



Australian Government Initiative

WATER QUALITY  
AUSTRALIA

# Guidelines for groundwater quality protection in Australia

## National Water Quality Management Strategy

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# 1 Introduction

## 1.1 Background

Groundwater is an important resource for drinking water supplies, irrigation, industrial development, and ecosystem and streamflow maintenance. Increasing demand and a trend towards a drier climate is placing pressure on some groundwater resources. Protection of groundwater quality is imperative to ensure the protection of healthy ecosystems and maintenance of environmental values as well as for future economic and population growth.

The National Water Initiative (NWI) (clause 7) supports the implementation of the National Water Quality Management Strategy (NWQMS). The NWQMS was developed collectively by the states, territories and Commonwealth during the 1990s through the Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australia and New Zealand Environment and Conservation Council (ANZECC). The two ministerial councils from the 1990s were replaced by the Natural Resource Management Ministerial Council (NRMMC) and the Environment Protection Heritage Council (EPHC). EPHC was subsequently replaced by the Standing Council on Environment and Water (SCEW) following a review of the ministerial council system by the Council of Australian Governments in 2010. In 2014, the SCEW was disbanded. The National Water Reform Committee (NWRC) was established as a national forum on water reform across Australia. The National Groundwater Sub Committee (NGSC) sits under the NWRC, with a focus on groundwater matters, including the development of the *Guidelines for groundwater quality protection in Australia*.

The NWQMS provides a national framework and comprises a description of policies, principles and guidelines for end users and water sources. As part of the NWQMS, the Guidelines for Groundwater Protection in Australia were developed and adopted in 1995. The importance of groundwater for water supply, the higher risk of water quality impacts and the improved understanding of groundwater management in recent years has provided the impetus for revising the guidelines. This publication forms the updated *Guidelines for groundwater quality protection in Australia* and focuses on the adoption of risk-based management to protect and enhance groundwater quality for the maintenance of specified environmental values.

An environmental value is a particular value or use of the groundwater that is important for the maintenance of a healthy ecosystem or for public benefit, welfare, safety or health, and which requires protection from the effects of contamination, waste discharges and deposits (ANZECC & ARMCANZ 2000a). Different environmental values, as defined in the NWQMS (ANZECC & ARMCANZ 2000a), are values or uses of the groundwater that support aquatic ecosystems, primary industries, recreation and aesthetics, drinking water, industrial water, and cultural and spiritual values. These updated guidelines set out a risk-based framework that can be implemented within existing jurisdictional policy and legislation to protect and enhance groundwater quality in Australia to support the associated environmental values.

State and territory governments are the target audience and primary users of these guidelines, as they are responsible for developing policies and regulatory systems tailored to their specific legislative and resource situations. Practical applications of the guidelines include the assessment of groundwater, the identification of groundwater quality objectives and the development of specific

groundwater protection mechanisms. The intention is that state and territory governments will take these guidelines into account when developing policies and legislation to protect the groundwater quality of each water resource, thus maintaining or enhancing the associated environmental value and preventing contamination within their respective jurisdictions.

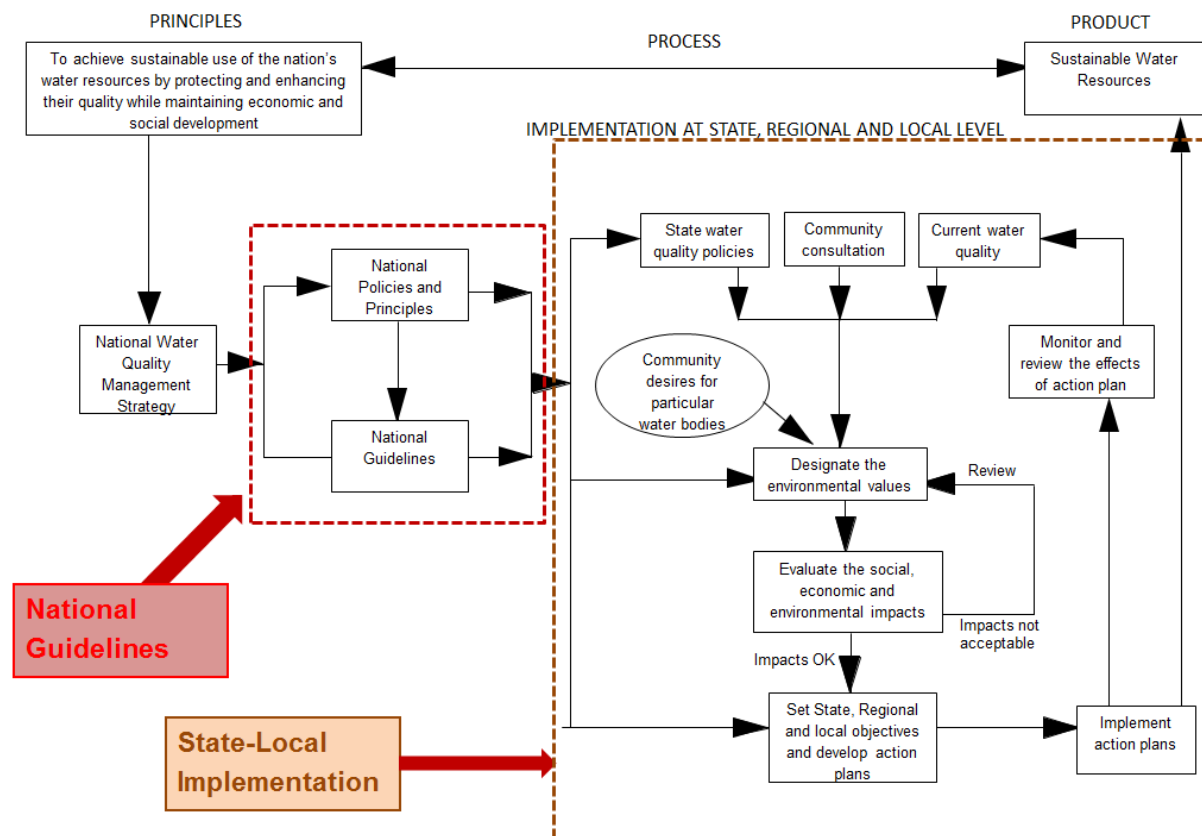
National groundwater quality guidance and harmonisation of policy and regulation will assist both development and environmental protection and provide a consistent approach across jurisdictions that is applicable at regional and local scales.

## 1.2 National Water Quality Management Strategy

The NWQMS aims to promote ecologically sustainable development by improving water quality while supporting industry, the environment and communities that depend on water (ANZECC & ARMCANZ 2000a). The objective of the NWQMS is ‘achieving sustainable use of the nation’s water resources by protecting and enhancing their quality while maintaining economic and social development’.

The NWQMS consists of a range of documents that focus on overarching policy and processes, protection of various water resources or various types of contaminating activities. Consolidation of NWQMS documents was being planned at the time this guideline was written. Figure 1 describes the implementation of the NWQMS. It shows the linkages between principles, processes and products of the NWQMS and the processes for implementation with the states and territories.

**Figure 1 Implementation of the NWQMS, involving principles and processes required to maintain water quality**



Currently, two types of information are incorporated within the NWQMS:

- a description of the principles and policies which target water quality
- guidelines which are aimed at management of particular uses and water sources.

The *Guidelines for groundwater quality protection in Australia* form one of the general management guidelines and they are currently the only national guidelines specifically focused on groundwater quality protection. Groundwater is mentioned in the overarching policies and principles document (ANZECC & ARMCANZ 1994), as it is recognised that tailored management strategies are required for groundwater due to the high risk of contamination from uncontrolled or difficult to control sources and the slow-moving nature of most groundwater.

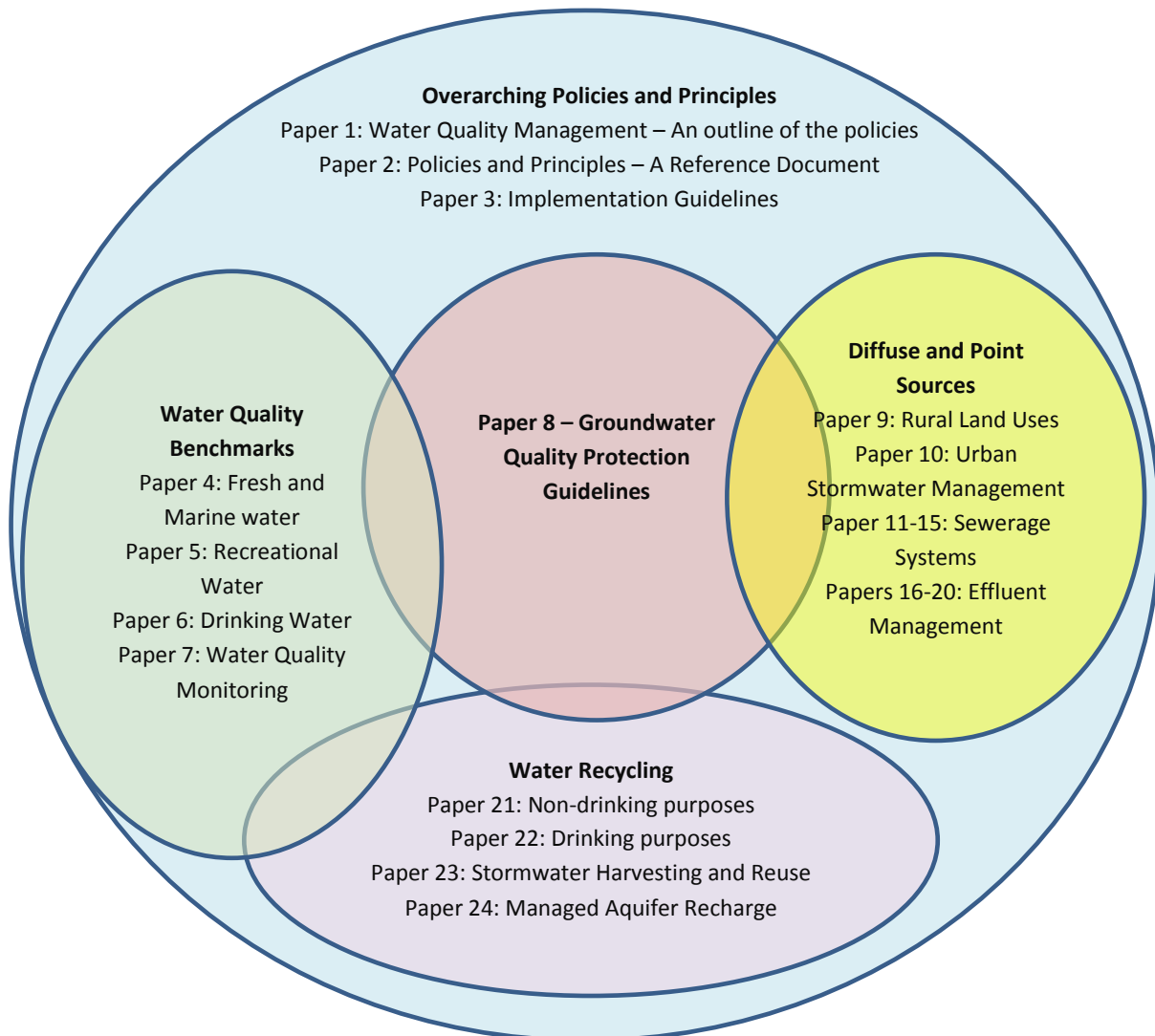
The guidelines have linkages to all other guideline documents in the NWQMS, which cover topics including:

- water quality benchmarks—for fresh and marine water, drinking water and monitoring of water quality
- diffuse and point sources—including rural land uses, urban stormwater management, sewerage systems and effluent management
- water recycling—for non-drinking purposes, drinking purposes, stormwater harvesting and reuse, and managed aquifer recharge.

Figure 2 shows this relationship in the context of the overall NWQMS.



**Figure 2 Relationship between the groundwater quality protection guidelines (NWQMS document no. 8) and other guidelines within the NWQMS**



Source: adapted from Geoscience Australia 2010a

Note: This portrays the relationship of other guidelines to the *Guidelines for groundwater quality protection in Australia* and is not meant to represent relationships more generally within NWQMS. As the NWQMS is currently being reviewed and updated, the suite of guidelines and their references as shown here is likely to change.

### 1.3 Objectives of these guidelines

These guidelines are designed to support the overall objective of the NWQMS, focusing on protecting and enhancing groundwater quality to support the nominated environmental values and preventing groundwater contamination.

The desired outcome of these guidelines is a consistent, high-level approach to groundwater quality protection across Australia, with the assignment of environmental values for all groundwater, particularly where there is a risk of contamination; and development of protection plans incorporating quality protection measures for these areas.

The framework presented in these guidelines is a practical strategy to maintain or enhance groundwater quality so as to support an environmental value. It is based on a set of overarching principles for groundwater quality protection, including ecologically sustainable development,

adoption of a risk-based approach, the polluter pays principle, recognition of intergenerational equity issues and the precautionary principle. The framework sets out a process for developing a groundwater protection plan, which includes assigning an environmental value category to a groundwater system, setting water quality objectives and developing management strategies that are tailored to individual groundwater protection scenarios.

The NWQMS aims to deliver a consistent approach to water quality management across Australia. The framework in these guidelines can be applied within existing Commonwealth, state and territory legislation. Detailed strategies and management rules can then be defined for individual groundwater protection scenarios within this framework.

### 1.4 Scope of the guidelines

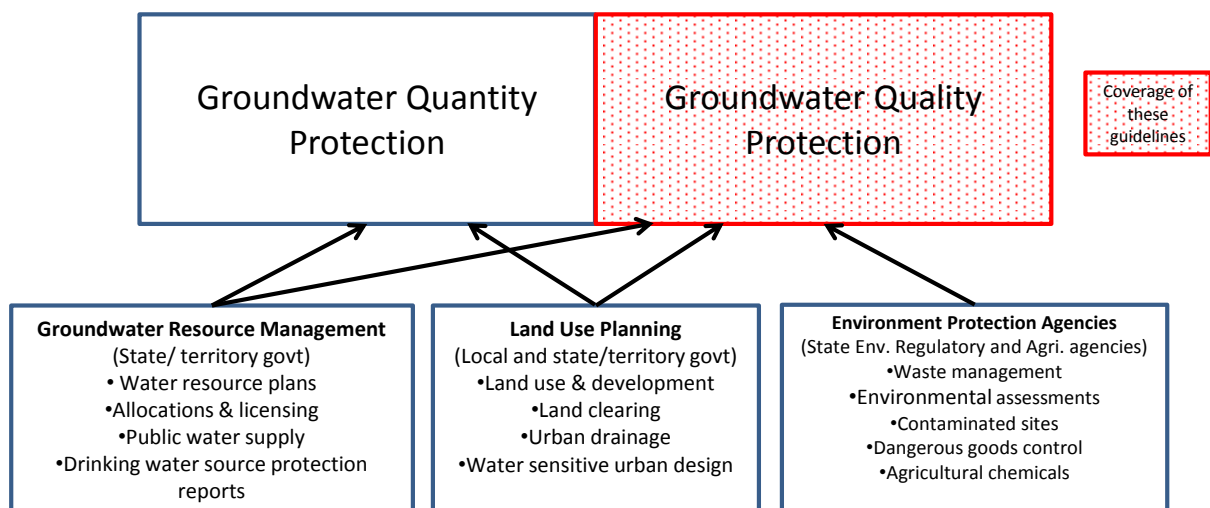
These guidelines provide currently known principles and key methods for maximising groundwater quality protection.

Protection of groundwater quality occurs within three existing legislative frameworks:

- Groundwater Management, which deals with groundwater entitlements and allocations
- Land-use Planning, which controls decisions on land development
- Environment Protection, which deals with environmental maintenance and hazardous activities.

The relationship of groundwater quality protection to each of these frameworks is demonstrated in Figure 3. Management of groundwater entitlement and allocations is not explicitly dealt with in these guidelines, although quantity and quality issues are related in most situations. Likewise, components of the Land-use Planning and Environment Protection frameworks are dealt with in these guidelines only as far as they relate to groundwater quality protection.

**Figure 3 Interaction between the legislative frameworks required to achieve groundwater quality protection**



These guidelines support a national approach to groundwater quality protection that applies to all groundwater in Australia, regardless of the current or potential uses of the groundwater. The national application of the guidelines will enable management of groundwater quality of aquifers, as well as their connected surface water systems, across traditional management boundaries. Groundwater quality protection also applies to groundwater that extends under coastal waters.

Consideration of the unsaturated zone within groundwater quality management is also enabled by these guidelines and may be required where state or territory legislation includes the unsaturated zone in their definitions of groundwater or where consideration of the unsaturated zone could contribute to more effective management of groundwater quality.

The guidelines are set out as follows:

- Section 1 provides an overview of the objective and scope of these guidelines within the NWQMS.
- Section 2 provides context on the current and emerging groundwater quality issues and the need for groundwater quality protection.
- Section 3 outlines the underlying principles for the revision of the guidelines, including ecologically sustainable development, adoption of a risk-based approach, the polluter pays principle, recognition of intergenerational equity issues, and the precautionary principle.
- Section 4 describes the overall framework and outlines the 12 key elements to be considered when developing a groundwater protection plan.

The appendices provide additional background material relating to current and emerging issues in the protection of groundwater and an overview of groundwater regulation and management in Australia.

## **1.5 How to use the guidelines**

The *Guidelines for groundwater quality protection in Australia* should primarily be used by government agencies developing legislation and policies regarding groundwater management and developing groundwater quality protection plans. Other interested parties will include consultants, water service providers, industries and communities seeking to manage or protect a groundwater source from contamination.

The framework presented in these guidelines includes 12 elements that should be followed in order to develop a groundwater quality protection plan to mitigate the risks posed by hazardous activities (see Section 4). The framework includes steps to deliver a commitment to groundwater quality protection, characterisation of the groundwater system requiring protection, activities that support the development of an effective groundwater quality protection plan, and review and adaptation steps. At a broad level, the development of a groundwater protection plan involves the activities shown in Figure 4, however the 12 elements of the framework provide further guidance to support the development of an effective plan.

It should be noted that a groundwater protection plan can relate to either:

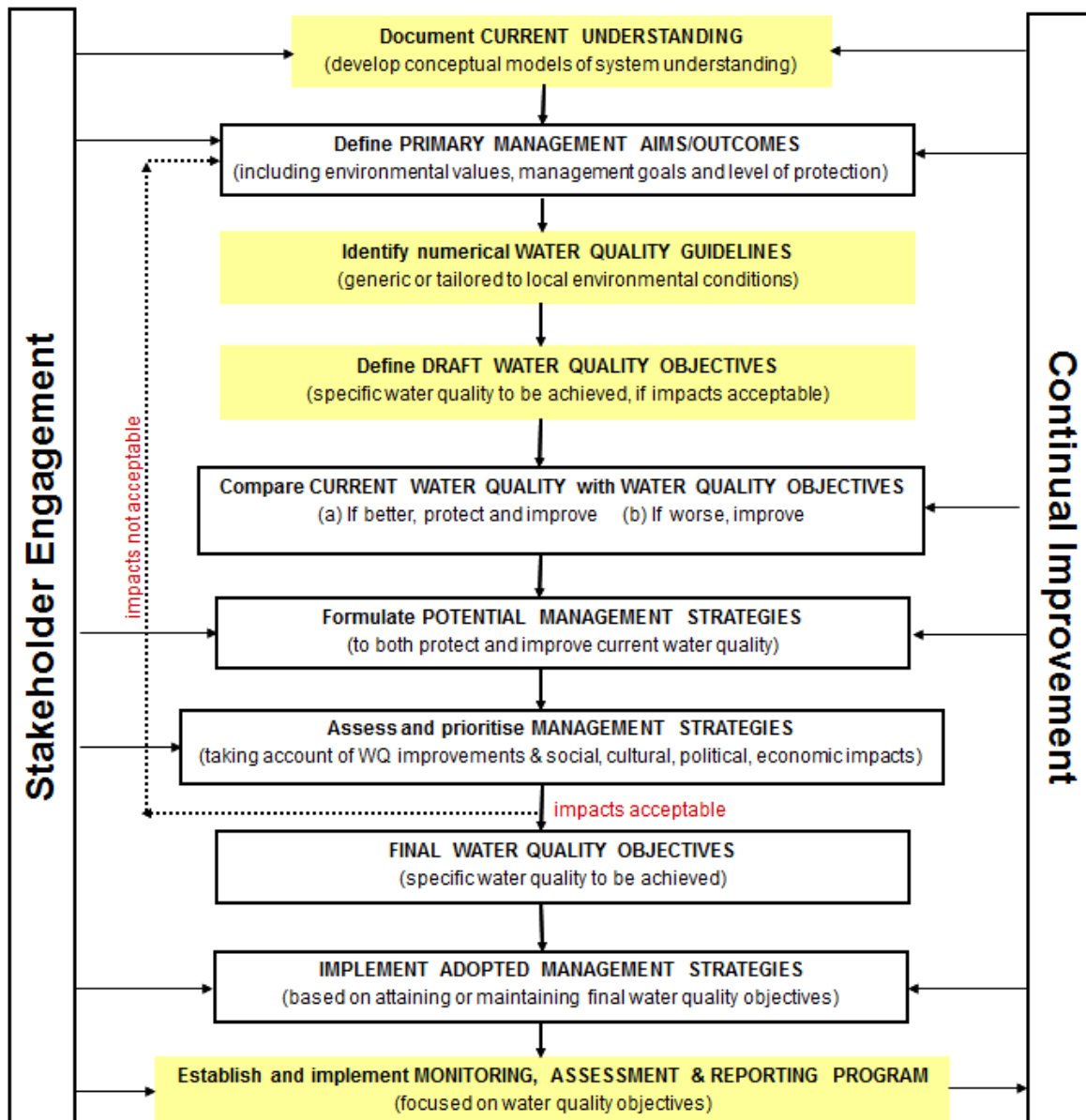
- a particular potentially hazardous activity
- a groundwater system.

