Draft

Guidelines for groundwater investigation and monitoring for landfills

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Call for comment

This draft EPA guidelines for groundwater has been released for public comment.

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1 INTRODUCTION

This guideline has been produced to advise proponents, developers, operators and licensees of landfill sites (and their environmental consultants) on methods to be used to monitor groundwater at landfill sites. It provides information on the desktop study, field investigations, monitoring, review, risk assessment and data management processes that are required for monitoring how landfills affect groundwater. The monitoring program may include sampling and testing of landfill leachate to identify potential groundwater pollutants.

The primary objective of monitoring is to gain information that can be used by the Environment Protection Authority (EPA) and the owners and operators of landfills to minimise risks to groundwater. The purpose of monitoring is to:

- demonstrate that the landfill is not having an adverse effect on the environment
- show that leachate is being adequately controlled
- indicate whether further investigation is required, or additional control measures are required to prevent, reduce or clean up groundwater pollution
- determine when a closed site is no longer a risk to human health or the environment.

In South Australia the key pieces of legislation that cover groundwater protection are the *Natural Resource Management Act 2004*, *Public and Environmental Health Act 1987*, and *Environment Protection Act 1993* (the EP Act) and its associated policies.

The EP Act requires that:

- where applicable, people who are engaged in polluting activities must improve their environmental performance
- polluters must bear a share of the costs that arise from their activities
- regular monitoring and reporting on environmental quality must be undertaken to ensure compliance with statutory requirements and to maintain a record of trends in environmental quality
- the water resources minister may, after consultation with the Authority, exercise such powers as he or she considers necessary to protect the quality of underground water in a water protection area.

In preparing this guideline, reference has been made to the *National Environment Protection (Assessment of Site Contamination) Measure* or NEPM (NEPC 1999), guidance on carrying out hydrogeological investigations, draft guidance on the management of water quality that has been used widely in the Australian water industry, and guidelines prepared in other countries, such as in the United Kingdom, the European Union, and the USA.

Figure 1 is a flow diagram that illustrates the overall process of landfill groundwater monitoring.

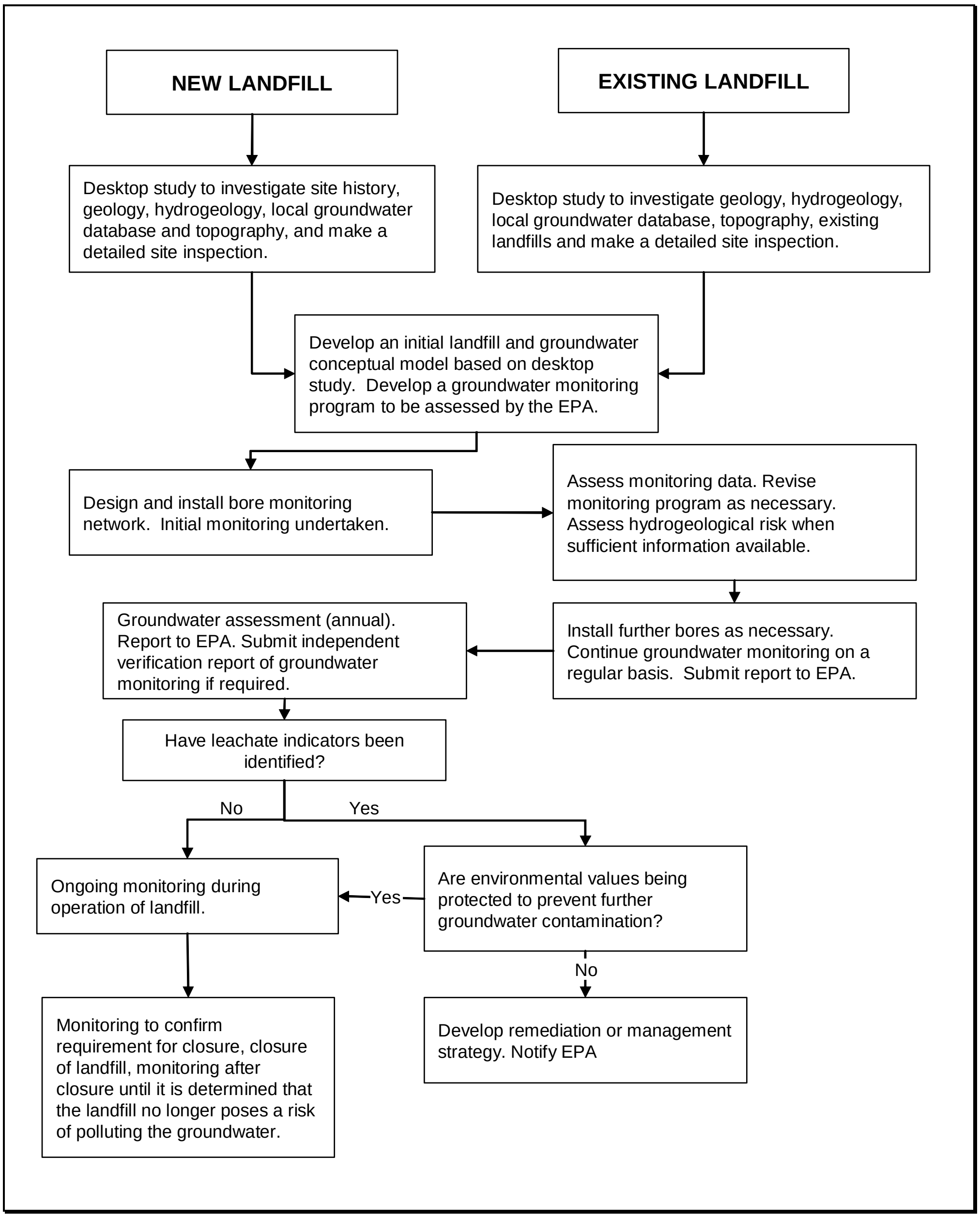

Figure 1 Overall process of landfill groundwater monitoring

2 OVERVIEW

This document outlines the investigation and monitoring that needs to be undertaken to ensure that groundwater is protected from leachate emanating from landfills. Details of the format and level of reporting required by the EPA are also given.

The landfill owner, operator or licensee must engage an experienced and appropriately qualified environmental professional to assess the site for its potential impacts on groundwater. To determine the risk to the groundwater from a landfill the EPA may require the licensee to:

- undertake a preliminary hydrogeological assessment to determine the risk of the landfill to groundwater
- develop a conceptual model of the landfill to establish the relationship between the landfill and groundwater
- investigate in detail whether the landfill has, or is likely to, impact on groundwater
- develop a regular groundwater monitoring program for the landfill.

The requirements of the monitoring program will be initially determined from an understanding of the design and operation of the landfill and the knowledge of the groundwater in the immediate vicinity of the landfill.

As more information is gained from regular groundwater monitoring, it can be expected that the monitoring program will need to be revised to reflect the issues that are identified.

In an existing landfill where there has been no regular monitoring, or the monitoring does not reflect the potential pollutants in the landfill and the extent and nature of the landfilling operation is uncertain, then the relationship between the landfill and the groundwater may have to be investigated.

As landfills contain wastes that may continue to degrade for many years after the closure of the landfill, it may be necessary to monitor a landfill for at least 25 years after landfilling has ceased. This monitoring will continue until there is sufficient evidence that the site is stable and poses an acceptable risk.

The phases in the life of a landfill and the requirements for groundwater monitoring for use in the assessment and management process are summarised in Table 1.

Table 1 Phases in the life of a landfill, and monitoring requirements

Phase	Requirements for monitoring
Planning and approval	Baseline monitoring to support the planning and approval process and to obtain data on the initial condition of the system Groundwater is monitored to determine its quality before commencing landfilling
Operation (construction, filling and closure)	Regular groundwater monitoring for specified parameters determined by the nature of the landfill to determine the nature and extent of any potential impacts on groundwater In the case of an existing landfill with an unknown or inadequate history, an initial investigation may be undertaken to establish the requirements of a regular monitoring program
Site closure	Continuation of the regular monitoring program using this data to identify the post-closure groundwater monitoring program
Post-closure and after-care	Regular groundwater monitoring is continued, the frequency of monitoring may be varied, depending on potential or existing risks to groundwater In the case of a landfill that has been closed and has had an uncertain history, monitoring may be used to investigate and develop an understanding of the groundwater in the vicinity of the landfill and the extent to which the landfill has interacted and still interacts with it For more detailed information refer to the *Guidelines for environmental management of landfill facilities (municipal solid waste and commercial and industrial general waste)* (EPA 2007)
Completion of monitoring	To support and justify termination of monitoring

3 HYDROGEOLOGICAL ASSESSMENT

3.1 Overview

A hydrogeological assessment is required for all new landfills and may be required for an existing landfill if the landfill is impacting on groundwater, or if the current groundwater monitoring program is not adequate or if there is no groundwater monitoring program for the landfill.

