CONTAMINATED SITES

Guidelines for the Assessment and Management of Groundwater Contamination

Limitations

These guidelines should be used in conjunction with other relevant guidelines made or approved by the Department of Environment and Conservation NSW under section 105 of the *Contaminated Land Management Act 1997* when assessing and managing groundwater contamination. The References section lists other relevant and useful documents.

These guidelines do not include occupational health and safety procedures. The NSW WorkCover Authority should be consulted on these. Appropriate action must be taken to manage any potential hazard and adequately protect the health of any workers on, or occupiers of, the site.

Disclaimer

Published by:
Department of Environment and Conservation NSW
59–61 Goulburn Street
PO Box A290
Sydney South 1232
Ph: (02) 9995 5000 (switchboard)
Ph: 131 555 (environment information and publications requests)
Ph: 1300 361 967 (national parks information and publications requests)
Fax: (02) 9995 5999
TTY: (02) 9211 4723
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

DEC 2007/144
ISBN 978 1 74122 366 8
March 2007
Printed on recycled paper

Preface

Background

Groundwater contamination can arise from either point sources or diffuse sources. Common examples of point sources that could contaminate groundwater are leaking underground storage tanks, inadequately-managed waste disposal sites and accidental chemical spills. An example of a diffuse source is pesticides and nutrients applied to broad-acre agricultural land that infiltrate through soils to groundwater.

These guidelines focus on groundwater pollution arising from point source contamination rather than on broad-scale groundwater issues arising from diffuse sources.

Contaminated groundwater can be unsuitable for use and may also adversely affect the quality of surface water and sediments. It may then harm human and ecological health. Contaminated groundwater may also affect the types of land uses that may safely be carried out above a contaminant plume.

The legacy of groundwater contamination can be a major burden on the community because once groundwater is contaminated it is generally difficult and costly to remediate. Therefore, preventing groundwater contamination is the most practical way of protecting groundwater quality.

Where contamination of groundwater is identified, acute risks, such as the possible accumulation of explosive vapours in subsurface utilities, must be immediately managed. The source of contamination must be removed to ensure the protection of human health and the environment. The following actions should also be taken whenever practicable:

- the environmental values of the groundwater must be restored
- groundwater quality must be restored to its natural background concentration.

These *Guidelines for the assessment and management of groundwater contamination* (the guidelines) outline a best-practice framework for assessing and managing contaminated groundwater in NSW.

The Department of Environment and Conservation NSW (DEC) must be notified about certain groundwater contamination under the *Contaminated Land Management Act 1997* and the *Protection of the*

Environment Operations Act 1997. Following notification, DEC may decide that the contamination warrants regulatory intervention. These guidelines should help consultants and industry to devise groundwater assessment and management strategies that are consistent with DEC's expectations.

The guidelines are not intended to be a text book for groundwater contamination nor to provide detailed technical advice on the assessment and management of contaminated groundwater. Information about groundwater fundamentals is presented in other publications, including those presented under 'Suggested further reading' on page 39. In all cases, groundwater contamination assessments and remediation must be conducted by competent professionals who already have relevant qualifications and experience. Where technical guidance material may be useful to readers, it is referred to in the relevant section of the guidelines or under 'References'. Reference to these documents, however, does not mean DEC endorses them. Policy documents endorsed by DEC are published every six months under the Freedom of Information Act. Contact DEC's Environment Line on 131 555 for further information.

Various other guidelines that may be updated from time to time are referred to throughout this document. Where a referenced guideline which is endorsed by the NSW Government or DEC is updated, the relevant reference(s) in this document should be read as if they were to the endorsed updated version. For all other guidelines, references should be read as if they were to the updated references as soon as updated versions have been released.

Table of contents

1 Introduction

1.1 About the guidelines

These *Guidelines for the assessment and management of groundwater contamination* (the guidelines) outline a best-practice framework for assessing and managing contaminated groundwater in NSW. While the guidelines do not articulate legislative requirements, they are made under section 105 of the *Contaminated Land Management Act 1997* (CLM Act), so the Department of Environment and Conservation (DEC) must take them into account whenever they are relevant. **DEC exercises certain statutory functions and powers (including those set out in the *Protection of the Environment Operations Act 1997* (POEO Act) and CLM Act) in the name of the Environment Protection Authority.**

Site auditors accredited under the CLM Act must also consider these guidelines when finalising site audits. The guidelines will also be useful for environmental consultants, local councils, industry organisations, water regulators, water users and other members of the community.

These guidelines should help consultants and industry to devise groundwater assessment and management strategies that are consistent with DEC's expectations.

1.2 Scope of the guidelines

The guidelines are set out as follows:

Section 2 – Assessing groundwater contamination – outlines ways of identifying whether groundwater is contaminated and describes how to conduct preliminary and detailed assessments.

Section 3 – Managing groundwater contamination – outlines ways of controlling groundwater contamination and identifying what remediation is needed to resolve it.

Section 4 – Cleaning up contaminated groundwater – describes a clean-up hierarchy including when it is essential to clean up so natural background water quality is restored and when clean-up to the extent practicable is acceptable.

Section 5 – Regulation – explains DEC's regulatory involvement in managing groundwater contamination.

Section 6 – References – contains references, relevant Acts and policies, and a suggested further reading list.

Appendix 1 – contains a glossary of terms used throughout these guidelines.

Appendix 2 – contains information about how to identify environmental values, and a list of major aquifers of drinking water quality identified by the NSW Department of Natural Resources (DNR).

Appendix 3 – contains more detailed information about monitored natural attenuation.

Appendix 4 – contains contact details for relevant NSW Government departments.

1.3 Policy, legislative framework and existing guidance

1.3.1 Key policy principles from NSW groundwater policies

Legislation and published policies in NSW have articulated key principles for assessing and managing groundwater contamination. These include the principles of ecologically sustainable development, which require the effective integration of economic, social and environmental considerations in decision-making. This can be achieved by implementing:

- the precautionary principle
- intergenerational equity
- conservation of biological diversity and ecological integrity
- improved valuation, pricing and incentive mechanisms for environmental factors (including the concept of 'polluter pays') – see section 10 of the CLM Act.

The groundwater policies set out in 1.3.3 encourage ecologically sustainable development to:

- slow and halt, or reverse, any degradation of groundwater resources
- ensure long-term sustainability of the ecological support characteristics of groundwater systems
- maintain the full range of beneficial uses of these systems
- maximise economic benefit to the region, state and nation.

The policies set out basic principles that should guide the management of groundwater in NSW. In relation to groundwater contamination, these include:

- preventing groundwater pollution so future remediation is not required
- managing all groundwater systems so their most sensitive identified beneficial use (or environmental value) is maintained, recognising the cumulative impacts of human activities on groundwater quality
- replacing processes and practices that degrade groundwater systems, either directly or indirectly, with ecologically sustainable alternatives
- requiring developments to minimise adverse impacts on the environment by preventing pollution of, or changes in, groundwater quality
- applying the precautionary principle to protect groundwater-dependent ecosystems where scientific knowledge is lacking
- affording town water supplies special protection against contamination
- rehabilitating degraded groundwater systems, where practical, to minimise the impacts of contamination on groundwater-dependent ecosystems, and to restore the ecosystem support characteristics of groundwater systems.

DEC will consider the above principles of ecologically sustainable development when exercising functions under the CLM Act, and others managing contaminated groundwater must also implement these principles.

These guidelines establish a decision-making framework for addressing groundwater contamination that is consistent with these principles.

1.3.2 Framework for groundwater management in NSW

Various government departments in NSW, including the Department of Natural Resources (DNR), Department of Environment and Conservation NSW (DEC), and the Department of Planning, along with local councils, share groundwater management responsibilities.

Department of Natural Resources

The Minister for Natural Resources and DNR regulate the use of groundwater through a licensing framework under the *Water Management Act 2000* (WM Act). The WM Act recognises that landholders overlying an aquifer can access groundwater for

domestic consumption and stock watering purposes without requiring an access licence or water use approval. However, landholders exercising this basic right require approval to construct a water bore, and the installation of any groundwater bore in NSW requires a licence from DNR.

Under the WM Act, environmental water rules for all planned environmental water sources in NSW (including groundwater) must be implemented as soon as possible. Environmental water rules are provisions for identifying, establishing and maintaining planned environmental water, which is water reserved through management plans for fundamental ecosystem health or other specified environmental purposes. The WM Act also requires all water sources, including groundwater, to be protected and restored, and their water quality to be protected, and wherever possible, enhanced.

At the time of writing, not all the provisions of the WM Act have commenced. Macro water sharing plans are being prepared for water sources, including groundwater sources, that have not been included in any water sharing plans in force under the WM Act. The macro plans will provide generic water sharing rules for four distinct aquifer types: coastal sands, unconsolidated sediments, porous rocks, and fractured rocks.

In the context of groundwater resource management, DNR is also the key agency for designating appropriate uses of groundwater in NSW, including potential uses. DNR helps make decisions about what risks may be present as a result of groundwater contamination and what degree of clean-up is required.

Department of Environment and Conservation

The key pieces of legislation for preventing and regulating groundwater contamination in NSW are the *Protection of the Environment Operations Act 1997* (POEO Act) and the *Contaminated Land Management Act 1997* (CLM Act), which are both administered by DEC.

The POEO Act governs the protection of the environment from pollution. Under this Act it is an offence to pollute waters, including groundwater. The Act also gives powers to the appropriate regulatory authority, generally DEC or local councils, to issue clean-up notices, which are one way of regulating the clean-up and ongoing management of groundwater contamination. The POEO Act also establishes a duty to notify the appropriate regulatory authority of pollution incidents that are causing or threatening material harm to the environment.

The CLM Act sets out a framework for assessing and managing contaminated land, which includes groundwater. It also places a duty on polluters and landowners to notify DEC of certain types of contamination.

Minister for Planning/Department of Planning/local councils

The Department of Planning and local councils have several responsibilities for groundwater and groundwater contamination.

Under Parts 4 and 5 of the *Environmental Planning and Assessment Act 1979* (EP&A Act), consent authorities and determining authorities must consider the likely impacts of proposed development and other activities on the environment, including groundwater. Under Part 3A of the EP&A Act (which applies to certain major infrastructure and other projects), the Minister for Planning, when deciding whether to approve a project, is required to consider the report by the Director General of the Department of Planning. The Director General's report is required to include, among other things, a copy of the proponent's environmental assessment report and any environmental assessment undertaken by the Director General.

Under *State environmental planning policy no. 55 – Remediation of land* (SEPP 55) (NSW DUAP and NSW EPA 1998), planning authorities must consider land contamination issues when assessing certain rezoning applications. Consent authorities must also consider whether the land is contaminated when assessing development applications. If the land has been contaminated, the planning or consent authority must be satisfied that it is suitable in its contaminated state, or will be suitable after remediation, for the purposes for which the land is to be rezoned or for which the development is proposed to be carried out. In some instances groundwater contamination can make the land unsuitable for a particular use and, therefore, management of the contamination may be necessary before the development or rezoning application is approved.

Local councils also have powers under the POEO Act to issue clean-up notices to deal with pollution at sites for which they are the appropriate regulatory authority. In addition, the *Local Government Act 1993* specifies that a charter of councils in NSW is to:

> 'properly manage, develop, protect, restore, enhance and conserve the environment of the area for which it is responsible in a manner that is consistent with, and promotes, the principles of ecologically sustainable development'.