Examples of potentially hazardous activities for which a groundwater protection plan may be developed include residential, agricultural, industrial, resource or infrastructure developments. The level of protection required in a plan depends on the current and potential future environmental values of the groundwater to be protected and the nature, severity and likelihood of the risk posed by the potentially hazardous event. Once the need for groundwater protection has been identified,

the framework described in Section 4 of these guidelines can be followed to develop a groundwater protection plan.

Coordination between disciplines such as groundwater management, land-use planning and contaminated land management is critical to developing and implementing an effective protection plan. The framework also emphasises the need to involve stakeholders and the community in the plan’s development.

**Figure 4 Activities involved in the development of a groundwater protection plan**



## 1.6 Terminology

A glossary is included in this document; however, it is important that some terms are clearly defined at the outset. The definitions given here have been adopted for the purpose of these guidelines, and it is acknowledged that legislative definitions of the same terms will vary between jurisdictions.

These guidelines refer mainly to groundwater contamination. Contamination is defined to mean a change in water quality derived from biological or chemical substances or entities that are not normally present in a system or any unusual concentration (high or low) of a naturally occurring substance that has the potential to produce an adverse effect in a biological system. Contamination can occur when substances are either introduced into an aquifer or mobilised from geological sources (minerals and organic materials) within the aquifer or by interactions between aquifers, seawater intrusion and other influences. Pollution occurs when the contamination reaches a level that restricts the use of the groundwater or the choice of environmental value category that can be assigned.

Contamination and pollution are used in a variety of state policies and legislation with many different meanings, and there is no standard use of the term across Australia or indeed worldwide.

The distinction between contamination and pollution is consistently applied throughout the guidelines, except for the term 'polluter pays'. This term really should be referred to for the sake of consistency in these guidelines as 'contaminator pays'. However, the term 'polluter pays' is adopted because of its broad use in international literature.

Point source contamination is contamination that comes from a single source (for example, from landfill), while diffuse source contamination is spread over a large area or region (for example, leaching of fertilisers from agricultural activities).

The term 'environmental value' is used throughout this text. This term replaces 'beneficial use', which was used in the 1995 guidelines. Environmental values are particular values, or uses, of the water resource that are important for a healthy ecosystem or for public benefit, welfare, safety or health, and which require protection from the effects of contamination, waste discharges and deposits (ANZECC & ARMCANZ 2000a). They reflect the ecological, social and economic values and uses of a water resource and include:

- *aquatic ecosystems*, comprising the animals, plants and microorganisms that live in water, and the physical and chemical environment and climatic conditions with which they interact (ANZECC & ARMCANZ 2000b)
- *primary industries*, including irrigation and general water users, stock drinking water, aquaculture and human consumption of aquatic foods (ANZECC & ARMCANZ 2000a)
- *recreation and aesthetic values*, including recreational activities such as swimming and boating and the aesthetic appeal of water bodies (ANZECC & ARMCANZ 2000a)
- *drinking water*, which is required to be safe to use and aesthetically pleasing (ANZECC & ARMCANZ 2000a)
- *industrial water*, such as water used for industrial processes, including cooling towers, process water or wash water
- *cultural and spiritual values*, which may relate to a range of uses and issues of a water source, particularly for Indigenous people, including spiritual relationships, sacred sites, customary use, the plants and animals associated with water, drinking water or recreational activities (ANZECC & ARMCANZ 2000a).

'Well' and 'wellfield' are generic terms which include bore and bore field respectively. The term 'well' is internationally accepted as meaning both small and large diameter boreholes and is independent

of the means of construction. The term 'bore' includes drilled holes that have not been constructed to access groundwater, such as exploration holes. The terms are used interchangeably throughout the text.

An aquifer is a geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Aquifers can vary markedly in the quality and quantity of water they hold and the extent of their connectivity with other aquifers or surface water bodies (NWC 2012). Aquifer types include confined, semi-confined and unconfined. A confined or semi-confined aquifer is an aquifer with a low permeability formation, as its upper boundary and its storage is increased by raising the pore pressure in the aquifer, causing elastic compression of aquifer materials and water (NRMMC, EPHC & NHMRC 2008). An unconfined aquifer has the watertable as its upper boundary and is usually recharged by infiltration from the surface (NRMMC, EPHC & NHMRC 2008). Unconfined aquifers are generally at greater risk of contamination from activities undertaken on the land and provide greater accessibility to the resource.

Aquifers can also be categorised according to the physical properties of the rock as unconsolidated (for example, sand), sedimentary (for example, sandstone) and fractured rock (for example, fractures in sandstone or granite).

The 'unsaturated zone' refers to the area between the land surface and the watertable. Water exists in the pores of the soil and rocks in the unsaturated zone, but this zone is not completely saturated.

Risk assessments use the terms 'hazard' to indicate a biological, chemical or physical agent that has the potential to cause groundwater contamination; and 'hazardous event' to refer to the situations that can lead to the presence of a hazard in groundwater. Risk can be defined as the likelihood of a hazard causing harm and the severity of the consequences of the hazard occurring (NHMRC & NRMMC 2011). In the case of groundwater quality, it can be further described as a combination of the likelihood of an identified water quality hazard adversely affecting the groundwater (and therefore the environmental value) and the consequence of not meeting the requirements of the assigned environmental value.

A water resource plan is a statutory or administrative plan for surface water and/or groundwater systems developed in consultation with relevant stakeholders on the basis of available scientific and socio-economic assessment to provide resource security for users and secure ecological outcomes.

A groundwater protection plan is a component of a broader water resource management plan. It is developed specifically to protect or enhance the existing and potential future environmental values. The plan should recognise community and stakeholder values of the resource, outline measures to reduce the risk of degrading the environmental value, an approach to monitoring, and a review and improvement approach.

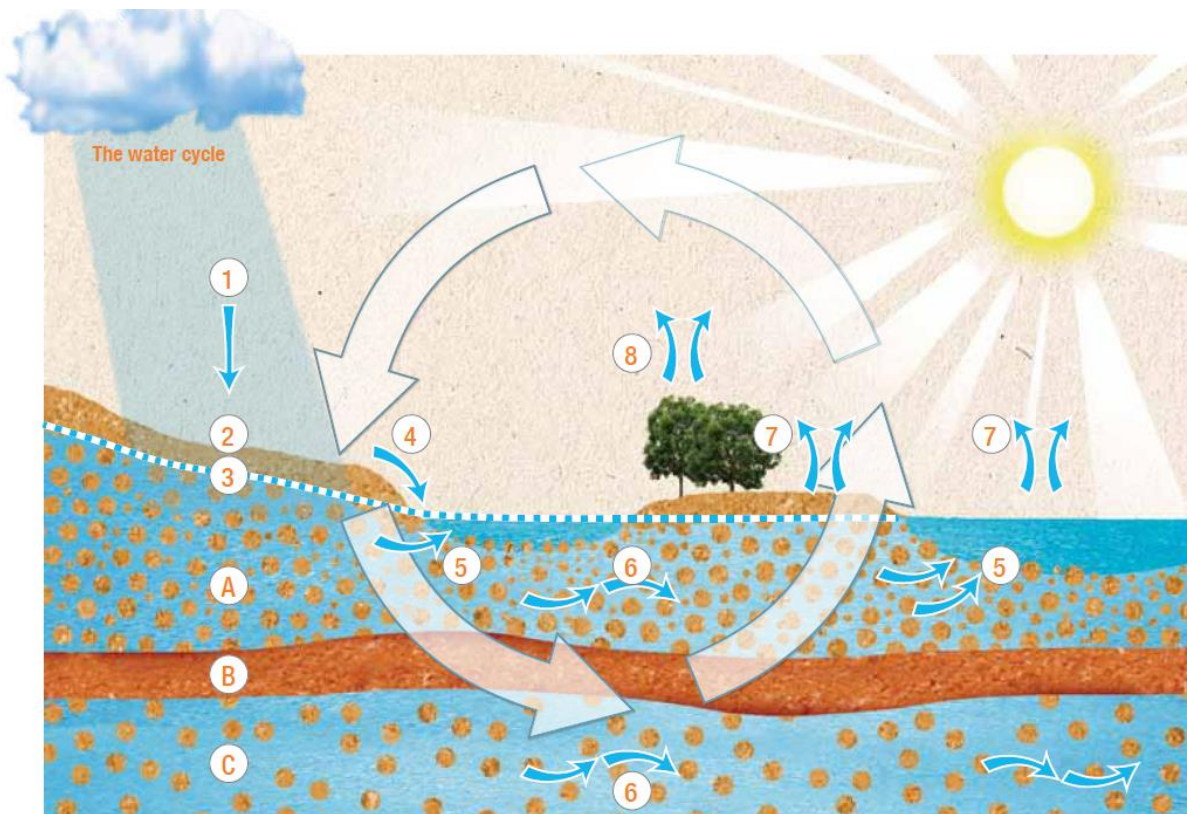
A groundwater quality protection plan is developed specifically to protect or enhance the existing and potential future environmental values of groundwater. It could be either a standalone plan or a component of a broader water resource management plan. The plan should recognise community and stakeholder values of the resource and outline measures to reduce the risk of degrading the environmental value. It should also define an approach to monitoring; and review and improvement requirements.

## 2 The need for groundwater protection

### 2.1 Groundwater as part of the water cycle

The definition of 'groundwater' varies in legislation across Australia. It is important to know and apply the definition that is relevant to the specific location being considered. For the purposes of this document, groundwater is defined as water located below the ground in the saturated zone (that is, an aquifer). It originates from two primary sources (NWC 2012). When it rains, water infiltrates the soil and unsaturated bedrock and may reach the watertable. Groundwater can also move between rivers, streams and wetlands where they are connected to aquifers. Groundwater can be lost from an aquifer via flow to surface water features such as rivers, streams, springs, wetlands and oceans as well as to other aquifers. Groundwater losses from aquifers also occur through evaporation from the watertable, transpiration by vegetation and groundwater pumping. Consequently, when groundwater quality is degraded, other water resources and users can be impacted. Figure 5 shows groundwater as part of the water cycle.

**Figure 5 Groundwater as part of the water cycle**



Source: NWC 2012

1. Precipitation
2. Infiltration / recharge
3. Watertable
4. Run-off

5. Groundwater discharge
  6. Groundwater flow
  7. Evaporation
  8. Transpiration
- 
- A. Unconfined aquifer
  - B. Impermeable layer
  - C. Confined aquifer

With the growing need to sustainably manage our natural resources, increased emphasis has been placed on holistically managing surface water and groundwater. This includes consideration of the significant role of groundwater in maintaining ecosystems as well as supporting the growing demands for water from population increases in the face of changing climate variability.

Groundwater quality requires careful management due to our increasing reliance on the resource, the high risk of contamination from uncontrolled sources, and for management of groundwater-dependent ecosystems (GDE). The *Aquatic ecosystems toolkit*, which includes GDE, was developed to provide a nationally consistent framework for classifying aquatic ecosystems (Aquatic Ecosystems Task Group 2012). The *Australian groundwater dependent ecosystems toolbox* provides techniques for assessing the groundwater requirements (quality and quantity) of GDEs (NWC 2012).

The typically slow-moving nature of groundwater presents a key management challenge, as impacts can be difficult to predict and may occur over a long timescale. Key hazardous events or activities include uncontrolled urban and industrial discharges, the cross-contamination of aquifers, and seawater intrusion caused by excessive use in coastal aquifers.

## 2.2 Human dependence on groundwater in Australia

Groundwater is an important water source across Australia, particularly in arid areas where access to surface water is limited. Usage has increased substantially over the past 30 years or so as a result of increased development and surface water shortages. Western Australia, South Australia and the Northern Territory rely heavily on groundwater, while the east coast of Australia has historically been more reliant on surface water.

Estimates of groundwater use in Australia reflect the growing reliance on groundwater over the last 30 years, with 30 per cent of our total water consumption now provided by groundwater (NWC 2008). Annual groundwater use between 1982–83 and 1996–97 increased by an estimated 58 per cent to a total of 4,200 gigalitres in 1996–97 (NLWRA 2001). With the drought in the 2000s and the introduction of surface water caps in many areas of Australia, groundwater use has further increased, with most recent estimates of around 6,000 to 8,000 gigalitres of groundwater use per year. As population growth increases demand and climate variability continues to impact on the availability of surface water supplies, reliance on groundwater is likely to further increase.

## 2.3 Water for the environment

It is now well known that many groundwater and surface water systems are connected to some degree and many ecosystems rely on groundwater for survival (NWC 2012). Poor groundwater quality therefore has the potential to impact on surface water quality and GDEs. GDEs can be categorised into three broad types:

- surface ecosystems that rely on groundwater discharge to rivers, wetlands and springs



- surface ecosystems that access groundwater from below the watertable—for example, vegetation
- subterranean aquatic ecosystems, which include stygofauna, in aquifers and caves.

The *Atlas of groundwater dependent ecosystems* shows the occurrence of potential GDEs across Australia and can be used as a resource to identify potential receptors of contaminated groundwater at regional scales (BoM 2012). Where more detailed GDE mapping is available, it is preferable to use this rather than the atlas. The *Australian groundwater dependent ecosystems toolbox* (NWC 2011a) is a set of tools for measuring the reliance of ecosystems on groundwater and developing strategies for managing impacts on GDEs. The tools presented in the toolbox allow water resource, catchment and ecosystem managers to identify GDEs and determine their environmental water requirements, including elements of groundwater quantity and quality (Richardson et al. 2011).

In many situations, the natural variability in quality of groundwater lessens the perceived need for protection unless the environmental significance of the groundwater is taken into account. Contamination of brackish aquifers, particularly where aquifers are highly permeable, can lead to serious degradation of interconnected surface waters and the ecosystems that depend upon them. Consequently, ecological issues can often be the critical factor that determines the need for protection measures for groundwater.

## 2.4 The aquifer structure as a resource

Groundwater systems provide an important source of public water supply and environmental water in Australia. In addition to this, aquifers with favourable hydraulic properties can also play other valuable roles. Hydrogeological environments are complex systems of aquifers and aquitards where each hydrogeological layer has distinctive hydraulic properties and geochemistry. Some aquifers, often those that are deep and confined, can be used as a storage or disposal facility for water, brine and carbon dioxide. The usefulness of aquifers in such situations results from the flow transmission, storage properties and structure of the hydrogeological layers.

Some aquifers are suitable for managed aquifer recharge (MAR) schemes, where they are used to store or transfer water for later use. Many aquifers (confined and unconfined) are suitable for MAR schemes. The *Australian guidelines for water recycling: Managed aquifer recharge* (NRMMC, EPHC & NHMRC 2009b) provides guidance on the protection of groundwater quality, aquifer and aquitard integrity. The MAR guidelines also outline water quality requirements for the intended use of recovered water from a MAR scheme. Water quality issues discussed in the guidelines relate to organics, inorganics, radioactive toxicities, pathogens, corrosion, chemical clogging and scaling, and mechanical clogging.

Different hydrogeological properties are required for the long-term storage of brine or carbon dioxide. Research undertaken by Geoscience Australia has demonstrated that sedimentary basins, specifically depleted gas fields, are the best hydrogeological systems for storage of carbon dioxide (Geoscience Australia 2013). This is because the conditions that allow trapping of oil and gas are the same conditions required for the storage of carbon dioxide and therefore provide protection for surrounding groundwater systems (Geoscience Australia 2013).

Well integrity is also an important aspect in maintaining aquifer structure. Wells have the potential to provide pathways for groundwater and gases to migrate from their original source. Potential

leakage pathways are the same for all types of wells, whether they are constructed as an observation well, an extraction well, an oil and gas well or an exploration hole. Three elements must exist for leakage in a bore to occur: a leak source; a driving force such as buoyancy or water level (head) differential; and a leakage pathway.

A cased well has cement in an annulus between the aquifer and the casing which protects the outside of the casing and the intersected aquifers. Leakage pathways are generally associated with poor cementing in the annulus, casing failure associated with corrosion or physical damage and decommissioning failure. Consequently, ensuring that all wells are constructed and decommissioned according to the appropriate regulatory standards is imperative to ensure aquifer structure is protected. For drilling, construction and decommissioning of water bores, readers are referred to the *Minimum construction requirements for water bores in Australia* (NUDLC 2012).

## 2.5 Groundwater contamination sources

Groundwater contamination can occur when three main components exist: a potential source of contamination; an aquifer as the receptor; and a pathway for transfer between the two.

One of the primary pathways for groundwater contamination is infiltration of contaminants from the land surface, through the unsaturated zone, and to the unconfined aquifer below. Shallow unconfined aquifers (including karstic, conduit and fractured rock aquifers) are particularly vulnerable to contamination, especially where the associated land use includes hazardous activities with uncontrolled contamination sources. The porosity and permeability of the unsaturated zone contributes significantly to the travel time of contaminants between the source and the groundwater. A highly porous or permeable unsaturated zone, such as karst limestone, can result in the relatively quick transfer of contaminants from the surface to groundwater. However, 'reaction' of contaminants with the soil and rock of the unsaturated zone can slow or even stop contamination reaching groundwater. The unsaturated zone can be an important consideration in groundwater quality management.

Other pathways for contamination can affect both the unconfined and confined aquifers, such as leakage of poor-quality groundwater into an aquifer; waste disposal via wells; or leakage from poorly constructed, maintained or decommissioned wells. In other cases, leakage can occur through aquitards that have been damaged by activities such as poorly managed mine subsidence or hydraulic fracturing.

Human-induced contamination is most often referred to as either point source or diffuse source. Point sources refer to localised contamination, often centred on one or more identifiable locations. Alternatively, diffuse sources are broad-scale and can be caused by a widespread land-use practice (for example, use of agricultural pesticides), a collection of small point sources (for example, septic tanks in an unsewered area) or widespread occurrence of a natural geological hazard (for example, acid sulfate soils or arsenic-rich parent materials). Figure 6 illustrates some examples of point and diffuse sources of contamination.

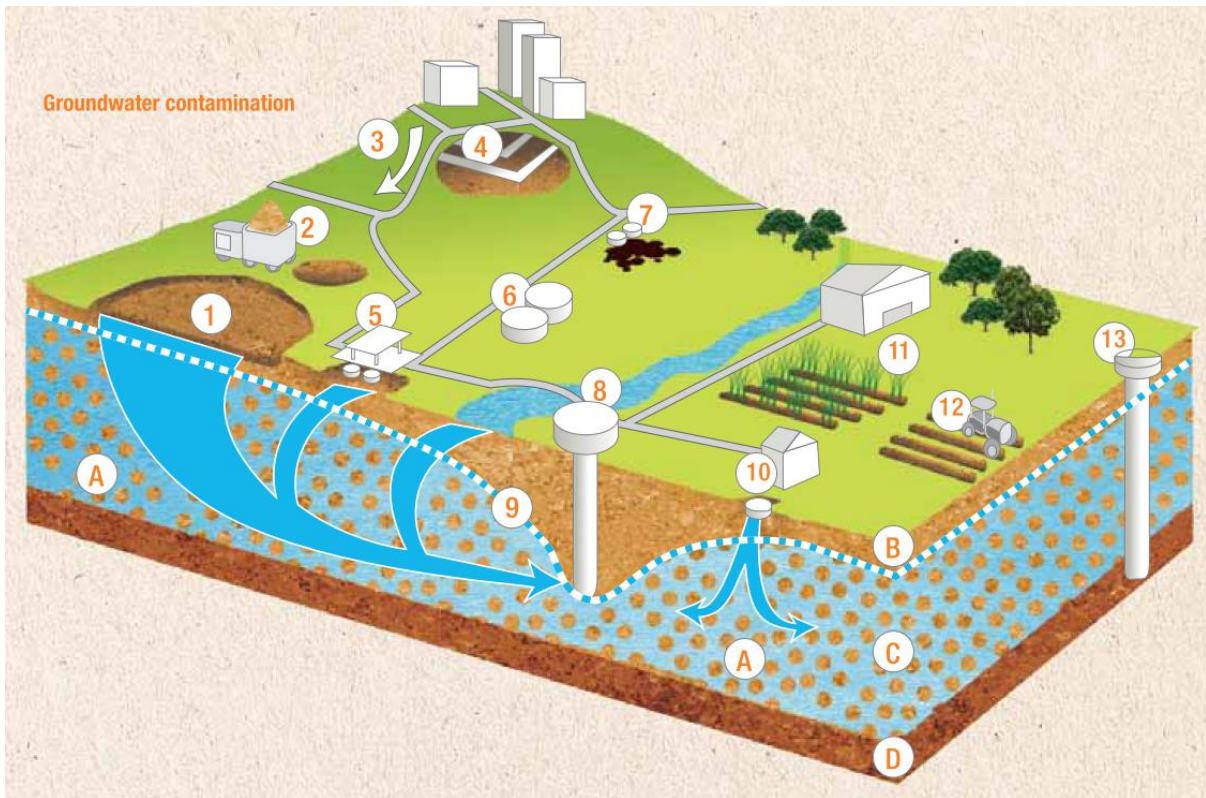
Many industrial chemicals are in use in Australia. Leaks, spills and other releases of these chemicals pose a risk to groundwater quality. Work is currently occurring under the Inventory Multi-tiered Assessment and Prioritisation (IMAP) framework, implemented by the National Industrial Chemicals

Notification and Assessment Scheme (NICNAS), to assess the risks of a selection of these chemicals to human health and the environment and to identify management measures.