The objective of the hydrogeological assessment is to develop an understanding of the hydrogeology around the landfill and the relationship between groundwater and the landfill. A hydrogeological assessment will identify the level of risk that the landfill poses to the groundwater. It is likely that the hydrogeological assessment will require field investigations. These may take the form of preparing a detailed site history and/or the installation of groundwater monitoring wells and sampling to determine the types of waste deposited in the landfill. The assessment may include a preliminary hydrogeological interpretation and a detailed landfill site investigation.

3.2 Preliminary hydrogeological interpretation

The preliminary hydrogeological interpretation is an initial evaluation of the site. It is made up of:

- a desktop study of the site (including geological and hydrogeological features)
- a detailed site inspection (including related onsite activities)
- development of a conceptual hydrogeological model of the site.

The preliminary hydrogeological interpretation should be of sufficient scope to indicate whether the landfill has affected groundwater, or is likely to in the future. It will also indicate whether a more detailed site investigation is needed.

As part of the development application process for new landfills, the initial hydrogeological conditions at the site must be investigated before development approval can be given. It is likely that, on conclusion of the initial appraisal, the site will need to be investigated further.

For existing landfills, a hydrogeological investigation may be necessary to make up for deficiencies in data on the hydrogeology of the site. If there is not enough information for the EPA to understand the hydrogeological conditions beneath the landfill site, a more detailed assessment will need to be completed.

A preliminary hydrogeological interpretation for an existing landfill must include information on its design and operation, including what types of wastes have been deposited in it. In many cases only limited information will be available, and more comprehensive field investigations to understand the site conditions will be necessary.

The initial appraisal of the hydrogeology of the site involves:

- collecting information on the site history and its surroundings from literature, public registers and a site inspection; for an existing landfill this will involve determining the types of wastes and the areas of the site that have been filled
- developing a conceptual model of the hydrogeological setting of the landfill and its surrounds. This model will indicate the risk that the landfill and its associated operations may pose to groundwater. Depending on the type of waste deposited, a more detailed investigation may be required. The requirements of a conceptual model are discussed in more detail in Section 3.3

- using the conceptual model to determine what investigations are needed to develop a regular groundwater monitoring program for the site. For an existing landfill this may include developing a remediation or management strategy if the landfill has impacted on the groundwater.

There are various guidelines used in Australia for conducting initial desktop studies and appraising sites and facilities. These can be referred to for further information. Section 3 of Schedule B (2) of the NEPM (NEPC 1999) discusses background information that can be useful for defining the site. In particular, information obtained needs to characterise site geology, hydrogeology and history of adjacent land uses. This includes, for example:

- **geology:** information on the geology underlying and surrounding the landfill, which will be available from existing borehole records or from geological maps
- **hydrogeology:** information on the aquifers at the site and in the region. This includes depth, types, quality, and hydraulic properties including permeability, and users and environmental receptors
- **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 contamination impact should be identified where practicable.

Section 5 of Schedule B (2) of the NEPM (NEPC 1999) discusses groundwater investigation approaches including in situ and ex situ technologies. 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
- anolyte specific characteristics
- financial/logistical constraints.

3.3 Conceptual model

A conceptual model is a simplified representation of the physical hydrogeological system and its hydrological behaviour. The conceptual model is usually presented graphically as a cross section or a block diagram with supporting documentation that outlines the essential system features. The conceptual model is fundamental to hydrogeological assessment. It describes the groundwater in the vicinity of the landfill and how the landfill interacts with the groundwater. The conceptual model is used as a basis for developing the monitoring program and needs to reflect site conditions accurately.

The conceptual model would include at a minimum, but is not limited to, the following:

- representation of how surface water bodies (such as rivers and lakes) interact with groundwater and the landfill
- the relationship between the base of the landfill and the groundwater (the base of some landfills is below the water table so dewatering may be required)
- the effect that the landfill would have on local groundwater flow direction and rate, level and quality; this will include maps, plans, cross sections, any existing groundwater quality results, and schematic diagrams of the environmental setting
- relationships between different aquifers at the site, and the potential for groundwater contamination from them.

Developing the conceptual model of the landfill and groundwater interaction involves describing the geology, hydrogeology (groundwater) and hydrology (surface water) in the vicinity of the landfill. The design, construction and operation of the landfill and how it could interact with the groundwater and surface water should be indicated. Possible sources of pollution (such as leachate) and the pathways and receptors should be identified, and the processes that are likely to occur along each of those source–pathway–receptor linkages described.

Figure 2 illustrates the various hydrology, hydrogeology and water balance components of a landfill in schematic form.

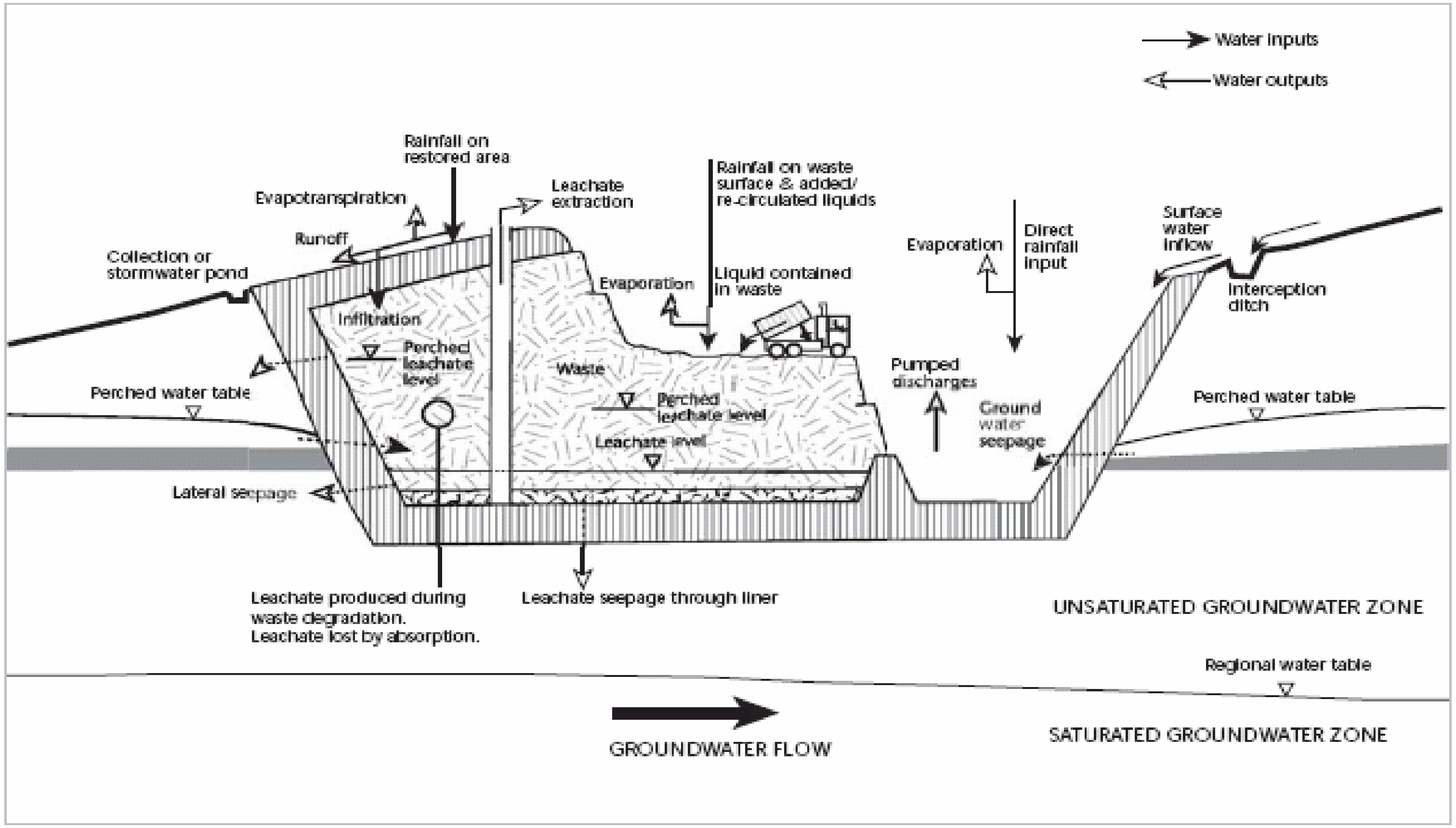

Figure 2 **Schematic representation of hydrology, hydrogeology and water balance components of a landfill (Source: UK Environment Agency 2002)**

3.4 Landfill site field investigations

A site investigation must be undertaken to validate the conceptual model for the site and to fill in any data gaps that may arise in the development of the conceptual model.

