

Environmental Defender's Office New South Wales

Technical Fact Sheet: Groundwater

1. INTRODUCTION

The purpose of this fact sheet is to provide assistance to members of the public in understanding the processes involved in groundwater assessments and monitoring programs undertaken as part of environmental impact assessments in NSW.

This fact sheet is a guide only. If you require legal assistance with an environmental matter, please contact the duty solicitor on our Environmental Law Advice line:

- www.edo.org.au/edonsw/site/advice_line.php.
- Sydney callers: (02) 9262 6989 (Monday to Thursday 2:00 pm – 5:00 pm).
- NSW callers outside the Sydney metropolitan area: 1800 626 239 (Monday to Friday 9:00 am – 5:00 pm).

Words in **bold** are links to other documents, websites or glossary entries. If you follow a link to another part of this document, pressing the Alt and left arrow buttons simultaneously will return you to the previous page.

2. EDO SCIENTIFIC ADVISORY SERVICE

The EDO provides expert scientific and technical advice on public interest environmental matters through the EDO's Scientific Advisory Service. The service comprises:

- In-house scientific officers
- a Technical Advisory Panel, comprising experts in various scientific fields
- an Expert Register, comprising experts in a range of scientific and technical fields who are willing to provide advice to the office on a pro-bono basis.

The EDO also has both legal and scientific factsheets on other topics at:

- Legal: <http://www.edo.org.au/edonsw/site/factsheets.php>.
- Scientific: http://www.edo.org.au/edonsw/site/science_advices.php.

3. TABLE OF CONTENTS

1.	Introduction	1
2.	EDO Scientific Advisory Service	1
3.	Table of Contents.....	2
4.	What is Groundwater?	3
5.	Groundwater Movement and Recharge	4
6.	Groundwater Quality	5
7.	Groundwater Dependent Ecosystems.....	5
8.	Impacts on Groundwater	6
9.	When are Groundwater Assessments Required?.....	7
10.	Relevant Legislation in NSW	8
11.	Relevant Policy and Guidelines in NSW	10
12.	What is a Good Groundwater Assessment?.....	12
	Appendix 1: Typical Model Data Requirements and Sources.....	27
	Glossary.....	28
	References and Resources	31

4. WHAT IS GROUNDWATER?

Groundwater is water that is found underground in the cracks and spaces in soil, sand and rock, and is an important ecological resource.¹ It is a valuable water supply for some communities and plays a vital role in sustaining both surface and subsurface ecosystems. Groundwater can be connected to surface water systems and can act as both a source and sink (i.e. an area of capture and storage) for surface water systems.² It is stored in, and moves slowly through the interconnected spaces underground which form systems called **aquifers**.

Aquifers typically consist of loose gravel and sand found on floodplains and along the coast (generally called alluvium), sandstone, or fractured rock. Alluvium may or may not be covered by soil. If not covered or capped by other rock layers, the aquifer type is '**unconfined**'.

'**Confined aquifers**' are generally located underground and covered by other rock layers that restrict the flow of groundwater. In reality, most aquifers are semi-confined as one end of the aquifer is often exposed to the surface (or connected to other aquifers) and the other end is buried deeper and covered by a confining layer.

Aquifer materials are **permeable** because they have connected spaces that allow water to flow through. The speed at which groundwater flows depends on the size of the spaces in the ground, how much the spaces are connected to each other, steepness of the slope, and whether there is any pressure moving the water.

Water in aquifers can escape to the surface naturally through a spring. Some groundwater aquifers adjacent to lakes and streams can discharge into these water channels without being easily detected. Groundwater can also be extracted through a **bore** or well drilled into the aquifer, and brought to the surface either by artesian pressure, that is, natural underground pressure, or by a pump. Wells that allow water to flow to the surface naturally without a pump are called artesian wells. Flowing artesian wells have a higher pressure than normal artesian wells, pushing the water above the surface and out of the well. A well may go dry if the **water table** falls below the bottom of the well, or when the pressure declines to the point it can no longer naturally lift the water up. Figure 1 illustrates several groundwater features, including unconfined aquifers and confined aquifers.

¹ CSIRO Land and Water. Available online at <http://www.clw.csiro.au/>.