NSW Health

Under the *Public Health Act 1991*, NSW Health has powers to close any water supply, including a groundwater source, if a drinking water source becomes unfit for human consumption or if the water constitutes, or is likely to constitute, a risk to public health.

1.3.3 Existing guidance on groundwater

There are several guidelines that relate to groundwater protection and assessment in NSW.

The key overarching policy, *The NSW state groundwater policy framework document* (NSW Government 1997), outlines the roles of the key NSW authorities in relation to groundwater, which are summarised in 1.3.2.

The framework's subordinate policy documents, including *The NSW state groundwater dependent ecosystems policy* (NSW Government 2002) and *The NSW groundwater quality protection policy* (NSW Government 1998) are also relevant.

The *National environment protection (assessment of site contamination) measure* (NEPC1999) (the site contamination measure) is a broad framework-setting statutory instrument that reflects agreed national objectives and contains guidelines for assessing groundwater contamination. The site contamination measure is implemented in NSW in the form of guidelines approved under the CLM Act.

Schedule B(6) of the site contamination measure provides a framework for a risk-based assessment of groundwater contamination, including guidance on applying the National Water Quality Management Strategy (NWQMS) criteria to groundwater.

Other documents belonging to the NWQMS are:

- the *National water quality management strategy implementation guidelines* (ARMCANZ & ANZECC 1998), which include principles outlining the need to develop a strong, growing and diverse economy, that can enhance the capacity for environment protection
- the *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ 2000a), which identify generic water quality criteria that protect environmental values from a wide range of potential contaminants, as well as articulating a process for undertaking site-specific assessments of water quality to determine whether the water can sustain aquatic ecosystems.

The ANZECC & ARMCANZ (2000a) guidelines also include a chapter on drinking water, which refers to the *Australian drinking water guidelines* (NHMRC & NRMMC 2004) for relevant guideline values.

The *Guidelines for groundwater protection in Australia* (ANZECC & ARMCANZ 1995) provide a framework for protecting groundwater from contamination. The document also defines beneficial uses of, and values for, groundwater.

1.4 Importance of groundwater

Groundwater is important for the health, and in some areas the economic wellbeing, of NSW's community. It is used:

- as a source of domestic, recreational, rural and industrial water, and, in some parts of NSW, as drinking water
- to irrigate gardens, parks, and playing fields in urban environments, especially in recent times
- by the agricultural and industrial sectors to support food production and other activities
- to help sustain life in streams and rivers
- to support fragile ecosystems such as wetlands in dry periods (note that groundwater itself can be a valuable ecosystem).

Groundwater is also important because humans can be indirectly exposed to groundwater contaminants. For example, the consumption of vegetable crops irrigated with contaminated groundwater or products from animals which drank contaminated groundwater can constitute a human health risk. Also, volatile contaminants in groundwater may accumulate in enclosed spaces above a contaminant plume and then pose risks from inhalation or explosion depending, for instance, on the type of the contaminants and the severity of the contamination.

1.5 Definition of groundwater contamination

Contamination of land, which includes groundwater, is defined in the CLM Act and the EP&A Act as:

> 'the presence in, on or under the land of a substance at a concentration above the concentration at which the substance is normally present in, on or under (respectively) land in the same locality, being a presence that presents risk of harm to human health or any other aspect of the environment'.

In practice, however, groundwater is considered to be contaminated where any substance or waste has been added at above natural background concentration, and represents, or potentially represents, an adverse health or environmental impact. For the purpose of these guidelines, any undesirable change in groundwater quality constitutes an adverse environmental impact.

In relation to the POEO Act, these guidelines also refer to the term 'pollution'. The dictionary of the POEO Act defines 'pollution of waters' to include:

> 'placing in or on, or otherwise introducing into or onto waters (whether through an act or omission) any matter whether solid, liquid or gaseous, so that the physical, chemical or biological condition of the waters is changed'.

2 Assessing groundwater contamination

2.1 Introduction

Assessing groundwater contamination involves identifying risks to human and ecological health, and providing the necessary information to manage these risks. Generally, the risks are unacceptable if groundwater quality has deteriorated to the extent that it can no longer support relevant environmental values including current and realistic future use and non-use values. While the risk from groundwater contamination may be unacceptable due to adverse effects of the contamination on the groundwater's environmental values, the level of risk to human and ecological health will vary depending on site-specific conditions. More detailed assessments of the risks posed by the groundwater contamination may then be required to identify an appropriate management response and evaluate the urgency of that response. Such a response may require additional groundwater investigations aimed at evaluating and selecting remedial technologies. Such investigations are not covered by these guidelines, and relevant guidance should be obtained from documents dealing with remedial technologies.

The following presents a framework for assessing risks from groundwater contamination, taking into account the environmental values of the groundwater. It recognises existing, nationally developed approaches, policies and water quality criteria developed to protect water under the National Water Quality Management Strategy (NWQMS) and the numerical guideline criteria for the protection of environmental values that have been presented in NWQMS documents. For the purpose of these guidelines, the NWQMS criteria are hereafter referred to as existing generic groundwater investigation levels (GILs). Note, however, that in addition to the existing generic criteria, GILs may also be derived on a site-specific basis.

These guidelines adopt a tiered approach for the assessment of groundwater contamination. They advise conducting both a preliminary assessment (see 2.2) and a detailed assessment (see 2.3).

DEC may consider information obtained from these groundwater assessments in deciding whether to regulate the management of the contamination. Details about DEC regulation are presented in Section 5.

Assessments of groundwater contamination require:

- careful planning
- a detailed sampling and analysis plan
- the establishment of data quality objectives
- appropriate data quality assurance and quality control procedures.

The data should be collected only by appropriately-trained personnel and interpreted by competent professionals with qualifications and experience relevant to assessing the presence, extent and behaviour of contaminants in groundwater. A good understanding of data uncertainty and temporal and spatial data variability is important as may be knowledge about remedial technologies. For detailed quantitative assessments, assessors should have training in the risk-based assessment of groundwater contamination and in modelling the transport of contaminants in groundwater. While relevant sources of toxicity data are listed in the site contamination measure and ecotoxicological information is provided in ANZECC & ARMCANZ 2000a, specialised toxicological advice may also be required.

These guidelines do not provide detailed technical advice on assessing groundwater contamination. Such guidance is available from other sources including guidelines in the References section.

2.2 Preliminary assessment

The potential for groundwater contamination due to, for instance, current or previous activities at a site, or the confirmed presence of contaminants in soil, should prompt a preliminary assessment of groundwater contamination. The preliminary assessment should aim to identify groundwater contamination and evaluate whether it may pose a threat to human and ecological health. If a potential threat is identified, the results of the preliminary assessment should assist in planning a more detailed groundwater contamination assessment (see 2.3)

The preliminary assessment of groundwater contamination begins with investigating readily available information through a desktop study, including:

- appraising the site history and identifying all past and present contaminating activities and associated potential contaminants

- finding out available information about the local and regional geology and hydrogeology, including identifying water-bearing zones which may, for instance, include perched groundwater near the surface, unconfined groundwater at shallow depth, and semi-confined or confined groundwater at greater depth
- identifying aquifers and confining layers, and at least conducting a basic assessment of expected hydraulic conductivities and porosities
- investigating the groundwater flow domain, including the expected elevation of the water table and any potentiometric surfaces, lateral and vertical hydraulic gradients, likely flow direction and flow velocity, sources of recharge, possible discharge points and other hydraulic boundaries
- identifying potential receptors, including current and realistic future water users, surface water bodies, groundwater-dependent ecosystems and groundwater ecosystems, and vapour flux receptors
- identifying the natural hydrogeochemistry of the groundwater system, such as pH, redox potential, total dissolved solids, and major anion and cation concentrations.

For the desktop study:

- relevant information on DEC's public record of declarations and orders under the CLM Act, and in the public register under the POEO Act, as well as information from local councils and DNR (e.g. in relation to known bore locations and beneficial uses) should be obtained
- the NSW Natural Resource Atlas (visit www.nratlas.nsw.gov.au) should be consulted, which includes relevant information such as the locations of registered bores.

In addition to the desktop study, the preliminary assessment includes intrusive investigations to identify the presence of contaminants and enable likely maximum contaminant concentrations in groundwater beneath a site to be compared with existing generic GILs (see 2.2.2). Contamination is present if there is an undesirable change in the natural background quality of the groundwater.

While the preliminary assessment may not reveal all the above information, the information obtained must be sufficient to gain a preliminary conceptual understanding of the hydrogeological

regime and the risks associated with any potential contamination. The preliminary assessment should also identify important data gaps.

2.2.1 Determining natural background groundwater quality

If potential site contaminants, such as metal compounds and non-metallic inorganics, are substances that might occur naturally at the site, an evaluation of natural background groundwater quality may be required to distinguish naturally occurring concentrations of substances from anthropogenic contamination. Where contamination has been identified, DNR should be informed about all water quality data obtained during the investigation.

While it is not essential to determine natural background concentrations, if the investigation does not uncover information about natural background concentrations, it must be assumed, for the purpose of the preliminary assessment that the detected substances are not naturally occurring and constitute contamination.

2.2.2 Comparing contaminant concentrations against GILs

Following the identification of contamination and likely maximum contaminant concentrations in groundwater at a site, these concentrations must be compared against existing generic GILs, if available, which protect the following environmental values:

- drinking water (see NHMRC & NRMMC 2004)
- aquatic ecosystems (see ANZECC & ARMCANZ 2000a).

For the protection of aquatic ecosystems, the GIL for 95% protection should be used. If the concentration in groundwater exceeds a GIL for any contaminant and there could be current or future exposure to the contaminant (e.g. if the contamination may migrate off-site or there are on-site potential human or ecological receptors for the contaminant), the contamination may pose a threat to human or ecological health and a more detailed assessment of the groundwater contamination, as outlined in 2.3, will be required. Because of the longevity of the contamination, a more detailed assessment is always required if non-aqueous phase liquids such as fuel are present in or on groundwater.

Regarding protection of aquatic ecosystems:

- where the existing generic GIL is below the naturally occurring background concentration of a particular contaminant, the background concentration becomes the default GIL

- where the existing generic GIL for a particular contaminant is below the practical limit of reporting or below the detection limit, the quantitative limit of reporting or the detection limit should be used instead of the existing generic GIL.

Where a generic GIL does not exist for a particular contaminant, DEC should be contacted for advice. DEC should also be contacted if the existing generic GILs for drinking water and aquatic ecosystem protection are not considered stringent enough to protect ecological and human health, given the potential exposure routes (e.g. dermal contact in relation to some contaminants).

2.3 Detailed assessment

Contamination that may pose a threat to ecological or human health requires more detailed assessment. The detailed assessment consists of developing, and progressively improving, a conceptual site model on the basis of the relationship between:

- sources of the contamination and release mechanisms
- the nature and extent of the contamination
- the dominant fate and transport characteristics of contaminants, – a detailed appraisal may mean using analytical or numerical solute fate and transport models – see 2.3.3
- potential receptors and exposure pathways.

In assessing potential receptors and exposure pathways, all relevant environmental values, including those associated with current and realistic future beneficial uses of the groundwater, need to be accounted for (see 2.3.1).

Information on developing conceptual site models for contaminated sites can be found in American Society for Testing and Materials 2003.

During the detailed assessment, uncertainties should be addressed via further investigations. New findings should then be used to validate and improve the conceptual site model in relation to, for instance, an improved understanding of the extent of the contamination, the fate of the contaminants, or the nature of the water bearing zones and any potential receptors.