As part of the development application process for all new landfills a site investigation must be undertaken in conjunction with the development of the conceptual model for the site. The level of assessment and information that is required in the site investigation must reflect the level of risk that the landfill poses (refer to Section 4).

A detailed landfill site investigation involves:

- validation of the conceptual model
- assessment of data from the preliminary hydrogeological interpretation
- identification and confirmation of sources of pollution
- provision of comprehensive information on the nature, extent and concentration of the pollutants (eg mobility, leachability, solubility, etc)
- detailing the trigger levels to be used for the site
- assessing the sensitivity of the receiving environment
- analysing the risk posed by the landfill to groundwater
- identifying potential off site impacts on soil, sediment, groundwater, surface water, air and biota
- providing a comprehensive geological and hydrogeological assessment.

Landfills in areas with the potential to compromise water quality concentration levels such as those listed in the *Environment Protection (Water Quality) Policy 2003* will necessitate a more comprehensive and detailed site investigation and assessment than for a similar site in a less sensitive area, (for example, landfills that intersect an aquifer which discharges into a nearby ecosystem, or that may be used for a drinking water supply, or landfills that are adjacent to a high quality (low salinity) aquifer.

Alternatively, landfills that contain highly toxic and leachable wastes may require a more comprehensive and detailed site investigation. In all cases, however, where potentially contaminating wastes have been deposited, site specific data for key constituents that may be in the wastes must be provided.

The landfill site investigation needs to be undertaken in accordance with the following guidelines:

- EPA Guidelines: *Regulatory monitoring and testing: Groundwater sampling* (EPA, June 2007)
- AS5667.1: *Water Quality—Sampling Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples* (Standards Australia, 1998)
- *Murray–Darling Basin groundwater quality sampling guidelines, Technical report No 3, Groundwater Working Group* (Murray–Darling Basin Commission 1997)
- *NEPM* (NEPC 1999).

These standards are reviewed and updated regularly and there may be discrepancies between them and the methods in this guideline. The EPA will endeavour to update the guideline to reflect changes in standards. However, for the purpose of monitoring, these guidelines take precedence.

3.5 Monitoring

Before designing a monitoring program, the objectives should be defined. These could include:

- preliminary sampling as part of a baseline study
- validating the conceptual model and filling in gaps in data
- determining the nature, extent and magnitude of pollution from an existing landfill
- provision of meaningful and accurate data on which to base human health and/or ecological risk assessments
- provision of validation data to demonstrate successful remediation of a site, or to show that a landfill after closure no longer poses a risk to the environment.

Establishing and conducting monitoring involves:

- setting the objectives and standards for monitoring
- designing the monitoring program to meet the objectives
- installing and maintaining the monitoring infrastructure
- gathering data
- comparing the data with water quality criteria and trigger levels
- responding to any problems by further monitoring, developing hydraulic or other controls (eg barriers), or by remediation.

4 GROUNDWATER RISK ASSESSMENT

The objective of risk assessment is to gain an understanding of the risks that a landfill may present to groundwater and human health, both current and future. The risk is then used to determine the landfill class and to determine the level of controls (such as buffer distances, base liner system, leachate contamination system) and the level of assurances (such as monitoring) required for a landfill. More information on the landfill classes, the issues that determine the landfill class and the recommended controls for each class can be found in *EPA guideline–Environmental management of landfill facilities* (January 2007).

For new landfills, the EPA will require risk to be assessed during the landfill site investigation stage. A preliminary risk assessment may be made as part of the preliminary hydrogeological interpretation.

The EPA has developed a staged approach to the level of detail required by a risk assessment. Assessment of risk commences with a risk screen and then progresses to greater levels of detail as necessary. The three levels of risk assessments are:

- **risk screening:** determination of whether the landfill may pose a risk to groundwater
- **simple risk assessment:** undertaken when potential sources, pathways and receptors can be defined as having probable linkages
- **detailed risk assessment:** undertaken when pathways, sources and receptors have been shown to be linked and there is a possibility that the receptors will be impacted.

A risk assessment should determine the risk to groundwater resources and other sensitive receivers that the groundwater supports in the short and long term. The risk assessment should:

- screen and prioritise all actual and potential risks to groundwater and the receiving environment
- determine the concentrations of pollutants or indicators, to be estimated for each receptor. The selection of pollutants or indicators should reflect the nature of the material in the landfill. The assessment should take into account attenuation processes in any landfill liner and unsaturated zone, and dilution and attenuation in groundwater
- determine physicochemical and bioavailability characteristics of contamination indicators
- estimate the changes in concentration of contaminants with time; this should include predictions of changes in leachate quality and quantity over time
- identify and assess events and incidents that could give rise to adverse effects (such as failure of an operational system)
- systematically evaluate landfill systems and identify hazards and their source, receptors, exposure pathways, and the potential for effects on receptors
- assess risks arising from normal operations
- assess, and provide input to, the design of landfill containment and control systems, and in the design and implementation of a monitoring program, and in the interpretation of the information arising from the monitoring program
- assess the long and short term performance of landfill engineering and management systems. It should be noted that leachate quality will generally improve post-closure over the long term. Drainage systems may be assumed to fail after active management ceases. The capping system may be subject to some settlement, and similar assumptions may apply to other elements of the capping as for the liner systems

- consider the risks posed by the landfill post-closure as well as during its operation
- develop appropriate contingency measures to manage the risks, including the development of control and trigger levels and periodic review
- incorporate the requirements of the WQEPP and any other relevant policies.

4.1 Risk screening

Risk screening is used to investigate whether a landfill is, or is potentially, a risk to receptors. The process involves the identification of sources, the pathways and receptor linkages. The likelihood and consequences of each pollution linkage is also assessed. Where the linkage is incomplete, then the risk is not considered any further.

Appendix E of *AS4360*: Risk management (Standards Australia 2004) provides further information on defining and classifying risk.

Based on the assessment of likelihood and consequences, the risks are prioritised. More detailed risk assessments will be required for risks determined to be significant.

4.2 Simple risk assessment

A simple risk assessment involves:

- assessing the receiving environment’s sensitivity
- assessing the predicted impact of the landfill on groundwater and surface water quality
- a systematic identification and assessment of risks, events and incidents that could have adverse effects (such as failure of an operational system)
- simple quantitative calculations and comparisons using conservative (worst case) input parameters, assumptions and methods, to consider what could happen under normal operation and if the events and incidents found above should occur
- risk management decisions based on the outcome of the assessment (this may include engineering options).

In general, the simple risk assessment may be sufficient where it is clear from the model and the risk screening that:

- the likelihood of trigger levels being exceeded is minimal, eg the landfill is on low permeability strata remote from groundwater usage points or surface water
- sources, pathways and receptors can be defined with sufficient certainty so as to be confidently represented by conservative inputs, models and assumptions. Note that if a lack of meaningful data makes outcomes uncertain, a detailed risk assessment may be required.

4.3 Detailed risk assessment

A detailed risk assessment is a quantitative assessment and should involve probabilistic techniques. Detailed hydrogeological risk assessments require specialist expertise and should therefore be performed by an experienced hydrogeological risk assessor. It is beyond the scope of this document to provide detailed information on how to assess the hydrogeological risk of landfills.

A detailed risk assessment may have to be undertaken if:

- sources, pathways and receptors are not well defined

- the site setting is sufficiently sensitive to warrant detailed assessment (eg where the landfill is on a permeable strata containing an important aquifer)
- there is uncertainty as to the sources, pathways or receptors (eg variable leachate quality, undefined groundwater flow patterns).

