.

The field investigations may involve:

- recovery of water samples from selected locations in the receiving water body
- recovery of sediment samples from selected locations within surface water bodies in the vicinity of the site.

2.8.2 Stream sampling

- samples should be recovered from the stream at locations designated in the sampling plan
- stream samples should be recovered from below the stream surface in order to prevent accidental sampling of surface slicks. A suitable sampling device, able to recover samples from a designated depth and prevent entry of surface water, should be employed. Such devices are readily available. If possible, the sample should be taken directly into the sample container prepared by the laboratory
- sampling should commence at the location furthest downstream, working back upstream in turn, with the exception that background samples should be recovered first
- care should be taken when sampling to avoid excess aeration of the sample.

Additional requirements are as follows:

- the sampling equipment should be lowered gently to avoid disturbance of any sediment
- contamination of equipment should be avoided during sampling. For example, before the start of sampling a clean piece of plastic should be placed on the ground beside the sampling location. All equipment should be placed on this sheet when not in use and all cleaning shall be carried out on the plastic sheet
- water samples should be placed in screw capped containers prepared by the laboratory. Polythene bottles should be used for samples to be analysed for metals and inorganic constituents, and glass bottles should be used for samples to be analysed for organic compounds
- only those samples which do not have preservatives in the bottles should be filled to overflowing; those bottles with preservatives should be filled to maximum capacity but not to overflowing
- sample containers should be placed in clean polyethylene bags to minimise the potential for cross-contamination.

2.8.3 Sediment sampling

Sediment samples should be recovered from selected locations within streams, drains and other surface water bodies in the vicinity of the site, as designated in the sampling plan. Samples should usually be recovered from locations where sediment, associated with run-off from the site, is likely to collect, i.e. areas of lower flow velocity adjacent to, or downstream from the site.

Sediment samples may be recovered using an appropriate scoop or other sampling tool in the case of shallow water bodies, or using purpose designed sediment core sampling equipment for recovery of samples from deeper water bodies and where a vertical profile of the sediment is required.

Sediment samples should be placed in clean glass sample jars, as for soil samples. Where samples are recovered using core sampling equipment the sample may be retained in the coring equipment (e.g. plastic or aluminium tube), sealed and transferred to the laboratory for analysis.

- observations such as river gauge levels, colour, etc. must be recorded in the field book. In particular information on how the sample relates to the general stream or drain bed should be recorded
- with the exception of background samples (which should be recovered first where practical) sampling shall start at the furthest downstream location, and work back upstream.

2.9 The use of blank and duplicate samples as quality assurance and quality control measures

The quality assurance framework for site assessment includes the development of Data Quality Objectives (DQOs), the establishment of procedures to ensure compliance with the DQOs and the establishment of data quality indicators which measure compliance with the DQOs. The DQOs may address issues such as:

- sample location and frequency
- sample collection procedures
- sample handling procedures
- constituents to be measured
- analytical methods used to measure the constituents.

The two data quality indicators most often used in field sampling to measure compliance with DQOs are bias and precision.

Bias is defined as a systematic deviation (error) in data. Precision is defined as a measure of random variation in data. Bias can be assessed using a variety of blank sample types, discussed in Section 2.9.1. Precision is typically estimated using duplicate samples, discussed in Section 2.9.2.

2.9.1 Blank samples used to estimate sampling bias

Various types of blank samples can be used to assess the following sources of bias:

- the possibility that extraneous material has been introduced to the samples
- whether the site of interest is truly different from surrounding sites
- whether the sample matrix affects the sampling and analytical process.

Blank samples often used in site assessment are outlined as follows:

Field blanks samples are samples of analyte-free media similar to the sample matrix. They are transferred from one vessel to another or exposed to the sampling environment at the sampling site. They measure incidental or accidental sample contamination during the whole sampling and analytical process (sample collection, transportation, or storage at the laboratory).

Equipment blanks (or rinsate blanks) are samples of analyte-free media (usually high purity distilled water collected in a suitable container) that have been used to rinse the sampling equipment. These blanks are collected after equipment decontamination and prior to re-sampling to assess potential cross contamination between samples as a result of poor decontamination procedures.

Material blanks are samples of construction materials such as those used in groundwater wells. They are used to assess the potential contamination of samples by these materials.

Trip blanks (or transport blanks) are test samples of analyte-free media taken from the laboratory to the sampling site and returned to the laboratory unopened. They are

used to measure cross-contamination from the container and preservative during transport, field handling and storage.