Changing groundwater levels have the potential to cause water quality changes as a result of processes such as seawater intrusion and mobilisation of acidity and metals in sulfidic soil or rock. In some cases, these can have detrimental impacts. Such changes in groundwater levels and consequent changes in groundwater quality may result from anthropogenic processes such as groundwater pumping and climate change as well as from natural climate variability. Falling groundwater levels have resulted in the drying of some wetlands. This can oxidise acid sulfate soils, which creates acidic conditions that mobilise metals and sometimes release arsenic. Falling groundwater levels due to pumping can also result in seawater intrusion into a fresh aquifer or leakage of higher- salinity groundwater into a fresher aquifer. On the other hand, rising groundwater levels or changes in groundwater flow directions can cause flow of contaminated or poor quality groundwater into streams and wetlands. They can also bring salts in the groundwater to the surface and cause dryland and stream salinity.

Geoscience Australia (2009) highlighted that the key groundwater quality issue in Australia is salinity, followed by acidity, trace elements, and nutrients and pesticides. In this context, salinity refers to the salinisation of groundwater as a result of dryland salinity, irrigation salinity, aquifer salinisation and seawater intrusion (Geoscience Australia 2009). Anthropogenically driven saline groundwater discharge occurs in coastal areas as well as inland areas and poses a high risk to wetlands, surrounding native vegetation and aquatic ecosystem health. Nutrients and pesticides have been detected in most intensively farmed irrigation agriculture areas, while contamination from industrial areas is largely in urbanised areas, but can also occur in regional areas (e.g. mine sites, CSG operations).

**Figure 6 Groundwater contamination—examples of potential sources and pathways**



Source: NWC 2012

1. Landfills
2. Mining
3. Urban run-off
4. Leaking sewers
5. Petrol station
6. Oil storage tanks
7. Illegal dumping
8. Public water supply
9. Watertable
10. Septic tank
11. Fertilisers and pesticides
12. Ploughing
13. Energy extraction

- A. Groundwater flow
- B. Unsaturated zone
- C. Saturated zone
- D. Impermeable layer

Activities which can sometimes lead to groundwater contamination if not well managed are:

- industrial effluent and manufacturing wastes
- leaking underground storage tanks and pipelines
- landfill stockpiles or contaminated soil producing leachate
- urbanisation
- land clearing

- intensive agricultural fertiliser and pesticide use or waste generation
- irrigation drainage
- septic tanks and sewage and wastewater lagoons
- bore construction
- construction and excavation activities
- dewatering of aquifers or intensive regional pumping leading to exposure and oxidation of acid sulfate soils or sulfidic rock
- mining, including extraction, processes and wastes
- unconventional gas (for example, coal seam gas, shale and tight gas) and onshore petroleum exploration and production
- hydraulic fracturing or subsidence due to mining or excessive dewatering, which can damage aquitards
- urban stormwater
- use of recycled water
- managed aquifer recharge
- geothermal energy
- inter-aquifer contamination by alteration of flow
- emergency response wastes during and after chemical fires
- thermal and chemical contamination during underground coal gasification processes
- energy generation and manufactured gas plants.

Appendix A provides a summary of activities that can result in groundwater contamination. Geoscience Australia (2009) discusses the current and emerging groundwater quality issues.

## **2.6 Groundwater quality protection in Australia**

In Australia, groundwater (and surface water) resources are vested in the Crown and allocated to individuals or organisations through allocation plans and licences. Groundwater management is primarily the responsibility of state and territory governments, with involvement from water authorities and water users.

Since 1995, when the groundwater protection guidelines were first published, the role of the Commonwealth has expanded significantly with respect to water management and water quality legislation, regulation and policy (Geoscience Australia 2009). The Commonwealth's role in groundwater protection has been strengthened through the *Water Act 2007*, which provides for management of the Murray–Darling Basin, establishment of an environmental water holder and expansion of water markets and water information systems. The National Water Initiative (NWI) was agreed in 2006 and incorporated the Raising National Water Standards Program. A later initiative—the National Groundwater Action Plan—invested in research to improve knowledge and management of groundwater resources. In addition, a 2013 amendment to the *Environment Protection and Biodiversity Act 1999* (Cth) (known as the water trigger) requires that the potential risks to water resources of coal seam gas and large coal mining developments are assessed by the Australian Government.

As well as the programmes being undertaken at a federal level, individual states and territories are also developing guidance around groundwater protection. Guidelines developed by the environmental regulatory bodies in states and territories reflect the significant improvements in groundwater pollution prevention; however, diffuse source contamination (for example, pesticides and fertilisers) remains a more difficult issue to manage.

## 3 Underlying principles for guidelines

The understanding and management of groundwater has improved considerably in recent decades. Using this improved knowledge and approach, the challenge is to adequately address the assessment of potential water quality impacts at local and regional scales.

Management of potential water quality impacts to groundwater can be achieved by the application of six underlying principles:

- protection or enhancement of a specified environmental value
- ecologically sustainable development (ESD)
- use of a risk-based approach
- the polluter pays principle
- intergenerational equity
- the precautionary principle.

These principles combine fundamental economic and social rationales for the protection of groundwater quality, incorporating consideration of the current and future value of the groundwater, management or prevention that is proportional to contamination risk, and responsibilities of the current generation to provide equitable access to resources for future generations.

These guidelines present a framework for groundwater quality protection based on these fundamental principles. The application of the six principles to groundwater quality protection is explained in more detail in the following sections.

### 3.1 Environmental values

The *Guidelines for groundwater quality protection in Australia* rely on a framework which requires the identification of existing and potential environmental value categories for groundwater. 'Environmental value' is the term applied to a particular category of value or use of the groundwater that is important for a healthy ecosystem or for public benefit, welfare, safety or health.

The environmental value classification for a groundwater body should be based on the potential inherent values of groundwater in the long term, as determined through baseline assessment of groundwater quality and stakeholder consultation. Six environmental value categories are described in the *Australian and New Zealand fresh and marine water quality guidelines* (ANZECC & ARMCANZ 2000a):

- aquatic ecosystem protection
- primary industries (irrigation and general water uses, stock drinking water, aquaculture and human consumers of aquatic foods)
- recreation and aesthetics
- drinking water
- industrial water

- cultural and spiritual values.

Additional environmental value categories have been defined in some jurisdictions to reflect local requirements or to provide more detail.

The environmental value category relevant to a specific groundwater system should be determined cooperatively with the involvement of government, industry, the community and other stakeholders. More than one environmental value category will often be applicable for a single groundwater system. Different parts of the groundwater system and connected surface water systems may also be assigned different environmental value categories due to natural variations in quality and value or variable land uses across the extent of the aquifer. This may result in the need to delineate zones of the groundwater system that encapsulate the different categories. Where there is not enough information to assign specific environmental values, all appropriate categories should be protected. Determining the environmental value is one of the key requirements of these guidelines. The application of this principle in the development of a groundwater protection plan is defined in Section 4.2.3.

Once an environmental value has been determined, it can be used to develop water quality objectives for the particular groundwater system. Water quality objectives are either numerical guideline concentration limits or narrative statements that specify the water quality objectives to be achieved in order to protect intrinsic system values. The water quality objectives may be based on water quality guideline values or may be modified by social constraints or existing groundwater quality. Exceeding water quality objectives should trigger investigation to either develop guideline values that are more specific to the local area or to implement management measures if the risk is considered to be significant.

The *Australian and New Zealand fresh and marine water quality guidelines* (ANZECC & ARMCANZ 2000a) and the *Australian drinking water quality guidelines* (NHMRC & NRMCC 2011) provide numerical water quality guidelines for drinking water, recreation and aesthetics and primary industries. If it has been agreed that more than one environmental value category applies to an aquifer, the most conservative water quality guideline should be selected for each water quality parameter so that the most sensitive intrinsic values of the groundwater are protected in accordance with the management objectives.

There are currently no specified water quality guideline values for protection of cultural and spiritual or industrial water use environmental value categories; however, guidelines for the cultural and spiritual values category are under development and are expected to be included in the revised *Australian and New Zealand Guidelines for fresh and marine water quality guidelines* in 2014. For the industrial water use category, water quality guidelines should be established cooperatively by water managers and industrial stakeholders where required.

Even where guideline values are available, it may be more appropriate to determine guideline values that are specific to an individual groundwater system so that local conditions, groundwater quality and its variability, and community values can be explicitly recognised in the guideline values. The *Australian and New Zealand fresh and marine water quality guidelines* (ANZECC & ARMCANZ 2000a) and the *Australian drinking water quality guidelines* (NHMRC & NRMCC 2011) outline the process for deriving water quality objectives.



Natural (pre-impact) groundwater quality can vary spatially and temporally in response to the local geology, residence time in the aquifer, groundwater chemistry and groundwater–rock interactions. In some circumstances, the natural groundwater quality will exceed some of the water quality guideline values for the agreed environmental value category. In this case, the groundwater quality should be maintained within the natural range of variability. This approach would require a detailed baseline assessment to establish natural groundwater quality and variability upon which the water quality objectives and guideline values can be based. The length of the baseline monitoring and the frequency of sampling must be sufficient to establish variability in groundwater quality.

Because groundwater can flow slowly through aquifers, significant attenuation and diffusion of groundwater contaminants can occur within the aquifer. Therefore, the location at which groundwater quality is measured can influence the contaminant concentrations detected and can determine whether groundwater quality objectives are exceeded. Point of application criteria refer to the location at which water quality objectives are applied and expected to be met. These are discussed in Section 4.2.5.

Within the context of these guidelines the ‘aquatic ecosystem’ category of environmental value refers to the groundwater quality that supports groundwater-dependent ecosystems (GDEs), such as groundwater discharge to rivers and wetlands, and to aquatic organisms that solely inhabit groundwater. Stygofauna are mostly invertebrates that inhabit pore spaces and voids within aquifers, occur in discrete communities and are likely to be sensitive to changes in groundwater quality (which may be poor quality and limited to a small number of environmental value categories). Where stygofauna communities have been identified, they should be accounted for in determining an appropriate environmental value and setting water quality objectives (Dillon et al. 2009).

### **3.2 Ecologically sustainable development**

The Australian Government’s National Strategy for Ecologically Sustainable Development (1992) defines ESD as ‘using, conserving and enhancing the community’s resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased’.

ESD aims to promote development that enables current needs to be met as well as preserving ecosystems for the benefit of future generations. The goal of the ESD strategy is to achieve development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends. The ESD strategy sets the direction to be taken by governments in Australia that will ensure future development is ecologically sustainable.

The core objectives of the ESD strategy are to:

- enhance individual and community wellbeing and welfare by following a path of economic development that safeguards the welfare of future generations
- provide for equity within and between generations
- protect biological diversity and maintain essential ecological processes and life-support systems.

ESD objectives are closely aligned with the other principles discussed in this section—in particular, the precautionary principle and intergenerational equity.

The parts of the ESD strategy that relate to water resource management promote an integrated approach to develop policies that govern the development and management of water resources and to implement the most effective mix of water resource management mechanisms. Groundwater quality protection fits within these objectives. The ESD strategy objectives regarding aquatic ecosystems, native vegetation and mining also relate to protection of groundwater quality.

### 3.3 Risk-based approach

The process for managing the protection of groundwater quality is one of risk assessment that identifies where action is required, followed by implementation of management measures to protect groundwater quality so that it continues to meet all its identified environmental value categories. The National Water Quality Management Strategy (NWQMS) consistently applies a risk-based management approach to mitigate risks. This is a strategy that aligns closely with World Health Organization (WHO) Water Safety Plans and incorporates adapted elements of hazard analysis and critical control points (HACCP), the quality management system ISO 9001 and the risk management standard AS/NZS ISO 31000:2009.

Risk management is used in the water industry to identify the level of effort required to protect water quality, subject to the likelihood and consequences of the hazards. Effective risk management will enable protection of the groundwater as well as minimising the costs of doing so. A risk-based approach could include a fully quantified risk assessment or it could consist of a more qualitative approach to estimating risk with a lower reliance on detailed baseline data. The key objective of adopting a risk-based approach is to guide investment in groundwater quality protection that is commensurate with the level of risk to the assigned environmental value for the groundwater system. It allows governments, service providers, industries and communities to prioritise investment in the areas that face the greatest risk.

Standard risk-based approaches involve the identification of a hazard and the assessment of risk for that hazard. In terms of groundwater contamination, risk is generally a qualitative (or sometimes semi-quantitative) measure that considers the likelihood of the hazard occurring and the consequences if the hazard occurs. The requirement for preventative or management measures should be evaluated using two levels of risk:

- *maximum risk* (sometimes called pre-mitigation or initial risk), which is the risk in the absence of preventative or management measures
- *residual risk*, which is the remaining risk after preventative and management measures have been applied.

Preventative measures to mitigate risks need to be identified for all hazards for which the maximum risk is not low. If the residual risk is not acceptable, further mitigating measures are considered in a multi-barrier approach until the residual risk is low. Uncertainty is managed through monitoring, review and adaptation of groundwater protection measures where necessary, recognising that the costs of remedial measures are generally many times the costs of prevention.

The approach adopted in these guidelines involves 12 elements that comprise a risk-based approach to water quality protection adapted from the *Australian drinking water guidelines* (NHMRC & NRMCC 2011) and the *Australian guidelines for water recycling: Managed aquifer recharge* (NRMCC, EPHC & NHRC 2009b). Section 4 discusses each of these elements in further detail.

### **3.4 Polluter pays principle**

The polluter pays principle is a concept where the costs of preventing or minimising contamination are borne by those who could potentially allow discharge of contaminants in a situation where they may ultimately conflict with an assigned environmental value.

Once environmental value categories have been assigned to a groundwater system, the developer of an activity that may contaminate the groundwater should bear the full costs of protecting the environmental value against any threats posed by the development. In these instances, the developer would be required to show, on an ongoing basis, that the activity does not pollute the groundwater system. The potential polluter should also be responsible for financing and operating monitoring, verification and reporting systems that will detect any changes in the quality of the groundwater at locations agreed with the regulator.

The polluter pays principle can also be applied to situations where pollution has occurred and the polluter is held responsible for remediating the aquifer and restoring a specific environmental value or compensating other users. Both options may not be possible or, if they are, they could be very costly.

In the past, it has been difficult to identify an individual source of contamination in large groundwater systems or in heavily developed areas. Advanced analytical methods now make fingerprinting of sources and tracing of contaminants viable. For diffuse sources or multiple point sources of contamination in rural or urban areas, it may be more effective to focus effort on collective arrangements across industries and local governments (for example, for septic tanks) than on addressing each point source of contamination.

For some instances of historical contamination, the water quality objectives needed to support the desired environmental value may not be realistically attainable through remediation or the costs of remediation may be prohibitive. Once the full costs of remediation are known, a consultative process may choose to accept a lower quality or a reclamation measure based on a full cost–benefit analysis. Where this is necessary, the primary management aims should be reviewed and revised through consultation to achieve a balance between the desired environmental value category of the groundwater and the achievable quality. In this sense, it is better to avoid this situation and manage potential contamination prior to development.

Various pieces of state and territory legislation formally give effect to the polluter pays principle, such as policy that requires ‘Clean up to the extent practicable’ (CUTEP) and ‘remediation to the extent necessary’ (RTEN). These are administered by environment protection agencies and set out the requirements for addressing significant contamination.

### **3.5 Intergenerational equity**

The concept of intergenerational equity refers to the protection of the health, biodiversity and productivity of the environment by the current generation for the benefit of future generations. The objectives of Australia’s two key pieces of Commonwealth environmental legislation—the *Water Act 2007* and the *Environment Protection and Biodiversity Conservation Act 1999*—recognise this principle.

To preserve or enhance groundwater quality so that the needs of future generations can be met, limits must be placed on development. However, intergenerational equity should not be used as an obstructive tool to prevent development; rather, it provides a rationale for protecting groundwater quality against long-term damage that is difficult or impossible to reverse (Weiss 1992).

Many of the intergenerational equity issues arise when trying to assign liability for existing pollution that originated in the past. However, protection is primarily about the future. The main objective is to create a 'benchmark' position so that new measures are developed to protect the groundwater from further contamination or to enhance groundwater quality in the future. Once the existing pollution has been acknowledged, the polluter pays for costs of future measures to prevent, monitor or remediate groundwater contamination. This reduces the risk of further contamination and results in the maintenance or improvement of groundwater quality that means the aquifer will satisfy the requirements for the designated environmental value for future generations.

Some contamination issues that are currently considered intractable may become remediable in the future through development of new or improved remediation technologies. Hence, future generations will have a responsibility for continual improvement of historical contamination where improved technology allows the groundwater quality to be enhanced.

### **3.6 Precautionary principle**

The precautionary principle is a component of a risk-based approach. It is a strategy that errs on the side of caution when the impacts are not fully understood or are uncertain and is essentially related to the management of scientific risk and uncertainty. The Intergovernmental Agreement on the Environment (IGAE 1992) essentially adopts principle 15 of the Rio Declaration on Environment and Development (1992) and defines the precautionary principle as follows: 'where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation'. 'Measures' is not usually defined but is generally interpreted to mean either non-approval of developments or amelioration conditions placed on approvals. In terms of groundwater quality management, it affords regulators the ability, in the absence of scientific consensus about the impacts of a particular risk, to implement actions or defer development approvals such that groundwater is protected from contamination. Effectively, the principle reverses the onus of proof to the proponent of an activity, as it requires the proponent to prove that a development will not cause serious or irreversible harm. The precautionary principle can also be used to implement risk minimisation measures by regulators during the approvals process without the need to clearly demonstrate that the likelihood or consequence of the risk is highly certain.

The precautionary principle is an integral component of an ESD strategy that encourages caution to reduce risk in situations where scientific uncertainties exist. Put another way, scientific uncertainty should not automatically preclude regulation of activities that pose a potential risk of significant harm.

There is no standard approach to whether the costs of inaction (opportunity costs of non-development) versus the potential costs incurred while new information about the risk is obtained, should be considered under the precautionary principle. However, there is clear evidence that the costs of remediating a contaminant plume can be very significant when compared to the costs of

prevention or risk reduction and, in many cases, contamination may be impossible to remediate (its impacts are irreversible).

## 4 Planning for the protection of groundwater quality

This section introduces a framework for the protection of groundwater quality and outlines how the framework can be applied to develop an effective groundwater quality protection plan within water resource planning. The framework and associated guidance are based on the *Australian drinking water guidelines* (NHMRC & NRMCC, 2011), which in turn incorporates adapted elements of hazard analysis and critical control points (HACCP), the quality management system ISO 9001 and the risk management standard AS/NZS ISO 31000:2009.

The framework addresses four general areas, which are described below and illustrated in Figure 7:

- *Commitment to groundwater quality management*—this involves developing a commitment to groundwater quality management within the state and territory based environment protection, groundwater management and land-use planning agencies and providing policy that facilitates groundwater quality protection.
- *Resource analysis and management*—this involves understanding the groundwater system, its assigned environmental value, the hazards and events that can compromise groundwater quality and the preventive measures necessary for maintaining its assigned environmental value.
- *Supporting requirements*—these requirements include basic elements of good practice such as employee training, community involvement, research and development, validation of process efficacy, and systems for documentation and reporting.
- *Review*—this includes review, evaluation and audit processes to ensure that the commitment to groundwater quality is maintained, the agreed protection measures are being consistently implemented and adaptive management is enabled.

The framework includes 12 elements considered good practice for management of groundwater quality (Figure 7). The elements are:

- a commitment to groundwater quality management
- resource analysis and management:
  - groundwater characterisation and quality assessment
  - groundwater quality protection measures
  - operational procedures
  - monitoring of protection measures
  - management of incidents and emergencies)
- supporting requirements:
  - stakeholder engagement and training
  - community involvement and awareness
  - validation, research and development
  - documentation and reporting
- review of the plan:
  - evaluation and audit
  - review and continuous improvement).