A detailed risk assessment should incorporate the following:

- the hydrogeological and hydrological settings in which the site is located, including the various aquifers in the vicinity of the landfill, the relationships between them and the presence and effectiveness of confining layers. This should already have been done as part of the landfill site investigation
- an investigation into the sensitivity of water receptors and the likelihood of environmental impacts over the life of the landfill
- quantification of the likely magnitude of environmental impacts of leachate generation and migration
- reference to Schedule B(4) Guideline on Health Risk Assessment Methodology, Schedule B(5) Guideline on Ecological Risk Assessment and Schedule B(6) Guideline on Risk Based Assessment of Groundwater Contamination of the NEPM (NEPC 1999) which details the processes involved in risk assessment
- quantification of source, pathway and receptor links over the life of the landfill, and determination of how the transport of pollutants along the linkages can be limited
- indicative completion criteria that can be used to demonstrate that the landfill is no longer capable of harming human health or the environment after it has been decommissioned (this may involve, for example, establishing a trend for improving leachate quality).

4.4 Trigger levels

Trigger levels are the concentrations of monitored pollutants or indicators that, if exceeded, indicate that the landfill may be impacting groundwater or another sensitive receiver. They are determined during the landfill site investigation phase and must be referred to in groundwater monitoring reports when evaluating results. Trigger levels for a landfill site are site specific and should be based on environmental values. You should use trigger levels as a management tool rather than as a compliance tool.

Where groundwater is being monitored, the appropriate trigger level depends on the discharge location and the environmental value of the groundwater. Depending on the location of the site, assessment against more than one criterion (eg potable, aquatic ecosystem) may be required.

It is the responsibility of the professional investigating the landfill site to recommend trigger levels. However, if the investigator fails to recommend trigger levels, or where the EPA considers that the trigger levels are not appropriate, the EPA may decide the trigger levels for the site.

Trigger levels should not exceed the guideline values in the WQEPP or, where criteria are already exceeded, the concentrations should not further exceed the criteria. Note that Schedule 2 of the WQEPP does not list guideline values for every known substance. Where a substance is not listed, levels in other documents may be applicable, eg *Water Quality Guidelines for Fresh and Marine Waters* (ANZECC 2000).

Important things to consider when setting trigger levels include:

- levels should be set for each monitoring location that indicate performance of landfill containment systems and verifies that pollution has not occurred. These monitoring points include points where pollutants or indicators are generated and are controlled (eg leachate concentration, leachate level in the leachate sump, or presence of leachate in drainage systems), groundwater monitoring wells immediately down the hydraulic gradient of the landfill and up gradient of sensitive receptors, and surface water where pollution is most likely to occur
- when setting trigger levels, consider what needs to be done if levels are exceeded, and the likelihood that trigger levels will be exceeded
- substances for which trigger levels are to be set should be able to confirm the performance of landfill systems and identify the potential for impact on groundwater. These may include indicators of the presence of leachate (such as ammonia), and a suite of landfill related analytes immediately down gradient of the landfill and up gradient of sensitive receptors
- trigger levels should reflect the expected performance of the landfill and indicate if landfill systems are not performing as expected and there is potential for adverse effects
- in some situations the trigger levels for a substance will be below the limits of reporting (LOR) of commercial, NATA accredited laboratories. In this situation the EPA will accept the use of the LOR as a trigger level, provided that the chemical analysis has been performed using the most sensitive NATA accredited technique available, and that a risk assessment has been completed to set the exposure scene.

5 MONITORING PROGRAM

Groundwater monitoring is an essential part of landfill risk assessment and management. It is used to gain information before starting operations to determine baseline conditions, and what is happening during the lifetime of the landfill and after closure.

A groundwater monitoring program must be developed and implemented for a landfill site unless you can demonstrate through the risk assessment process that there is no potential for groundwater to be impacted. Before collecting any samples from the site a monitoring plan must be developed. The program must be independently verified to ensure that the results it provides can be used to measure effects on the environment. The monitoring program should be site specific and based on the site investigation.

There are two components to a groundwater monitoring program: water level monitoring and water quality monitoring. Both have to be undertaken at all sites, but the frequency may vary for each component. The EPA may require monthly water level measurements from a new landfill to determine seasonal changes in water level, but only biannual water quality monitoring. However, the monitoring program will include both components.

5.1 Groundwater level monitoring

You must monitor groundwater level to determine groundwater flow direction and rate. Some important factors to consider in the measurement of groundwater levels should include:

- groundwater levels should always be measured and recorded on the same day using the Australian Height Datum (mAHD) as a reference before purging the well
- in some areas irrigation or tides may cause groundwater level fluctuations
- methods and instruments used to measure water level vary and the most suitable will depend on what is being monitored and the conditions under which monitoring will be taking place
- a minimum of three wells in the same aquifer is necessary for triangulation of water levels and to indicate groundwater flow direction; additional wells may be required to accurately determine flow direction
- for accurate comparison of groundwater level, all monitoring wells must be accurately surveyed to the top of the casing and ground level to mAHD and have coordinates recorded in Australian Map Grid (AMG) by a licensed surveyor
- when you measure groundwater level you should also measure the depth of the well to ensure that there has been no backfilling of the well and it is suitable for sampling.

Groundwater level should be measured before sampling. This must be done on the same day at around the same time for all wells so that an accurate groundwater flow direction can be determined and changes in the groundwater flow regime can be noted and assessed. Changes in the groundwater flow regime may occur naturally as a result of seasonal or rain events, or from groundwater pumping or other activities at the landfill site, or adjacent sites.

Horizontal groundwater flow direction is determined by comparing a minimum of three triangulated wells in an aquifer. If there is suspicion that changes are localised, for example where groundwater pumping has occurred, or where there are irregular changes in topography, a greater number of wells may be required. Many landfills intersect the water table, causing localised fluctuations in the water table level. If this is the case, then more wells will generally be required. You should note that a greater number of wells would generally be required for groundwater quality monitoring than for level monitoring.

Vertical flow direction between aquifers can be determined by drilling nested wells screened in a number of aquifers, and comparing water levels of each aquifer.

5.2 Groundwater quality monitoring

Initial monitoring

Initial monitoring defines the baseline or background chemical properties of groundwater and surface water before landfill operations are commenced. The frequency and range of monitoring data collected must be sufficient for characterisation of seasonal and other non landfill influences. A range of measurements is required because, in most cases, detailed characterisation of the surface water and groundwater will not previously have been performed and, without this information, it will not be possible to assess and predict the potential for future effects.

For new landfill sites initial water quality monitoring is critical in establishing baseline parameters and trigger levels before the start of operations. Assessment frequency and compliance conditions can then be incorporated into the landfill licence conditions. At older operational or closed sites, where historical monitoring data is absent or inadequate, locations up gradient of groundwater flow may need to be monitored in order to establish background levels.

The EPA may require monitoring of surface water quality if it considers that the landfill may affect surface water quality.

5.3 Regular monitoring

Groundwater is regularly monitored at landfill sites because they have the potential to pollute groundwater. The monitoring program is usually an extension of initial monitoring. However, the monitoring program is a continuing process and may need to be updated to reflect changes in the hydrogeology or the landfill.

Regular monitoring of groundwater at all landfill sites should be conducted unless it can be demonstrated through a risk assessment that the landfill will not impact on groundwater. In order to assess impacts of seasonal changes on the quality of groundwater, monitoring should be conducted in the same month. More frequent monitoring may be required if groundwater has been impacted or if the risk assessment indicates that it is necessary.

After each sampling event, if any guideline or trigger level has been exceeded, the EPA must be informed. Results of groundwater monitoring should be submitted in the form of an annual report.

Monitoring must include, at a minimum:

- groundwater level monitoring and an assessment of changes to hydrogeology due to the landfill (such as generation of radial flow associated with high local recharge)
- regular monitoring of indicators that best characterise the performance of the landfill and indicate if groundwater has been contaminated by leachate. The indicators should be selected from the indicators you used for initial characterisation. Selection of monitoring indicators must take into account the type of waste received at the landfill and the pollutants that are likely to leach from it. Section 5.8 provides further information on the design of monitoring programs and the selection of analytical suites. The monitoring program must also include any parameters specified in the landfill license.

The frequency of groundwater sampling events should be based on the following:

- the objectives of the monitoring program
- the variation in quality of the groundwater under investigation (temporal and spatial)

- the nature and type of pollutants (mobility, dispersion, specific gravity)
- historical monitoring results and trends which may indicate that groundwater indicator values concentrations exceed trigger levels or appear to be changing.

Leachate monitoring

The EPA may require monitoring and analyses of landfill leachate to determine if any pollutants are present that may impact groundwater.