Background samples (or matrix blanks or field control samples) are samples of the media similar to the test sample matrix (soil, surface water, sediment etc.). They are taken near the time of sampling, and from a site where the analytes may be present at background levels. The background sample measures the background concentration of analytes of interest. Background samples assist in demonstrating whether the site of interest is contaminated or whether the elevated concentrations reported are occurring naturally.

Background samples can be taken from two different kinds of sites, "local control sites" and "area control sites".

Local control sites are usually adjacent to or very near the test sample sites. The following principles apply to their use:

- local control sites should be upwind or upstream of the sampling site
- when possible, local control site samples should be taken first to avoid contamination from the sample site
- travel between local control sites and sampling areas should be minimised to reduce contamination caused by people, equipment and/or vehicles.

Area control sites are in the same area, e.g. city or district as the sampling site, but are not adjacent to it. They are chosen where a suitable local control site cannot be found. All possible efforts should be made to make the sites identical except for the presence of the analytes of interest at the site under investigation. The principles applying to local control sites are relevant to area control sites.

2.9.2 Number and frequency of blank samples

It is advisable to take a range of the blank sample types described above. The number and frequency of blank samples to be collected depends largely on the data quality objectives (DQOs) developed in the planning phase of the site assessment (refer to Appendix 2B). For example, if only a general indication of the level of contamination is needed then fewer blank samples will be needed than for a highly reliable, quantitative estimate of the level of contamination.

Costs of analysis are determined by the number of blank samples analysed from the pool of those collected. Where these costs are high it may be possible to minimise the number of blank samples that require analysis. For instance, if the field blanks show no sign of contamination, then trip blanks can be discarded or stored as necessary. Similarly, if the primary samples show analyte levels below the limit of detection or below levels considered significant, then there is less need to run all blank types. This approach is especially relevant for groundwater samples where there are likely to be several types of blank samples.

It is recommended that the following be collected per day or per 10 samples (whichever is more frequent) per collection apparatus:

- one field blank³
- one equipment blank
- one trip blank
- one duplicate sample.

Background samples of every matrix type should be taken during sampling.

The following additional blank samples are suggested for groundwater samples:

- one standpipe material blank per batch of standpipe material

³ A field blank is not usually taken for soil or sediment samples

- one filter pack (sand or gravel) material blank per batch of filter pack material
- one drilling equipment blank per day
- one sampling equipment (e.g. pump, bailer, etc.) blank per day or every 10 wells (whichever is the more frequent).

Although collection of a range of blank samples is needed to assess the potential for cross contamination of samples, it may be necessary to analyse only a proportion of the blank samples collected. Blank samples that give the best indication of whether any cross contamination may have occurred should be analysed, and other samples may be held for follow-up analysis should a problem be identified.

2.9.3 Duplicate sampling to estimate precision

Duplicate samples are independent samples which are collected as close as possible to the same point in space, and at the same time. They are two separate samples taken from the same source, stored in separate containers and analysed independently. The laboratory should have no indication of the association between the two samples. These duplicates are useful in assessing the consistency of the sampling technique and the precision of the analytical laboratory.

2.10 Documentation and record keeping

2.10.1 Documentation

The following documentation should be prepared before starting the field investigations:

- **Work plan or site sampling plan**
Used to define the exact work requirements for a given site, including sample locations, depths, analytes, etc. Also used to document variations from the standard quality assurance procedures
- **Health and safety plan**
Used to inform workers of potential physical and chemical hazards, health and safety responsibilities, normal work precautions, monitoring requirements and action plans. An example table of contents for a Health and Safety Plan is included as Appendix 2E.

These documents can be used to set out site-specific requirements regarding procedures, sampling and analysis of soils and other environmental media.

2.10.2 Record keeping

A field log book must be maintained by each investigation work group. The log book must be used to record general progress, any deviation from the QA, Work Plan or Site Sampling Plan, and Health and Safety Plans, any changed conditions, health and safety incidents and any other notable observations. These may include a record of unusual or unexpected sub-surface conditions, the presence of perched groundwater, odours or significant Photo Ionisation Detector (PID) readings. Photographing of material removed from bores and pits can be a useful way of recording information. This information should be recorded on the log sheets where relevant.

- Sampling Locations will be located with reference to the site plan and by measuring distances from permanent features identified on the site plan. All sampling locations will be referenced by using a system of unique numbers, for example, a location number and one of the following prefixes:

HA	Hand Auger
BH	Borehole
TP	Backhoe Test pit
GW	Groundwater Monitoring Bore

All sampling locations must be recorded. Testpits should be photographed with a measuring tape and the test pit number in the photo, where practical.