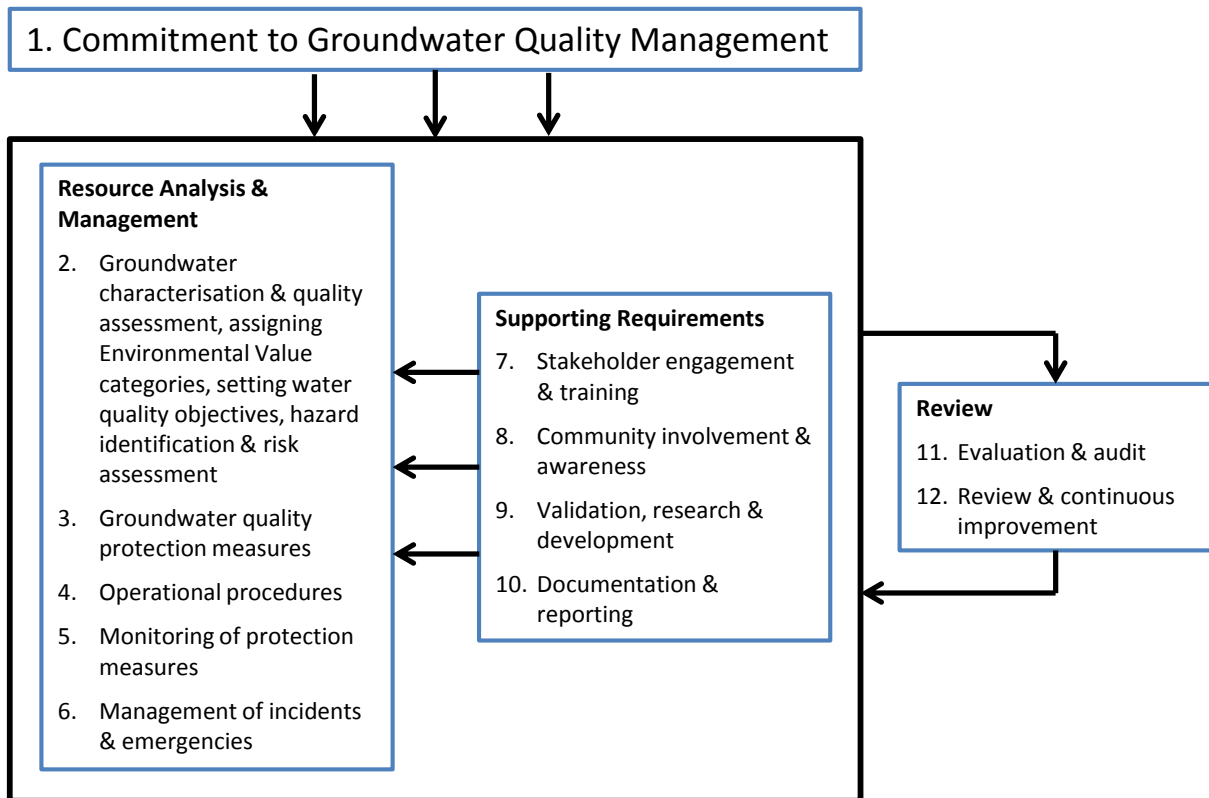
The elements are interrelated and each supports the effectiveness of the others. To reflect the diversity of groundwater systems and the varying jurisdictional arrangements and levels of risk, the framework presented in the sections below is flexible.

The framework presents a risk-based approach to adaptive management and outlines a process for groundwater quality protection that can be applied to any groundwater system regardless of size, vulnerability or relative importance. The principles within the framework are applicable at all scales. In this context, a groundwater system for which a protection plan is developed could refer to one of the following:

- a whole aquifer
- an existing groundwater management unit or other management area
- a water resource plan area
- an area encompassing a specific groundwater or land use
- a catchment
- the area of impact of a proposed development.

It is recognised that the scale of the area to be protected and the level of risk are key determinants in the level of effort required to develop a groundwater protection plan. Where a plan covers a small area or a single activity, not all steps in the framework may be necessary or some of the steps can be addressed in a high-level manner. The groundwater quality protection plan could be developed as either a standalone plan or a component of a broader water resource management plan. Although the definition of 'groundwater' used in these guidelines refers to the saturated zone, consideration of the unsaturated zone may also be required in groundwater protection plan—for example, where state or territory legislation includes the unsaturated zone in their definitions of 'groundwater' or where consideration of the unsaturated zone could contribute to more effective management of contamination.

**Figure 7 The 12 elements for developing a groundwater quality protection plan**



Element 1 of the framework relates to the policy development required in each state and territory to establish the framework within which groundwater quality protection can operate. Once the high-level policy is in place, elements 2 to 12 can then be undertaken by groundwater quality managers to develop groundwater protection plans for individual groundwater systems. Due to the specialist and technical nature of groundwater quality protection, there is a need to engage with people who are experienced in groundwater and contamination management and land-use planning when working through the framework.

#### **4.1 Element 1: commitment to groundwater quality management**

Government support and long-term commitment is fundamental to implementation of an effective system for groundwater quality management. Successful implementation and lasting commitment to groundwater quality protection requires:

- awareness and understanding of the importance of groundwater quality management and how decisions affect the protection of assigned environmental value
- the development of a philosophy across stakeholders that fosters commitment to adaptive management and cultivates responsibility and motivation
- the ongoing and active involvement of government to maintain and reinforce the importance of groundwater quality management to stakeholders
- strong, clear regulatory and policy controls, including commitment to compliance measures.

Government actions and policies should support the effective management of groundwater quality (for example, appropriate resources, training, active participation and reporting). The commitment to groundwater quality management needs to be embedded within all government agencies working



within the Groundwater Management, Land-use Planning, and Environment Protection legislative frameworks, as coordination between these areas is critical for effective groundwater quality protection.

#### **4.1.1 Groundwater quality policy**

Groundwater quality policy is a key part of the commitment to groundwater quality management. Formulation of a groundwater protection policy (or a groundwater quality policy) is required by each state and territory jurisdiction to establish the framework within which groundwater quality protection plans can be developed. This policy should set out the priorities and commitments for groundwater protection in the jurisdiction, formalise the level of protection expected for groundwater sources and provide guidance on how to implement the policy, principles and framework for development of a groundwater protection plan. The policy provides high-level direction for groundwater protection and will be the basis on which all subsequent management actions can be framed. It should be clear and succinct and cover topics such as:

- commitment to groundwater quality management
- compliance with relevant regulations and other requirements
- governance structures for water management, assigning responsibilities for water quality management and showing interaction between water quantity management, land-use planning and environment protection agencies
- liaison and cooperation with relevant agencies, including water authorities and other regulators
- adoption of management principles, including ecologically sustainable development, risk-based approaches, polluter pays, equity considerations, the precautionary principle and an adaptive management approach
- a requirement for development of groundwater protection plans for certain aquifers
- specific guidance on setting and adoption of an environmental value category (or categories) for groundwater sources
- commitment to a consultative approach, allowing for incorporation of community and stakeholder feedback
- requirement to understand and manage groundwater quality implications in connected groundwater / surface water systems
- requirements for collecting, managing and providing access to groundwater data
- continual improvement in the water quality management of groundwater systems.

The opinions and requirements of stakeholders such as groundwater users, groundwater planners and regulators and land-use planners should be considered in the development of the policy. The policy should be continually communicated, understood and implemented by groundwater managers.

In most jurisdictions, environment protection authorities (EPAs) are responsible for implementation of the relevant state or territory policy for groundwater quality protection in collaboration with state or territory government water departments. These agencies should work in cooperation with water resource managers and land-use planners.

## **4.2 Element 2: groundwater assessment, assignment of environmental value, setting water quality objectives, hazard identification and risk assessment**

Understanding the groundwater system to be protected is an important initial step in applying the risk-based framework. Element 2 describes the process of characterising the groundwater system (quality and quantity aspects), assigning environmental value categories and water quality objectives, identifying hazards and assessing risks to the groundwater system.

In this context, the 'groundwater system' means the body of water for which a groundwater quality protection plan is being developed. This may be defined as one of the following:

- a whole aquifer and associated unsaturated zone
- an existing groundwater management unit (GMU) or other management area
- a water resource plan area
- an area encompassing a specific groundwater or land use
- a catchment
- the area of impact of a proposed development.

It may be appropriate to develop a groundwater quality protection plan for a whole aquifer, with smaller protection plans within the larger area that relate to specific land uses or issues. The guidance in elements 2 to 12 predominantly relates to the development of a protection plan for a larger area such as an aquifer. The requirements within each element also apply to protection plans for smaller areas within the larger plan but can be scaled down proportionally to the size of the development and the potential risks. Key components of element 2 are discussed below.

### **4.2.1 Characterisation of the groundwater system**

A conceptual model of the groundwater system is needed to provide a common understanding of the system being protected. This provides the basic conceptual understanding that allows an environmental value for groundwater, and hazards and risks to groundwater quality, to be identified. Suitably qualified and experienced staff should be involved in the assessment with involvement from researchers and other agencies with knowledge of the specific area.

Where information is available, the conceptual model of the groundwater system should define:

- groundwater system boundaries
- stratigraphy
- structural geology
- magnitude of resource
- groundwater elevations over time and flow paths
- recharge and discharge processes and volumes and a water balance
- interaction with surface water, other aquifers and groundwater-dependent ecosystems over time
- aquifer hydraulic properties such as hydraulic conductivity, permeability, porosity, transmissivity and storativity where information exists

- groundwater quality over time, including vertical and horizontal water quality gradients if information exists
- historical, current and proposed land uses
- historical, current and expected future groundwater uses and demands
- current extent of contamination and potential for clean-up
- potential future sources of groundwater contamination based on land uses associated with current land zoning
- the potential size of future impact(s).

More guidance on the development of conceptual models can be found in the Australian Groundwater Dependent Ecosystems Toolbox (NWC 2011a) and the eWater CRC's Catalogue of Conceptual Models for Groundwater-Stream Interaction in Eastern Australia (Reid et al. 2009). The conceptual model should be reviewed periodically and updated as more data becomes available or as components of the system change (for example, land use).

In data-poor environments, many components of the conceptual model may not be known. These knowledge gaps can be dealt with in two ways: either further research/investigation should be undertaken to address the knowledge gaps or they should be identified as areas of uncertainty to which the precautionary principle is applied in the groundwater quality protection plan. A lack of knowledge concerning the potential impacts of a hazard should not be used to justify a delay in establishing groundwater protection measures. Rather, the knowledge gaps should be identified and addressed through adaptive management where necessary within a risk-based approach. The level of risk will assist in determining the most appropriate course of action where data is limited, as high-risk areas may warrant further investment to fulfil knowledge gaps, while in lower-risk areas acknowledgment of the uncertainties and application of precautionary measures may be sufficient.

Where appropriate, the conceptual model can be used as the basis for developing a numerical groundwater model of the system to be covered by the protection plan. Numerical groundwater modelling is a complex undertaking for water quality issues, and the investment may only be justified where the risks to an assigned environmental value are significant. For larger-risk or higher-risk areas, the investment in numerical groundwater modelling may be warranted. For smaller, site-specific plans, analytical modelling of contaminant transport is usually sufficient. In karst and conduit systems, direct water tracing experiments may be more useful than classic grid-based numerical modelling. The National Water Commission's *Australian Groundwater Modelling Guidelines* (SKM & NCGRT 2012) promote a consistent approach to the development of groundwater flow and solute transport models.

Conceptual and numerical modelling should be based on the best information available. Data warehouses exist for individual jurisdictions as well as nationally, and these should be used where they contain the relevant data. National data sets should also be used where relevant.

#### **4.2.2 Assessment of groundwater quality**

Groundwater quality data is necessary to establish baseline conditions in the groundwater protection plan area and can also assist in identifying an environmental value and defining water quality objectives. Many assessments will be data limited and will have to rely on regional interpretations of groundwater quality (such as broad-scale mapping or summaries in literature), while others will have

site-specific bore data that may report on a range of parameters over time. In the complete absence of water quality data for the groundwater system, the current water uses may be used to infer 'typical' water quality. High-risk areas will warrant collection of additional data to support the protection measures and allow adaptive management within the groundwater quality protection plan.

Historical data can help identify changes to groundwater quality in response to other pressures. For example, changes in salinity may be related to changes in rainfall or groundwater extraction regimes or changes in anthropogenic contaminants may correlate with changes in land use, attenuation or success of remediation attempts. This information can add to the conceptual model and is useful for defining natural variation, gradual changes and cumulative effects.

In undeveloped areas, the natural variation in groundwater quality must be established through baseline assessment in order to be able to attribute future contaminants to a new development or activity. The length of baseline monitoring and the frequency of sampling must be sufficient to establish the natural variability of groundwater quality in the area. A minimum of two years' baseline data is recommended in ANZECC & ARMCANZ (2000a), but to establish natural variability a longer period may be required in some areas. This baseline groundwater quality data is needed to implement an effective monitoring programme, as described further in Section 4.5. Trend analysis of individual parameters or suites of contaminants and periodic mapping of groundwater quality over time can be useful tools for understanding groundwater quality variations due to either natural processes or anthropogenic causes. The *National Environment Protection (Assessment of Site Contamination) Measure 1999* provides additional guidance on the assessment of site contamination (NEPC 2013).

### 4.2.3 Assigning environmental value categories

The environmental value of a groundwater system is the key tool used to set water quality objectives. The Commonwealth is not prescriptive about how an environmental value is assigned; however, some guidance is provided in this section.

Specific environmental value categories that need protection are primarily established through a stakeholder and community consultation process (discussed further in Sections 4.7 and 4.8). In some instances, the natural properties of groundwater (such as salinity and other geogenic constituents) might preclude the adoption of some environmental value categories. To determine whether this is the case, naturally occurring water quality parameters of the groundwater system should be compared to guideline values in the *Australian and New Zealand Fresh and Marine Water Quality Guidelines* (ANZECC & ARMCANZ 2000a) and the *Australian Drinking Water Guidelines* (NHMRC & NRMMC 2011) or other locally developed guideline values to determine which environmental value category is appropriate. Because much Australian groundwater is brackish or saline and therefore not suitable for drinking and possibly irrigation supplies, salinity is a useful parameter to initially screen environmental value categories. This approach to defining an environmental value has been adopted in Victoria and is provided as an example in Box 1. Acceptable salinity levels must be viewed along with other water quality parameters, as other natural geogenic contaminants such as arsenic, fluoride or radionuclides may also exceed suitable limits and therefore preclude certain environmental value categories.

**Box 1 Example of using salinity to determine appropriate environmental value categories for groundwater**

The Victorian *State environment protection policy—groundwaters of Victoria* (EPA Victoria 1997) uses groundwater salinity to define the beneficial uses to be protected. The state environment protection policy (SEPP) includes **Error! Reference source not found.** below, which shows the eneficial uses to be protected for various salinities.

**Table 1 Beneficial uses to be protected for various salinities**  
Segments (mg/L TDS)

Beneficial use	A1 (0–500)	A2 (501–1,000)	B (1,001–3,500)	C (3,501–13,000)	D (>13,000)
Maintenance of ecosystems	YES	YES	YES	YES	YES
Potable water supply					
Desirable	YES				
Acceptable		YES			
Potable mineral water supply	YES	YES	YES		
Agriculture, parks and gardens	YES	YES	YES		
Stock watering	YES	YES	YES	YES	
Industrial water use	YES	YES	YES	YES	YES
Primary contact recreation	YES	YES	YES	YES	
Buildings and structures	YES	YES	YES	YES	YES

Source: EPA Victoria 1997

This approach recognises that salinity often determines the possible uses of groundwater. The policy also includes provision for precluding certain beneficial uses if another background quality indicator will be detrimental to the beneficial use (determined based on salinity); if aquifer yields cannot sustain a particular beneficial use; or if an existing polluted groundwater zone has been identified by the EPA.

This approach focuses on an environmental value determination for which numerical guidelines can be used, and additional consideration of whether other categories such as cultural and spiritual environmental value would need to occur through community consultation.

Suggested steps for assigning an environmental value are as follows:

- 1) Define limitations on which environmental value category is appropriate based on natural groundwater salinity.

- 2) Establish interim environmental value categories for the groundwater systems through a consultative process.
- 3) Compare other water quality objectives for the proposed environmental value category to the groundwater quality of the resource and:
  - a) where natural groundwater quality does not meet health requirements for other water quality objectives, disregard the relevant environmental value category
  - b) where natural groundwater quality does not meet aesthetic considerations for the proposed environmental value category, undertake further community consultation to determine an environmental value and appropriate water quality objectives.

Physical constraints on groundwater extraction may cause some environmental value categories to be disregarded through community consultation—for example, where aquifer yields or soil characteristics mean groundwater cannot be extracted for industrial or agricultural use. Location, remoteness or absence of hazards are not reasons to disregard certain environmental value categories, as developments may shift towards water sources in the future. Similarly, aquifer depth is not a sufficient reason to disregard certain environmental value categories since the economics of water supply could make deep groundwater sources viable in the future. Potential use of the groundwater in the future should also be a determinant of environmental value.

While water treatment could improve natural groundwater quality such that it can support additional environmental value categories, these potential future environmental values arising as a result of treatment (aside from remediation of contamination) would be considered as required during future revision of groundwater quality protection plans.

For some larger groundwater systems, it may be necessary to identify different environmental value categories for different parts of the system. Some reasons for adopting a variety of environmental value categories in different parts of a groundwater system are as follows:

- Natural variations in groundwater quality make certain parts of the groundwater system appropriate for some environmental value categories and not others.
- Natural variability in groundwater yield, surface characteristics or accessibility mean the groundwater system is not viable for certain environmental value categories.
- Natural variations in confinement of the groundwater system or proximity to GDEs suggest that different environmental value categories be set.
- Community choices of a specific environmental value vary across the groundwater system.

In some cases, existing groundwater contamination may be inconsistent with the proposed environmental value; however, this should not automatically be used to disregard environmental value categories. Rather, the issue should be dealt with through groundwater quality planning by identifying appropriate management strategies to achieve the water quality objective associated with the assigned environmental value unless there is acknowledgement that the assigned environmental value is unlikely to be achievable in the long term due to incompatible land uses.

There may be circumstances where a groundwater system has no obvious current or future environmental value category due to its depth, remote location or poor-quality water. An example of this is where a deep, confined aquifer in a stable geological formation contains extremely poor natural quality water (for example, due to high salt or radionuclide levels) and there are no current

users of the aquifer. This confined aquifer may be sought to be developed as a long-term depository for wastes. As a consequence, an environmental value of industrial water use would apply, and this would set the baseline for future groundwater quality protection measures. Another example is the extraction of poor-quality groundwater associated with coal seam gas extraction. In such situations, these guidelines should be applied, particularly the precautionary principle, to ensure that changes in pressure and quality do not result in deterioration of the assigned environmental values of overlying or adjacent aquifers.

The long time frames involved in contaminant transport in deep, confined groundwater systems mean that impacts may not be observed for a long time and are difficult to predict and remediation may not be possible. Waste disposal and further degradation of aquifers must be assessed with a strong emphasis on the precautionary, intergenerational equity and polluter pays principles. These principles imply that an aquifer should not be further degraded if there is a chance of significant future problems or if the potential to assign certain environmental value categories in the future could be precluded.

#### 4.2.4 Setting water quality objectives

Once the environmental value category has been identified and agreed through stakeholder consultation, water quality objectives can be defined. These set out the specific targets required to protect or enhance groundwater quality and may be either numerical guideline concentration limits or a narrative statement that specifies water quality objectives. Guideline values that can be used as water quality objectives for specific environmental value categories are listed in other National Water Quality Management Strategy (NWQMS) documents, including:

- *Australian and New Zealand Fresh and Marine Water Quality Guidelines* (ANZECC & ARMCANZ 2000a)
- *Guidelines for managing risks in recreational water* (NHMRC 2008)
- *Australian drinking water guidelines* (NHMRC & NRMMC 2011)
- *Australian guidelines for water recycling: Managing health and environmental risks (phase 1)* (EPHC, NRMMC & AHMC 2006)
- *Australian guidelines for water recycling: Managing health and environmental risks (phase 2)—augmentation of drinking water supplies* (NRMMC, EPHC & NHMRC 2008)
- *Australian guidelines for water recycling: Managing health and environmental risks—stormwater harvesting and reuse* (NRMMC, EPHC & NHMRC 2009a)
- *Australian guidelines for water recycling: Managing health and environmental risks—managed aquifer recharge* (NRMMC, EPHC & NHMRC 2009b).

Other water quality guidelines may be available for local areas, such as in the *Queensland water quality guidelines 2009* (DEHP 2009).

The NWQMS guideline documents do not provide guideline values for industrial or cultural and spiritual environmental value categories. These must be determined on a case-by-case basis. Industrial water quality objectives need to be set with consideration of the potential industries and land-use planning restrictions on the location and a knowledge of ‘typical’ water quality required for these industries. Guidelines for the cultural and spiritual environmental value category should be agreed in consultation with Indigenous custodians and communities. Guidance on setting water

quality objectives for the cultural and spiritual environmental value is provided in Collings (2012). Sections 4.7 and 4.8 outline the requirements for community consultation.

Even where generic guideline values are available in NWQMS documents, water quality objectives may be locally defined to consider water quality issues specific to the groundwater system in question. This enables existing water quality, community values and potential and future uses to be considered within water quality objectives.

Where there are multiple environmental value categories identified with multiple water quality objectives, groundwater quality should be maintained to the most conservative water quality objective so that the most sensitive environmental value category is protected. For example, for some parameters (such as nitrate and phosphate), ecosystem protection is the most conservative constraint, whereas for others (such as salinity and pathogens), drinking water is the most sensitive environmental value category and therefore is associated with the most conservative water quality objectives.

The ANZECC & ARMCANZ (2000a) water quality guidelines for aquatic ecosystems are also applicable for GDEs 'that rely on groundwater discharge to rivers or wetlands', as the quality of the groundwater component needs to be preserved so that it does not alter the surface water quality at its discharge environment. Subterranean fauna (stygo fauna) live in pore spaces and voids within some aquifers. Their sensitivity to contamination is likely to vary between taxa and in response to different contaminants (Tomlinson 2011). No water quality guidelines are available for these communities. Where stygo fauna communities have been identified, water quality objectives should be set to protect their habitat, in consultation with the community and stakeholder groups.