Leachate analysis provides information on possible source pollutants. Because of the complex processes involved in leachate production, there is likely to be significant variation in the composition and physical characteristics of leachate, both over time and between different parts of the landfill. The greatest variation will be shortly after initial landfilling, and intensive monitoring is likely to be necessary during this period. The monitoring program needs to be flexible to respond to these changes.

Typically leachate monitoring will involve:

- initial leachate monitoring, involving detailed tests to characterise the leachate; these are to be continued until a recognisable pattern of change in leachate level and composition has been established
- routine leachate monitoring to measure important indicators
- monitoring a suite of indicators, such as those used in the initial monitoring (see Section 5.8), when a detailed characterisation of the performance of the landfill is required for assessment purposes.

Assessment monitoring

If regular monitoring of a landfill site indicates that the landfill is impacting groundwater, or if the type of waste being received has changed, the EPA may require you to make a more detailed assessment to determine the extent, source and magnitude of the pollution.

Monitoring for assessment purposes may be triggered by the observation of a significant departure from baseline or design conditions (ie when trigger levels as defined in Section 4.4 are exceeded), or when more information is needed to quantify attenuation and migration processes. For example, this would be appropriate if the type of waste placed in the landfill has changed, or where the landfill may have polluted groundwater.

Assessment monitoring provides a more detailed assessment and understanding of the groundwater impacts and may involve:

- analysis of a wider range of contaminants
- more frequent monitoring
- more frequent groundwater level measurements
- monitoring at a greater number of locations
- monitoring another aquifer
- groundwater modelling.

If it is determined that the landfill is impacting on groundwater, the source, concentration and extent of the pollution must be found by implementing a site specific monitoring program. The program should be reviewed by the independent verification process.

Post-closure monitoring

Completion monitoring programs are required when a landfill is closed to assess whether pollutants in the waste disposed of on the site are an ongoing risk to the environment. Completion monitoring must continue until there is sufficient evidence to indicate that the site is stable and is an acceptable risk.

Completion monitoring for landfill may continue for at least 25 years after the landfill has ceased operation and must not cease until an audit has been performed, and satisfactory to the EPA that there are no more pending environmental issues associated with the site.

5.4 Monitoring locations

Selection of sampling locations should take into account the following:

- findings of the landfill site field investigation
- depth to groundwater (and seasonal variations in depth)
- characteristics of the aquifer that is being sampled (unconfined, confined, vertical and horizontal homogeneities)
- hydraulic gradient
- direction of groundwater flow (and seasonal variations in flow direction)
- presence of other groundwater wells on the site or in its vicinity (monitoring wells, extraction wells)
- expected pollutant pathways
- potential risks to uncontaminated aquifers and surface water resources.

Table 3 will help to select the number and location of monitoring points for a landfill site. However, as each landfill site is different, the number and location of monitoring points will need to be decided on a site specific basis.

Table 3 Probable locations of monitoring points

Monitoring location	Purpose	Type	Minimum number and spacing*
landfill presenting low risk to water receptors			
groundwater between landfill activity and site boundary to allow for remedial action to prevent off site impact	to assess quality and levels	wells	one up gradient and two down gradient per groundwater system
surface water outfall monitoring	to assess potential impacts on receiving water	surface water	in each outfall

Monitoring location	Purpose	Type	Minimum number and spacing*
surface water at stormwater outfall from site	impact on quality from suspended solids and other pollutants in runoff	surface water	at least one point upstream and one point downstream of each outfall
landfill presenting moderate to high risk to water receptors			
landfill cells	leachate level and quality	sumps, boreholes and drainage collection point	two locations for leachate head and one of these for leachate quality per 5-ha cell
leakage detection layer	to determine leakage	drainage collection point	at least one per 5-ha cell
electrical resistivity array in unsaturated zone	to determine leakage	resistivity array	at least one per 5-ha cell
groundwater between landfill activity and site boundary	to determine quality and levels	wells	at least one up gradient and two down gradient per groundwater system
groundwater between site and receptors at risk	to determine potential impact on receptor	wells	at least one for each receptor and/or pathway
surface water outfall monitoring	to assess potential impacts on receiving waters	surface water	in each outfall
surface water at stormwater outfall from site	impact on quality from suspended solids and pollutants in run off	surface water	at least one point upstream and one point downstream of each outfall

* Requirements must be determined from an assessment of risk. It is anticipated that the majority of landfills will require more wells than the minimum requirements.

The number and location of monitoring points for a landfill should be identified as part of the site field investigation program and in the development of the monitoring program.

The proposed locations of monitoring points to be included in the monitoring program for the site will be reviewed in accordance with the monitoring program guidelines.

Leachate monitoring

Sufficient leachate monitoring is required to characterise the leachate from each landfill cell, accounting for differences in leachate content due to variations in the waste deposited in different parts of the cell, varying moisture content and therefore leachate production rates, varying aerobic states, etc. For larger cells, fewer points per hectare are generally needed. Leachate level monitoring points should include points remote from leachate drainage and pumping systems. Leachate levels must be measured after leachate pumping systems have been switched off and sufficient time elapsed to allow reliable leachate level determination. Additional monitoring points and controls may be needed if leachate levels cannot be controlled adequately (generally in older landfills where the leachate drainage system is inadequate or absent, and/or where inflow from rain derived runoff is not controlled), and there is a threat of the leachate overspilling the cell surface or laterally seeping into groundwater.

Leachate should generally be sampled from the sump of each cell, or from wells screened in the cell.

Location and number of groundwater wells

Groundwater monitoring wells should be located:

- immediately down gradient of the leachate source, but no closer than 10 m from the edge of a landfilled area
- further down hydraulic gradient to ensure that there is no adverse impacts outside the landfill; groundwater monitoring wells may need to be outside the area of the landfill
- up hydraulic gradient wells for ongoing monitoring of the quality of groundwater flowing into the site
- wells situated across the groundwater flow gradient to capture any changes in groundwater flow direction from natural hydraulic variations or as a result of landfilling activities
- wells delineating the vertical extent of any pollution based on the conceptual model.

The number of wells required in a landfill is a function of the following:

- the size of the area filled with waste
- number and complexity of landfill cells
- complexity of the hydrogeology
- expected rate of movement of pollutants through the groundwater
- sensitivity and proximity of potential receptors of any groundwater impacts.

The use of existing wells for sampling should not be considered unless you can show that they are suitable for the purpose of the sampling program (ie they are constructed to intercept pollutants and intersect the correct aquifer).

Surface water monitoring

Surface water that could be impacted by the landfill, either from overland flow or groundwater discharge, should be monitored. The monitoring program will need to look for potential influences on surface water. With flowing water, this may include monitoring points upstream of the potential zone of impact of the landfill and monitoring points downstream. You may be required to review hydrology and water quality to support monitoring programs designed to assess impacts on hydrologically complex water bodies such as ponded water, wetlands or lakes. Monitoring programs will probably need to look at a range of physicochemical and biological indicators.

Groundwater well permits, construction and maintenance

Before drilling commences, a well construction permit must be obtained from the Resource Management Division of the Department of Water, Land and Biodiversity Conservation (DWLBC). Drilling and construction of monitoring wells must be carried out by a driller licensed under the *Natural Resource Management Act 2004* and in accordance with the DWLBC conditions and guidelines.

Drilling

When conducting a site investigation:

- contractors (eg drillers, earth movers, surveyors) must have been trained to operate on landfill sites, and all people on the site must be familiar with the health and safety aspects of the site
- drilling contractors must hold an appropriate water well drillers licence if groundwater wells are to be installed
- all intrusive investigations must be supervised by a competent environmental professional.

Well construction or alteration must be performed in a manner consistent with the provisions in *Minimum construction requirements for water bores in Australia* (Land and Water Biodiversity Committee 2003).

Drilling methods chosen should be the least disruptive to the zone to be monitored. Drilling techniques can smear and compact borehole walls and result in groundwater and contaminant pathway blockage.

If a monitoring well is to be drilled through a contaminated upper zone into an uncontaminated lower zone, isolation casing must be installed in the contaminated zone, and aquitards sealed to stop the contamination migrating during drilling. An appropriately qualified driller should complete this work under the supervision of an experienced and appropriately qualified professional.

Well construction

The construction of groundwater wells depends on the hydrogeology of the site and the pollutants that are of interest. Casings and screens should be chemically compatible with the contaminants of concern and the immediate groundwater environment. If incompatible, either leaching or sorption of analytes could occur and this may result in changes in the water quality.