Groundwater monitoring bores may need to be professionally surveyed and marked on a base map using an appropriate co-ordinate system, particularly where bore locations cannot be reasonably defined by reference to site features.

- Sub-surface conditions at every borehole, test pit or auger hole must be logged on standard field log sheets. An example of the field log sheet is included in Appendix 2F.
- All depths must be referenced to the ground surface and recorded in metric units (metres). The elevation of each sample location, relative to an appropriate height datum, should be determined by suitably experienced field personnel taking levels.
- A record of all samples collected must be kept by the field supervisor. This record should incorporate the following information:
 - Job Number
 - Client/Job/Project Name
 - Sampling Location Number
 - Sample Number (as defined in work plan. The Sampling Location Number and Sample Number may be combined).
 - Sampling Depth (where appropriate)
 - Date of sampling
 - Initials of sampling personnel
 - Weather conditions if odour is likely to be problem.
- Each sample will be labelled with the following information, which should correlate with the record of sampling to be kept by the field supervisor:
 - Job Number
 - Client/Job/Project Name
 - Sampling Location Number
 - Sample Number (as defined in work plan. May be combined with Sample Location Number)
 - Sampling Depth
 - Date of sampling
 - Weather conditions if odour is likely to be problem.

For duplicate samples (if the sample is a duplicate sample) and triplicate samples (if the sample is a triplicate sample), do not label the sample for lab as such but make sure this is recorded in the record of sampling to be kept by the field supervisor.

The primary objective of labelling is to give each sample a unique and clearly understood identifier.

- Chain-of-Custody Documentation shall be prepared on site by the field supervisor before the samples are delivered to the laboratory. Its purpose is to trace sample possession from the time of collection through analysis. It is especially important in cases when court litigation might be necessary. A copy of a standard Chain-of-Custody form is included in Appendix 2F. A copy is retained by the field supervisor and a copy is delivered to the laboratory with the samples.

Information to be recorded in the Chain-of-Custody will include:

- Job Number
- Client/Job/Project Name
- Date of Sample Collection
- Chemical Analysis Required
- Preservation requirements and maximum holding times
- Sample Numbers (as defined in work plan)

- Person/organisation delivering samples
- Person/organisation receiving samples
- Waste type

When the samples have been submitted to the laboratory, and the relevant sections have been signed by the person relinquishing and the person receiving the samples, a copy of the Chain-of-Custody form will be sent to the site assessor and the original Chain-of-Custody form will be returned with the certified results sheet.

If the Chain of Custody is extended to include the appropriate information it may also be used as the record of samples collected outlined above.

Record-of-Progress documentation should itemise all activities carried out, including details of equipment placed into the holes, decontamination procedures and sampling episodes. The Record-of-Progress documentation is particularly useful in tracing the installation and sampling of groundwater monitoring bores.

2.11 Field cleaning procedures

An area must be established on site where all sampling equipment can be cleaned without risk of contaminating areas to be sampled, or spreading contamination around or off the site. All field tools which are used for sampling and which come into direct contact with the material to be sampled, must be cleaned and stored as described in this section.

The following field cleaning procedures should be used for cleaning field sampling equipment (e.g. hand augers, trowels, split barrel samplers, bailers, sampling pumps):

- all field tools that cannot be washed in detergent solution should be steam cleaned before starting field sampling and before sampling at each location. It is not practical or safe to steam clean small items of equipment using commonly available steam cleaning equipment
- all smaller sampling equipment should be washed in laboratory grade phosphate-free detergent, rinsed with tap water, rinsed with analytical grade acetone, then rinse in high purity analytical grade deionised water
- all sampling tools should be stored in such a way as to prevent recontamination.

If a drilling rig or backhoe is used for soil sampling or groundwater bore construction, the drill string or backhoe bucket should be steam cleaned and the sampling equipment, e.g. split barrel sampler, cleaned as above. Wastes from equipment cleaning may be sent to the site waste treatment and disposal system, or put into drums for off-site disposal as appropriate. Where tools such as crowbars and shovels do not come into contact with the material to be sampled, a less rigorous cleaning procedure, such as that used for a backhoe (i.e. steam cleaning), may be used.

Where steam cleaning equipment is not available, suitable equipment may be hired. Steam cleaner and high pressure hot water washers are synonymous for the purposes of this document.