The assessment must provide enough information about the nature and severity of the risks associated with the contamination to develop meaningful conclusions about the need for, and the urgency

of, management responses. The findings of the detailed assessment should assist in identifying a management response that, at a minimum, ensures that groundwater quality – when groundwater comes to the surface from natural seepages or existing or potential future bores – does not compromise relevant environmental values. An exception to this is the protection of organisms in groundwater, if applicable. Further information about the protection of such organisms is included in Appendix 2.

Where the detailed assessment includes predictions of future contaminant concentrations and concludes that these will not compromise environmental values, appropriate groundwater monitoring needs to be implemented to verify the predicted concentrations. Also, contingency measures including triggers for implementing these measures should be developed as the groundwater monitoring may show that the prediction is invalid.

2.3.1 Protecting the groundwater's environmental values

'Environmental values' are defined in ANZECC & ARMCANZ 2000a as:

> 'particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health which require protection from the effects of pollution, waste discharges and deposits'.

To protect the groundwater's environmental values, the current and projected contaminant concentrations at the points of existing and realistic future use may need to be estimated. If analytical or numerical fate and transport models are used to estimate contaminant concentrations over time at these points, the models must be based on a valid conceptual site model.

The current and projected contaminant concentrations should then be compared against GILs to determine if the relevant environmental values may be adversely affected. The principle for determining the appropriate GILs for the relevant environmental values is articulated in *The NSW groundwater quality protection policy* (NSW Government 1998), which states that:

> 'water quality objectives should always protect the groundwater quality to a level that meets the most sensitive end user's requirements'.

All relevant environmental values should be considered, including current and potential uses of the groundwater and ecosystems.

The concept of environmental values recognises that the nearest receptor of the groundwater may change as a result of development occurring between the site and the receptor, i.e. there may be future uses for the groundwater.

Schedule B(6) of the site contamination measure (NEPC 1999) provides a methodology for using GILs to assess contaminated groundwater. The following six environmental values are presented:

- aquatic ecosystems
- aquaculture and human consumers of food
- agricultural water
- recreation and aesthetics
- drinking water
- industrial water.

Details about how to identify environmental values are provided in Appendix 2. For each environmental value, a set of generic GILs is provided that defines acceptable water quality at the point of use. For some environmental values, the existing generic GILs are an adequate guide to the water quality required to protect environmental values, such as drinking water criteria at the point where the groundwater is used for drinking. For other environmental values or for a point of groundwater extraction where groundwater is not used, exceeding GILs may trigger further investigation.

As GILs protect relevant environmental values, groundwater quality that meets the GILs does not generally pose unacceptable risks. If the groundwater quality does not meet the relevant GILs, the groundwater may not be safe for the environmental values and action would have to be undertaken to more accurately determine whether the groundwater is safe or to resolve the problem.

2.3.2 Site-specific risk assessment

Generic GILs do not exist for all contaminants or exposure scenarios (e.g. the protection of human health from the inhalation of volatile contaminants). If there is no generic GIL, relevant criteria from overseas or GILs developed from a site-specific risk assessment may be used. Such GILs may also be used if contaminant concentrations exceed an existing generic GIL at a point where groundwater is not used and is not likely to be used in the future.

Any detailed (e.g. quantitative) assessment of risks posed by groundwater contamination requires a thorough understanding of all relevant aspects. Of particular importance are aspects relating to sampling methods, the fate and transport of contaminants in groundwater, spatial and temporal data variability, and data uncertainty. Particularly where groundwater contamination may already affect a receptor such as an aquatic ecosystem, other specialist advice, for instance, ecotoxicological advice, may be needed.

Any site-specific assessment of risks must follow the risk-assessment guidance in the site contamination measure (NEPC 1999). In a site-specific risk-based assessment, the following may also need to be considered as they present additional information:

- for assessing human health risks, Department of Health and Aging & EnHealth 2002
- for assessing risks to aquatic ecosystems, ANZECC & ARMCANZ 2000a.

Whenever criteria from overseas or site-specific risk-based criteria are used, agreement from DEC should be obtained. The study results plus the accompanying analysis should be provided to DEC for review and, if appropriate, endorsement of the criteria for use at the site in question.

In the context of site-specific risk assessment, risk perception may influence the type or level of risk considered 'acceptable'. The perception of risk may not be the same as the level of risk assumed by those undertaking the study. Also, where there is significant uncertainty about the risks associated with exposure to groundwater contamination, measures to prevent exposure should be implemented before resolving complex aspects of risk.

2.3.3 Contaminant fate and transport modelling

Contamination assessment commonly incorporates contaminant fate and transport predictions, including analytical and numerical mathematical modelling. Such modelling can be used to:

- assist in validating the conceptual site model and identifying important data gaps
- predict the travel times of contaminants from the point of groundwater extraction to a point of groundwater use

- predict contaminant concentrations, mass fluxes, and exposure doses
- assess the impact of assumptions and uncertainty in parameter values on the predictions
- assist in selecting a management strategy and demonstrating its effectiveness
- assist in remedial design.

Contaminant fate and transport modelling will often be necessary to assess the likely effectiveness of natural attenuation in achieving remedial goals and demonstrating remedial progress and success.

Where fate and transport modelling is undertaken for predictive purposes (e.g. for a risk assessment), the model must be based on a valid conceptual site model and the information obtained from the modelling study must adequately assist in making decisions about the action needed to address groundwater contamination.

Modelling the fate and transport of groundwater contaminants is a complex task. In all cases:

- modelling should only be undertaken by appropriately qualified professionals experienced in groundwater contamination
- the model used must reflect best industry practice, and the proponent must clearly demonstrate the applicability and adequacy of the model for a specific site and modelling objective
- model assumptions and parameter values must be appropriately conservative and the associated report must clearly explain the validity of all assumptions made and all input parameter values selected.

The degree of conservatism required in the model will depend on various factors. Generally, the level of conservatism can be reduced by improved site characterisation, adequate model calibration and sensitivity analyses.

While contaminant migration in groundwater occurs in three dimensions, not all dimensions need to be incorporated into the mathematical model, depending on the objective of the modelling study and the degree of conservatism that is employed.

Some guidance on fate and transport modelling is provided in Schedule B(2) of the site contamination measure (NEPC 1999).

2.3.4 Additional aspects to consider

Although a wide range of analytical and numerical modelling tools and visualisation aids is now available to assist in the assessment of groundwater contamination, professionals using these tools must have considerable knowledge of relevant processes combined with analytical skills and professional judgement.

Among other aspects, the following issues should be taken into account in planning investigations into groundwater contamination:

- Appropriately qualified and experienced groundwater professionals must plan and implement a suitable groundwater investigation.
- Schedule B(2) of the site contamination measure (NEPC 1999) and the *Australian guidelines for water quality monitoring and reporting* (ANZECC & ARMCANZ 2000b) should be considered.
- Data quality objectives, for instance as per the *Guidelines for the NSW site auditor scheme* (second edition) (DEC 2006), should be defined before the investigation.
- The existence of groundwater has to be acknowledged at every potentially contaminated site. If there is the potential for groundwater contamination, intrusive groundwater investigations should generally be carried out unless groundwater is present at greater depth (e.g. more than 15 m below the ground surface), in which case the risks to potential receptors should be considered in assessing the need for intrusive investigations. Intrusive investigations at greater depth may not be required where the natural background quality of the groundwater is poor and the groundwater yield is low. In any case, advice from relevant agencies should be obtained if intrusive investigations are considered unwarranted.
- Groundwater investigations at a source site require careful planning and execution to avoid groundwater contamination as a result of bore construction. Under certain circumstances (e.g. contamination with dense non-aqueous phase liquid (DNAPL)), observation bores may need to be installed away from suspected source areas.
- The complexity of the groundwater system, which may include perched groundwater near the surface, an unconfined aquifer at shallow depth and semi-confined or confined aquifers at greater depths, needs to be considered.

- Different water-bearing zones at a site may have different attributes, such as permeability and yield, and different environmental values.
- Properly constructed groundwater monitoring wells are essential. Aquifer interconnection and cross-contamination must be avoided. Guidance on construction and use of monitoring wells is provided in *Minimum construction requirements for water bores in Australia* (LWBC 2003) and in *Groundwater sampling guidelines* (EPA Victoria 2000).
- Many methods are available for obtaining groundwater samples from monitoring wells. Depending on the conditions (e.g. chemicals of concern, geology), some give more reliable results than others. It is important to select the most appropriate sampling technique for a particular well and contaminant suite, taking account of modern sampling methods. In this context, the *Groundwater sampling guidelines* (EPA Victoria 2000) should be considered.
- The collection of groundwater samples from pits is subject to potential interference, including gas exchange and mixing during pit excavation and high suspended solid loads. Although useful qualitative indications may often be obtained from such samples, they should not be included in the same data set as samples from monitoring wells.
- The Australian Standard AS2368 (Standards Australia 1990) *Test pumping of water wells* should be considered in the context of assessing hydraulic properties of aquifers.
- Appropriate licences/consent for groundwater bores must be obtained from DNR.
- Extracted groundwater must be disposed of in accordance with the POEO Act and the trade wastes agreement with the appropriate water authority. Off-site disposal must consider the *Environmental guidelines: assessment, classification and management of liquid and non-liquid wastes* (NSW EPA 1999).
- Groundwater investigations must consider that groundwater flow and contaminant transport occur in three dimensions. Generally, observation wells should be designed to sample discrete, relatively short, vertical intervals targeting a depth of sampling based on expected concentration profiles and relevant exposure scenarios.

- Geophysical techniques that may contribute to valuable information about the contaminant plume should be considered.
- Both natural and emplaced ground materials are heterogeneous. The potential presence of preferred pathways should always be considered when designing a groundwater monitoring well network.
- Off-site groundwater investigations will generally be required to delineate a contaminant plume. Such investigations may also be important to gain evidence that the site under investigation is not the source site.
- The effect of groundwater recharge on the depth of contaminant plumes must be considered in deciding on sampling depths.
- Information in the *Groundwater management handbook* (Sydney Coastal Councils Group 2006) should be considered as the handbook contains relevant details on, for instance, decommissioning bores.

3 Managing groundwater contamination

3.1 Introduction

In these guidelines, the term 'management' covers all measures taken to address groundwater contamination, including measures to mitigate risks from the contamination. Measures may include, but are not limited to:

- notifying DEC, DNR, NSW Health, local councils, affected property owners, groundwater users, owners of subsurface utilities and others, as appropriate, of the presence of groundwater contamination
- plume containment
- active or passive clean-up of contaminated groundwater
- ongoing monitoring of groundwater, and contingency plans
- implementing groundwater management plans to mitigate risks
- restricting groundwater use in, and down-gradient of, the contaminant plume.

Managing groundwater contamination, for instance, to protect town water supply wells may also include implementing strategies such as wellhead protection plans to prevent groundwater in areas that supply water to a public well from becoming contaminated. More details about wellhead protection plans can be found in *The NSW groundwater quality protection policy* (NSW Government 1998).

The most appropriate management strategy for a particular site where groundwater is contaminated will depend on a range of factors including the nature and extent of contamination, the severity of the contamination, the availability of practical remedial options, and community expectations. Public involvement is important in identifying appropriate management responses. In this context, the *Guidelines for groundwater protection in Australia* (ANZECC & ARMCANZ 1995) and Schedule B(8) of the site contamination measure (NEPC 1999) should be considered.

The following sections discuss ways of determining an appropriate management strategy. Note that the issues discussed in these sections are relevant to the management of contaminated groundwater irrespective of whether the contamination is managed under the CLM Act.