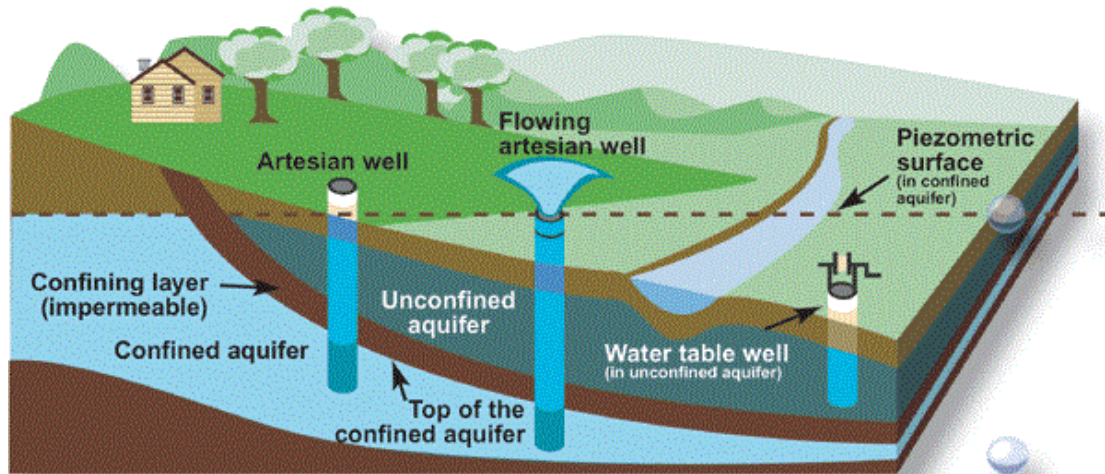


Figure 1: Types of aquifers (USGS 2011)

5. GROUNDWATER MOVEMENT AND RECHARGE

Groundwater moves in the direction and at the rate determined by the **hydraulic gradient**. In unconfined aquifers, the difference in water table elevation drives groundwater downgradient (i.e. from high to low water levels). In confined aquifers, differences in pressure may have a bigger effect on the movement of groundwater than the differences in water table elevation.

Groundwater stored in aquifers is replenished, or recharged naturally, by rain or snow melt,³ which soaks into the ground. Recharge may also occur through leakage from the base or banks of rivers, streams, wetlands and dams.

Groundwater in alluvium can be recharged almost instantaneously during rains while groundwater in confined aquifers may take a long time to be replenished, depending on how their depth, level of connection and position in relation to a surface water source.

On average, deep groundwater may spend up to 10 000 years underground. In some undisturbed areas, shallow groundwater can remain in aquifers for 100 to 200 years.⁴ As such, groundwater quality can be extremely difficult or impossible to restore once it has been degraded, as the slow rate of recharge means any contaminants are neither flushed through the aquifer nor quickly diluted.⁵

² Further information on connectivity between groundwater and surface water systems can be found on the Connected Water website. Available online at <http://www.connectedwater.gov.au/index.html>.

³ The Groundwater Foundation. Available online at <http://www.groundwater.org/>.

⁴ Michael Pidwirny and Scott Jones, *The Hydrologic Cycle*. Available online at <http://www.physicalgeography.net/fundamentals/8b.html>.

⁵ Department of Land and Water Conservation, *NSW State Groundwater Quality Protection Policy*. Available online at <http://www.water.nsw.gov.au/Water-Management/Water->

6. GROUNDWATER QUALITY

Groundwater quality is mostly affected by the type of material through which it flows. Major dissolved non-biological components of groundwater include cations (e.g. calcium, magnesium and sodium), anions (e.g. bicarbonate, sulfate and chloride) and dissolved silicon. Minor dissolved non-biological components of groundwater include boron, carbonate, fluoride, iron, nitrate, potassium and strontium. Trace elements in groundwater can include aluminium, arsenic, barium, beryllium, bromide, cadmium, chromium, cobalt, copper, lead, lithium, manganese, nickel, phosphate, selenium and zinc.

Groundwater quality is also affected by land use in the vicinity of the aquifer. For example, irrigation water which seeps into the ground from agricultural land may be contaminated with pesticides and nutrients. Underground storage tanks at petrol stations may leak petroleum hydrocarbons into the groundwater. Landfills which are not appropriately lined and covered may leach a range of contaminants including ammonia, salts and oils.⁶ On-site sewerage systems could also potentially introduce bacteria and other microorganisms into shallow groundwater. Some contaminants attenuate (concentrations in groundwater are reduced through decay, dissolution or stabilisation into other compounds) with time while others could persist and be difficult to remove.