2.12 Disposal of sampling wastes

A range of wastes may be generated as part of any sampling programme. Examples of such wastes include:

- washwater and solid residues from cleaning procedures
- waste foil, cloth pads, plastic sheeting, etc. from cleaning and wrapping tools
- excess spoil from sampling locations
- groundwater from bore development and purging.

Each of these wastes may be contaminated and should be packaged and disposed of in accordance with health and safety, dangerous goods and landfill disposal regulations.

Contaminated wastewaters may be disposed of via the site wastewater treatment system, if available, subject to the necessary approvals. Planning for a field sampling programme should include planning for the disposal of waste materials.

2.13 References

1. CCME (1991) "Guidance Manual on Sampling, Analysis and Data Management for Contaminated Sites. Volume 1: Main Report". Canadian Council of Ministers of the Environment, Report CCME EPC-NCS62E, Winnipeg, December.
2. Gilbert, R.L. (1987) "Statistical Methods for Environmental Pollution Monitoring" Van Nostrand Reinhold, New York.
3. NSW/EPA (1995) "Contaminated Sites, Sampling Design Guidelines". NSW Environment Protection Authority, EPA 95/59, September.
4. Smith F. et al. (1988) "Chapter 10: Evaluating and Presenting Quality Assurance Sampling Data" in Principles of Environmental Sampling , L.H. Keith ed., American Chemical Society.
5. Standards Australia (1996). "Draft Australian Standard, Sampling of Soils, Part 1: The sampling and investigation of potentially contaminated soil".
6. USEPA (1991) "Description and Sampling of Contaminated Soils: A Field Pocket Guide" EPA/625/12-91/002.
7. USEPA (1991b) "Risk Assessment Guidance for Superfund, Volume 1, HHEM, Supplemental Guidance, Standard Default Exposure Factors".

Appendix 2A

Quality assurance/quality control approach to site assessment

Overview

Site assessment planning should be based on quality assurance/quality control (QA/QC) principles. This appendix shows the amount of planning needed, and focuses on the way decisions should be made. It presents a formal QA/QC process with defined steps and documents. Although this formal process may not be necessary for every site assessment, a similar level of planning and information collection is essential.

Regardless of the size or complexity of the site contamination or waste evaluation problem, management decisions must be based on information of known quality. Quality assurance must be an integral part of the site assessment process. The basis of a quality assurance/quality control (QA/QC)¹ programme is ensuring that data produced from any part of a study designed to evaluate the problem, is sufficient to support the decision-making process. Every "problem" evaluation should follow a pattern of development similar to that shown in Table 1.

Table 1 Steps followed to ensure the decisions made to solve a problem are based on data of known quality

	Step
1	Define the goal or purpose of the study and how it will be achieved
2	Define the data quality objectives that specify the quality of the data that is acceptable
3	Design a QA plan defining overall QA policy
4	Design a QA plan detailing specific QA and QC requirements for the study
5	Undertake study based on the stipulations established in the previous steps
6	Evaluate data and make decisions

Decision-making may not always require information of the best possible quality. For example, a preliminary investigation of a potentially contaminated site might use a low-cost screening analytical technique, which although sensitive, might respond simultaneously to a number of different species, including the one of immediate interest. This technique would have lower specificity and accuracy, with a tendency for over-estimation of results (have a positive bias). From the outset of the study the investigator should be aware of the limitations of the technique. Its application should be appropriate to the objectives of the study, (e.g. the rapid, cost-effective assessment of a potentially contaminated site to establish if contaminant levels are likely to give rise to an unacceptable human health risk).

For a preliminary screening study, data quality objectives should be defined to overestimate risks. The QA/QC plans would evaluate the techniques' bias by comparing the results with those of a reference method or the analyses of a standard material. Consequently the final evaluation of the study results would be based on a defined set of objectives and on data of known quality.

¹ Quality assurance (QA) and quality control (QC) are concepts which have some degree of overlap. Quality assurance is a system of activities that assures the producer or user of a product or a service that defined standards of quality are met with a stated level of confidence. Quality control differs in that it is an overall system of activities that controls the quality of a product or service so that it meets the needs of users. Quality control consists of the internal day to day control and assessment of measurement, whereas quality assurance is the management system that ensures that an effective quality control system is in place and working as intended.

Similar considerations can be applied to sampling strategies, allowing site investigations to achieve defined objectives cost effectively.

The individual steps shown in Table 1 are discussed in more detail in the following sections.