3.2 Management responses to contamination

While prevention of groundwater contamination is a key principle, contamination of groundwater is in many cases a legacy of past practices. Where contamination is identified, the management objectives are to protect human and ecological health and to ultimately restore the groundwater to its natural background quality. To achieve these objectives, the following management responses must be considered:

- control short-term threats arising from the contamination (see 3.3)
- restrict groundwater use (see 3.4)
- prevent or minimise further migration of contaminants from source materials to groundwater (see 3.5)
- prevent or minimise further migration of the contaminant plume (see 3.6)
- clean up groundwater to protect human and ecological health, restore the capacity of the groundwater to support the relevant environmental values and, as far as practicable, return groundwater quality to its natural background quality (see Section 4).

As a minimum, management of contaminated groundwater should continue until human and ecological health is protected and the capacity of the groundwater to support relevant environmental values is restored.

Management responses to groundwater contamination should focus on the greatest threats first, and the benefits of groundwater clean-up must outweigh any incidental negative impacts that could arise.

3.3 Controlling short-term threats

Immediate action is required where short-term threats, that is, acute risks, are identified. Such risks include the accumulation of explosive vapours in underground utilities, or unacceptable risks to human or ecological health from short-term exposures to contamination.

As an example of the type of management response that may be required, DNR may impose a ban on the extraction of groundwater from bores to prevent exposure to contaminants. In certain circumstances, NSW Health also has powers to restrict the use of groundwater in NSW.

3.4 Restricting groundwater use

In some circumstances, the use of contaminated groundwater both on- and off-site may need to be restricted.

DNR is the lead agency for managing groundwater use in NSW. DNR also determines whether use restrictions are necessary where contamination precludes the safe use of groundwater. Liaison with DNR is essential if groundwater use restrictions are considered necessary.

In specific cases, DNR may restrict groundwater use near a contaminated site to prevent exposure while groundwater remediation occurs. This type of institutional control may be necessary, for example, where a site is implementing a long-term groundwater remedy. In general, use restriction, other than as an emergency response to reduce risks, would only be supported where:

- the sources of contamination have been controlled
- the existing boundaries of the contaminant plume have been identified
- the groundwater contamination is being cleaned up or has been cleaned up consistent with DEC's requirements
- there is an acknowledgement from the party responsible for the remediation of its obligations to protect human and ecological health, and a commitment that groundwater management actions will continue until the groundwater quality protects relevant environmental values
- the groundwater management plan, including provisions for the regular reporting of ongoing groundwater quality, has been documented and provided to DNR.

Restricting access to groundwater will not be considered an appropriate management strategy in isolation unless there are no other remediation options available.

Where groundwater use is restricted because of contamination, DEC or DNR may require the party responsible for the contamination to undertake some actions to support the use restrictions. These could include, for instance, the development and implementation of a communication strategy to inform the community about groundwater contamination or ongoing bore sampling in the area of the contaminant plume.

In any case, the fact that the use of groundwater is restricted should not be be used to argue the case for lower clean-up standards, although the timeframe to achieve the clean-up may be affected.

3.5 Source control

The elimination or control of all known and suspected sources of groundwater contamination is important. A source is any material that acts as a reservoir for the continued contamination of groundwater. Sources of ongoing groundwater contamination include primary sources, such as leaking chemical storage tanks, and secondary sources, such as separate phase liquids in groundwater and overlying soils.

Source control refers to a range of actions, including removal, treatment in place, and containment, which are designed to minimise migration of contaminants into groundwater. Source control is important because minimising further contaminant releases to the environment is often required for the successful management of a contaminant plume. Sources of groundwater contamination also need to be addressed because it is an offence under the POEO Act to pollute groundwater.

Source control actions should be undertaken early in the assessment and management process. In particular:

- Leaking underground tanks must be repaired or replaced in accordance with appropriate standards such as *The design, installation and operation of underground petroleum storage systems* (Australian Institute of Petroleum 2002) as soon as a leak is confirmed, and further investigations must determine the extent, if any, of contamination of soils and groundwater.
- Non-aqueous phase liquids must be cleaned up to the extent practicable – see 3.5.1.
- Contaminated soils need remediating so they no longer pose a potential risk to groundwater quality. This may require the development of soil criteria that take into account the leaching potential of contaminants from soil into groundwater. Note that the health-based soil investigation levels adopted in *Guidelines for the site auditor scheme* (DEC 2006) and the site contamination measure (NEPC 1999) do not take groundwater protection into account.

Where complete source removal or treatment is not possible:

- the remaining source should be contained for the entire time that it is present in the groundwater
- any source containment will generally need to be supported by ongoing groundwater quality monitoring.

Source containment as part of a long-term management response will generally only be appropriate where there are significant difficulties in removing or treating the contamination, for instance where:

- treatment technologies are not available or treatment is not technically feasible
- the volume of materials or complexity of the site make source removal or treatment impracticable
- removing or treating the source would have unavoidable severe adverse effects on other aspects of the environment.

3.5.1 Non-aqueous phase liquids

Non-aqueous phase liquids (NAPLs) in the subsurface provide an ongoing source of contamination. NAPLs that are in contact with groundwater constitute groundwater contamination. Where light NAPLs (LNAPLs) or dense NAPLs (DNAPLs) are present in the subsurface, they must be removed or treated as much as practicable. Particular care, however, is required in the assessment and clean-up of DNAPL contamination to prevent mobilisation or an increased rate of dissolution.

Where complete removal or treatment of the NAPL is impracticable, as may be the case with some DNAPLs in complex geological media, ongoing monitoring and management of the contamination is required as a minimum for as long as necessary, to ensure the protection of human and ecological health. Sources and plumes will need to be contained to the maximum extent practicable, and remediation to address the dissolved-phase contaminants may also be required.

A strategy for controlling NAPL contamination should have the following objectives:

- to ensure the protection of human and ecological health
- to control further migration of contaminants from subsurface NAPLs to the surrounding groundwater (source control)

- to reduce NAPL mass to the extent practicable (source removal or treatment).

It is recognised that clean-up of NAPL contamination can be difficult. For instance, there can be high costs and uncertain benefits in aggressive source zone treatment of some NAPLs. Therefore, the remedial objective for some sites with recalcitrant sources of NAPL may be to contain the source material and prevent or minimise further contaminant migration. Nonetheless, presumptions about the practicability of source zone remediation must keep pace with emergent technology; it should not automatically be assumed that source zone remediation is not feasible.

Any assessment that source removal of NAPL contaminants is impracticable should be clearly documented.

3.6 Plume containment

In responding to groundwater contamination, one goal is to contain the extent of the contaminant plume, that is, to prevent or minimise further plume migration while other management actions are taking place. Plume containment, as the sole long-term response to groundwater contamination, is generally only acceptable when cleaning up contaminated groundwater is not practicable.

Proponents of long-term containment must demonstrate they have adequately considered all risks posed by the groundwater contamination. Systems must be developed to monitor the effectiveness of the containment in the long term, and contingency plans must be developed if monitoring data shows that the containment is not effective. In this context, the responsibilities for, and resourcing of, long-term management and contingency plans need to be addressed.

3.7 Clean-up of contaminated groundwater

Clean-up is an important part of managing groundwater contamination. Section 4 provides in-depth information on objectives and procedures for cleaning up contaminated groundwater, and should be read in conjunction with this section.

4 Cleaning up contaminated groundwater

This section should be read in conjunction with Section 3 as clean-up is an important part of managing contaminated groundwater, and material in Section 3 will also be relevant for this section. Discussion of clean-up has been separated from Section 3 for ease of readability.

Clean-up objectives for contaminated groundwater should be established in the following preferential order:

1 Clean up so natural background water quality is restored.

2 Clean up to protect the relevant environmental values of groundwater, and human and ecological health.

3 Clean up to the extent practicable.

This hierarchy is discussed below.

4.1 Clean up so natural background water quality is restored

Ideally, contaminated groundwater should be restored as much as practicable to its natural background quality. This is particularly important for pristine or near-pristine groundwater systems of high yield.

In practice, cleaning up so natural background concentrations are restored can be technically difficult and extremely costly. Therefore, where it is not practicable to restore background quality, an interim clean-up goal can be based on protecting environmental values and preventing potential risks to human and ecological health.

Even where it is not practicable in the short term, restoring water quality to its natural background state should remain the long-term remedial objective for contaminated groundwater. In this context, the use of monitored natural attenuation should be considered.

4.1.1 Monitored natural attenuation

Natural attenuation of contaminants in groundwater may be defined as the:

> 'effect of naturally occurring physical, chemical and biological processes to reduce the load, concentration, flux or toxicity of polluting substances in groundwater' (UK Environment Agency 2000).

These processes include biodegradation, dispersion, diffusion, sorption, volatilisation, and chemical or biological stabilisation, transformation or destruction.

Monitored natural attenuation (MNA) can also be part of a strategy for managing risks from contaminated groundwater. However, a detailed evaluation of the contamination, the aquifer characteristics and potential risks is necessary to confirm that MNA should be part of the management strategy.

A proposal for MNA must include clear evidence demonstrating that:

- significant attenuation of contaminants is occurring
- remedial goals can be met in an adequate timeframe
- the proposed monitoring program is suitable.

For DEC to accept MNA as a suitable approach at a site, natural attenuation processes that reduce the mass of dissolved contaminants (e.g. biodegradation) will generally need to be clearly demonstrated.

Appendix 3 presents more detailed guidance on the appropriate evaluation and implementation of MNA for use in NSW.

4.2 Clean up to protect the relevant environmental values of groundwater, and human and ecological health

Where the clean-up goal is to protect the environmental values of groundwater, and human and ecological health, numerical clean-up criteria may need to be used to measure the success of remedial actions.

Clean-up criteria at the point of use must employ relevant existing generic GILs or GILs derived on a site-specific basis. At the point of extraction, site-specific clean-up criteria may be derived that protect the applicable environmental values, and human and ecological health, at the point of use. Where numerical clean-up criteria for either the point of use or the point of extraction are proposed, based on a site-specific assessment of risks, the criteria must be derived through comprehensive evaluation of all actual and potential exposure pathways.

The site-specific use of clean-up criteria must take into account schedules B(4) and B(5) of the site contamination measure (NEPC 1999). Clean-up criteria derived for the point of use which are

considered to be protective of aquatic ecosystems may also need to consider the process outlined in ANZECC & ARMCANZ 2000a. DEC should be consulted if site-specific risk-based criteria are used.

4.3 Clean up to the extent practicable

Where DEC has decided to regulate the management of contaminated groundwater under Part 3 of the CLM Act, DEC must be satisfied with any remediation plan or proposal for a voluntary remediation agreement. In this context, DEC will consider what is practicable and may seek independent expert verification of any supporting claims. In some cases, it may not be practicable to continue cleaning up the groundwater to the point where all its environmental values are restored. In such instances, when regulating the remediation, DEC may consider proposed interim clean-up goals in consultation with stakeholders.

4.3.1 Demonstrating restoring environmental values is impracticable

If a proponent considers that clean-up to restore the protection of environmental values is impracticable in the future, this must be clearly demonstrated to DEC. The evaluation of practicability should be documented against each factor listed below:

- technical capability to achieve the clean-up
- clean-up costs
- the value of the groundwater resource
- threats the contamination poses to human or ecological health.

Proposed clean-up measures should correlate with the value of the groundwater resource and the severity of the contamination. Further, any proposal for the clean-up that argues impracticability must include an acknowledgement that the long-term objective is to restore the protection of all relevant environmental values, and ultimately achieve natural background quality. In such cases, ongoing management and monitoring of the groundwater may be required to ensure the protection of human and ecological health.