The materials used in the annular space between the casing and the borehole wall have to be appropriate for the site. Any of the filter materials (gravel, sand) and seal materials (bentonite and cement) may alter the chemistry of the groundwater entering the well. Cement, for example, may change pH.

The location and length of the screened interval is very important. As groundwater flow is generally laminar, contaminated groundwater flows in discrete zones. Long screens can result in dilution of contaminants.

All wells used for groundwater monitoring must be developed before sampling to maximise the hydraulic connection between the well and the formation.

All wells must be clearly labelled and identified.

Wells must be protected from being destroyed. Employees driving large machinery on the site must be aware of the well locations and avoid destroying them.

Wells must be capped with a lockable cap to prevent ingress of surface water, dust or other foreign matter, and to avoid tampering.

Wells must be constructed in a manner that avoids hydraulic connection between different aquifers under the site.

Wells must be constructed so that there is no hydraulic connection between any leachate generated on the site and the aquifers underlying the site.

Wells must be large enough to accommodate sampling equipment.

Construction design must be recorded in detail, including geology, screen length, drilled depth, depth to water, drilling method, screen type and interval, filter pack type, seals, backfill and method and time of development.

Wells must be provided with a unique identifying number and their location and must be survey levelled to AMG and mAHD respectively to the top of casing and ground surface at each location.

Where it is not possible to obtain representative samples of groundwater from wells (due to vandalism, blockages, etc), they must be replaced. Replacement wells must be uniquely numbered to prevent confusion and ambiguity, but this could contain reference to the original well (ie GW2 and GW2a).

The status of each well must be reviewed at each monitoring event. Where wells are not meeting their objectives and cannot be rehabilitated, they must be replaced.

When wells are no longer required for monitoring, they must be decommissioned by a licensed driller, or under the personal supervision of a licensed driller. Backfilled wells must be permanently sealed against ingress of surface water or waste, and all aquifers must be permanently separated from each other. Prior to decommissioning a well, approval must be obtained from DWLBC.

5.5 Monitoring measurements

Physical monitoring includes observational, water balance, flow and level measurements. The resulting data should be kept by the landfill operator and may need to be provided to the EPA.

Observational records that should be kept during normal daily management activities include surface water runoff from the landfill, ponding of stormwater and any other potential sources of contamination.

Water balance measurements of rainfall, leachate levels and pumped leachate volumes may assist you to determine the effectiveness of stormwater diversion, or the effectiveness of a cap in a completed landfill cell.

Level and flow measurements of cell leachate and surface water, and level measurements of groundwater, provide information on hydraulic gradients and potential contaminant pathways. Additionally, these measurements may indicate changes to site hydrogeology.

Records must be kept until the landfill site has been signed off by an environmental auditor.

5.6 Sampling

Groundwater samples should only be collected from appropriately constructed wells. Groundwater samples collected from test pits, trenches or similar, are not acceptable as they are not representative of groundwater at the site.

Sampling should be undertaken in accordance with the *Guidelines for regulatory monitoring and testing: Groundwater sampling* (EPA 2007) and the appropriate Australian Standards, the

NEPM (1999) and the *Murray–Darling Basin groundwater quality sampling guidelines* (MDBC 1997).

Field measurements (eg pH, EC, dissolved oxygen Eh and temperature) must be measured after purging groundwater wells and after the aforementioned field parameters have stabilised.

Other observations should also be recorded during sampling, including colour, turbidity and odour.

All instruments used on site should be accurately calibrated.

Sampling equipment should be decontaminated prior to use, or dedicated to an existing sampling point.

Sample preservation, transportation and storage requirements of samples collected as part of the monitoring event must be completed according to the relevant Australian Standards such as *AS/NZS 5667.1* (1998).

It is recommended that you confirm sample preservation, transportation and storage requirements with the analytical laboratory before collecting samples.

5.7 Quality

It is essential that the quality and reliability of the quality assurance/quality control (QA/QC) information be assured to avoid incorrect conclusions and the possibility that the work will need to be redone. Quality must be assured by using field investigation procedures that comply with the guidance of Schedule B (2), Section 4.10 of the NEPM (1999), and QA/QC that complies with the requirements of *AS4482.1 Guide to the investigation of sites with potentially contaminated soil—Non-volatile and semi-volatile compounds* (2005), *AS4482.2 Guidance to the sampling and investigation of potentially contaminated soil, Part 2: Volatile substances* (1999), *AS/NZS5667.1* (1998), *AS5667.10 Water quality—Sampling—Guidance on sampling of waste waters* (1998) and *AS/NZS 5667.11 Water quality—Sampling—Guidance on sampling of groundwaters* (1998).

Accurate QA/QC is required to ensure that the samples collected are of the highest quality and integrity, and that analysis is completed with the highest accuracy.

Where results are produced with inadequate QA/QC procedures, they cannot be considered to be accurate or representative of the site. Details on QA/QC measures are covered in the *Guidelines for regulatory monitoring and testing: Groundwater sampling* (EPA 2007), the *AS/NZS 5667.1* (1998) and the NEPM (1999).

QA/QC measures are required, regardless of the number of samples taken. The minimum field QA/QC procedures that should be observed are:

- use of chain of custody forms and documentation
- use of a NATA accredited laboratory
- collection of quality control samples (for sampling, transportation and preservation methods)
- the types of quality control samples to be collected in monitoring events are detailed in *Guidelines for regulatory monitoring and testing: Groundwater sampling* (EPA 2007).

5.8 Analysis

The landfill site investigation will determine the parameters to be analysed as part of the monitoring program. The analytical suite should be determined by assessing the risk presented by the landfill and should take into account the nature and composition of the waste received. At a minimum, groundwater, surface water and leachate should be analysed during routine monitoring for the following analytes, in addition to any site specific analytes identified in the leachate or waste material:

- pH
- EC
- TDS
- Eh
- COD
- ammoniacal nitrogen
- major cations and anions (calcium, magnesium, sodium, potassium, chloride, bicarbonate and sulphate)
- nitrite and nitrate
- total iron
- TOC
- total phenols
- metals (As, Cd, Cr*, Cu, Hg, Ni, Pb, Se, Zn, Mn)
- boron
- leachate should also be analysed for volatile fatty acids.

A wider monitoring suite for initial characterisation and assessment may also include the following but is not limited to:

- phosphorous
- fluoride
- BOD
- total suspended solids
- total petroleum hydrocarbons (or total recoverable hydrocarbons)
- pesticides, herbicides
- cyanide
- SVOC which may include phenols, PAH and chlorinated hydrocarbons
- volatile organics which may include BTEX.

* Cr(VI) may be analysed for if site history or type of waste indicates that Cr(VI) may be present.

6 REPORTING AND REVIEW

A report must be submitted to the EPA at the completion of the preliminary hydrogeological interpretation and detailed site investigation.

Results from regular groundwater monitoring must be submitted if trigger levels or guideline values are exceeded for the monitoring event.

At a minimum, a report must be submitted annually, giving a full assessment of monitoring at the site.

The EPA may return reports to the licensee without assessing them if the information is not considered consistent with this guideline.

A post closure report must be submitted for a closed landfill.

6.1 Reports

Periodic groundwater monitoring and groundwater assessment reports that assess groundwater quality and flow regime are important components of the overall management of a landfill. The periodic monitoring report provides information on any exceedences of trigger levels and/or guideline levels. It is submitted after the sampling event. The EPA requires you to submit this report if trigger levels or guideline values are exceeded.

Compliance dates for the submission of reports are site specific and will be given in licence conditions. The requirements for reporting are:

- **preliminary hydrogeological interpretation report:** to be submitted to the EPA. This report may be submitted in stages as the result of the desktop study and detailed site inspection. A checklist of the information that should be considered when reporting to the EPA on the preliminary hydrogeological interpretation is provided in Appendix A
- **landfill site investigation report:** depending on the size and complexity of the site this report may be developed in stages. It will include validation of the conceptual model, identification of risks through the risk assessment, setting of trigger levels for the site and results of an initial monitoring program. The final stage of this report is the development of a regular monitoring program. A checklist that lists the information that should be considered when reporting to the EPA on the landfill site investigation report is provided in Appendix B
- **exceedance report:** to be submitted to the EPA each time that a monitoring round is undertaken and the results indicate that trigger levels and/or guideline values have been exceeded. These would generally only be factual reports stating results, but may include a brief appraisal of the events
- **landfill groundwater assessment report (annual):** this report is to be submitted to the EPA annually. It will provide results and analysis of recent sampling events and compare these results with past sampling of the site to determine if there are any trends that indicate that the landfill is impacting on the groundwater. This report should recommend changes to the monitoring program (if necessary) and highlight anything that needs to be done. A checklist that lists the information that should be considered when reporting to the EPA on the annual groundwater monitoring report is provided in Appendix C
- **independent verification report:** the EPA may require that the landfill owner or operator arrange for independent verification of reports submitted to the EPA in accordance with the *EPA Guideline: Independent verification of monitoring programs* (EPA 2006). The EPA will review reports and independent verification reports received and advise the licensee

or landfill operator of required action (if any). A checklist that lists the information that should be considered in an independent verification report is provided in Appendix D.