Defining the goal or purpose of the study

The study goal will usually be defined in terms of a response to a regulatory requirement or potential regulatory requirement (e.g. clean-up notice), commercial or business decisions (sale of land), or assessment of liability for due diligence or accounting purposes.

Before the study starts, its goal or purpose should be defined concisely, but with sufficient detail to allow all parties to understand it clearly. An example goal may be to determine the suitability of a particular site for redevelopment for unrestricted residential use, the requirements for which are defined under local legislation, regulation or guidance.

In Australia, the Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines set out the general requirements for the assessment and management of contaminated land, however more detailed requirements are established on a State level (e.g. Victorian Environment Protection Authority auditing system). In New Zealand most studies will be directed towards fulfilling the requirements of the Resource Management Act (1991) and to a lesser extent, the Health Act (1956). The Resource Management Act is based on the philosophy of sustainable management and is an effects-based legislation. The Resource Management Act requires that processes (current or historical) shall not cause an actual or likely adverse effect on human health or on the environment downstream of the operation⁴.

Guideline levels, where applicable, are an essential component of any study and must be incorporated into study goal statements at an early stage. Studies which are part of due diligence audits, transfer of land or in quantifying liability, (whilst initiated in a legal, commercial context), must be designed with reference to the relevant local legislation or regulations.

Data Quality Objectives

Data Quality Objectives (DQOs) describe the level of uncertainty that a decision-maker is willing to accept in results derived from environmental data. DQOs then allow for data of known quality to be generated as part of the study.

DQOs may be qualitative or quantitative. Quantitative DQOs contain quantitative terms such as standard deviations, percent recoveries and concentrations whereas qualitative DQOs are descriptive and may refer to specific actions that would be taken in a particular instance.

DQOs are developed for a study by stepwise consideration of relevant issues. They might involve the following decision-making stages:

- state the problem to be resolved
- identify the decisions that need to be made
- identify the inputs to the decision
- narrow the boundaries of the study
- develop a decision rule
- develop uncertainty constraints
- optimise design for obtaining data

One advantage of the DQO approach is clear communication at the beginning of the study between the teams involved with study management, sampling, analysis and data interpretation. The development of DQOs may involve completion of a mental checklist for a relatively simple site, or preparation of a separate scoping document for a large and complex investigation. They are a part of good project management and become part of the record of due diligence.

⁴ Note also, the RM Act S.107(g) refers to “Any significant adverse effects” on aquatic life.

Once programme goals and DQOs have been appropriately defined, a programme must be designed to meet them. QA and QC measures should be used to monitor the programme and to ensure that all data generated are suitable for their intended use.

A useful approach for developing a manageable structure for appropriate QA/QC measures is the preparation of separate QA programme and QA project plans. Example DQOs are presented in Appendix 2B. Where possible reference has been made to later sections in this document which illustrate aspects related to specific points in the QA project plan.

Data quality indicators

A data quality indicator is a property that can be used to assess the quality of data acquired in a sampling programme and may be used to assess whether data quality objectives have been met. Quantifying or describing data quality indicators dictates many of the quality assurance procedures that will be adopted during the sample design, collection and analysis programme. Data quality indicators therefore provide the conceptual bridge between specifying the data quality required and measuring it through quality assurance practices (such as the acquisition of blank samples, field replicate samples etc.).

The United States Environment Protection Agency (USEPA) lists five data quality indicators that it considers important in contaminated site assessment: precision, bias, representativeness, completeness and comparability.

Precision - can be described as a "measure of mutual agreement among individual measurements of the same property". More simply, it can be thought of as a measure of how greatly an analytical result varies on repeated analysis of a sample. It is best expressed as a standard deviation or variance. In contaminated site sampling components associated with sampling design, sample collection and analysis will contribute to the overall estimate of precision. It is not possible to estimate the contribution from sampling design. Combined sampling and analytical precision can be estimated by collection and analysis of duplicate (i.e. co-located) samples. Analytical precision alone can be measured by repeated analysis of laboratory replicated samples.

Bias - can be defined as "the degree of agreement of a measurement (or an average of measurements) with an accepted reference or true value". If "X" is the measurement value and "T" the true value then bias is often expressed as the difference between the two values (X-T), or a difference as a percentage of the reference or true value ($100 [X-T]/T$), or as a ratio (X/T).