In considering the nature of the remediation required for a site, DEC may consider what actions are practicable. If it is impracticable to clean up groundwater to a concentration needed to restore the protection of environmental values, DEC may accept that clean-up to the extent practicable has occurred and that, subject to appropriate ongoing management of exposures to the contaminants and periodic review, further clean-up is not required. However, acute risks

from the contamination, such as risks from short-term exposure or a risk of explosion from the accumulation of vapours, must be resolved without delay.

In all cases where clean-up to restore environmental values cannot be achieved:

- it is still necessary to clean up to the extent practicable, to minimise the impact on environmental values
- human and ecological health must be protected
- plume containment should be implemented to prevent the plume from spreading
- ongoing groundwater monitoring may be required
- the possibility of cleaning up the groundwater contamination should be periodically reassessed to account for emerging technologies
- provisions are required for long-term resourcing and responsibility for any ongoing management strategy
- information must be recorded and disseminated.

In considering the practicability of cleaning up the groundwater contamination, DEC will take into account technical, logistical and financial considerations.

Before DEC agrees to the proposal, it may seek input from DNR on the current and realistic future uses of the groundwater and the implications that residual contamination may have for groundwater resource management. DNR would consider the information provided in a groundwater management plan where long-term restrictions on groundwater use are required.

Where DEC agrees that clean-up to the extent practicable has occurred, this does not remove the proponent's responsibility for ongoing management of the residual contamination. The remediation proposal should be accompanied by:

- a commitment to ongoing monitoring and re-evaluation of the practicability of clean-up. A satisfactory monitoring and reporting program must be implemented to continually evaluate the contamination.
- a groundwater management plan (GMP) that specifies measures which will be implemented to mitigate risks to human and ecological health (see 5.3.2).

- acknowledgement that future management including clean-up action may be required by the government to ensure the protection of human and ecological health.
- provision for long-term resourcing and responsibility for any ongoing management strategy.

Any ongoing management actions may be enforceable through statutory means such as a regulatory instrument issued under the CLM or POEO Act.

4.4 Clean-up impacts

The benefits from undertaking groundwater clean-up must outweigh any incidental negative impacts to human health or the environment that could arise from the clean-up.

Groundwater remediation technologies that involve discharge to surface water, land or air must not pollute the receiving environment. Remediation incorporating discharge to groundwater must not cause unacceptable contamination, such as an adverse impact on environmental values, from the uncontrolled presence of treatment products or compounds derived from contaminant degradation. Where it is proposed to add any substance to groundwater for treatment purposes, such as chemical or biological agents to help the contaminants degrade, the proponent must ensure that all necessary approvals and licences have been obtained.

4.5 Clean-up timeframe

The clean-up of groundwater contamination should occur in a timeframe that is commensurate with technical difficulties and potential risks.

Where remediation is being managed under the CLM Act, DEC will set appropriate clean-up timeframes.

Unacceptable exposures to contaminants must be addressed as a priority. If receptors are already being exposed to potentially unacceptable concentrations of contaminants in groundwater, directly or indirectly (e.g. contaminants emitted from groundwater to indoor air), action must be taken as soon as possible to prevent these exposures.

Examples of factors that should be taken into account when developing clean-up timeframes for a specific site include:

- the risks from exposure to contamination
- the relevant environmental values which may be affected
- the source, nature and extent of contamination
- hydrogeological conditions
- the reliability of interim exposure controls
- the availability and effectiveness of suitable clean-up technologies and disposal options
- community preferences
- the financial resources of the party responsible for clean-up
- intergenerational equity.

When evaluating remedial options, those that achieve the desired clean-up goals in the shortest timeframe should be preferred.

Uncertainties associated with cleaning up groundwater may make it difficult to exactly specify when a remedial strategy will achieve the clean-up goals. It is not always possible to predict how long it will take to return groundwater quality to a state that protects the relevant environmental values because of complexities associated with, for example, specific contaminant types and contaminant interactions, hydrogeological characteristics and technology limitations. Nonetheless, predicting clean-up timeframes is valuable in evaluating and selecting the preferred remediation options.

Longer timeframes for cleaning up groundwater contamination may be acceptable when there are adequate monitoring and reliable controls to protect human and ecological health, and the plume has been appropriately contained.

4.6 Degraded local groundwater quality

In some cases, the extent to which the groundwater can be cleaned up may be limited by the presence of contamination from other sources, such as contaminant releases from other sites that are hydraulically up-gradient of the subject site.

Where elevated concentrations of contaminants in groundwater are identified entering a site, DEC should be contacted to discuss what implications these may have for clean-up strategies.

The local groundwater may also be degraded due to naturally occurring substances. The local council and DNR may need to be

informed in such cases because unacceptable human health and ecological risks may be associated with these substances.

Pollution prevention remains of paramount importance. Where less stringent clean-up is justified in the interim to deal with degraded local groundwater quality, this does not diminish the need to prevent further contamination.

4.7 Environmental monitoring

Environmental monitoring and reporting are often needed to assess whether management actions at a particular site are achieving, or moving towards, the clean-up goals. Environmental monitoring is a key component of any remediation strategy, and is also implemented through an ongoing management strategy if residual contamination remains at a site after remedial works have ceased.

Monitoring groundwater is not a management response in isolation but is needed to supplement other management actions.

Monitoring strategies should articulate:

- appropriate monitoring locations and depths within and down-gradient of the contaminant plume
- the relevant assessment criteria to be used in evaluating monitoring results
- the frequency of monitoring and reporting
- the process for reviewing monitoring data and ways in which the data will feed into decisions about the contamination and management strategy
- the length of time for which monitoring is expected to continue (generally, monitoring should continue while there is residual groundwater contamination)
- the regulatory authorities involved (including state and local government) and the management inputs required from each.

4.8 Groundwater management plans

A groundwater management plan (GMP) provides a mechanism for managing risks from potential exposure to contaminants in groundwater. For instance, where skin contact with contaminated groundwater is possible, a GMP can outline procedures that protect people who could come into contact with groundwater, such as workers undertaking excavations below the water table. GMPs

should be tied to a regulatory framework to ensure that they are appropriately implemented and enforced.

A GMP should include a contingency plan which will need to state clearly what the objectives of the plan are, what circumstances will trigger clean-up actions, and who will be responsible for its implementation.

4.8.1 Regulatory controls for ongoing management of groundwater contamination

Where ongoing management of groundwater contamination is proposed at a regulated site:

- The management plan should be reasonably enforceable (e.g. via a regulatory instrument issued under the CLM Act or development consent conditions issued by the relevant planning authority). The management plan should include well-defined reporting arrangements to local or state authorities as applicable.
- There should be appropriate public notification of the restrictions applying to the land to ensure that potential purchasers or other interested parties are aware of the restrictions, for example, appropriate notations on a planning certificate issued under section 149(2) of the *Environmental Planning and Assessment Act 1979* or a covenant registered on the title to land under section 88B of the *Conveyancing Act 1919*.
- There should be a clear delineation of monitoring and reporting responsibilities.
- The party responsible for the contamination (i.e. the polluter or current owner or other parties as per the CLM Act) would normally be responsible for implementing and maintaining all necessary ongoing management.

5 Regulation

5.1 Regulation under the CLM Act

Owners of contaminated sites and parties who caused contamination must notify DEC under the CLM Act. Once DEC is notified of contamination, it will review relevant information to determine whether the assessment and management of the contamination warrants regulatory control under the CLM Act. At the time of writing, the CLM Act is under review and amendments to the Act, including amendments to the notification requirements, have been proposed.

On the basis of this information, DEC may require further investigation, clean-up, or another appropriate management response. If there is no acceptable voluntary proposal to carry out the required works, DEC may require the 'appropriate person' (as defined in the CLM Act), or a public authority that is not an 'appropriate person', to carry out the works in accordance with the CLM Act.

The cost of investigation or remediation carried out under the CLM Act can be recovered in court from the people who were responsible for the contamination. Management under the CLM Act also ensures that the assessment and management process is transparent so the affected or interested community is kept informed.

Involvement by DEC can be initiated at any stage during the assessment or management of contaminated groundwater. The possibility of future involvement by DEC does not prevent a party from undertaking the investigations outlined in Section 2. When contaminated groundwater is being managed under the CLM Act, DEC may require a person responsible for managing the contamination, such as the polluter or site owner, to notify DNR of the contamination. DNR may use and make this information available as it sees fit for groundwater resource management, which may include implementing necessary use restrictions. The appropriate persons may also be required to notify other affected parties including the local community where, for instance, groundwater uses are precluded by contamination.

5.2 Regulation under the POEO Act

Prevention of groundwater pollution is a key factor. Pollution of groundwater is an offence under the POEO Act and prosecution for offences against the provisions of the Act can result in significant

fines. If an appropriate regulatory authority reasonably suspects that a pollution incident has occurred or is occurring, they can also direct the occupier of a premises or person causing the pollution to take clean-up action. DEC will be the appropriate regulatory authority for activities licensed under the POEO Act.

5.3 Requirements under SEPP 55

State environmental planning policy no. 55 – Remediation of land (SEPP 55) contains requirements for remediating contamination, including groundwater contamination.

In summary, SEPP 55:

- requires planning authorities to consider, when considering a rezoning application, whether the land is contaminated. If the land is contaminated, the planning authority must be satisfied that it is suitable in its contaminated state, or will be suitable after remediation, for the purposes for which the land will be rezoned. If the land requires remediation before use for a particular purpose, the planning authority must be satisfied the land will be so remediated before being used for that particular purpose.
- provides that a consent authority must not agree to the carrying out of any development unless it has considered whether the land is contaminated. If the land is contaminated, the consent authority must be satisfied that it is suitable in its contaminated state, or will be suitable after remediation, for the purposes for which the development is proposed to be carried out. If the land requires remediation before use for a particular purpose, the consent authority must be satisfied it will be so remediated before being used for that particular purpose.
- provides that, before determining an application for rezoning or development consent for certain classes of land, a planning authority/consent authority must consider a report on the findings of a preliminary investigation carried out in accordance with contaminated land management guidelines.
- makes remediation permissible across NSW despite any provision of an environmental planning instrument to the contrary, although in some cases only with consent.
- requires all remediation to comply with certain standards and guidelines including guidelines in force under the CLM Act.