7. GROUNDWATER DEPENDENT ECOSYSTEMS

Groundwater dependent ecosystems represent a distinct and diverse component of the earth's biological diversity and as such they often have a high conservation value. Examples of groundwater dependent ecosystems include:⁷

- *River base flow systems and springs* – **aquatic** and **riparian** ecosystems that exist in or adjacent to streams or springs that are fed by groundwater base flow during low rainfall periods.
- *Wetlands* – ecosystems that are seasonally **waterlogged** or flooded may be dependent on groundwater during dry periods. Examples include paperbark swamp forests and woodlands, swamp scrubs and heaths.

[quality/Groundwater/default.aspx](#). Please note that the Department of Land and Water Conservation has been replaced by the Office of Water.

⁶ Sydney Coastal Councils Group and Groundwater Working Group (2005) *Sydney Regional Groundwater Management Handbook, A Guide for Local Government*.

⁷ Australian Government. *Connected Water: Groundwater dependent ecosystems*. Available online at http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html.

- *Aquifer and cave systems* – aquatic ecosystems that occupy caves or aquifers involve organisms that have specifically adapted to the darkness and constant temperature conditions usually found in this environment. The typical example is the **karst** systems found in the central west areas of New South Wales. Other, less obvious species that are dependent on groundwater include micro-organisms and minute invertebrates that exist within the saturated pore spaces of an aquifer.
- *Terrestrial vegetation and fauna* – forests and woodlands may develop a permanent or seasonal dependence on groundwater, by extending their roots deep into the water table. Where the water table is close to the surface and permeable soils exist, reliance on groundwater may be significant in maintaining the diversity of species forming a particular ecological community. Any impacts on terrestrial vegetation can also affect animal species dependent on the habitat provided by plant communities for survival. Examples of groundwater dependent terrestrial vegetation include paperbark and *Melaleuca* swamps.
- *Estuarine and near-shore marine ecosystems* – evidence suggests that these ecosystems may be heavily reliant on the nutrients and other constituents, such as salts, transported by groundwater. Examples include coastal mangroves and salt marshes, coastal lakes, sea grass beds and marine animals.

8. IMPACTS ON GROUNDWATER

Groundwater responds to changes caused by both natural and artificial factors. Some examples are:

- *Overdrawing* – occurs when extraction or discharge of groundwater exceeds the rate that groundwater is recharged. This may result in groundwater levels declining and, in some cases, cause some wells to dry up. Declining groundwater tables can cause sediment compaction, blocking pathways through which water can travel, and potential land subsidence.
- *Contamination* – occurs when good quality groundwater comes into contact with either natural or man-made contaminants. This may occur through groundwater flowing into contaminated soil and rocks resulting in groundwater quality deteriorating. Contamination can occur naturally when chemicals in the rock such as salts and minerals dissolve into the water as it passes through, or artificially when waste products come into contact with the water. This can result in a decline in groundwater quality. If the substances are toxic or if they are chemicals in very high concentrations, the groundwater in the aquifer could become unusable.

- *Changes in water pressure* – with enough pressure, groundwater is easy to extract through bores or wells as the water naturally flows to the surface. It is possible that pressure will decline if there is too much discharge of groundwater. Reduced water pressure may ultimately result in the loss of artesian flow. If this occurs, groundwater can only be extracted from the aquifer through pumping.

Ecosystems respond to changes in groundwater conditions in different ways. In some cases, there may be a very sudden response such as where an ecosystem collapses completely if conditions change too much. For example, mound spring communities (that is, areas where artesian water has naturally risen to the surface through fractures or fault lines) supported by the groundwater of the Great Artesian Basin (GAB) would cease to exist if pressures in the GAB fell to the point where there was no further surface discharge at the spring.

In other cases a more gradual change in the health, composition and/or ecological function of a groundwater dependent ecosystem is expected as, for example, may occur with increasing groundwater salinity or contaminant concentration.

Further information on groundwater systems in NSW and their dependent ecosystems can be found in the [NSW Groundwater Dependent Ecosystems Policy](#).

9. WHEN ARE GROUNDWATER ASSESSMENTS REQUIRED?

Groundwater assessments are required for developments or activities that are likely to impact on groundwater.⁸ If a development will:

- intersect an aquifer (e.g. excavation through an aquifer for mining, an underground car park, building foundation, extraction of groundwater for use, etc.); or
- interact with groundwater in some other way (e.g. causes changes to water quality or the infiltration of water through the aquifer due to changes to the **impervious** surface area),

then it is important that a groundwater impact assessment is undertaken as part of the environmental impact assessment process.