6.2 Notification of EPA

Requirements for notification of pollution incidents and non compliance with the requirements for a licence are outlined in the licence for the landfill and must be complied with.

Under Section 83 of the EP Act, where pollution occurs so that serious or material environmental harm is caused or threatened by the landfill operations, the owner or operator must, as soon as reasonably practicable after becoming aware of the incident, notify the EPA of the incident, its nature, the circumstances in which it occurred and the action taken to deal with it.

7 DATA MANAGEMENT

Data on the operation and monitoring of the landfill must be properly managed and maintained to provide an accurate and reliable long term reference. Data must be quality assured and collated logically in a manner that will allow it to be readily manipulated and interpreted. Each operating landfill is expected to make reference to a landfill environment management plan (LEMP), which should include information on database and records management.

7.1 Quality assurance

Quality objectives must be clearly stated and uncertainty minimised during measurement and sampling. This is achieved by good monitoring program design and standardised data collection practices and handling. All quality control checks should be documented, with paper trails that can be audited.

7.2 Data collection

Data gathering activities must be carried out by experienced and appropriately qualified environmental professionals. Sampling and handling protocols must be specified, there must be standardised recording procedures, and NATA accredited laboratories must be used for analysis

7.3 Data collation and storage

Data collected must include information on the construction of the landfill, site details and observations, compliance standards, field and laboratory measurements and records, chain of custodies and observational notes.

Data entry and storage must be systematic and easily cross referenced. All original field laboratory and other relevant paper copies should be archived.

7.4 Data validation

Data validation involves checking the data for simple errors and inconsistencies. People responsible for data validation should understand the meaning of the data.

Internal data checks include simple transcription errors and missing data, logical checks, ie are the data sensible and consistent. External data checks may include comparisons of QA/QC samples, historical analyses from a particular monitoring point, and the evaluation of other sample attributes such as handling procedures.

Erroneous data must be remedied where possible, or otherwise noted. Where critical data cannot be verified, repeat sampling may be necessary. Procedures should be implemented to avoid repetition of errors.

7.5 Storage and archiving of validated data

Data should be stored in a readily accessible electronic format for regular review. Data is required for the lifetime of the site, and should therefore be handled appropriately to ensure its survival for this time. Electronic data must be backed up and copies stored securely off site. Data from different sources should be stored on a single database by the licensee and/or site owner.

7.6 Data presentation, review and interpretation

Data must be presented in simple tabular format accompanied by graphical representations.

Data must be reviewed and compared with compliance conditions (statutory regulations), and trigger levels for further investigation. Monitoring program objectives must also be reviewed, for example, whether objectives for the number of monitoring points are being met, or whether monitoring frequency is adequate.

The site model must also be periodically reviewed as data provides better understanding of site conditions, or as site conditions change (such as changes in the groundwater flow direction).

7.7 Reporting

Reporting must be in accordance with the requirements of Section 6 of these Guidelines. Monitoring results must be provided to the EPA when requested. Data records should be provided to the EPA in a format agreed between the site operator and EPA. Appendices A to D provide information on the reporting structure of reports to be submitted to the EPA. Data presented to the EPA must be consistent, quality assured and submitted within 2 weeks of request.

At a minimum, the performance of the landfill and adequacy of the monitoring program must be assessed on an annual basis, and more frequently if data anomalies are noted by the persons undertaking the testing.

8 REFERENCES

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Legislation and environment protection policies in South Australia

Public and Environmental Health Act 1987

Environment Protection Act 1993

Environment Protection (Water Quality) Policy 2003

Natural Resource Management Act 2004

GLOSSARY

adverse effect	change in morphology, physiology, growth, development or lifespan of an organism which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility due to harmful effects of other environmental influences
As	arsenic
Australian Map Grid (AMG)	equivalent to the Universal Transverse Mercator (UTM) map projection, AMG is broken up into several zones, which span six degrees of longitude; coordinates are expressed as easting and northing
analyte	refers to any chemical compound, element or other parameter as a subject for analysis
ANZECC	Australian and New Zealand Environment and Conservation Council
aquifer	rock or sediment in a geological formation, or group of formations, or part of a formation which is capable of being permeated permanently or intermittently, and can thereby transmit water
Australian Height Datum (mAHD)	national level datum based on the average mean sea level around the Australian coast line
aquitard	a layer in the geological profile that separates two aquifers and restricts the flow between them
background concentration	naturally occurring ambient concentration in the locality of a site
baseline monitoring	concentration of analytes at a landfill before landfilling
bioavailability	availability of contaminants in a form in which organisms or biota can assimilate, eg in a dissolved state or capable of being solubilised once ingested
biota	plants, animals, including humans, fungi or bacteria.
BOD	biological oxygen demand—a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water, BOD is used as an indirect measure of the concentration of biologically degradable material present in organic waste
BTEX	benzene, toluene, ethylbenzene, xylene
Cd	cadmium
Cr	chromium
COD	abbreviation for chemical oxygen demand, the amount of oxygen required for the chemical oxidation or decomposition of compounds in water

confined aquifer	aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure
Cu	copper
development of wells	the removal of fines (including drilling mud) from the aquifer immediately surrounding the well and creating a filter zone around the well that prevents further movement of aquifer particles into the well
dispersion	irregular spreading of contaminants due to aquifer heterogeneities
EC	abbreviation for electrical conductivity, commonly used to indicate the salinity of water
ecosystem	a community of organisms, the physical and chemical environment of that community, and all the interactions among those organisms and between the organisms and their environment
Eh	redox potential
electrical resistivity	electrical method of geophysics used to identify leachate migration from a landfill
EPA	South Australian Environment Protection Authority
exposure pathway	the course a chemical takes from a source to an exposed organism
geology	the scientific study of rocks, the earth's crust and interior
groundwater	all water below the land surface
Hg	mercury
hydraulic gradient	the change in the static head (of groundwater) per unit of distance in a given direction
hydrogeology	the study of groundwater, especially the distribution of aquifers, groundwater flow and quality
independent verification	verification of monitoring results by an independent specialist who is able to confirm that the report is accurate and whether appropriate controls and procedures have been followed
leachate	water that collects contaminants as it seeps through waste; may enter groundwater
limits of reporting	the minimum concentration of a substance that can be detected
mobility	ability of contaminants to move in the aquifer
NATA	National Association of Testing Laboratories
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
Ni	nickel

NHMRC	National Health and Medical Research Council
OC/OP	organochlorine/organophosphate pesticides
outfall	the place where water is discharged into receiving water
PAH	polycyclic aromatic hydrocarbons
Pb	lead
permeability	the rate at which liquids pass through soil or other materials in a specified direction
pollutant	a substance which presents a risk of harm to human health or any environmental value
pollution	is the condition of land or water where any chemical substance or waste has been added at above background and represents, or potentially represents an adverse health or environmental impact
QA/QC	quality assurance/quality control
receptor	the entity that will be adversely affected by contact with or exposure to a contaminant of concern
remediation	action taken to eliminate, limit, correct, counteract, mitigate or remove any contaminant or the negative effects on the environment or human health of any contaminant
risk assessment	process of estimating the potential effect of a chemical, biological or physical agent on humans, plants, animals and the ecology
Se	selenium
sediment	loose particles of sand, clay, silt and other substances that settle at the bottom of a body of water
spatial	variation over area
specific gravity	ratio of a weight of a given volume of a substance to the weight of an equal volume of water
TDS	abbreviation of total dissolved solids, a measure of dissolved materials in water that indicates salinity
temporal	variation over time
TOC	abbreviation for total organic carbon, sum of all organic carbon compounds in water
trigger level	guideline concentrations of contaminants adopted by the EPA to use as a comparison against which to assess the presence and severity of contamination at a site; determined during the risk assessment process
turbidity	the cloudy appearance of water caused by suspended and colloidal matter, a turbidity measurement is used to indicate the clarity of water—technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. turbidity cannot be directly equated to suspended solids

unconfined aquifer	aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure
well	a hole drilled into an aquifer for the purpose of monitoring or extracting groundwater. another common term is 'bore'
WQEPP	Water Quality Environment Protection Policy (2003)
Zn	zinc