6 References

American Society for Testing and Materials 2003, *Guide for developing conceptual site models for contaminated sites*, ASTM E1689-95e1

ANZECC & ARMCANZ 2000a, *Australian and New Zealand guidelines for fresh and marine water quality*, National Water Quality Management Strategy, Paper No. 4, Commonwealth of Australia, www.mincos.gov.au/pub_anzwq.html

ANZECC & ARMCANZ 2000b, *Australian guidelines for water quality monitoring and reporting*, National Water Quality Management Strategy, Paper No. 7, Commonwealth of Australia, www.mincos.gov.au/pub_agwq.html

ARMCANZ & ANZECC 1998, *National water quality management strategy implementation guidelines*, National Water Quality Management Strategy, Commonwealth of Australia, www.mincos.gov.au/pdf/nwqms/implementationguidelines.pdf

ANZECC & ARMCANZ 1995, *Guidelines for groundwater protection in Australia*, National Water Quality Management Strategy, Commonwealth of Australia, www.mincos.gov.au/pdf/nwqms/guidelines-for-groundwater-protection.pdf

Australian Institute of Petroleum 2002, *The design, installation and operation of underground petroleum storage systems*

Danielopol DL, Griebler C, Gunatilaka A & Notenboom J 2003, 'Present state and prospects for groundwater ecosystems', in *Environmental Conservation* 30, pp 104–130

DEC 2006, *Guidelines for the NSW site auditor scheme*, 2nd edition, Department of Environment and Conservation NSW, www.environment.nsw.gov.au/resources/auditorglines06121.pdf

Department of Health and Ageing & EnHealth 2002, *Environmental health risk assessment: Guidelines for assessing human health risks from environmental hazards*, Commonwealth of Australia, www.health.gov.au/internet/wcms/Publishing.nsf/Content/health-pubhlth-publicat-document-metadata-env_hra.htm/$FILE/env_hra.pdf

EPA Victoria 2000, *Groundwater sampling guidelines*, Publication 669, http://epanote2.epa. vic.gov.au/EPA/publications.nsf/2f1c2625731746aa4a256ce90001cbb5/6bc0feabe895bc044a25670f00215055

Hancock PJ, Boulton AJ and Humphreys WF 2005, 'Aquifers and hyporheic zones: Towards an ecological understanding of groundwater', *Hydrogeology* 13, pp 98–111

LWBC 2003, *Minimum construction requirements for water bores in Australia*, Edition 2, revised September 2003, Land and Water Biodiversity Committee, Commonwealth of Australia, www.nrme.qld.gov.au/water/pdf/bore_aust/mcrwba.pdf

NEPC 1999, *National environment protection (assessment of site contamination) measure 1999*, (site contamination measure), National Environment Protection Council, www.ephc.gov.au/nepms/cs/con_sites.html

NHMRC & NRMMC 2004, *Australian drinking water guidelines*, www.nhmrc.gov.au/publications/_files/awgfull.pdf

NSW DUAP & NSW EPA 1998, *Managing land contamination: Planning guidelines, SEPP 55 – remediation of land*, NSW Department of Urban Affairs and Planning and NSW Environment Protection Authority, www.epa.nsw.gov.au/resources/gu_contam.pdf

NSW EPA 1999, *Environmental guidelines: assessment, classification and management of liquid and non-liquid wastes*, NSW Environment Protection Authority, www.environment.nsw.gov.au/resources/waste_guide.pdf

NSW Government 2006, *Environmental objectives for water quality and river flow*, www.environment.nsw.gov.au/ieo

NSW Government 2002, *The NSW state groundwater dependent ecosystems policy*, NSW Department of Land and Water Conservation, www.dlwc.nsw.gov.au/care/water/wr/pdfs/ policy_180602.pdf

NSW Government 1998, *The NSW groundwater quality protection policy*, NSW Department of Land and Water Conservation, www.dlwc.nsw.gov.au/care/water/wr/pdfs/quality_policy.pdf

NSW Government 1997, *The NSW state groundwater policy framework document*, NSW Department of Land and Water Conservation, www.dlwc.nsw.gov.au/care/water/wr/pdfs/gfrmpol.pdf

Standards Australia 1990, *Test pumping of water wells*, AS2368 (1990) www.standards.com.au/select/Script/Details.asp?DocN=stds000000718

Sydney Coastal Councils Group Inc 2006, *Groundwater management handbook*, www.sydneycoastalcouncils.com.au

UK Environment Agency 2000, *Guidance on the assessment and monitoring of natural attenuation of contaminants in groundwater*, Environment Agency, Bristol, http://publications.environment-agency.gov.uk/pdf/SR-DPUB95-e-e.pdf

Relevant Acts of Parliament and policies

Contaminated Land Management Act 1997 www.epa.nsw.gov.au/legal/envacts.htm

Conveyancing Act 1919 www.austlii.edu.au/au/legis/nsw/consol_act/ca1919141/

Environmental Planning and Assessment Act 1979 www.legislation.nsw.gov.au/viewtop/ inforce/act+203+1979+first+0+N

Local Government Act 1993 www.austlii.edu.au/au/legis/nsw/consol_act/lga1993182/

NSW Public Health Act 1991 www.austlii.edu.au/au/legis/nsw/consol_act/pha1991126/

NSW Water Sharing Plans www.naturalresources.nsw.gov.au/water/ind_sharing_plans.shtml

Protection of the Environment Operations Act 1997 www.epa.nsw.gov.au/legal/envacts.htm

Water Act 1912 www.austlii.edu.au/au/legis/nsw/consol_act/wa191283/

Water Management Act 2000 www.dlwc.nsw.gov.au/care/water/wml/pdfs/wmact2000-92.pdf

Suggested further reading

American Petroleum Institute 2000, *Non-aqueous phase liquid (NAPL) mobility limits in soil*

American Petroleum Institute 1998, *Evaluation of sampling and analytical methods for measuring indicators of intrinsic bioremediation*

American Society for Testing and Materials 2004, *Standard guide for remediation of groundwater by natural attenuation at petroleum release sites*, ASTM E1943-98

American Society for Testing and Materials 1992, *Standard practice for evaluating mathematical models for the environmental fate of chemicals*, ASTM E978

Bedient PB, Rifai HS and Newell CJ 1999, *Groundwater contamination: transport and remediation*, Prentice Hall & Sons

British Geological Survey 2003, *Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management*, report on behalf of the United Nations Environment Programme's Division of Early Warning and Assessment

BP Oil International 2001, *RISC-integrated software for clean-ups*, *user's manual,* Sunbury, UK

Building Research Establishment 2001, *Concrete in aggressive ground, Special Digest No.1, Part 1: Assessing the aggressive chemical environment*, UK Department of Trade and Industry, BRE Centre for Concrete Construction, BRE Centre for Ground Engineering and Remediation, London, UK

Davis GB, Trefry MG, and Patterson BM 2004, *Petroleum and solvent vapours: quantifying their behaviour, assessment, and exposure*, a CSIRO Land and Water Report to the Western Australian Department of Environment

Department of Environmental Protection (Western Australia) 2004, *Use of monitored natural attenuation for groundwater remediation*

Department of Environmental Protection (Western Australia) 2001, *Potentially contaminating activities, industries and land uses*

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

EPA Victoria 2002, *The clean up and management of polluted groundwater*, Environment Protection Authority Victoria, Information Bulletin, Publication 840

Fetter CW 2000, *Applied hydrogeology*, Prentice Hall Inc, Englewood Cliffs, NJ, USA

Fetter CW 1998, *Contaminant hydrogeology*, Prentice Hall Inc, Englewood Cliffs, NJ, USA

Freeze RA & Cherry JF 1979, *Groundwater*, Prentice Hall Inc, Englewood Cliffs, NJ, USA

Interstate Technology and Regulatory Cooperation Work Group 2001, *Technical and regulatory guidance for in-situ chemical oxidation of contaminated soil and groundwater*

Interstate Technology and Regulatory Cooperation Work Group 2000, *Dense non-aqueous phase liquids (DNAPLs): review of emerging characterization and remediation technologies*

Murray-Darling Basin Commission 2000, *Groundwater flow modelling guideline*

Nielsen DM 2005, *Practical handbook of environmental site characterization and ground water monitoring*, Taylor & Francis, CRC Press

NSW EPA 1999, *Guidelines on significant risk of harm from contaminated land and the duty to report*, NSW Environment Protection Authority

Pankow JF & Cherry JA 1996, *Dense chlorinated solvents and other DNAPLs in groundwater: history, behaviour and remediation*, Waterloo Press, Portland, Oregon, USA

PASCALIS 2002, *Sampling manual for the assessment of regional groundwater biodiversity*, F Malard (chief editor), European Project: Protocols for the Assessment and Conservation of Aquatic Life in the Subsurface

Schwartz FW and Zhang H 2002, *Fundamentals of ground water*, John Wiley & Sons

Standards Australia 1996, *Alkali aggregate reaction – Guidelines on minimising the risk of damage to concrete structures in Australia*, document reference number HB-79 1996

State of California 1998, *Guidelines for groundwater investigation reports*, Board for Geologists and Geophysicists, Sacramento, California

Todd, DK and Mays, LW 2004, *Groundwater hydrology*, John Wiley & Sons.

UK Environment Agency 2002, *Guidance on the use of permeable reactive barriers for remediating contaminated groundwater*

UK Environment Agency 2001, *Benchmarking and guidance on the comparison of selected groundwater risk-assessment models*, NGWCLC Report NC/00/14

UK Environment Agency 2001, *Guidance to good practice for the development of conceptual models and the selection and application of mathematical models of contaminant transport processes in the subsurface,* NGWCLC Report NC/99/38/2

US Army Corps of Engineers 1997, *In-situ air sparging*

USEPA 2004, *User's guide for evaluating subsurface vapor intrusion into buildings*

USEPA 2002, *Handbook on groundwater protection and clean up policies for RCRA corrective action*, EPA/530/R-01/015

USEPA 2002, *Draft guidance for evaluating the vapor intrusion to indoor air pathway from groundwater and soils (subsurface vapor intrusion guidance)*

USEPA 2002. *Handbook of groundwater protection and cleanup policies for RCRA corrective action*, EPA/530/R-01/015

USEPA 2002, *Groundwater sampling guidelines for Superfund and RCRA project managers*, EPA 543-S-02-001

USEPA 2001, *The state of the practice of characterization and remediation of contaminated groundwater at fractured rock sites,* EPA 542-R-01-010

USEPA 1998, *Technical protocol for evaluating natural attenuation of chlorinated solvents in ground water*, EPA/600/R098/128

USEPA 1997, *Design guidelines for conventional pump and treat systems*, EPA/540/S-97/504

USEPA 1996, *Low-flow (minimal drawdown) ground-water sampling procedures*, EPA/540/S-95/504

USEPA 1996, *Hydrogeologic characterization of fractured rock formations: a guide for groundwater remediators*, EPA/600/S-96/001

USEPA 1996, *Pump and treat groundwater remediation – A guide for decision makers and practitioners*, EPA/625/R-95/005

USEPA 1995, *Light nonaqueous phase liquids*, EPA/540/S-95/500

USEPA 1993, *Suggested operating procedures for aquifer pumping tests*, EPA/540/S-93/503

USEPA 1992, *General methods for remedial operation performance evaluations*, EPA/600/R-92//002

USEPA 1992, *Statistical analysis of groundwater monitoring data at RCRA facilities – addendum to interim final guidance*

USEPA 1992, *Fundamentals of groundwater modelling*, EPA/540/92/005

USEPA 1991, *Dense nonaqueous phase liquids*, EPA/540-4-91-002

USEPA 1989, *Statistical analysis of groundwater monitoring data at RCRA facilities – interim final guidance*

Water Technology International Corp 1997, *Site remediation technologies: a reference manual*, Contaminated Sites Management Working Group, Burlington, Ontario, USA

Wiedemeier TH, Rifai HS, Newell CJ and Wilson JT 1999, *Natural attenuation of fuels and chlorinated solvents in the subsurfac*e, John Wiley & Sons Inc

Appendices

Appendix I: Glossary

Aquifer: a geological unit capable of storing and transmitting useful quantities of groundwater.

Contamination of groundwater: defined in 1.5 of these guidelines.

Ecological health: the ability of an ecosystem to support and maintain key ecological processes and organisms so their species' compositions, diversity and functional organisations are as similar as possible to those occurring in natural habitats within a region.

Ecosystem: a community of organisms plus the physical and chemical environment in which they live and interrelate.

Environmental health: aspects of human health and disease that are determined by factors in the environment.