There are currently no water quality guidelines for groundwater-dependent ecosystems (GDEs) 'that rely on the subsurface presence of groundwater' (vegetation). In setting water quality objectives to protect these GDEs, parameters that are important for vegetation health should be considered, such as nitrogen, phosphorus, organic carbon, metals, salinity, dissolved oxygen and pH.

The adoption of guideline values for water quality objectives should not be interpreted as upper limits to which groundwater contaminant concentrations can be increased. Rather, if existing groundwater quality is below the adopted water quality guideline values, the groundwater should be maintained within the range of natural quality variations established through baseline characterisation as described in Section 4.2.2.

#### **4.2.5 Point of application criteria**

Significant attenuation of groundwater contaminants and inactivation of pathogenic microorganisms can occur within the aquifer. Therefore, the distance between the contamination source and the monitoring of groundwater quality influences the contaminant concentrations detected. Policy decisions must be made on the point of application of adopted groundwater quality objectives. Three options are usually available for this location:

- monitoring at the point of contaminant discharge to groundwater
- monitoring at the boundary of an 'attenuation zone' sufficient to allow for dilution and possible sub-surface degradation of contaminants
- monitoring at the boundary of the property upon which the effluent is discharged.



The water quality parameters monitored should not exceed the water quality objectives defined by the relevant plan or guideline at the selected point of application. This provides evidence that the contaminants are not impacting on the assigned environmental value categories. More detail on the monitoring requirements associated with each point of application option is described in element 5 (Section 4.5).

The 'point of discharge' approach is a preventive approach. It ensures much tighter control of the discharge quality and limits accumulation of significant contamination in the aquifer. Water quality standards for point of discharge policies can be developed based on the expected natural dilution and degradation within the aquifer and on its expected attenuation capacity. This approach is difficult to implement when dealing with diffuse sources of contamination which may occur over large areas and from multiple different land users (for example, farmers) and for variable source water concentrations and pathogen numbers. Point of discharge monitoring should be combined with verification monitoring within the aquifer to confirm the accuracy of assumptions regarding dilution and attenuation.

The 'attenuation zone' approach is a more flexible approach to managing contaminating activities; however, by allowing increases in contaminant concentrations in a part of the groundwater system, it presents a risk to overall groundwater quality. Effective management of an attenuation zone requires knowledge of the hydrogeology and hydrochemistry of the receiving groundwater system and requires the installation of monitoring networks to ensure compliance. It also requires discharged contaminated water quality to be known and to be relatively consistent so as to ensure sufficient attenuation of those contaminants within the aquifer. As such, monitoring at the point of discharge should occur in conjunction with monitoring at the boundaries of the attenuation zone.

The attenuation zone may be within or extend beyond the boundaries of the property containing the discharge point. If the zone extends beyond the boundaries, there must be careful consideration of the impact of contaminated water underlying adjoining properties in relation to water allocation planning and groundwater licensing. A decision needs to be made on the allowable size of the attenuation zone to avoid the attenuation zone threatening the assigned environmental value of the overall groundwater system and impinging on the rights of other users.

Selection of individual monitoring locations at the edge of an attenuation zone or the boundary of a property should recognise the travel times associated with the contamination plume. In some cases, such as developments that require dewatering and create a drawdown cone, the contaminant plume may not migrate from the point of discharge until dewatering ceases. Monitoring would therefore need to consider the size of the plume during dewatering and the size and migration of the plume when groundwater levels have recovered.

The main disadvantage of the 'attenuation zone' or 'property boundary' approach is the potential for a concentrated plume of contaminated water to exist within the groundwater system boundaries. The future movement of this plume may result in criteria being exceeded at the designated boundaries. Hence, validation monitoring close to the contaminant source would be required to give confidence that attenuation will be sufficient. Verification monitoring at the edges of the attenuation zone would also be required as evidence of effective contamination management for regulators. Remediation or contingency action may be difficult and expensive. Whilst confining contamination to an attenuation zone or a property boundary limits the movement of the plume away from the source

of contamination, at some stage the full extent of contamination will need to be addressed once the contaminating activity ceases. That is, remediation is most likely to be required under all scenarios.

The adopted approach needs to recognise the environmental value category being protected so that the groundwater quality objectives of the relevant environmental value will be protected. However, maintaining water quality objectives at the point of contaminant discharge to groundwater is best practice and presents the least-risk option for protecting groundwater quality. Combining these two approaches allows for monitoring and management of the discharge at the source and provides for monitoring and management in terms of the effect of the discharge within the aquifer. While attenuation zones may be required in certain situations, they represent a significant risk to groundwater quality and would need to be managed accordingly.

#### 4.2.6 Hazard identification and review of risks

These guidelines recommend a risk-based approach to groundwater quality management, which requires the level of effort for groundwater protection to be commensurate with the risk of contamination. The risk-based approach proposed here is based on the *Australian drinking water guidelines* (NHMRC & NRMCC 2011), which in turn incorporates adapted elements of AS/NZS 3100:2009 on risk management.

Effective risk management requires identification of all hazards, sources and hazardous events; and the level of risk presented by each hazard. A hazard is distinct from a risk. 'Hazard' and 'risk' can be defined as follows (NHMRC & NRMCC 2011):

- *Hazards* are contaminants that have the potential to degrade groundwater quality.
- *Hazardous events* are situations or incidents that can lead to the presence of a hazard.
- *Risk* is the likelihood that the hazard will occur and the consequence of the hazard occurring.

Groundwater quality protection needs to be prioritised based on the level of risk rather than the presence of a hazard, as there will be cases where hazards exist but the likelihood of occurrence is low or the consequences are low. Investment and management controls should prioritise higher-risk situations, where hazards are present and the likelihood and consequences of detrimental impacts to groundwater quality are high.

In most cases, the level of knowledge required to predict hazards and risks will be limited and will necessitate completion of a qualitative risk assessment rather than a detailed quantitative risk assessment. It should be recognised that risk assessments will usually involve making subjective judgments that result in uncertainty in predictions. For this reason, flexibility in the approach is required so that management responses can be implemented to address unexpected events.

Hazards to the environmental value categories of groundwater can occur through either point source or diffuse sources of contamination. A broad range of hazards exist. Examples of contaminant hazards identified in NWQMS guidelines are:

- pathogens (for example, viruses)
- inorganic chemicals (for example, major ions and metals)
- salinity and sodicity
- nutrients (for example, nitrogen, phosphorus and organic carbon)

- organic chemicals (for example, pesticides and hydrocarbons)
- turbidity and particulates (for example, suspended solids)
- radionuclides (for example, alpha radiation).

Other changes in physico-chemical conditions can also constitute a hazard to groundwater quality protection, as can thermal contamination, which can alter aquifer structure and influence the concentration of other contaminants. Changing groundwater levels and pressures also have the potential to mobilise contaminants.

Identification of hazards should follow a transparent and consistent methodology. Hazards can be identified based on current, historical and potential future land uses, climate variations (droughts and floods), introduction of new technologies and changes in policy leading to variations in land management. Appendix A lists a series of potentially hazardous events and activities. The identification of hazards should be reviewed and updated periodically.

Once hazards have been identified, the level of risk associated with each hazard should be assessed so that the priorities for management actions can be established. Groundwater contamination risks are site-specific; therefore, established quantitative measures of risk are generally unavailable for most groundwater contamination hazards. One exception to this is the quantitative risk defined for some microbial hazards associated with recycled water injection (see NRMCC, EPHC & NHMRC 2009b).

Qualitative ranking of risks allows priorities for management to be established. A common method for ranking risks involves estimating the likelihood of each hazard occurring (for example, almost certain, possible or rare) and the severity of the consequences associated with each hazard (for example, catastrophic, moderate or insignificant), which relates to the nature and values of the receptors that are impacted on. Assigning likelihood/consequence to each hazard will usually generate some uncertainty. The precautionary principle should be applied in these cases, and all assumptions made during the risk assessment should be clearly documented to provide context for future managers.

The requirement for preventative or management measures should be evaluated using two levels of risk: maximum risk and residual risk. Maximum risk helps to identify the highest priority risks, where the level of action required may be high. This will usually involve collection of additional information on the sources of hazards, ability to reduce or substitute the hazards, fate of hazards in the aquifer, characterisation of groundwater system and connections between aquifers and with surface water and GDEs, and understanding the consequences of exposure to hazards. This information can be used to define the preventative measures that will assure groundwater quality protection and the monitoring requirements to verify this.

Residual risk indicates whether additional preventive or management actions are required. The level of action chosen to address contamination issues should be reviewed periodically even if risks are low. Box 2 gives an example of levels of action that could be adopted in response to the prioritisation of risks. Box 2 shows that the types of action that can be taken will depend on the level of risk.

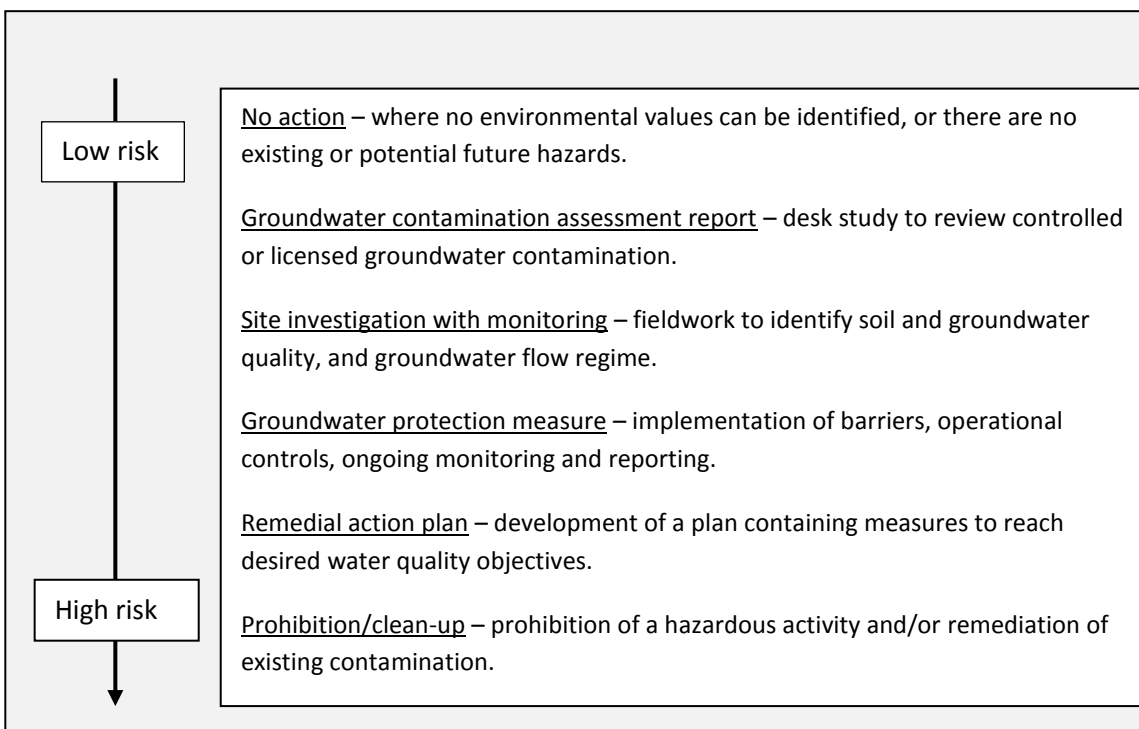
Actions can include:

- no action (for lowest risk activities)

- groundwater contamination assessment reports
- site investigation with monitoring
- groundwater protection measures
- remedial action plans
- prohibition and clean-up (for highest risk activities).

The available levels of action increase in effort as the risk to groundwater quality increases. Uncertainty and application of the precautionary principle may also increase the level of action adopted. The assessment and management of groundwater contamination should occur in partnership with contaminated sites regulators in each jurisdiction and in accordance with the *National Environment Protection (Assessment of Site Contamination) Measure 1999* (NEPC 2013).

**Box 2 Levels of action that could be adopted to respond to risk**



**4.3 Element 3: groundwater quality protection measures**

Groundwater quality protection measures can occur through a range of government intervention mechanisms and be implemented within the Groundwater Management, Land Use Planning and/or Environment Protection legislative frameworks. These high-level considerations support the selection of groundwater protection measures for a groundwater quality protection plan and are discussed in Sections 4.3.1 and 4.3.2. More specific details on the range of protection measures that may be considered are provided in Sections 4.3.3 to 4.3.5. The aim of protection measures is to reduce the risk of groundwater contamination to acceptable levels and, in some cases, to assist in managing existing contamination or the restoration of environmental value categories.

**4.3.1 Forms of intervention**

Groundwater quality protection strategies can be implemented through three intervention mechanisms (Geoscience Australia 2010b):

- intervention by ‘command’, such as use of legislation or regulation to control contamination
- financial and economic incentives, which provide a financial incentive for minimising waste production and releases of contamination
- public education, which seeks to change behaviours by increasing community awareness of contamination issues.

It is likely that the most effective contamination control strategies will employ a tailored mix of all three intervention measures.

*Intervention by ‘command’* is most effective for management of point sources such as wastewater treatment plants and industrial waste releases. Legal techniques to directly control activities that may pollute groundwater have developed substantially in recent years. They now include flexible and adaptable tools such as ‘best-practice environmental management’ and general environmental duties (Geoscience Australia 2010b).

Regulatory measures can be extended to more diffuse sources of contamination in some cases—for example, to urban run-off by licensing stormwater drains, as is now done in the United States, or to the use of agricultural chemicals (Geoscience Australia 2010b). However, compliance monitoring and enforcement are more difficult for diffuse sources.

*Financial and economic incentives* can be implemented to support regulatory approaches to intervention and usually take the form of financial bonds that encourage compliance with licence conditions. The incentives are most commonly applied within an environment protection framework rather than a Groundwater Management or Land-use Planning framework. Other examples of financial and economic incentives include (Geoscience Australia 2010b):

- tradeable effluent permits, contamination charges or emissions schemes (tradeable permit schemes)
- offset schemes that create a market for ‘offset credits’
- tariffs, levies or surcharges for materials that may affect water quality, such as soluble fertilisers
- subsidies to encourage adoption of contamination reduction measures, such as for slow release fertilisers
- bubble licence schemes, where a share in the total allowable contaminant volume is allocated amongst members of a group, allowing flexibility within the group for achieving water quality objectives
- rewards for implementing best-practice approaches to contamination minimisation or grants for innovation in reducing contamination
- taxation or rate relief for those who adopt measures to achieve water quality objectives.

The polluter pays principle is a financial incentive that aims to deter land users from polluting activities; however, it needs to be strongly enforced to be effective.

*Public education* is an important intervention mechanism for environmental protection, as it both engages stakeholders and contributes to changing behaviours regarding contamination management. Elements 7 and 8 of the framework (Sections 4.7 and 4.8) discuss this mechanism in further detail.

#### 4.3.2 Legislative base for groundwater protection measures

A range of groundwater protection measures are available that are suited to various types of contamination issues and various regulatory, financial, social, environmental or political situations. Table 2 lists protection measures that are available within each legislative framework for groundwater quality protection.

**Table 2 Groundwater protection measures within each legislative framework for groundwater quality protection**

Groundwater resource management	Land-use planning	Environment protection
<ul style="list-style-type: none"> <li>• Bore construction standards</li> </ul>	<ul style="list-style-type: none"> <li>• Hazards to groundwater accounted for in land-use planning</li> </ul>	<ul style="list-style-type: none"> <li>• Point and diffuse source controls</li> </ul>
<ul style="list-style-type: none"> <li>• Bore integrity controls</li> </ul>	<ul style="list-style-type: none"> <li>• Wellhead protection zones</li> </ul>	<ul style="list-style-type: none"> <li>• Hazardous substance controls (for example, pesticides)</li> </ul>
<ul style="list-style-type: none"> <li>• Groundwater level triggers</li> </ul>	<ul style="list-style-type: none"> <li>• Aquifer vulnerability mapping</li> </ul>	<ul style="list-style-type: none"> <li>• Requirements to monitor</li> </ul>
<ul style="list-style-type: none"> <li>• Groundwater quality triggers</li> </ul>	<ul style="list-style-type: none"> <li>• Requirements to monitor</li> </ul>	
<ul style="list-style-type: none"> <li>• Licensing and management of extraction</li> </ul>	<ul style="list-style-type: none"> <li>• Water-sensitive urban design</li> </ul>	
<ul style="list-style-type: none"> <li>• Groundwater protection zones</li> </ul>		

Groundwater management legislation focuses on the management of groundwater allocation and utilisation; however, within this framework, groundwater quality protection is considered as part of practices such as well construction and well integrity controls, and control of groundwater levels and pressure.

In June 2013, the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) was amended to take into consideration the potential impacts of coal seam gas and large coal mining developments on water resources. Under the Act, coal seam gas and large coal mining companies are now required to submit detailed water management and monitoring plans, including a programme for aquifer connectivity studies, and water quality monitoring and management (surface water and groundwater).

Land-use planning legislation controls the types of development in certain areas largely through development approvals and land zoning. Its value in the protection of groundwater is likely to increase as groundwater contamination begins to impinge on an environmental value. For unconfined aquifers in peri-urban areas where the environmental value categories include drinking water supplies, it should be recognised by urban planners that the opportunity cost of urban development in those areas is the potential loss of the aquifer as a drinking water supply source. Box 3 provides an example of land-use planning that explicitly recognises the protection of water resources.

### Box 3 Example of land-use planning to protect water quality

The protection of assigned water environmental values has been built into the land use planning framework in Queensland with the release of the *State planning policy 4/10 guideline: Healthy waters* (DEHP 2010).

Environmental value categories and water quality objectives are being established in Queensland by DEHP. The state planning policy (SPP) recognises the opportunity to include water protection measures within their planning scheme in order to limit and reduce the impacts of development on water environmental values.

The SPP provides for control and management of point and diffuse source of contamination that may arise from construction, wastewater management and non-tidal urban waterways.

Environment protection legislation is based on pollution control concepts and provides tools for controlling point and diffuse sources of contamination. It can protect groundwater quality by requiring authorisations for potentially contaminating activities. Specific legislation is often available to control contamination from certain activities, including mining, quarrying, pesticide use, hazardous chemicals, petroleum, dangerous goods, agricultural chemicals, geothermal energy and greenhouse gas sequestration and storage. Such legislation may also provide for adoption of a waste hierarchy (waste avoidance, waste re-use, recycling or waste reclamation, waste treatment and waste disposal), environmental impact assessments, implementation of monitoring requirements, contingency activities such as remediation, and control of contamination from diffuse sources (Geoscience Australia 2010b).

A groundwater protection plan should consider groundwater protection measures within each of these three legislative frameworks. Adoption of particular groundwater protection measures within each of the legislative frameworks is the decision of groundwater quality managers and should be based on the specific environment requiring protection and existing state/territory legislative requirements.

#### 4.3.3 Groundwater management

A range of groundwater quality protection strategies exist within the groundwater management framework. These are usually most appropriate when considering contaminant impacts over a regional area such as an aquifer, as groundwater resource management currently occurs at that scale.

##### Groundwater plans

Groundwater plans are the primary regulatory tool used to manage groundwater resources. These plans focus on resource allocation and extraction for human uses of groundwater sources. With recognition of environmentally sustainable levels of take (ESLT), they also have provisions for environmental uses of the groundwater resource. Resource allocation is linked to groundwater quality through potential impacts of over-extraction, such as saline intrusion, inter-aquifer leakage and acid sulfate soils. Groundwater plans should consider water quality impacts associated with over-extraction as well as management of water quality impacts associated with other uses of the land or water resources in the plan area. Existing contamination and potential new sources of contamination should also be considered within groundwater plans.

To improve the protection of groundwater quality within existing groundwater management planning, managers need to consider a broader group of beneficiaries than consumptive groundwater users. Agreed choices of environmental value need to be included in the general groundwater planning process so that benefits of the planning process are assigned to both humans and ecosystems. This is occurring to some extent with the consideration of environmental impacts from groundwater extraction; however, water quality impacts are not generally part of the process.

The growth of financial and economic measures to manage water resources promoted under the National Water Initiative (NWI) include pricing reform to move further towards a user pays market and establishment of groundwater trade markets. As this starts to become normal practice for groundwater allocation and extraction processes, water products with defined quality characteristics can also be introduced into the market.

The effectiveness of a combined groundwater management and protection plan will depend on its enforcement. This requires a good monitoring programme (discussed further in element 4 (Section 4.2.4) and element 5 (Section 4.5)) and adequate enforcement procedures. Periodic review of groundwater plans and quality protection plans should occur concurrently to enable consistent adaptations to be made.

#### **Groundwater protection zones**

Establishing groundwater protection zones is a similar concept to wellhead protection zones (see Section 4.3.4) but is based on protecting an area from developments that are incompatible with protecting the quality of the groundwater for future supplies. Groundwater protection zones usually consider a regional area and focus on protecting the capture zone for down-gradient groundwater discharge to wetlands, rivers or bore fields. An example of a groundwater protection zone in Western Australia is outlined in Box 4. In the context of these guidelines, a groundwater protection zone may form part of the overall groundwater protection plan. Defining zones within the overall area for groundwater protection should be based on the assigned environmental value, existing and potential land uses and other hazards and resource considerations identified in element 2.

#### **Box 4 Example of the use of groundwater quality protection zones in Western Australia**

In Western Australia, contamination risks in public drinking water source areas (PDWSAs) are addressed through an integrated land-use planning and PDWSA protection programme.