For contaminated site evaluation, as with variance, the bias parameter may contain components from sample design, collection and analysis phases. Again the contribution from sampling design cannot be estimated. However, combined sampling and analytical steps bias can be estimated by using collected samples spiked in the field. In this process the field sample is subdivided in the field, at least one fraction is spiked with a known quantity of the target analyte and each fraction is analysed. The percent recovery of the spike is calculated. By combining several such results an average percent recovery or bias is obtained (i.e. average percent recovery - 100%).

Representativeness - expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point or an environmental condition.

When estimating an average concentration over some region, representativeness of a sample is assured by random sampling from the target population. Maximum concentration estimates over the same region require scientific judgement to choose sampling locations at or near the maximum.

Completeness - is a measure of the amount of valid data obtained from a measurement system, compared to the amount that was expected to be obtained under correct normal conditions.

Use of the completeness parameter acknowledges that data may be lost by a number of different routes including specific sampling sites being inaccessible at the time of sample collection,

breakage or spilling of sample during handling or shipping and sample holding time being exceeded before analysis.

Circumstances, such as where statistical parameter tests are used to assess data, may dictate a certain level of completeness, so contingency plans for resampling or re-assessment of the sampling site should be made.

Comparability - expresses the confidence with which one data set can be compared to another.

Comparability between different monitoring exercises can be assessed by considering such variables as sample site selection, how experimental results are reported (corrected to the same standard conditions e.g. dry weight, standard temperature and pressure etc.) and similarity of data quality measurement steps.

Quality Control - Samples of use in assessing the quality of environmental data are presented in Appendix 2D.

The QA programme plan

The QA programme plan is a document that commits the study overseers to a specific QA policy and sets out the requirements for data needed to support programme objectives. The QA programme plan describes the policies, organisation, objectives and functional responsibilities for achieving data quality goals.

The five major parts of a QA programme plan are as follows:

- a statement of the purpose and importance of a QA plan
- a description of the procedures that will be used to carry out the programme
- a description of the resources committed to perform the QA work
- an identification of the individual projects or packages of work in a study that require QA plans
- a description of how QA implementation will be evaluated.

The QA project plan

The QA project plan is a technical document that provides unified information on the project for all parties and provides details of specific QA and QC requirements. The QA project plan also specifies any QA/QC activities required to achieve the data quality goals of a project and describes how all data is to be assessed.

The QA project plan is readily divided into sections addressing different aspects of the assessment (e.g. sampling, analysis etc.). Alternatively a number of generic stand-alone documents may be prepared, each addressing an aspect of the work, with a simple site-specific work plan to be developed as part of each project.

A list of essential QA/QC activities and the area under which they would apply are presented here.

Overall project management

- project description
- project organisation and designated responsibilities
- quality assurance objectives for the experimental data including precision, accuracy, completeness and comparability
- experimental design and analytical procedures
- ensuring on-going quality assurance reports to management
- corrective actions
- defining statistical techniques for assessing the experimental data

Field sampling

- sampling network design
- selection of specific sampling sites

- sampling methodology - detailing procedures to be used in the field
- sampling devices, storage containers and preservatives
- sample custody, transportation, preservation, and storage
- replicate sampling
- documentation needed
- special operating conditions (e.g. heat, light, reactivity etc.)
- information on health and safety practices in sampling and field testing operations
- accepted procedures designed to control and define errors associated with field measurements.

Laboratory analysis

- sample custody
- sample storage
- instrument selection and use
- analytical methodology and standard operating procedures.
- calibration procedures and frequency
- reference standards and quality control standards
- internal quality control checks and frequency
- replicate analyses
- blank and spiked samples
- intra and inter-laboratory QC procedures
- specific routine measures to be used to assess data quality
- data reduction, validation, verification and reporting.

Practical implementation of the QA/QC framework

Assessment stages at which QA/QC elements should be reviewed

- on identifying the need for site assessment
- on seeking proposals from consultants
- on engaging a qualified consultant
- on receiving a report from the consultant
- on deciding further action.

In the above context the timing and responsibility for each of the QA/QC tasks may be as follows:

Defining the goal or purpose of the study and how it will be achieved

This should be carried out by the site owner or operator before engaging the consultant to undertake the investigation. It is one of the principal items in the brief provided to consultants. Although the owner or operator should define the goal of the study, inputs should be sought from regulatory authorities and consultants on the legislative or regulatory requirements.

Data Quality Objectives

The consultant needs to define the DQOs as an integral part of the quote for the study (refer to examples presented in Appendix 2B). The DQOs define the scope of work to scope the cost of the study (e.g. how many samples to take, what analytical methods to use etc.).