Environmental values: particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health, which require protection from the effects of pollution, waste discharges and deposits.

Exposure: contact of a physical, chemical, or biological agent with the outer boundary of an organism, e.g. through inhalation, ingestion, or dermal contact.

Exposure pathway: physical course a chemical or pollutant takes from its source to the exposed organism.

Groundwater: all waters occurring below the land surface.

Groundwater investigation level (GIL): the concentration of a groundwater parameter at which further investigation (point of extraction) or response (point of use) is required. Includes both

ANZECC & ARMCANZ 2000a and NHMRC & NRMMC 2004 criteria, and site-specific criteria.

Harm: in relation to contaminated land, harm to human health or the environment (including any direct or indirect alteration of the environment that degrades the environment), whether in, on or under the land or elsewhere.

Hazard: the capacity of an agent to produce a particular type of adverse health or environmental effect.

Hyporheic ecosystem: ecosystems that exist in alluvial sediments, commonly linked to the base flows of rivers and streams.

Natural background concentration: the naturally occurring ambient concentration of a substance in groundwater in the local area of a site.

Plume: a volume of groundwater containing dissolved-phase contaminants, extending from the source of contamination.

Point source: a source of contamination which comes from a contaminating activity at a particular site.

Receptor: the entity that may be adversely affected by a contaminant.

Remediation: all measures taken to mitigate risks from contamination.

Risk: the probability in a certain timeframe that an adverse outcome will occur in a person, a group, or an ecological system that is exposed to a particular dose or concentration of a hazardous agent.

Appendix 2: Identifying environmental values

For assessing potential risks from groundwater contamination, all environmental values of the groundwater need to be identified. The principle of basing decisions about water quality on environmental values is outlined in the *Environmental objectives for water quality and river flow* (NSW Government 2006), which have been developed for 31 surface water catchments across the state. Note that the term 'environmental values' includes consideration of human as well as ecological health, and incorporates values associated with what are commonly termed the 'beneficial uses' of groundwater.

Typically, groundwater quality at a particular site may protect some or all of the following environmental values, depending on the location of the contaminated site:

- **Aquatic ecosystems**: these include surface water ecosystems and groundwater ecosystems.
- **Human uses**: these include but are not limited to potable water supply, agricultural water supply (irrigation and stock watering), industrial water use, aquaculture and human consumption of aquatic foods, recreational use (primary and secondary contact with surface waters) and visual amenity of surface waters.
- **Human health in non-use scenarios**: this includes consideration of health risks that may arise without direct contact between humans and the groundwater, for example, exposure to volatile contaminants above groundwater contaminant plumes.
- **Buildings and structures**: this includes protection from groundwater contaminants that can degrade building materials through contact, for example, the weakening of building footings resulting from chemically aggressive groundwater.

Cultural and spiritual values that are associated with the environment, including groundwater, should also be protected. Cultural and spiritual values may include spiritual relationships, sacred sites, customary uses, the plants and animals associated with the water, drinking water supplies and recreational activities. In managing groundwater contamination, it is generally considered that cultural and spiritual values will be protected where groundwater quality protects all other relevant environmental values on a site.

In identifying applicable environmental values for groundwater on a particular site, the following matters must be considered.

Water sharing plans for groundwater resources

Water sharing plans (WSPs) and macro plans for groundwater resources are being developed for aquifers across NSW. These plans are statutory instruments created under the *Water Management Act 2000* with the primary aim of establishing management rules for the extraction of groundwater and provision of environmental water.

Although focused mainly on groundwater extraction, water sharing plans and macro plans also provide an additional source of information to identify beneficial uses or environmental values of groundwater. These plans are available at www.naturalresources.nsw.gov.au/water/plans.shtml. Note that DEC regards aquatic ecosystems and drinking water as default environmental values in all

preliminary assessments of groundwater contamination, including where these values are not identified in water sharing plans.

Protecting aquatic ecosystems

Many aquatic ecosystems are partially or wholly dependent on interactions with groundwater to sustain ecological structure and function. Aquatic ecosystems include, but are not limited to, springs, wetlands, karst and cave systems, and rivers and estuaries with a strong base flow component, especially in the dry season. Also, groundwater, while it supplies water for rivers, wetlands and other ecosystems, may itself form part of a critical aquatic ecosystem. It has become increasingly obvious that organisms in groundwater contribute significantly to biodiversity, and are also important for the self-purification processes in groundwater. General background information about groundwater ecosystems is available in the References section, for example, Danielopol et al 2003 and Hancock et al 2005.

In NSW, little is known about groundwater organisms and their sensitivity to pollutants. Hyporheic systems (those present in groundwater within alluvial sediments linked to the base flow of streams) are better known, and research suggests they play a key role in cycling organic matter and processing pollutants.

Where organisms in groundwater that require protection have been identified, for instance, by DNR in the process of identifying priority groundwater dependent ecosystems (GDEs), management of the contamination should aim to restore groundwater quality as much as practicable to its natural background state in the shortest time practicable, and prevent further groundwater pollution. The local DNR office should be contacted for information about GDEs.

While it is vital to protect all known GDEs, ecosystems that have not been specifically identified by DNR also require protection from contamination. Therefore, in the preliminary assessment of groundwater contamination, it must be assumed that aquatic ecosystem protection is an applicable environmental value of groundwater. A subsequent, more detailed assessment of groundwater contamination may, however, demonstrate that this environmental value does not apply.

Determining whether groundwater is a potential drinking water supply

Because of basic landholder use rights, the preliminary assessment of groundwater contamination must assume that drinking water is

an applicable environmental value of the groundwater, although subsequent more detailed assessment may show that this value does not apply at the site.

For the detailed assessment, there are three key steps in determining whether drinking water supply is a relevant environmental value at a site:

- checking DNR's list of major aquifers of drinking water quality
- identifying actual groundwater users in the site vicinity
- referring to total dissolved solids (TDS) as an indicator parameter.

DNR has developed a list of major aquifers of drinking water quality, which is included in Appendix 2.1. DNR has indicated that these major NSW aquifers must be protected for drinking water supply at the time of these guidelines being published. This list may be updated. DNR should be consulted during an assessment of groundwater contamination about an aquifer that does not appear on this list.

This list and updated versions of it should also be consulted as part of the groundwater assessment to determine whether drinking water use has already been specified by DNR for a particular aquifer.

The list is a useful screening tool to find out whether drinking water is a relevant environmental value, although it is not an exhaustive list of all groundwaters in NSW which require protection to that level. If the groundwater under consideration is not listed, the site investigator needs to determine whether it should be considered as a drinking water supply. This determination would need to take into account the current uses of groundwater in the local area. If in the process of site investigations, the site investigator obtains additional water quality information at a specific location that may supersede DNR information, DNR should be contacted for confirmation.

If neither of the first two steps identifies groundwater as a potential drinking water supply, the site investigator should use an indicator parameter, namely total dissolved solids (TDS), to reach a conclusion. To do this, the site investigator should first determine the TDS concentration of groundwater samples obtained at the site.

Groundwater with TDS concentrations below 2000 mg/L is suitable for potential drinking water supply, and hence should be afforded this level of protection from contamination unless other site-specific factors, such as low yield, render such use unlikely. A TDS concentration of 2000 mg/L has been selected as the level above

which groundwater is unlikely to be acceptable as drinking water because of taste. While it is acknowledged that, based on the Australian drinking water guidelines (NHMRC & NRMMC 2004), the TDS content in drinking water should not exceed 500 mg/L because of taste considerations, the World Health Organisation (WHO) states that there is an enormous variation in the taste that is regarded as acceptable by different individuals and communities.

In addition, there is significant variation between individuals in their ability to detect tastes in drinking water. WHO indicates that TDS concentrations above 1000 mg/L may give rise to consumer complaints. This suggests that some individuals will accept water with a TDS higher than 1000 mg/L for drinking. Further, in some cases higher TDS water may be diluted before drinking. Therefore, a 'filter' TDS concentration of 2000 mg/L should be used in NSW to confidently rule out the use of groundwater as a likely drinking water supply.

If aquifers with a TDS concentration of less than 2000 mg/L are or could be affected by contamination (e.g. due to contamination in perched groundwater in low permeability sediments overlying a higher permeability aquifer), relevant information should be provided to DNR and DEC prior to discounting drinking water as an applicable environmental value.

TDS is not an appropriate filter for considering the relevance of environmental values other than drinking water supply.

Determining the relevance of other environmental values

People use groundwater for a variety of purposes. The relevance of these environmental values needs to be considered on a site-specific basis.

Information on current or proposed extraction of groundwater, such as for agricultural or industrial use, may be obtained by searching for licensed groundwater extractors in the area, and seeking other advice from DNR. The potential presence of yet unidentified extractors also needs to be considered.

Basic landholder use rights need to be considered when identifying the environmental values that require protection from contamination. These rights mean that in NSW water, including groundwater, may be able to be used for domestic consumption (including drinking water) and stock water purposes as well as for uses consistent with native title rights without requiring the approval of DNR. Note, however, that licensing requirements apply to the

construction of groundwater bores irrespective of the requirements to approve groundwater use.

It should always be assumed that groundwater is discharging to identified surface water bodies and, therefore, all environmental values of the surface water such as recreational uses, visual amenity and aquaculture operations, require consideration unless the local hydrogeology has been fully characterised and groundwater discharge is unlikely to occur. Allowance should be made in such cases for any possible alteration to groundwater flow (e.g. due to differing climatic conditions).

Where groundwater discharges to surface waters, the community in 31 catchments across NSW has agreed to environmental values for surface waters known as water quality objectives (WQOs). These have been endorsed by the NSW government and are available on www.environment.nsw.gov.au/ieo. The ANZECC & ARMCANZ 2000a guidelines are used to establish the numerical default criteria (trigger values) supporting the environmental values established by the WQOs.

In identifying environmental values, it must be recognised that information about aquifer yield, groundwater quality and beneficial uses which is valid regionally may not necessarily be valid locally. For instance, while a rock formation may have generally low yield which may not sustain certain beneficial uses, locally the yield may be sufficient to sustain these uses.

Groundwater uses consistent with basic landholder rights do not require significant yield. Moreover, the lack of a sufficient yield in the context of specific uses is not enough to disregard such uses in groundwater or surface water systems, including wetlands, rivers, or creeks, that are hydraulically connected to the groundwater that is being assessed. For instance, contaminated groundwater in a low yielding formation may leak into an underlying aquifer that is extracted for human use, or may discharge to surface water that supports aquatic and benthic life, recreation or a drinking water supply.

The concept of environmental values of groundwater extends to considering the potential impact of contamination on media other than water and sediments. It is, therefore, important that all relevant exposure pathways are carefully considered in determining the relevant environmental values of groundwater. Also, concrete structures, such as building footings, may need to be considered as these can be susceptible in some circumstances to corrosion by

particular types of groundwater contamination, particularly sulphur compounds and acidity. Section 6 lists several publications that may be useful in assessing risks to building materials under 'Further reading'.

Indoor air quality is another important environmental value of groundwater quality which can be affected when groundwater is contaminated with volatile chemicals, for instance, beneath or near a building. Risks from inhaling volatile contaminants from groundwater have received significant attention over recent years, particularly in the USA where technical guidelines have been developed by state and federal agencies. Assessing inhalation risks associated with contaminated groundwater is complex, and a relevant technical discussion is beyond the scope of this document. In general, however, a weight of evidence approach should be used taking into account relevant information, which may include geology, soil moisture, depth to groundwater, water table fluctuations, building details, soil–gas measurements, flux hood measurements, indoor air quality, spatial and temporal variations in contaminant mass flux estimates and other factors. Section 6 lists some documents assessing risks from volatile contaminants from contaminated groundwater under 'Suggested further reading'.