The first step in protecting water quality in a PDWSA is to define its boundary and proclaim it under state legislation. This ensures the location of a PDWSA can be identified on publicly available maps and be recognised in land-use planning documents. It also defines the area within which by-laws can be applied to protect water quality and public health.

The second step is to define the priority areas (P1, P2 and P3) of land within the PDWSA. These priority areas are based on the strategic value of the water source, the existing or approved planning scheme zoning, land tenure (ownership) and current or approved land uses:

- priority 1 (P1) areas (for example, state forest and other Crown land); risk avoidance—preventing the development of potentially harmful activities
- priority 2 (P2) areas (for example, rural land); risk minimisation—no increased risk of water source contamination



- priority 3 (P3) areas (for example, urban or light industrial/commercial areas); risk management—for the higher risks of water source contamination from land-use intensification.

The third step is to define protection zones within the PDWSA where they are most vulnerable to contamination risks from inappropriate land uses. In groundwater sources, wellhead protection zones are defined around the areas where water is abstracted by production bores. Specific conditions or by-laws may apply within these zones, such as restrictions on the storage of chemicals.

The Department of Water has prepared more than 125 drinking water source protection reports based on this approach consistent with the relevant state planning and water legislation and policies.

Source: Department of Water (WA) 2013

### **Bore construction standards**

Good drilling, bore installation, monitoring and decommissioning practices can prevent contamination occurring via the bore infrastructure itself (for example, through inter-aquifer leakage along bore casing). National bore construction standards (*Minimum construction requirements for water bores in Australia* (NUDLC 2012)) or the state/territory equivalents should be adhered to during installation and decommissioning of groundwater bores. Standards are also available for constructing and abandoning coal seam gas extraction bores for Queensland (DEEDI 2011) and New South Wales (DTIRIS 2012).

#### **4.3.4 Land-use planning options**

Land-use controls are a principal means of providing protection for groundwater. One of the measures that can be used is land zoning, where hazardous land uses are restricted to protect underlying groundwater quality. A groundwater source with a sensitive environmental value, such as drinking water supply, may require severe restrictions on land use, while, for a poorer quality groundwater source (with fewer or less sensitive environmental value categories), there may be fewer restrictions on land use. Most land uses can be managed to reduce the risk of contamination, although it is particularly difficult to protect unconfined aquifers in urban environments.

Management requirements should be determined on a case-by-case basis for each land-use option, recognising a risk-based approach and the precautionary principle.

A helpful approach may be to develop a land-use risk matrix for a particular groundwater source to help decision making on the compatibility of land uses with groundwater quality protection. The land-use alternatives can be few or many depending on specific needs, and the risks of each can be assessed in terms of particular water quality hazards and parameters.

Land zoning and groundwater management options to provide required levels of groundwater protection must account for the existing situation in terms of land tenure and existing land planning. There needs to be a balance between groundwater protection objectives and broader community expectations and considerations for land use. Two protection measures related to land-use planning are discussed in the following sections.

### **Vulnerability and vulnerability mapping**

Vulnerability mapping has been used as a tool to allow comparative review of groundwater vulnerability across broad areas. Developing a vulnerability map requires a conceptualisation of the hydrogeological factors that may influence the likelihood of groundwater contamination occurring, including depth to watertable, recharge zones, aquifer composition, topography and vadose zone. An approach and methodology for vulnerability mapping is described in Dixon (2005).

Vulnerability mapping is usually biased towards identification of hazards at or near the surface and so may not be appropriate where deeper hazards exist, such as multiple aquifer wells and inter-aquifer leakage. The most effective use of vulnerability mapping is as a screening tool to highlight areas where detailed hydrogeological field investigation is essential for management decision making and special precautions (such as restrictions on development) will be likely for groundwater quality protection. It should not typically be relied upon as a standalone method for groundwater protection.

### **Wellhead protection plans**

Wellhead protection plans aim to prevent contamination in the vicinity of groundwater extraction bores and are generally applied to public water supply bore fields. Wellhead protection plans protect against leakage of surface contaminants to the groundwater via bore casing and from the potential for bore integrity failures that can result in leakage between aquifers. The concept of maintaining bore integrity to protect groundwater also applies to non-groundwater bores such as coal seam gas extraction bores, petroleum bores, reinjection bores and monitoring bores.

Compliance monitoring is important to ensure that standards are maintained. More comprehensive wellhead construction may be required to protect groundwater in the vicinity of the bores in the watertable aquifer, where surface contamination such as spills is a hazard.

Depending on the perceived hazards, a wellhead protection plan might include:

- specification of comprehensive bore construction standards
- requirement for bore completion reports
- bore maintenance schedule and integrity monitoring
- operational constraints on pumping (such as specified timing and volumes; and restrictions on pump depth)
- delineation of protection zones around the wellhead, which need to consider the extent of drawdown and the effects of dispersion and diffusion on contaminant distribution
- safe storage of hazardous materials
- access and land development restrictions within the wellhead protection zone
- broader monitoring network requirements, including early warning of contamination
- contamination response plan (see element 6, Section 4.6).

### **Water-sensitive urban design**

Water-sensitive urban design (WSUD) is an approach to urban design and development that adopts principles of integrated and sustainable management of all water sources. It is a fundamental shift in urban planning and design which recognises that water streams which have traditionally been viewed as waste products, such as stormwater and wastewater, can be used as resources. With

effective design and management, these resources can be harnessed to create water use efficiencies, aesthetic benefits and environmental benefits.

The objectives of WSUD include:

- reducing potable water demand through demand and supply side water management, incorporating the use of water-efficient appliances and fittings as well as a fit-for-purpose approach to the use of potential alternative sources of water
- minimising wastewater generation and treatment of wastewater to a standard suitable for effluent reuse and/or release to receiving water
- treating stormwater to meet water quality objectives for reuse and/or discharge
- restoring or preserving the natural hydrological regime of catchments
- improving waterway health by the management of the previous two objectives
- improving aesthetics and the connection with water for the residents of developments where it is applied
- promoting a significant degree of water-related self-sufficiency within a development by optimising the use of water sources from within the development to minimise potable water inflows and water outflows from a development, both stormwater and wastewater.

The NWI (clause 92ii) recognised the opportunities for more efficient management of urban water through adoption of WSUD, and national guidelines are available to provide guidance on evaluating options for implementing WSUD in both new urban subdivisions and high-rise buildings (JSCWSC 2009).

#### **4.3.5 Environment protection options**

Environment protection is generally managed by state and territory based environmental protection agencies. Activities focus on waste management, point source and diffuse contamination, environment protection in the resource industries, environmental impact assessment, contaminated sites, State of the Environment reporting, control of chemicals and water quality objectives. Environment protection currently operates largely through regulatory intervention mechanisms, with potentially polluting activities such as landfills, waste disposal and chemical storage controlled through licensing. The principles of the Environment Management Framework are waste minimisation, cleaner production, best management practices and reuse and recycling.

There are many strategies or measures that can be considered to enable waste disposal to an extent that does not degrade an existing Environmental Value. Box 4 gives the conditions used in Queensland for the approval and management of certain activities under environmental protection frameworks.

Financial and economic incentives can be introduced to improve the efficiency of the existing regulatory approaches to environment protection. For example, capping the total volume of waste discharged in an area has the potential to create a market for waste discharge licences. When licences become very expensive, focus will turn to reduction of waste in preference to disposal.

It can be difficult to determine the amount of waste that will enable a specific Environmental Value to be maintained. Significant investigation, modelling and monitoring is required to make this decision. It may be more cost effective to employ a precautionary approach and prohibit disposal at

low levels that are likely to be acceptable, depending on the Environmental Value assigned to the area.

#### **Box 5 Strategies for controlling potentially contaminating activities**

The Queensland Environmental Protection Regulation 2008 states a selection of measures that can be used to implement controls within the environment protection framework on a potentially polluting activity. These include:

- strategies for avoiding or minimising the waste disposal or release
- the use of buffer zones or setback distances to ensure adequate distance between sensitive receptors and the waste disposal location
- limiting the size of the mixing or attenuation zone that may be created from waste disposal
- treatment of contaminants prior to release
- restrictions on the type, quality, quantity, concentration or characteristics of contaminants that can be released
- restrictions on how contaminants are released—for example, low flow rates, location of release or timing of release
- recycling, storage or transfer of waste in a particular way
- capacity for rehabilitation of land and groundwater.

For many urban centres, it is likely that environment protection measures will be more effective in the long term than traditional groundwater protection measures. In several jurisdictions, integration of Groundwater Management and Environment Protection legislative frameworks has already occurred. For example, the Victorian state environment protection policy (SEPP) (Groundwaters of Victoria) recognises the specific protection needs for groundwater that must form part of all works approvals, licences or notices issued under the *Environment Protection Act 1970*. Similarly, the *Queensland Environmental Protection Policy (EPP) 2009* falls under the *Environmental Protection Act 1994* and specifically relates to the consideration of potential water impacts as a result of decisions regarding potentially polluting activities. In Western Australia, a specific statutory policy under the *Planning and Development Act 2005* relates to the Gnamptara Mound and restricts certain activities to protect groundwater quality in the aquifer.

Most contaminant sources that fall within the Environment Protection legislative framework are point sources, or collections of point sources, which are regulated by environment protection regulatory agency licensing. For example, waste discharge, landfills and septic tanks often need to be licensed by the environment protection regulatory agencies, and the potential for groundwater contamination should be assessed as part of the licence approval process. The protection measures may include multi-barrier protection, which involves stable design, controls on the types of waste disposed and prevention of flow of water through the contaminant source.

#### **Groundwater Quality Restricted Use Zones**

In areas where contamination has occurred, a zone may be established that recognises the impact on environmental values and restricts use of the contaminated groundwater. In Victoria, these are called Groundwater Restricted Use Zones (GQRUZs). They are established by the EPA to provide information about the contaminated groundwater. The GQRUZs are a means of communicating

groundwater quality impacts and associated restrictions on use to potential users of the groundwater (EPA Victoria 2002).

#### **4.4 Element 4: operational procedures**

Where specific groundwater quality protection measures are in place, operational procedures should be established to ensure the continued effective implementation of the protection measures. This could relate to a wide range of protection measures—for example, operational procedures may be required to ensure:

- correct installation and decommissioning of bores
- maintenance of bore integrity
- effective operation of remediation systems
- operation of barriers to contamination
- continued effective waste storage or transfer
- maintenance of monitoring systems
- modelling of changes in contaminant load, such as discharge volumes, quality or location
- effective implementation of emergency response protocols.

Any operational procedures required should be documented, communicated and understood by those involved in implementation of protection measures and periodically reviewed and updated as needed.

#### **4.5 Element 5: monitoring of protection measures**

A monitoring programme is an integral component of any protection plan. There are three distinct purposes of monitoring:

- *baseline monitoring*—used to establish natural (pre-development) variations in groundwater quality (as discussed in Section 4.2.2)
- *validation monitoring*—used to demonstrate effectiveness of control or remediation measures. For point sources this may occur at the discharge location, such as at low hydraulic conductivity barriers, or to quantify biodegradation or inactivation in the unsaturated zone and the aquifer. For diffuse sources this may occur at ‘hotspots’ in the aquifer to assess compliance with controls on contaminant release, such as application of pesticides. This also provides data for model calibration to test assumptions and predict the fate of contaminants in an aquifer
- *verification monitoring*—used on the perimeter of the groundwater attenuation zone to verify that all specified water quality objectives are met in the aquifer and that trends in concentrations of contaminants do not trigger implementation of further management actions. For diffuse sources, this will need to occur over a broad area to encompass the contaminant plume.

A combination of all three options is the most effective approach to ensuring that water quality objectives at the selected point of application of the guidelines values is not exceeded.

The parties responsible for any potential contamination should be responsible for the costs of monitoring and review of the data. Agreement on the implementation of a monitoring and review programme and remediation measures should be reached before any potential contaminating activity is approved.

An understanding of the natural variability of non-anthropogenic contaminants should be established prior to the potentially hazardous activity occurring. This background data will enable impacts of contamination to be distinguished from natural variations and increase the power of the monitoring programme to detect impacts. A before/after/control/impact (BACI) approach fulfils this criterion. Where data does not exist or the location is confounded by existing activities, a gradational change monitoring assessment may be appropriate. Monitoring approaches are described in the *Australian guidelines for water quality monitoring and reporting* (ANZECC & ARMCANZ 2000c).

The monitoring programme should include a commitment for regular professional review and reporting of the data to the regulating agency (framework elements 10 and 11). Provisions also should be made for contingency action when adverse impacts to groundwater quality have occurred (element 6).

#### **4.6 Element 6: management of incidents and emergencies**

Although preventative strategies are preferred for groundwater quality protection, incidents may still occur and planned responses must be in place to deal with these events. Many of the potential impacts to groundwater quality occur gradually over a long timescale and cannot be attributed to a single incident—for example, seawater intrusion and inter-aquifer leakage. These gradual impacts should be monitored to detect slow changes in groundwater quality and identify the need for further management controls.

Specific incidents that can impact on groundwater quality may also occur and need to be managed—for example:

- spills or dumping of hazardous material over an unconfined aquifer (for example, leaks from underground storage tanks, spills from chemical storage sites or run-off from tailings dams)
- accidental changes in content or quality of licensed waste disposal, such as changes in quality of an industrial waste stream
- failure of barriers against groundwater protection, such as cracks in waste containment facilities
- spills in the catchment of stream sinks or sinkholes in karst and conduit systems.

Management of these incidents would occur within the Environment Protection framework and incident response plans should be developed as part of the conditions of approval for hazardous activities. Components of the response should include:

- detection—through validation or verification monitoring
- response—implementation of the response plan
- communication to stakeholders.

Further guidance on management of incidents and emergencies for drinking water supplies is contained in the *Australian drinking water quality guidelines* (NHMRC & NRMCC 2011).

Approvals for potentially contaminating activities should include provisions for contingency measures, which specify the contingency action that will be implemented. They should also prescribe as closely as possible when an action should be implemented. Contingency measures may vary and may involve simply doing nothing, ceasing the contaminating activity, containing the area of contamination or clean-up action. Some regulatory measures used by environment protection

agencies include 'Clean up to the extent practicable' (CUTEP) and 'remediation to the extent necessary' (RTEN), which require significant contamination to be remediated to an agreed level. In contingency planning, it is useful to assess the costs of proposed action against the benefits likely to be achieved. This will require several assessments, including:

- the extent to which any existing or future environmental value category may be compromised by the contamination incident
- the alternative water sources available to those affected by the contamination incident
- the range of potential remedial actions that may be implemented
- the likely outcome of any proposed remedial action in terms of meeting water quality standards; and the time expected to achieve the outcome.

#### **4.7 Element 7: stakeholder engagement and training**

To design and implement an effective groundwater quality protection plan, groundwater quality managers will interface with other agencies—namely, groundwater resource managers, land-use planners and environment protection officers. Land users also need to be engaged in the development of groundwater quality protection plans. While the managers of the process to develop a groundwater quality protection plan will make the final decisions, the contribution of stakeholders is an important part of the process.

To facilitate useful contributions, stakeholders need to have a basic level of understanding of groundwater quality protection measures so that protection plans are appropriate for local conditions and can be effectively implemented. This engagement with stakeholders can also be used as a form of intervention, where education about the issues can be used to change behaviours and increase commitment to protecting assigned environmental values.

The knowledge gained from stakeholders when developing a groundwater protection plan is an important benefit of the engagement process. Stakeholders should be engaged to help identify the environmental value categories that are desired, determine water quality objectives, and identify risks to the groundwater. Another benefit of engaging with stakeholders during the implementation phase of a groundwater protection plan is to discuss and potentially address knowledge gaps in the understanding of the resource or test the assumptions made during the review of risks identified in element 2. Discussion on the level of risk perceived by stakeholders may result in further investment to fill knowledge gaps or adoption of the precautionary principle to address uncertainties.

The principles of stakeholder engagement are outlined in the *NWI policy guidelines for water planning and management* (COAG 2010). They are:

- *Stakeholder identification*—identify all major stakeholders that could affect or be affected by groundwater quality management. This list may include:
  - state and territory environmental protection agencies
  - local government planning authorities
  - state and territory government water managers
  - politicians such as local members of parliament or councillors
  - potential groundwater polluters
  - catchment management authorities
  - groundwater retailers

- conservation councils
  - landowners and the local community
  - Indigenous land councils, custodians and their communities
  - state and territory parks and reserves managers and flora and fauna managers
  - current and potential groundwater users, such as mining companies, farmers, local stock and domestic users, industrial groundwater users.
- *Timing of stakeholder engagement*—engage stakeholders early in the process.
  - *Type of engagement*—consider a range of communication methods, such as meetings or written communication, and clearly state the objectives, expectations and process for the consultation.
  - *Adequate information and opportunity for input*—schedule consultation throughout the planning process, make regular updates and allow adequate time for stakeholders to consider information and respond.
  - *Stakeholder engagement in setting outcomes*—provide opportunity for stakeholders to comment on objectives and outcomes.
  - *Consideration of structural adjustment*—consult on adaptations or adjustments to plans.

The potential impact of the groundwater quality management process on each stakeholder should be identified, and responsibilities of each should be defined. Stakeholder roles, responsibilities and commitment to groundwater quality protection should be agreed and documented. Methods of engagement, such as workshops or committees, should also be defined.

To assist with this, jurisdictions are close to finalising a package of guidance material aimed at incorporating Indigenous cultural and spiritual values into water quality planning (this guidance will be incorporated under the NWQMS *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000a)).

Groundwater protection plans declaring the defined environmental value, showing wellhead and groundwater protection zones and containing information relevant to those considering developments in an area should be published on the web and communicated. This information could be made available in periodic public consultation processes associated with groundwater allocation plan reviews and in setting the preferred environmental value.

Personnel involved in groundwater or underground infrastructure are required to be aware of groundwater quality protection requirements. For example, drillers are required to have adequate training in well construction, maintenance and decommissioning to assure well integrity. Industry-wide awareness and training is an efficient approach where multiple operators are involved (for example, cattle feedlot operators, coal seam gas companies and on-site sanitation installers).

#### **4.8 Element 8: community involvement and awareness**

Community consultation, involvement and awareness can have a major impact on the effectiveness of, and public confidence in, the protection of groundwater quality. In developing a groundwater quality protection plan, community involvement is most important for identifying the range of environmental value categories to be protected, determining water quality objectives and identifying risks to groundwater quality. The specific role of the community as contributors but not decision makers should be clearly communicated. Community awareness of the issues can also be used as an intervention measure and may result in improved behaviours amongst target groups with respect to protecting groundwater quality.



The *NWI Policy guidelines for water planning and management* (COAG 2010) highlight that, for stakeholders to have confidence in decisions affecting water resources and the wider environment, they need to know that these decisions are based on sound information; have canvassed all the issues; and have been subjected to a methodical, transparent and accountable decision-making process.

Community involvement has two related components: education and participation. Education is the comprehensive provision of information to the community to improve awareness of the nature, value and sensitivity of groundwater. Participation is the involvement of various sectors of the community in the development and implementation of programmes to protect, conserve, use and monitor groundwater. However, the responsibility for making decisions and finalising plans rests with the accountable agency and/or relevant minister. Integral to this approach is a considered engagement process that incorporates clear communication, open access to supporting information and documentation of the decision-making process and outcomes. For communication of issues relating to groundwater, visualisation tools are helpful to demonstrate sub-surface features and contaminant transport.

Assessing what is required for effective community involvement can be a difficult task depending on the issues and the community involved. The key requirements that need to be considered for a community consultation process include:

- defining the scope of the issue and the potential links with wider issues or problems. This will provide an indication of the extent of consultation or education required
- identifying specific interest and community groups that may be affected and their needs, existing level of knowledge and attitudes on the issues. All groups should be able to participate in the consultation process irrespective of barriers of language, distance, technical knowledge or lack of resources
- presenting factual information to the community, consumers and groups in a form that is accessible, understandable and suitable as a basis for informed discussion; and providing adequate time for consultation. The community should understand and agree to the process proposed for the consultation
- identifying or developing measures to evaluate the effectiveness of the community consultation process.

There are many different types of community consultation processes. They include:

- briefings targeted to specific groups with interests or responsibilities
- workshops or seminars on key issues or for special groups
- informative media programmes targeting print media, radio and television
- social media programmes
- community education or information exchange programmes
- school programmes
- preparation of technical issues papers
- media advertising of activities and available papers
- public hearings for major and controversial initiatives.

Community consultation should be undertaken during the development of groundwater protection plans, groundwater resource management plans, changes to land-use strategies and changes to environmental protection policy.

#### **4.9 Element 9: validation, research and development**

Validation involves investigating the accuracy of assumptions used in developing a groundwater quality protection plan. A lack of data or knowledge does not preclude the development of a groundwater quality protection plan; therefore, assumptions will often have to be made when characterising the resource (element 2). If the level of risk has increased or the uncertainties are considered untenable, it may be necessary to conduct further research to verify either the conceptualisation of the resource or the understanding of the hazards and their fate and consequences. This information would provide a more robust indication of the level of risk and hence the need for protection measures. Validation plays a key role during the development, implementation and revision of a groundwater protection plan.

An important aspect of validation is also to validate the effectiveness of the controls applied to prevent contamination. This validation monitoring is discussed in element 5 (Section 4.5).