QA programme plan

The QA programme plan is a statement of the commitment to QA for the study and the outline of how this will be implemented. It would often be included in the consultant's proposal or documentation accompanying the quotation.

QA project plan

Much of the information included in the QA project plan will be normally addressed as part of the following generic documentation:

- internal company (consultant) Quality Assurance procedures, such as those complying with ISO 9000. (e.g. project organisation and responsibilities project planning, management, reporting of corrective action).
- generic field sampling manuals or procedures developed by consultants as the documented procedures employed in site assessment field investigations. An example of such procedures are presented in Appendix 2C.
- documented laboratory procedures (specific to each laboratory, and in accordance with relevant registration (e.g. sample custody and storage, instrumentation)).

A site-specific work plan should also be prepared. If an item that is normally included in the generic documentation needs to be altered (e.g. number of duplicate samples to be analysed by an independent laboratory), this should be explicitly noted in the work plan. Other items that would normally be in the work plan include: the chemicals of concern; QA objectives for experimental data (e.g. precision); experimental design and analytical procedures; use of statistical techniques for data evaluation; sampling network design and definition of sampling locations; and analytical detection limits.

Appendix 2B

Example of the process of developing Data Quality Objectives (DQO)

- **State the problem to be resolved**

For example, to determine whether there is the potential for a significant adverse effect on human health or the environment from soil groundwater contamination at a gasworks site.

- **Identify the decisions that need to be made**

For example, does the site pose an immediate risk to human health or the environment? Is there a requirement for immediate remedial action? Is there potential for an adverse effect on human health or the environment in the longer term? Is there need for further, more detailed, investigation to define the extent of contamination, the current impact on human health and the environment and the specific requirements for any remedial action in the longer term?

- **Identify the inputs to the decisions**

For example, the contaminants that may be present at the site may be at concentrations near or above the guideline levels; the concentration of contaminants in soil, groundwater surface water, dust that may have accumulated on surfaces of structures, and in the air; the effects the contaminants may have on human health and the environment, and the concentration in each of the media at which those contaminants have the potential to have a significant impact on human health and the environment.; the level of protection required for human health and the environment, i.e. is it a pristine ecosystem or an urban environment.

- **Narrow the boundaries of the study**

For example, to undertake a sampling programme targeted toward identifying contaminant concentrations in the areas most likely to be contaminated, in order to provide a cost effective assessment of whether there is the potential for a significant adverse effect on human health or the environment.

- **Develop a decision rule**

For example, if the identified concentrations of contaminants in the environment exceed the guideline values nominated in the Health and Environmental Guidelines for Selected Timber Treatment Chemicals, more detailed investigation to determine the extent of contamination is required.

- **Develop uncertainty constraints**

For example, that the Relative Percent Differences⁵ (RPD) shall be less than 30% for the results of QA/QC check analyses undertaken by an independent laboratory on duplicate samples; that the sampling programme will give a high level of confidence (notionally 95%); that a significant area of potential contamination, (say greater than 10 sq.m) would be sampled (such confidence would be measured, in effect, by the independent review of the plan based on professional judgement of an experienced, senior professional in the site contamination area.)

- **Optimise design for obtaining data**

⁵ $RPD(\%) = (C_o - C_s) / [(C_o + C_s) / 2]$
 where C_o = concentrations in original sample
 C_s = concentrations in duplicate or split sample

For example, review sampling plan to ensure all areas of significant potential contamination have been targeted, and that within an area of potential contamination the sampling is such that the level of uncertainty about whether an area of significant contamination may be missed is consistent with the constraint about uncertainty.

- **Example Data Quality Objectives**

Example DQOs for a gasworks site assessment are presented as follows:

- that the investigation shall be sufficient to determine whether there is the potential for a significant adverse effect on human health or the environment
- that the data shall at least be representative of the higher contaminant concentration that is likely to be encountered at the site, in order to determine whether a further detailed evaluation of the extent of contamination is required. (On this basis a targeted cost-effective sampling programme may be used to achieve this objective)
- that the level of confidence that a significant area of contamination shall be sampled shall be notionally greater than 90%
- if a contaminant concentration in a sample is reported as not detectable, the confidence that the actual concentration is less than one fifth the relevant acceptance criteria shall be greater than 90%
- that the reported concentration in a sample shall be representative (e.g. within +/- 50%) of the actual concentration in the media in situ at the point of sampling (this can be notional only as it cannot be measured)
- the RPD of duplicate samples analysed by independent laboratories shall be less than 30%.