2.1 Major aquifers of drinking water quality

DNR has deemed the aquifers below to be actual or potential drinking water supplies and to require protection of groundwater to this level:

- Araluen alluvium and weathered granite
- Clarence-Morton Basin (except the Grafton Formation)
- coastal alluvium (part only)
- Cudgegong Valley alluvium
- Great Artesian Basin intake beds
- Hunter alluvium and tributaries
- Lachlan Fold Belt Province (part only, e.g. limestones)
- Lower Gwydir alluvium
- Lower Lachlan alluvium
- Lower Macquarie alluvium
- Lower Murrumbidgee alluvium
- Lower Murray alluvium

- Lower Namoi alluvium
- Mangrove Mountain sandstone
- Maroota tertiary sands
- mid Murrumbidgee alluvium and tributaries
- miscellaneous coastal sand beds
- miscellaneous tributaries of Namoi (alluvium)
- New England fold belt province (part only e.g. granites and basalts)
- Orange basalt
- Oxley Basin
- Peel River alluvium
- Tomago/Stockton/Tomaree sand beds
- Triassic sandstones in the Sydney Basin
- Upper Lachlan alluvium and tributaries
- Upper Macquarie alluvium and tributaries
- Upper Murray alluvium
- Upper Namoi alluvium
- Young granite.

Where a groundwater contaminant plume is identified within one of these aquifers the remediation target should at least meet the water quality criteria in the *Australian drinking water guidelines* (NHMRC & NRMMC 2004).

If it is considered that the designation as drinking water supply is not appropriate at a particular site above one of these aquifers, it is possible to seek confirmation of this conclusion from DNR's regional hydrogeologist. The proponent should make available to DNR sufficient evidence of the groundwater quality to support their conclusion.

Apppendix 3: Monitored natural attenuation

Natural attenuation of contaminated groundwater is defined as:

> 'The effect of naturally occurring physical, chemical and biological processes to reduce the load, concentration, flux or toxicity of polluting substances in groundwater' (UK Environment Agency 2000).

These processes include biodegradation, dispersion, diffusion, sorption, volatilisation, and chemical or biological stabilisation, transformation or destruction. Although natural attenuation is sometimes referred to as intrinsic bioremediation, non-biological processes may also be important.

The term monitored natural attenuation or MNA refers to reliance on natural attenuation processes – as part of a planned, controlled and monitored remedial approach – to achieve site-specific remediation objectives within a timeframe that is reasonable compared to that offered by other more active methods. It emphasises that monitoring to demonstrate and document the progress of MNA must be an integral part of a natural attenuation strategy for any site.

Natural attenuation may reduce the potential risk posed by site contaminants, for instance through:

- reducing toxicity due to transformation of contaminant(s) through destructive processes such as biodegradation or abiotic chemical transformations. Note that contaminant transformation will not always reduce the risk. Some contaminants, for example, some chlorinated organic compounds, may transform to more toxic contaminants as they degrade in the environment. A proposal for MNA must therefore evaluate the impacts of all degradation pathways and their effect on the suitability of MNA at a site.
- reducing contaminant mobility and bioavailability through sorption into the soil or rock matrix
- reducing dissolved contaminant concentrations and subsequently reducing potential exposure concentrations.

Note that dilution within a receptor, such as a surface water body or groundwater abstraction system, is not considered to be natural attenuation.

Research over the last 20 years has resulted in a sound technical understanding of natural attenuation processes for many groundwater contaminants and knowledge of the specific conditions under which contaminants may be degraded. On this basis, MNA is accepted as one remedial strategy that should be considered when evaluating clean-up options for sites where groundwater is contaminated. MNA may be particularly useful in areas of a plume where contaminant concentrations are low. Based on this, MNA may often be applied where more aggressive clean-up has already reduced contaminant concentrations in the core of the plume.

Advantages of MNA

Used alone or in combination with other strategies, such as secondary source removal, MNA may be a non-intrusive, safe and cost-effective strategy to remediate groundwater contamination. In some circumstances, it may be the only practicable strategy that can be used.

Disadvantages of MNA

There may not be the necessary environmental conditions for effective natural attenuation of a particular contaminant at the location of concern. Natural processes may work slowly in the subsurface environment, where reaction rates may be restricted by low temperatures and limited availability of the necessary microorganisms, electron acceptors or electron donors, co-metabolites and nutrients. Natural attenuation may not achieve remediation goals within adequate timeframes in those cases. Sometimes intervention or enhancement may change the conditions to allow natural processes to work more effectively, but in other cases this will not be possible, and MNA must be discounted as an option. Also, sometimes the concentration of a contaminant is so great, or the risks to human or ecological health so severe, that other strategies with a shorter effective timeframe must be used.

Demonstrating whether MNA is applicable

To decide whether remediation by monitored natural attenuation is appropriate for a particular site (relative to site-specific remedial goals), professionals should:

- characterise the site
- assess potential risks
- ensure there is primary and secondary source removal or control
- evaluate potential effectiveness.

Remediation by natural attenuation requires demonstrating progress towards attaining the remedial goals. This is achieved by using converging lines of evidence, which are obtained through monitoring and evaluating the resulting data. Monitoring should continue until the remedial goals have been met.

Primary evidence that remediation by natural attenuation is working is seen when there is a reduction in the lateral and vertical extent of the plume, and reductions in concentrations of the contaminants of concern within the plume.

Secondary evidence is provided by geochemical indicators of naturally occurring degradation and estimates of attenuation rates.

Additional optional lines of evidence can be provided by microbiological information, including field and laboratory microcosm studies, where this information directly demonstrates the occurrence of a particular biodegradation process at a site. Further analysis of primary and secondary lines of evidence may also be required using, for example, solute transport modelling or estimates of assimilative capacity.

Any application of MNA at a site requires extensive hydrogeological and geochemical site characterisation, which may often need to be supported by appropriate modelling. It is not sufficient to simply indicate that, for example, groundwater conditions beneath the site are being reduced, and therefore reductive dechlorination of chlorinated aliphatic hydrocarbons will occur.

When is MNA appropriate?

Generally, monitored natural attenuation should only be considered as a remediation methodology where the following conditions are met:

- the source of the contamination, including contamination 'hot spots', have been removed as much as practicable
- the three-dimensional extent of the contamination has been defined
- the site and hydrogeology have been adequately characterised and there is clear evidence that attenuation rates are sufficient to achieve the remedial goals within an adequate timeframe
- the natural attenuation processes include those which reduce the mass of dissolved contaminants
- the effects of degradation have been considered.

As with other remedial approaches, it is expected that where monitored natural attenuation is proposed as part of a remedial strategy for a site, its feasibility and appropriateness would be demonstrated in a remedial action plan (RAP). The RAP should draw on site characterisation and risk assessment data acquired during previous investigation of the site. Within the RAP, the proponent should:

- demonstrate an understanding of the particular attenuation processes relevant to the contaminant(s) of concern under the conditions at that site

- define remedial goals and set out the scope, frequency and expected duration of the monitoring required to demonstrate that natural attenuation has been effective and the goals have been met
- define monitoring frequency, which should be sufficient to allow the progress of natural attenuation to be tracked, and to provide early warning if expectations are not being met, or if adverse impacts on sensitive receptors become possible
- address the integration of MNA with other remedial technologies that may be proposed for source removal or reduction, and any potential interactions or interferences.

The long-term sustainability of MNA during and following any proposed redevelopment of the site must be considered. Where reference is made to experience from other sites, an understanding of the potential impacts of differences in, for instance, hydrogeological conditions between the sites must be demonstrated.

The RAP and ongoing monitoring and validation reports should set out the lines of evidence for the progress and success of natural attenuation. Unless the primary line of evidence is conclusive, it will be necessary to evaluate secondary and additional lines of evidence. A checklist has been provided on the next page to assist in undertaking a review of the suitability of MNA at a particular site.

Considering the effect of contaminant degradation on toxicity and mobility

Some contaminants degrade and become more toxic. Vinyl chloride, from the reductive dechlorination of trichloroethene (TCE), is a well-known example. Therefore, the potential effects of degradation products on the toxicity and mobility of the contamination need to be carefully considered when evaluating the appropriateness of MNA.

In some cases, and in the right hydrogeological conditions, the more toxic degradation products may break down further to form less toxic compounds. In such instances, MNA may be deemed acceptable if it can be demonstrated that the more toxic compounds will not represent a threat to human or ecological health.

Checklist for assessing the applicability of monitored natural attenuation

- ❑ Has the site been adequately characterised in relation to stratigraphy, lithology, structure, water-bearing zones, groundwater flows, solute transport, lateral and vertical hydraulic gradients, hydraulic conductivities and porosities?
- ❑ Has the site been adequately characterised in relation to geochemical conditions, including salinity, temperature, pH, redox potential, organic carbon sources, nutrient availability, sorption capacity and the availability of electron donors and acceptors?
- ❑ Have all contaminants of potential concern been identified?
- ❑ Has the toxicity of the contaminants of concern been adequately assessed?
- ❑ Has the plume been fully delineated for all contaminants of concern?
- ❑ Have all potential receptors been identified?
- ❑ Have all potential beneficial uses and environmental values of the groundwater been identified?
- ❑ Are proposals to remove or control primary sources (e.g. leaking infrastructure) and secondary sources (e.g. residual NAPL, adsorbed phase) adequate and feasible?
- ❑ Is the proposed attenuation mechanism feasible for all the contaminants of concern under the conditions prevailing at the site?
- ❑ Do the natural attenuation processes include processes that reduce the dissolved mass of the contaminants of concern?
- ❑ Are there condition conflicts among multiple contaminants of concern?
- ❑ Have the toxicity and fate of all potential degradation products been considered?
- ❑ Will attenuation to acceptable concentrations be achieved well before potential human or ecological receptors could be impacted on?
- ❑ Have all feasible alternative remedial options been considered?

- ❑ Will the remediation goals be reached within a timeframe that is reasonable compared with other remedial options, and community expectations?
- ❑ Is monitored natural attenuation sustainable, considering proposed source control measures and redevelopment of the site and surrounding area?
- ❑ Are there financial mechanisms in place to ensure that monitoring can be continued for the required period?
- ❑ Have adequate contingency measures been proposed?

Appendix 4: Contacting NSW government departments for advice on groundwater contamination

These guidelines refer to the need to contact one or more government departments throughout the course of groundwater contamination assessment and management.

The proponent will need to collate and present a variety of information to the relevant department to assist it in providing advice or reaching agreement on proposed management strategies.

The contact details are summarised below.

Department of Environment and Conservation (DEC)
Manager Contaminated Sites
59–61 Goulburn Street, Sydney NSW 2000
PO Box A290, Sydney South 1232
Telephone: (02) 9995 5000 (switchboard)
Telephone: 131 555 (NSW only)
www.environment.nsw.gov.au

Department of Natural Resources (DNR)
For advice on beneficial uses of groundwater, contact the regional hydrogeologist.
For hydrogeological information, visit www.nratlas.nsw.gov.au.
Contact details for DNR's regional offices are available at:
www.DNR.nsw.gov.au/aboutus/contactus.shtml.

NSW Health
Area Health Service Public Health Unit
Contact details for regional Public Health Units are available at:
www.health.nsw.gov.au/public-health/phus/phus.html or in the Business Section of the White Pages.