#### **4.10 Element 10: documentation and reporting**

Documentation provides a basis for effective communication between groundwater quality managers as well as with the broader community and stakeholders. Ongoing monitoring can generate large amounts of data that need to be recorded. Efficient record keeping is an essential tool for indicating and forewarning of potential problems and providing evidence that the activities are not posing a risk to the groundwater quality. Each individual or organisation that poses a potential hazard to groundwater quality is required to document all monitoring methods, quality controls and results; and to provide a summary interpretation relating to the terms of their licence and demonstrating protection of the assigned environmental value of the aquifer.

Documentation and records systems should be kept as simple and focused as possible. The level of detail in the documentation of monitoring requirements and procedures should be sufficient to provide assurance of operational control when coupled with a suitably qualified and competent operator. Retention of corporate memory needs to be considered in the documentation of monitoring and reporting requirements. Mechanisms should also be established to review documents periodically and, where necessary, to revise them to reflect changing circumstances. A document control system must also be developed to ensure that current versions are in use.

External reporting includes reporting to regulatory bodies, consumers and other stakeholders in accordance with licence requirements and ensures that groundwater quality management is open and transparent. Reporting requirements should be agreed with environmental and health regulators and include:

- regular reports summarising performance and water quality data
- events reports on significant system failures that may pose an environmental or health risk or adversely affect groundwater quality
- quality analysis / quality control requirements for reports.

Reports should be provided to regulatory authorities on agreed incidents and emergency response protocols. If necessary, the relevant authority can then ensure that public health concerns are reported to the community. A commitment should also be made to transparent public reporting, with water quality monitoring data being made accessible to governments, researchers and the community in a timely and cost-effective manner. Web-based reporting is an effective way to reach a majority of stakeholders.

Reports should include an assessment of the groundwater quality performance against water quality guideline values and regulatory requirements and identify water quality trends and problems. Information should enable individuals or groups to make informed judgments about changes to the groundwater quality and review potential impacts on the identified environmental value. The reporting should use the water quality data to assess the overall performance of the groundwater protection plan and implement adaptive measures where necessary.

#### **4.11 Element 11: evaluation and audit**

Long-term evaluation of groundwater quality trends and audit of groundwater quality protection measures are required to determine whether protection measures are effective and whether they are being implemented appropriately. These reviews enable performance to be measured against objectives and to help to identify opportunities for improvements.

A systematic review of monitoring results over an extended period (typically at least the preceding 12 months or longer) is needed to assess the overall performance against water quality objectives and regulatory requirements and identify emerging problems and trends that need to be addressed. Any occasions of noncompliance need to be assessed and responses determined.

Auditing of groundwater quality protection is required to systematically evaluate activities and processes to confirm that objectives are being met. Auditing includes assessment of the implementation and capability of the protection plan, and it provides valuable information on aspects of the plan that are effective as well as identifying opportunities to improve. Specific auditing systems are in place in states and territories to audit the assessment and remediation of contamination.

Periodic auditing of the groundwater protection plan is also needed to confirm activities are being undertaken in accordance with defined requirements and are producing the required outcomes. The frequency and schedule of audits should be defined, as should the responsibilities, requirements, procedures and reporting mechanisms. The results of an audit should be documented and communicated to management and personnel responsible for the groundwater protection plan.

#### **4.12 Element 12: review and continuous improvement**

The evaluation and audit process indicates whether the protection strategy is functioning satisfactorily. These results provide a basis for review and continual improvement through adaptive management. In order to ensure continual improvement, senior managers should maintain oversight of the effectiveness of the groundwater protection plan and evaluate the need for change. Annual reports, audits and groundwater quality performance all need to be reviewed by an appropriate experienced person in the relevant organisation. The review should also consider concerns of regulators and other stakeholders as well as changes in legislations, expectations and requirements;

advances in science or technologies; outcomes of groundwater quality incidents and emergencies; and reporting and communication. The review process should also be clearly documented.

It may be relevant to consider developing an improvement plan if the groundwater quality protection plan will be referred to over the long term. Improvement plans can be short-term (for example, one year) or long-term programmes. An improvement plan should include objectives, actions to be taken, accountability, timelines and reporting, and it should be communicated throughout the organisation, regulators and community.

Results of validation, research and development (element 9) should be reviewed to determine the appropriate monitoring programme (analytes, sampling locations, sampling frequency and detection limits) to improve the value of the investment in information relating to operational and environmental protection objectives. In many cases, evidence from monitoring may suggest that future monitoring efforts may be reduced based on a revised assessment of risk and uncertainty.

## 5 Appendix A: current and emerging issues in the protection of groundwater quality

This section provides an overview of some of the current and emerging issues in Australia regarding the protection of groundwater quality. These activities and issues are potential hazards and should be considered within the context of groundwater quality management and be explicitly recognised in groundwater protection plans. Specifically, consideration of hazards in element 2 of the framework (Section 4.2.6) would need to address the quality issues associated with these activities and hazards where they occur within a groundwater protection plan area.

### 5.1 Acid sulfate soils

Acid sulfate soils (ASS) in inland aquatic ecosystem are an emerging issue of national significance. ASS are essentially soil, sediment or rock that contains high levels of reduced inorganic sulphur. When these sediments are exposed to oxygen, they undergo complex chemical reactions that ultimately produce acid-rich water that can mobilise metals. Until recently, it had been assumed that ASS in Australia were largely restricted to coastal regions (EPHC & NRMCC 2011). However, they have recently been identified in inland aquatic ecosystems, such as lakes, wetlands, creeks and rivers, and in drainage channels (EPHC & NRMCC 2011). Acid mine drainage (AMD) is caused by the dewatering and subsequent oxidation of sulfidic rocks during mine dewatering.

Changes to land use, hydrological regimes and the growing demand for water are increasing the likelihood of the formation, accumulation, exposure and subsequent oxidation of sulfides in ASS (EPHC & NRMCC 2011). Where the sediments remain undisturbed and under water, they present a low risk of oxidation and subsequent impacts to groundwater quality. However, if ASS are disturbed or oxidised, this can result in acidification and the release of heavy metals. ASS can cause changes to surface water quality, groundwater quality and soils.

The national guidance for the management of ASS in inland aquatic ecosystems was developed to help natural resource managers, planners, policy makers and other practitioners understand the complexities associated with managing ASS and describes how to manage ASS in a range of aquatic environments (EPHC & NRMCC 2011).

### 5.2 Balancing economic and environmental pressures on groundwater quality

The balance between economic and environmental pressures of water resources was explicitly recognised in the National Water Initiative (NWI) through the key objective of achieving a 'system of managing surface and groundwater resources for rural and urban use that optimises the economic, social and environmental outcomes' (NWI clause 23). The National Action Plan for Salinity and Water Quality and the National Water Quality Management Strategy (NWQMS) play an important and complementary role to the NWI in improving water quality management in Australia.

The principles of ecologically sustainable development specifically aim to optimise social, economic and environmental outcomes for developments that aim to preserve ecological function for the benefit of future generations, as discussed in Section 3.2. The *Draft multiple land use framework* (SCER 2012) also recognises the need to achieve the best use of resources by maximising the social, economic, environmental and heritage values of land use for current and future generations.

Achieving a balance between economic and environmental pressures requires an understanding of the value of each in terms of groundwater quality. For economic value, an assessment may consider the direct commercial value of the groundwater, future commercial value and broader economic benefits of groundwater quality to communities and local industries. The environmental value category can be assigned using the basic concept of environmental value described in these guidelines but will often also need to consider the value or significance of ecosystems that rely on the groundwater quality, such as their inclusion on international inventories of significant ecosystems (such as Ramsar Convention on Wetlands of International Importance or Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)), presence of threatened species or communities or designation as a matter of national environmental significance. Assigning and comparing intrinsic economic and environmental values requires stakeholder involvement, as described in elements 7 and 8 of these guidelines.

### 5.3 Groundwater and ecosystem services

Ecosystem services are the natural conditions and processes that help sustain and fulfil human life (Daily et al. 1997). The concept of ecosystem services recognises the benefits to humans of maintaining ecosystem health.

There are many ecosystem services associated with groundwater, which are categorised into four types of service (Millennium Ecosystem Assessment 2005):

- *provisioning*—water for drinking, irrigation, industrial uses
- *supporting*—bioremediation, nutrient cycling, sustaining connected ecosystems (groundwater-dependent ecosystems (GDEs)), providing refugia, and ecosystem engineering
- *regulating*—flood control and erosion prevention
- *cultural*—tourism, religious and scientific values.

The ecosystem services of subterranean GDEs have been overlooked until recently, but the ability of stygofauna to bio-remediate groundwater contaminants means they provide an important ecosystem service for maintaining groundwater quality. Connected surface water systems and terrestrial ecosystems also benefit from the ecosystem services of subterranean GDEs (Tomlinson & Boulton 2008).

### 5.4 Managed aquifer recharge

Managed aquifer recharge (MAR) is the intentional recharge of water to aquifers for storage and subsequent recovery or environmental benefit. It is not a method for waste disposal. MAR offers a means of generating water supplies, storing water and protecting the environment using water that may otherwise be wasted.

The source water for a MAR scheme could be any water source, including stormwater, rain water or treated effluent. The water recharged into an aquifer is stored and then recovered and used for

water supply (for example, drinking, industrial, irrigation or emergency supplies), for environmental benefits such as sustaining environmental flows and deep-rooted vegetation in stressed groundwater and surface water systems or as a barrier to prevent saline groundwater intrusion (NRMMC, EPHC & NHMRC 2009b). MAR has the potential to cause local groundwater quality issues if not managed appropriately. If well designed, MAR schemes have the potential to improve local groundwater quality.

The *Australian guidelines for water recycling: Managing health and environmental risks—managed aquifer recharge* were developed in 2009 and form an integral part of the NWQMS (NRMMC, EPHC & NHMRC 2009b). These guidelines focus on the protection of human health, the environment and the quality of recovered water in MAR projects. The guidelines outline a clear process which involves establishing the environmental principles which need to be protected, a risk assessment process and compliance monitoring. These guidelines do not apply to the use of reinjection as a means of disposal of contaminated water (such as hazardous wastes and brine) into suitable underground systems. Management of reinjection for disposal in situations where there are no impacts or implications for other water users or the environment, where it is not intended that the water is recovered for subsequent use, has not been widely addressed in Australia (DRET 2012).

## 5.5 Geological storage of carbon dioxide

Geological storage of carbon dioxide (CO<sub>2</sub>) refers to the permanent storage of CO<sub>2</sub> in deep underground formations, typically at depths greater than 1 kilometre. The driver behind geological storage of CO<sub>2</sub> is to reduce the amount of CO<sub>2</sub> released into the atmosphere from the burning of fossil fuels (particularly from energy generation) and ultimately to reduce the impact of global warming (CO<sub>2</sub>CRC 2012). CO<sub>2</sub> geological storage is seen as safe and long-term way of addressing CO<sub>2</sub> emissions.

When stored at depths greater than 1 kilometre, the CO<sub>2</sub> is no longer in the gaseous phase, but it still has the propensity to migrate upwards. As such, it needs to be hydro-geologically trapped to ensure that it does not reach the surface. The exact trapping mechanism used depends on the geology of the reservoir. Mechanisms include:

- geological (such as anticlines, folds or faults) or impermeable layers
- residual trapping (where small amounts of CO<sub>2</sub> are trapped in the pores of the rock as it moves through the formation)
- solubility trapping (dissolution of CO<sub>2</sub> into any water present in the reservoir)
- mineral trapping (CO<sub>2</sub> reacting with minerals in the rocks to form stable carbonate minerals) (CO<sub>2</sub>CRC 2012).

Sites would normally be selected only after establishing the presence of one or more thick impermeable regional seals to prevent the CO<sub>2</sub> from rising to the surface or migrating to sources of useable groundwater. Modelling indicates that the CO<sub>2</sub>-rich water, which has a higher density than the surrounding formation water, will tend over time to finger downwards, decreasing the risk of any trapped CO<sub>2</sub> leaking to the surface.

## 5.6 Climate change

Climate models suggest an increase in temperature and in the frequency of extreme weather events. Climate change is likely to increase the stress on groundwater that is already under pressure from

salinity, over-allocation and declining groundwater quality (Geoscience Australia 2009). Groundwater quality impacts will be most severe in highly transmissive, sandy coastal aquifers due to changes in recharge, temperature and sea level rise (Crosbie 2007).

Overall, reduced groundwater recharge is predicted to be one of the most significant impacts of climate change. Lower groundwater levels have the potential to alter hydraulic gradients between streams and connected aquifers, which can result in increased flow of poor-quality water into aquifers. Lower groundwater levels may also result in oxidation of ASS and organic matter resulting in decreased pH and mobilisation of metals. Drought attenuates the flushing of nitrates and dissolved organic carbon into groundwater, which limits microbial activity and supply of energy and nutrients to streams (Dahm et al. 2003 in Geoscience Australia 2009). The greater variation in rainfall that is anticipated as a result of climate change may also result in the pulsed flushing of groundwater contaminants, potentially contaminating waterways and GDEs.

Climate change is also predicted to cause a rise in sea level. The impacts of this are discussed in Section 5.7.

## **5.7 Saltwater intrusion and contamination of coastal aquifers**

Contamination of coastal aquifers by saltwater intrusion can be caused by rising sea levels and over-extraction of groundwater near the coast. Groundwater salinity has increased in coastal aquifers due to intrusion of sea water resulting from groundwater extraction (Geoscience Australia 2009). The changes in the location of the saline/freshwater interface reduces availability of fresh groundwater and therefore affects both the yield and quality of the coastal aquifer.

Rises in sea level also have the potential to affect both the yield and quality of coastal water resources. Geoscience Australia (2009) highlighted that climate change and sea level rise have the potential to cause:

- seawater intrusion and inland migration of the fresh/saline interface
- seawater inundation and flooding of unconfined coastal aquifers
- contamination of bores by storm surges and flooding of surface infrastructure
- changing recharge due to variable rainfall and evapo-transpiration, resulting in an altered distribution of fresh water in the aquifer
- changing discharge patterns, which can generate waterlogged conditions and may disrupt the balance in aquatic and wetland ecosystems.

High watertables can also cause adverse impacts on infrastructure, including septic tanks, sewer systems and basements, and cause instability of tanks and other sub-surface structures that are not anchored.

## **5.8 Mine and formation dewatering**

Mining activities have the potential to affect the quality of groundwater through mobilisation of salts, metals, acidity, alkalinity or radionuclides. One such activity is mine dewatering, whereby groundwater is pumped from the aquifer to lower the groundwater level to reduce groundwater inflow into the mining pit and create a dry and safe working environment. Dewatering is a significant engineering design component in most large-scale open-pit and underground mining operations. The



water extracted from dewatering bores is often used for multiple purposes, including the steam cycle, plant cooling and general-purpose use associated with mining and power generation.

Mine dewatering has the potential to increase the mobilisation of contaminants. Increased mobilisation of contaminants can affect the quality of groundwater overlying and underlying units, nearby surface water bodies and GDEs as well as affecting soil quality and vegetation. Lowering the groundwater level by dewatering also increases the risk of poorer-quality water leaking into the aquifer from adjacent aquifers or from connected surface water bodies. Mine dewatering in coastal aquifers is particularly vulnerable to intrusion of sea water into the aquifer. Where sulfidic soils and minerals are present, dewatering can cause oxidation of sulfides, acidification and mobilisation of metals.

*The Framework for assessing potential local and cumulative effects of mining on groundwater resources* was released by the National Water Commission (NWC) in 2011 to provide guidance to both mining proponents and regulatory agencies in undertaking environmental approvals studies. NWC (2011b) highlights that the cumulative impacts of dewatering, such as impacts on surface water bodies, GDEs and vegetation, should be considered as well as effects on aquifers and groundwater systems. Expected environmental consequences and monitoring procedures associated with dewatering are required to be detailed in the project environmental impact statement.

Mining activities can also involve MAR or reinjection for disposal (see Section 5.4).

## **5.9 Soil amendment impacts**

Soil amendment refers to the mixing of agents into soil to improve its physical or chemical properties, such as its water-holding capacity, pH, friability, nutrient content or aeration. Soil amendments can either be inorganic (fertilisers and lime) or organic (manure, biosolids from sewage treatment plants, straw or compost). The goal is to provide a better growing environment for plants.

Over-application of soil amendments can cause groundwater contamination, with common contaminants including nitrates, phosphates, salts, metals and pathogens. Different amendments have differing levels of persistence in the environment, which alters their likelihood of causing groundwater contamination. Groundwater contamination occurs through infiltration of rainfall or irrigation water through the soil amendment and to the watertable aquifer. Impacts can also occur where surface run-off washes contaminants into down-gradient groundwater recharge areas.

Plumes of nutrient-rich groundwater have been identified in areas of intensive farming, such as in areas where market gardens exist. The contaminated groundwater can discharge to waterways and GDEs, impacting on aquatic ecosystems. Surface run-off during rainfall can also wash soil amendments into waterways.

## **5.10 Solution mining in aquifers**

Solution mining, known as in-situ leaching or in-situ recovery, involves pumping an acid or alkaline leaching solution into an aquifer, where it dissolves metals and salts from an ore body. The solution is recovered and processed at the surface to extract the desired metals or salts. Hydraulic fracturing is sometimes used to create pathways within the ore body for the solution to penetrate. Solution mining allows an ore body to be exploited without the need for conventional extractive mining methods such as open pits or underground mining. It is best suited to ore bodies where the

mineralisation is within water-saturated permeable formations and the surrounding geology allows effective confinement of the mining solution. It is also often used when the deposit is too deep or too small to make conventional mining commercially viable.

Extraction of metals such as copper and uranium is often achieved through solution mining, and the efficient recovery of these metals generally requires use of an acidic or alkaline leachate solution. Salt deposits may be mined using fresh water to dissolve the salts. There is significant potential for impacts to groundwater from both the leaching solution used and the mobilisation of metals and salts from the ore body.

Uranium produced through solution mining accounted for over 28 per cent of world uranium production in 2009. Sandstone deposits are commonly mined for uranium using solution, and these are typically low-grade deposits (Commonwealth of Australia 2010). The use of leachate solutions in uranium mining can cause low or high pH and high contents of metals and radioactive elements in the groundwater. Another concern with the use of acids in solution mining is the unknown impact they may have on the aquifer structure through dissolution of minerals or precipitation within the aquifer (Schmidt 1989). To date, remediation of groundwater that has been affected by solution mining in the United States has not achieved regulatory requirements, which require a return to pre-mining conditions or to drinking water standards (whichever is higher). In Australia, solution mining at the Beverley mine in South Australia is confined by low-permeability strata surrounding the ore body, which contains poor quality, saline, and radioactive groundwater. The lack of current or potential future uses of the aquifer has meant that natural attenuation and an extensive monitoring programme have been considered suitable means of rehabilitation (Commonwealth of Australia 2010).

### **5.11 Unconventional gas production**

Unconventional gas is natural gas which is found in difficult-to-extract, unconventional deposits such as coal beds (coal seam gas (CSG)), shales (shale gas) and low-quality reserves (tight gas). Shale gas and CSG exist within the source rock and are held there by water pressure, which keeps the gas as a thin film on the surface of the source rock. To produce gas, groundwater is extracted from the formation to depressurise and release the gas. Coal formations are generally embedded within low-permeability aquitards and typically have minimal connection with surrounding aquifers. The source rock for shale gas tends to be deeper and less permeable than coal seams and consequently produces less co-produced water. This also typically means less potential to impact on groundwater resources.

CSG is now an integral part of the gas industry in eastern Australia and accounted for 35 per cent of the eastern Australian natural gas production in December 2012 (Energy Quest 2013). This is expected to significantly increase in 2014–15, when three CSG–LNG projects in Queensland commence production. Most of the CSG reserves in Australia are located in New South Wales and Queensland, and these make up 85 per cent of the Eastern Gas Market reserves (AER 2012).

The impact of CSG development on groundwater resources is a significant source of community concern. The key issues that arise can be broadly categorised as depletion and contamination of groundwater resources (DRET 2012). Various activities associated with the CSG industry have the potential to impact groundwater quality either by changing the proportions of natural chemical

constituents present in groundwater or through the introduction of additional constituents. Potential hazards to groundwater quality are:

- contamination of shallow and deep aquifers as a result of drilling and hydraulic fracturing activities (for example, contaminants entering aquifers)
- bore failure (casing or cement) causing increased hydraulic connectivity between aquifers
- inappropriately decommissioned bores and wells (legacy wells)
- changes to groundwater chemistry due to the changes in hydraulic gradients from depressurisation
- mobilisation of naturally occurring chemicals in the formations as a result of hydraulic fracturing
- structural damage to confining layers from hydraulic fracturing if fracturing processes are not managed appropriately
- disposal of brine produced through reverse osmosis of co-produced water
- gas migration and gas leakage in surrounding bores
- aquifer reinjection of treated co-produced water (see Section 5.4).

### **5.12 Coal and shale gasification**

Coal gasification can be used to produce synthesis gas, or syngas, which is a mixture of carbon monoxide and hydrogen gas. Syngas can be converted into a range of other products in both gaseous and liquid form and has been used since the last century, when natural gas was not commercially available, to produce gas. A number of demonstration and near-commercial scale coal-fired integrated gasification combined cycle (IGCC) power plants are already operating around the world). However, large-scale application for power generation from coal is not widespread, and costs are still comparatively higher than existing technologies.