Appendix 2C

Sampling plan and protocol checklists

Sampling plan checklist

What are your data quality objectives (DQOs)?

- What will you do if your DQOs are not met (i.e. resample or revise DQOs)?

Do programme objectives need exploratory or monitoring sampling, or both?

Have arrangements been made to obtain samples from the sites?

- Have alternative plans been prepared in case not all sites can be sampled?

Is specialised sampling equipment needed and/or available?

Are samplers experienced in the type of sampling required available?

Have all analytes been listed?

- Has the level of detection (LOD) for each been specified?
- Have methods been specified for each analyte?
- What sample sizes are needed based on method and desired LOD?

List specific good laboratory practice.

- Are there percentages or required numbers and types of QC samples?
- Are there specific instrument tunings or other special requirements?

What type of sampling approach will be used?

- Random, systematic, judgemental, or combinations of these?
- Will the type of sampling meet your DQOs?

What type of data analysis methods will be used?

- Geostatistical, control charts, hypothesis testing, etc.?
- Will the data analysis methods meet your DQOs?
- Is the sampling approach compatible with data analysis methods?

How many samples are needed?

- How many sample sites are there?
- How many methods were specified?
- How many test samples are needed for each method?
- How many control site samples are needed?
- What types of QC samples are needed?
 - Will the QC sample types meet your DQOs?
- How many of each type of QC samples are needed?
 - Are these QC samples sufficient to meet your DQOs?
- How many exploratory samples are needed?
- How many supplementary samples will be taken?

Number of samples = Test + control + QC + Exploratory + Supplementary

- Test samples = Methods x Sample sites x Samples per site

- Control samples = Methods x Sample sites x Samples per site
- QC samples = Methods x Type of QC sample x % Needed to meet DQOs
- Exploratory samples = (Test samples + Control samples) x 5 to 15%
- Supplementary samples = (Test samples + Control samples) x 5 to 15%

Appendix 2D

Field quality control samples

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

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

Appendix 2E

Site specific health and safety plan for investigation of subsurface contamination at gasworks sites

Table of contents

- 1 Introduction
- 2 Project organisation
 - 2.1 Names and numbers of contact people
- 3 Site description
- 4 Hazard evaluation
 - 4.1 Chemical hazards
 - 4.2 Physical hazards
- 5 Hazard control
 - 5.1 Project planning
 - 5.2 Site entry
 - 5.3 Personal protective equipment
 - 5.4 Site safety equipment
 - 5.5 Precautionary procedures
 - 5.6 Air quality monitoring
 - 5.7 Underground services
 - 5.8 Training
- 6 Levels of protection
- 7 Decontamination
 - 7.1 Green level of personal protection
 - 7.2 Amber level of personal protection
 - 7.2 Red level of personal protection
- 8 Emergency procedures
 - 8.1 General
 - 8.2 Action plan
 - 8.3 Emergency site evacuation procedures
 - 8.4 Accident reporting
- 9 Changed conditions

Appendix 2F

Field logs

Borehole Log Report

Client:				Page 1 of							
Job Name:				Job Number							
Borehole location			Borehole depth			Contractor					
Date hole commenced			RL casing			Driller					
Date hole completed			RL surface			Drill rig					
Logged by			Datum			Drilling fluid					
Checked by											
Drilling method	Piezometer construction details				(1) DTW	Depth (m)	Graphic log	Material description	Field sample (analysed)	Field rank	PID reading (ppm) Other notes
						1.0					
						2.0					
						3.0					
						4.0					
						5.0					
						6.0					
						7.0					
						8.0					

Testpit Log Report

Client			Page 1 of			
Job Name			Job Number			
Test pit location		Test pit depth		Contractor		
Date pit commenced		RL surface		Excavator		
Date pit completed		Datum		Bucket size		
Logged by		Surface conditions				
Checked by						
Depth (m)	(1) SWL	Graphic Log	Material description	Field sample	Field rank	PID readings (ppm), water inflow, stability/Other notes
0.25						
0.5						
0.75						
1.0						
1.25						
1.5						
1.75						
2.0						

Chain of Custody

Client			Analytes										Sample by					Primary lab						
Project													Signature					Secondary lab						
Job no													Sampled by					Contact						
													Signature					Method of shipment						
Sample No	Date	Preservative														Containers								
																Jar	Vial	500ml	1 litre	2 litre	Winchester	Other	Comments	