APPENDIX A PRELIMINARY HYDROGEOLOGICAL INTERPRETATION

Report section	Information to be included where relevant	Comments
Executive summary	• background • objectives of the investigation • scope of work • summary of conclusions and recommendations	mandatory
Scope of work	• clear statement of the scope of work	mandatory
Site identification	• street number, lot number, street name and suburb • common title/name of site • certificate of title reference • locality map • current site plan showing infrastructure, scale bar, north arrow, local environmentally significant features • local government authority	mandatory
Site history	• land owner—past and present • zoning—previous, present and proposed • land use—previous, present and proposed • surrounding land use and zoning • possible contamination sources and potential impacts • discharges to land and water • relevant complaint history • local knowledge of site representatives and residents • local usage of groundwater and surface water and locations	include readily available information where applicable

Report section	Information to be included where relevant	Comments
Site conditions and surrounding environment	• topography • visible signs of contamination, such as discolouration and staining of soils • visible signs of vegetation stress • presence of drums, wastes and fill material • conditions of buildings and roads • odours • quality of surface water • preferential pathways for contaminants, eg drains • flood potential • residents in close proximity to site • details of any sensitive environments, eg water courses, wetlands, etc	include readily available information where applicable
Geology and hydrogeology	• soil stratigraphy using recognised soil classification method • description of actual or potential contamination • detailed description of the location and construction of all on site wells • description of wells and surface waters within one km of the site • known or expected depth to groundwater • direction and rate of groundwater flow • presence of multi-layered aquifer • permeability of strata on site • groundwater discharge location • ambient water quality • groundwater–surface water interaction • groundwater conditions, eg unconfined, confined • beneficial use of groundwater in area • location of receptors • preferential migratory pathways • leachate quality	this is generally a desktop assessment—includes readily available information where applicable

Report section	Information to be included where relevant	Comments
Conclusions and recommendations	• brief summary of all findings • assumptions used in reaching those findings • extent of uncertainties in results • recommendations of further sampling	mandatory

APPENDIX B LANDFILL SITE INVESTIGATION

Report section	Information to be Included	Comments
Executive summary	• background • objectives of the investigation • scope of work • summary of conclusions and recommendations	mandatory
Scope of work	clear statement of the scope of work	mandatory
Site identification	• street number, lot number, street name and suburb • common title or name of site • certificate of title reference • locality map • current site plan showing infrastructure, scale bar, north arrow, local environmentally significant features. • local government authority	mandatory
Geology and hydrogeology	• site borehole or test pit logs • known or expected depth to groundwater • confirmation of site geology and hydrogeology through fieldwork • direction and rate of groundwater • ambient groundwater quality • permeability of strata • groundwater–surface water interaction • groundwater conditions • preferential migratory options	data collected here is a result of field investigations and should validate the data obtained in the preliminary review.
Sampling and analysis plan and methodology	• location of sampling points • depth of wells • sampling methodology and justification for use of particular sampling method • analytical methods for all sampling points	mandatory

Report section	Information to be Included	Comments
Field QA/QC	• decontamination procedures carried out between sampling events • field data sheets for each sample point recording, time, location, initials of sampler, depth of collection and field chemical parameters • purging of wells • stabilisation of field parameters • chain of custody records • field duplicate and blank results • rinsate results • field instruments calibration • holding times	mandatory
Laboratory QA/QC	• a copy of signed chain of custody forms acknowledging sample receipt • analytical methods used • laboratory accreditation for analytical methods used • description of surrogates and spikes • per cent recoveries of surrogates and spikes • method detection limits • matrix or practical quantification limits • laboratory duplicate and blank results	mandatory
QA/QC data evaluation	• evaluation of all the QA/QC information listed above • discussion of data completeness • data representativeness, precision and accuracy	mandatory
Basis for adoption of trigger levels	• table listing all selected trigger levels and references • rationale for and appropriateness of the selection of trigger levels • assumptions and limitation of trigger levels	mandatory

Report section	Information to be Included	Comments
Results	• summary of previous results • summary of all results (in a table that shows details of well numbers, trigger levels and highlights all results above trigger levels) • site plan showing all sample locations • site plan showing extent of contamination • site plan with water level contours • graphs presenting trended data	mandatory
Site characteristics	• assessment of all environmental contamination • assessment of the vertical and lateral extent of contamination • assessment of the chemical degradation • assessment of receiving environment's sensitivity	include readily available information where applicable
Health risk assessment	• data collection and evaluation of the chemical condition of the site • exposure assessment of contaminants at the site • identification of exposure populations • discussion of assumptions • risk management decisions based on the assessment	include readily available information where applicable
Ecological risk assessment	• problem identification • receptor identification identifying the ecological values at risk • exposure assessment • toxicity assessment • discussion of assumptions • risk management decisions based on assessment	include readily available information where applicable
Conclusions and recommendations	• summary confirming sources of contamination • assumptions used in reaching the conclusions • extent of uncertainties in the results • recommendations for further sampling	mandatory

APPENDIX C ANNUAL GROUNDWATER MONITORING REPORT

Report section	Information to be Included	Comments
Executive summary	• background • objectives of the investigation • scope of work • summary of conclusions and recommendations	mandatory
Scope of work	• clear statement of the scope of work	mandatory
Site identification	• street number, lot number, street name and suburb • common title or name of site • certificate of title reference • locality map • current site plan showing infrastructure, scale bar, north arrow, local environmentally significant features • local government authority	mandatory
Monitoring program background	• development of monitoring program • when monitoring program commenced • how and when program was designed • details on monitoring network including wells no longer sampled	mandatory

Report section	Information to be Included	Comments
Groundwater sampling methodology	• details on the measurements of water levels • details on the techniques used to collect groundwater samples • details on the analytical program • decontamination procedures carried out between sampling events • field data sheets for each sample point recording, time, location, initials of sampler, depth of collection and field chemical parameters • purging of wells • stabilisation of field parameters • chain of custody records • field duplicate and blank results • rinsate results • field instruments calibration • holding times	mandatory
Groundwater level results	• location of sampling points • depth to water in wells • depth to water reduced to mAHD • discussion of groundwater levels • inclusion of groundwater flow contours • comparison with existing water level data and determination of any trends	mandatory
Assessment criteria	• table listing all selected trigger levels and references • rationale for and appropriateness of the selection of trigger levels • assumptions and limitation of trigger levels	mandatory
QA/QC data evaluation	• evaluation of all the QA/QC information from the laboratory and the field data • discussion of data completeness • data representativeness, precision and accuracy	mandatory

Report section	Information to be Included	Comments
Results	• summary of previous results • summary of all results (in a table that shows details of well numbers, trigger levels and highlights all results above trigger levels) • site plan showing all sample locations • site plan showing extent of contamination • site plan with water level contours • graphs presenting trended data • assessment of results with respect to trigger levels • assessment of all environmental contamination • assessment of the vertical and lateral extent of contamination	mandatory
Conclusions and recommendations	• summary confirming sources of contamination • assumptions used in reaching the conclusions • extent of uncertainties in the results • recommendations for further sampling • recommendations of any changes to monitoring program	mandatory

APPENDIX D INDEPENDENT VERIFICATION REPORT

Report section	Information to be Included	Comments
Executive summary	• background • objectives of the investigation • scope of work • summary of conclusions and recommendations	mandatory
Introduction	• background of site • summary of relevant licence conditions • title of primary document submitted for verification • objective of the independent verification • assumptions of the independent verifier • details of the independent verifier (including qualifications, experience and professional affiliations) • disclaimer of independence from the verifier with the licensee and the authors of the primary document	mandatory
Monitoring conditions and compliance	• summary of monitoring conditions from the EPA licence • determination of compliance with the monitoring conditions	mandatory
Discussion	• discussion of compliance with recognised standards • assessment of sampling laboratories methodologies with recognised standards • discussion of results and highlighting discrepancies not reported in primary report	mandatory
Conclusions and recommendations	• recommended changes to procedures • recommended changes to documentation • conclusions on compliance of licence conditions and regulatory requirements • recommendations to the licensee on improvements to the monitoring program • suitability of the primary document that the results of the monitoring program accurately reflect the impact of activities on the environment	mandatory