Underground coal and shale gasification—also known as in situ-coal gasification—has emerging potential to produce syngas. It may be able to exploit low-quality, economically un-mineable, deeper coal seams and shale with relatively low capital cost. The process involves heating the underground coal seams and shale to the point of combustion. One well is used to inject oxidants (a mixture of water and air/oxygen), while the second well allows gas to flow to the surface. Underground coal and shale gasification has the potential to impact on groundwater quality (in particular, by releasing hydrocarbons and phenols) through similar hazards that the CSG industry poses to groundwater, which are detailed in Section 5.11. Subsidence is also an issue with coal gasification, and this may impact flow regimes and hence groundwater quality in overlying aquifers (Geoscience Australia 2008).

### **5.13 Dewatering for urban development**

Dewatering for urban development is now occurring on a wider scale due to the increasing population of Australia's cities and the move towards higher-density living. New inner city developments frequently include basements or excavations that may be deeper than the watertable. These excavations require dewatering during construction and, depending on construction techniques, may require ongoing groundwater management. Building excavations beneath the watertable are likely to require a lowering of watertables at least temporarily and may also cause groundwater to mound behind the excavation in the longer term.

Where sulfidic soils such as marine muds or peats are present, dewatering for urban development can lead to oxidation of sulfides, which produces acid, and the lower pH mobilises metals, resulting in a low-pH, metal-rich groundwater (Section 5.1 also discusses the issues associated with ASS). Some metals mobilised through oxidation of sulfidic soils are iron, arsenic and aluminium (Appleyard et al. 2004). Discharge of contaminated groundwater may also pollute receiving waterways and GDEs, impacting on aquatic ecosystems and making the surface water unsuitable for use.

### 5.14 Geothermal energy production

Geothermal energy—the renewable heat contained within the rocks below the earth’s surface—can be used to generate baseload power with little to no greenhouse gas emissions. This can be done in one of two ways in Australia (ABARE 2010):

- traditional hydrothermal projects, which use naturally occurring hot water or steam circulating through permeable rock
- enhanced geothermal systems (EGS)—a technique of drilling into the ground and then injecting one or more of:
  - high-pressure fluid to widen existing fractures (hydro-shearing)
  - acids to dissolve particular minerals
  - cold water to cause thermal shocking in the well in order to enhance existing fractures in the rock and create an artificial reservoir that mimics a natural hydrothermal resource

Additional ‘production wells’ are then drilled to intersect the fractures, creating a closed-loop system through which fluid super-heated by the hot rock is pumped to the surface, where it is used to power turbines and create electricity.

Australia does not have wet, high-temperature geothermal environments like those found in volcanically active countries. Australia has large but as yet inadequately defined and quantified geothermal energy resources. These include hot-rock type geothermal resources associated with deeply buried (greater than approximately 3,000 metres), high heat producing granites which require the continued development of EGS technologies for widespread commercialisation as well as hot, sedimentary aquifer-type geothermal resources present in deep (up to approximately 3,000 metres) aquifers in a number of sedimentary basins (ABARE 2010).

Geothermal technology has the potential to affect groundwater in a number of ways:

- Previously unconnected aquifers may become connected during drilling. To guard against fluids leaking into shallow freshwater aquifers, well casings are designed with multiple strings to provide redundant barriers between the inside of the well and the adjacent formation.
- Geothermal power generation plants may use water for cooling, which increases demand for and pressure on existing surface and shallow groundwater resources. This may be mitigated by alternative cooling technologies, including ground source heat pumps or air heat pumps. Water used in the deep underground geothermal energy process must be retained within the closed-loop system to maintain reservoir pressure, and geothermal projects are expected to require very little water to function.
- Shallow aquifer open-loop systems may either dump heat into or extract heat from the groundwater. Possible contamination effects to water quality (including bacteria and fauna) will vary depending on:
  - what the water interacts with

- the amount of heat added or extracted compared to the volume and mixing characteristics of the groundwater reservoir.

## 6 Appendix B: summary of groundwater regulation and management in Australia

Groundwater resource management in Australia is governed by individual water resource management legislation in states and territories, where state/territory government departments are responsible for their implementation. In the Murray–Darling Basin, the *Water Act 2007* (Cth) recognises water quality objectives as one of the environmental outcomes of the Murray–Darling Basin Plan and lists water quality data as one of the data sources to be held by the Bureau of Meteorology on a national scale. Individual water resource management legislation exists in states and territories, where state/territory government departments are responsible for its implementation.

Environment protection (such as contamination prevention, waste control and licensing of hazardous activities) is usually implemented within each state/territory by an environment protection authority (EPA) or similar body under specific jurisdiction-based legislation. This legislation considers protection of groundwater from contamination.

Land-use planning is managed through a complex arrangement of responsibilities that includes some involvement from all three levels of government, although the Commonwealth involvement is largely due to referrals under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth).

The sections below present the key legislative documents in each state and territory that manage groundwater quality protection within the Groundwater Management framework, the Environment Protection framework and the Land-use Planning framework. This section provides a general overview of groundwater quality legislation and regulation at this point in time. This is not a complete list; other legislative documents may exist that have a bearing on groundwater quality management.

### 6.1 Commonwealth

The *Water Act 2007* is administered by the Australian Government Department of the Environment. The Act provides for Commonwealth management of the water resources of the Murray–Darling Basin, establishment of a Commonwealth Environmental Water Holder and promotion of water markets, and it assigns responsibility for managing water information to the Bureau of Meteorology. Water quality is considered within the Act. Water planning guidelines were released under the National Water Initiative (NWI): *NWI policy guidelines for water planning and management* (COAG 2010).

The *Environment Protection and Biodiversity Act 1999* is the key piece of Commonwealth environmental legislation. It sets out the Commonwealth requirements for environmental approvals, focusing on matters of national environmental significance. The Act is implemented by the Australian Government Department of the Environment. In June 2013, the Act was amended to take into consideration the potential impacts of coal seam gas and large coal mining developments on water

resources. Under the Act, coal seam gas and large coal mining companies are now required to submit detailed water management and monitoring plans, including a programme for aquifer connectivity studies and water quality monitoring and management (surface water and groundwater).

The *National Environment Protection (Assessment of Site Contamination) Measure 1999* establishes a nationally consistent approach to the assessment of site contamination to ensure sound environmental management practices by the community, which includes regulators, site assessors, environmental auditors, landowners, developers and industry. The measure is made under the *National Environment Protection Council Act 1994* (Cth) and is given effect by individual legislation and guidelines in each state and territory.

There is no Commonwealth planning legislation.

## **6.2 Western Australia**

Numerous pieces of legislation are used in Western Australia to manage water quality protection, including:

- *Country Areas Water Supply Act 1947*
- *Metropolitan Water Supply, Sewerage and Drainage Act 1909*
- *Rights in Water and Irrigation Act 1914*
- *Water Agencies Powers Act 1984*.

These Acts deal with water licensing and allocation and also allow for groundwater quality protection. Several other Acts relate to specific water boards, agencies or supply systems. The Western Australian Department of Water administers this legislation.

The *Planning and Development Act 2005* promotes sustainable use and development of land in the state and conservation of natural resources.

The *Environmental Protection Act 1986* aims to protect the environment and is administered by the Western Australian EPA and the Department of Environment Regulation.

## **6.3 Northern Territory**

The *Water Act 2011* is implemented by the Water Resources Branch of Department of Land Resource Management. It relates to groundwater quantity and quality management and recognises beneficial uses and pollution as an offence.

The *Planning Act 2013* is implemented by the Department of Lands, Planning and the Environment (Land Services). It has the objective of controlling development to provide protection of the natural environment, including by sustainable use of land and water resources, minimising adverse impacts of development on existing amenity and, wherever possible, ensuring the amenity if it is enhanced as a result of development.

The *Waste Management and Pollution Control Act* is implemented by the newly formed Northern Territory EPA. It controls licensing of hazardous activities to protect environmental values.

## 6.4 South Australia

The *Natural Resources Management Act 2004* is administered by the Natural Resource Management Council. It promotes sustainable and integrated management of the state's natural resources. The Act gives the minister power to reduce water allocations if extraction is seen to reduce the quality of the water resource.

The *Environment Protection Act 1993* provides for the protection of the environment. The Act is administered by the EPA.

The *Development Act 1993* is the legislation related to planning and development matters. It does not specifically recognise the protection of water quality. Major developments or projects must follow considerations outlined in the *Environment Protection Act 1993*.

## 6.5 Queensland

The *Water Act 2000* aims to maintain or improve the quality of naturally occurring water. The Act regulates allocation and sustainable management of groundwater resources. The Act is administered by the Department of Natural Resources and Mines.

The *Sustainable Planning Act 2009* requires planning to coincide with the *Environmental Protection Act 1994* and overall environmental protection. Land use is a core matter to the planning scheme, along with valuable features (such as quality of water). The Act is administered by the Department of State Development, Infrastructure and Planning.

The *Environmental Protection Act 1994* aims to protect Queensland's environment. The Act permits the Department of Environment and Heritage Protection to prepare environmental protection policies, which can protect environmental values such as water quality.

## 6.6 New South Wales

The *Water Management Act 2000* promotes the sustainable and integrated management of the state's water and is managed by the Office of Water.

The *Contaminated Land Management Act 1997* is administered by the New South Wales EPA, which regulates the management of the contaminated sites by ordering investigation and management of significantly contaminated land.

Under the *Protection of the Environment Operations Act 1997* there is a broad allocation of responsibilities between the EPA, local councils and other public authorities. The Act has a scheme for the making of policy instruments called Protection of the Environment Policies (PEPs). PEPs set environmental standards, goals, guidelines or protocols. The EPA, planning authorities and any other authorities specified in a PEP must take a PEP into account when making decisions that affect the environment. This includes quality of water, particularly from polluting activities.

Planning and development is carried out under the *Environmental Planning and Assessment Act 1979* and Environmental Planning and Assessment Regulation 2000. Environmental planning instruments (state environmental planning policies and local environmental plans) are legal documents that regulate land use and development. These instruments are included under the *Environmental Planning and Assessment Act 1979*. The Act encourages proper management and conservation of water, protection of the environment and ecologically sustainable development.



## 6.7 Australian Capital Territory

The *Water Resources Act 2007* prevents waterway work that may adversely affect the quality of water. There is a statutory obligation under the Act for the government to manage a water monitoring and assessment programme for the Australian Capital Territory (ACT) that includes water quality.

The *Environment Protection Act 1997* provides for protection of the environment. It includes provisions for the prevention of pollutant discharge that would otherwise adversely affect water quality. Water quality is managed by the Environment and Sustainable Development Directorate (Environment Protection and Water Regulation) to develop and enforce Environmental Authorisations and Environmental Protection Agreements between the EPA and people or companies conducting activities that pose environmental risks.

The *Planning and Land Management Act 1988* makes provision for the planning and management of land in the ACT. It is governed by the Minister for the Environment. However, the Act does not include explicit reference to water quality or environmental protection.

## 6.8 Victoria

The *Water Act 1989* is the legislation that governs the way water entitlements are issued and allocated in Victoria. It defines water entitlements and establishes the mechanisms for managing Victoria's water resources. Quality of water is preserved under the Act in terms of preventing adverse impacts to quality, creating 'environmental reserves' for water (maintaining quality for ecological function) and implementing 'Sustainable Water Strategies' to identify ways to improve water quality. The Act is managed by the Department of Sustainability and Environment and local water authorities.

The *Environment Protection Act 1970* sets out to prevent pollution and environmental damage, which covers the protection of water quality. The Act is implemented by the EPA, which can recommend state environment protection policies (SEPPs) and industrial waste management policies (WMPs) to the Governor in Council, issuing works approvals, licences, permits, pollution abatement notices and implementing National Environment Protection Measures (NEPMs).

The *Planning and Environment Act 1987* sets out the framework for planning the use, development and protection of land in Victoria. It does not explicitly protect water quality; however, planning applications may be considered under the *Environment Protection Act 1970*. The Act is managed by the Department of Planning and Community Development.

## 6.9 Tasmania

The *Water Management Act 1999* is part of the state's integrated Resource Management and Planning System and provides for the management of Tasmania's freshwater resources. It defines licensing and allocation of water and is managed by Department of Primary Industries, Parks, Water and Environment. The Act provisions 'water management plans' that consider and protect water quantity.

The *Environmental Management and Pollution Control Act 1994* is the primary environment protection and pollution control legislation in Tasmania. It is a performance-based style of legislation, with the fundamental basis being the prevention, reduction and remediation of environmental harm.

The clear focus of the Act is on preventing environmental harm from pollution and waste. The Act governs the quality of water and is administered by the EPA.

The *Land Use Planning and Approvals Act 1993* establishes processes for approvals of planning schemes, land-use strategies and planning agreements. The Act ensures that planning schemes have regard to the environment; however, it does not explicitly protect an assigned environmental value or water quality. If a planning activity is deemed to be a project of state significance, a state policy may be implemented.

The *State Policies and Projects Act 1993* provides for the integrated assessment of projects of state significance. The Act encourages sustainable development of natural and physical resources, land-use planning, land management, environmental management and environment protection. It does not explicitly protect water quality but promotes 'sustainable development' for the protection of natural resources (which would include water).

# Glossary

Adaptive environmental management	An iterative process of decision making where uncertainties exist in understanding of how an activity may impact on a system.
Aquifer	Rock or sediment in a formation, group of formations or part of a formation which is saturated and sufficiently permeable to store and transmit quantities of water to wells and springs.
Aquifer, confined	An aquifer with a low permeability formation as its upper boundary, where storage is increased by raising the pore pressure in the aquifer, causing elastic compression of aquifer materials and water (NRMMC, EPHC & NHMRC 2008).
Aquifer, unconfined	An aquifer that has the watertable as its upper boundary and is usually recharged by infiltration from the surface (NRMMC, EPHC & NHMRC 2008).
Artesian	When the piezometric surface (hydraulic head) of a confined aquifer is above the ground surface. An uncontrolled artesian well will spurt water out of the ground.
Attenuation	The reduction in contaminant or pathogen concentration as a result of treatment processes, including passive sub-surface treatment.
Attenuation zone	The area surrounding the zone of recharge where natural attenuation takes place. All of the pre-existing environmental value categories of the aquifer are continually met beyond this zone.
Baseflow	The component of stream flow or river flow that is supplied by groundwater discharge.
Bore	(Also known as a borehole, well or piezometer.) A narrow, artificially constructed hole or cavity used to intercept, collect or store water from an

	aquifer or to passively observe or collect groundwater information.
Confining bed or layer	A low-permeability rock or sediment overlying an aquifer. The confining bed has a significantly lower permeability than the aquifer.
Connectivity	A descriptive measure of the interaction between water bodies (groundwater and/or surface water).
Contamination	A change in water quality derived from biological or chemical substances or entities not normally present in a system, or any unusual concentration (high or low) of naturally occurring substance, that has the potential to produce an adverse effect in a biological system.
Diffuse source	A source of contamination that is spread across a large area or region.
Discharge area	An area in which there are upward movements of hydraulic head in the aquifer. Groundwater flowing toward the land surface in a discharge area may escape as a spring, leading to a discharge, seep or baseflow; or by evaporation and transpiration.
Dispersion	The phenomenon by which a solute in flowing groundwater is mixed with uncontaminated water and becomes reduced in concentration. Dispersion is caused by both difference in the velocity that the water travels at the pore level and differences in the rate at which water travels through different strata in the flow path.
Drainage basin	The land from which run-off drains into a stream system.
Drawdown	The distance between the static water level and the surface of the cone of depression.
Ecosystem	A community of organisms and the non-living environment all interacting as a unit.

Entitlement	A perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool, as defined in the relevant water plan.
Environmental value	Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of contamination, wastes discharges and deposits.
Evapo-transpiration	The combined loss of water from a given area during a specified period of time by evaporation from the soil or water surface and by transpiration from plants.
Geogenic	Resulting from geological processes.
Groundwater	Sub-surface water located in the zone of saturation in pores, fractures and cavities in rocks.
Groundwater-dependent ecosystem (GDE)	Natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis to maintain their communities of plants and animals, ecological processes and ecosystem services.
Groundwater basin	The area pertaining to a groundwater flow system, which is more or less separate from neighbouring groundwater flow systems. A groundwater basin may be separated from adjacent basins by geologic or hydrologic boundaries.
Groundwater flow	The movement of water through an aquifer.
Groundwater protection plan	A plan developed to protect the environmental value category of groundwater, which recognises community and stakeholder values of the resource and sets out measures to reduce the risk of degrading an assigned environmental value, an approach to

	monitoring and a review and improvement approach.
Groundwater system	A generic term that refers to groundwater and its associated processes at a specific location. A groundwater system includes consideration of recharge, flow, discharge and interaction with other aquifers and surface water. It may refer to multiple aquifers or it may refer to a part of a single aquifer.
Hazardous waste	<p>Any waste present in sufficient quantities to present a danger:</p> <ul style="list-style-type: none"><li>• to life or health of living organisms when released in the environment</li><li>• to the safety of humans</li><li>• to the safety or operation of equipment in disposal plants if incorrectly handled.</li></ul> <p>Hazardous substances may possess toxic, carcinogenic, mutagenic or teratogenic characteristics as well as flammability, chemical reactivity or infectious or other biologically damaging properties (including radioactivity).</p>
Hydraulic conductivity	A coefficient of proportionality describing the rate at which water can move through a permeable medium. Horizontal hydraulic conductivity ( $K_h$ ) refers to the coefficient of proportionality in the horizontal direction, whereas vertical hydraulic conductivity ( $K_v$ ) refers to the coefficient of proportionality in the vertical direction.
Hydraulic gradient	The rate of change in total head per unit distance in a given direction. The direction of gradient is that yielding the maximum rate of decrease in head.
Hydrogeology	The study of groundwater, including flow in aquifers, groundwater resource evaluation, and the chemistry of water–rock interaction.
Inactivation	The degradation of pathogens over time until they are no longer harmful.

Indicator	Any physical, chemical or biological characteristic used as a measure of environmental quality.
Infiltration	The flow of water downward from the land surface into the sub-surface.
Leachate	A liquid which has percolated through and/or drained from waste material and which contains soluble components of the waste, including products of decomposition.
Major ions	Constituents commonly present in concentrations exceeding 1.0 milligram per litre. For dissolved cations this includes calcium, magnesium, sodium and potassium; the most prevalent anions include sulfate, chloride, fluoride, nitrate and those contributing to alkalinity, which are most generally assumed to be bicarbonate and carbonate.
Managed aquifer recharge	A term applied to all forms of intentional recharge enhancement for the purpose of reuse or environmental benefit.
Model, conceptual	Documentation of a conceptual understanding of the location of GDEs and interaction between ecosystems and groundwater.
Model, analytical/numerical	Simulates groundwater flow indirectly by means of governing equations considered representative of the physical process occurring in the system, in addition to equations describing heads or flow along the model boundaries. Mathematical models can be solved analytically or numerically.
Municipal landfill	A site for the disposal of municipal waste to land.
Permeability	The measure of the ability of a rock, soil or sediment to yield or transmit a fluid. The magnitude of permeability depends largely on the porosity and the interconnectivity of pores/spaces in the ground.

pH	Value that represents the acidity or alkalinity of an aqueous solution. It is defined as the negative logarithm of the hydrogen ion concentration of the solution.
Perched aquifer	A region in the unsaturated zone where the soil or rock may be locally saturated because it overlies a low-permeability unit.
Piezometer	A non-pumping well, generally of small diameter, that is used to measure the elevation of the watertable or potentiometric surface. A piezometer generally has a short well screen through which water can enter.
Point source	A source of contamination which comes from a single point.
Pollution	The point at which contamination reaches a level that restricts the use of the groundwater or the choice of environmental value category that can be assigned.
Porosity	The proportion of the volume of rock consisting of pores, usually expressed as a percentage of the total rock mass or soil mass.
Potable water	Water which is fit for human consumption.
Recharge area	A geographical area in which water infiltrates then percolates to reach an aquifer.
Saturated zone	The part of the ground in which all the voids in the rocks or soil are filled with water. The watertable is the top of the saturated zone in an unconfined aquifer.
Salinity	The concentration of soluble salts in a solution, soil or other medium.
Saturated zone	The part of the ground in which all the voids in the rocks or soil are filled with water. The watertable is the top of the saturated zone in an unconfined aquifer.



Stygofauna	Aquatic animals found in groundwater; sometimes used as a synonym of stygobite.
Travel time	The time that it takes a contaminant to travel from the source of contamination to the point of interest in the aquifer.
Unsaturated zone	The areas below the ground where void spaces are filled with a mixture of water under pressure less than atmospheric, which includes water held by capillarity and air (gases) under atmospheric pressure.
Vadose zone	See 'unsaturated zone'.
Validation monitoring	Used to demonstrate effectiveness of control or remediation measures.
Verification monitoring	Used to verify that all specified objectives are met.
Vulnerability	A relative evaluation of the potential exposure of a groundwater system to contamination.
Water plan	Statutory plans for surface water and/or groundwater systems developed in consultation with relevant stakeholders on the basis of available scientific and socio-economic assessment to provide resource security for users and secure ecological outcomes.
Watertable	The upper surface of a body of groundwater occurring in an unconfined aquifer. At the watertable, pore water pressure equals atmospheric pressure.
Water quality guideline	Numerical concentration limit or narrative statement recommended to support or maintain a designated water use.
Water quality objective	A numerical concentration limit or narrative statement that has been established to support and protect the designated uses of water at a specified site. It is based on scientific criteria or water quality guidelines but may be modified

by other inputs such as social or political constraints.

Well

A man-made hole in the ground, generally created by boring, to obtain groundwater (also see 'bore').

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