Examples of developments that can impact on groundwater include coal seam gas operations, **dewatering** during mining, certain construction and irrigation, especially with recycled effluent.

10. RELEVANT LEGISLATION IN NSW

The following legislation includes requirements relating to groundwater:

10.1 WATER ACT 1912 AND WATER MANAGEMENT ACT 2000 (NSW)

The *Water Act* controls the extraction of water, the use of water, the construction of works such as dams and weirs and the carrying out of activities in or near water sources in New South Wales where no water sharing plan is in place. This Act will be fully repealed when the Water Management Act is operational in its entirety.

The *Water Management Act* governs the issuance of new water licences, trading of licences and allocation of water resources in NSW where the water sources are 'regulated'; that is, where a water sharing plan is in place

10.2 ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979 (NSW)

Under this Act, proposed developments require the approval of the Minister for Planning or other relevant authority before commencement. Part 4 of the *EP&A Act* states that an Environmental Impact Assessment (EIA) may be required as part of the approval process, which may include consideration of groundwater impacts. As part of the integrated development approval scheme, which requires State Government agencies to forward general terms of approval to the consent authority, the consideration of contamination, protection of groundwater systems and other environmental health requirements can be incorporated into the conditions of consent.

10.3 CONTAMINATED LAND MANAGEMENT ACT 1997 (NSW)

This Act regulates the management of currently contaminated sites, including groundwater that has been impacted by point source pollution. Point source pollution comes from a single particular identifiable location. The NSW Environment Protection Authority (EPA) has powers to order the investigation and remediation of land which presents a 'significant risk of harm' under the Act. The EPA is only responsible for sites where it believes that there is a 'significant risk of harm' from the contamination. Where contamination does not pose a significant risk of harm, the responsibility falls to local councils by means of land use planning processes directed by **State Environmental Planning Policy (SEPP) 55 - Remediation of Land**.

⁸ *Environmental Planning and Assessment Regulation 2000*, Schedule 2.

10.4 PROTECTION OF THE ENVIRONMENT OPERATIONS ACT 1997 (NSW)

This Act regulates the pollution of all water, including groundwater, in New South Wales. It empowers regulatory authorities to issue pollution licences (called environment protection licences) which authorise pollution to certain capped levels and pollution notices which notify breaches of licences. The Act also creates a range of pollution offences with associated penalties, and sets up a regime for enforcing pollution laws. For example, the Act empowers members of the public to take legal action to enforce the law.

10.5 LOCAL GOVERNMENT ACT 1993 (NSW)

Councils have responsibilities under this Act to manage groundwater resources by the regulation of waste management and disposal practices, protection of environmentally sensitive areas, application of standards to the construction, operation and maintenance of various facilities and prevention of contamination and environmental degradation.

10.6 THREATENED SPECIES CONSERVATION ACT 1995, NATIONAL PARKS AND WILDLIFE ACT 1974 AND FISHERIES MANAGEMENT ACT 1995 (NSW)

These Acts require that native species, particularly threatened species, communities and populations are protected unless otherwise authorised. Groundwater dependent ecosystems may be listed under these Acts.

10.7 ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999 (CTH)

This Act applies 'controlled actions'. Controlled actions are actions that are proposed to take place in Commonwealth owned regions, activities that are to be carried out by the Commonwealth and activities that are likely to have a significant impact on a 'matter of national environmental significance'. Matters of national environmental significance include Ramsar wetlands as well as migratory and threatened species and communities, all of which could potentially be dependent on groundwater. Where a proposed activity relates to a controlled action, the activity must be referred to the Commonwealth Government for assessment by the Environment Minister. In this way, the Commonwealth Government can oversee certain developments that will impact of groundwater.

11. RELEVANT POLICY AND GUIDELINES IN NSW

11.1 NATIONAL WATER INITIATIVE (2004)⁹

Builds on the 1994 COAG Water Reform Framework and includes:

- commitment to restoring over-allocated water systems and returning these to sustainable levels;
- expansion of trade in water;
- more secure water access entitlements and more confidence for those investing in the water industry; and
- more sophisticated, transparent and comprehensive water planning and better management of urban water.

The **COAG Water Reform Framework 1994** proposed an integrated approach to address environmental degradation of river systems such as allocation of water to the environment, ecological sustainability of new developments, institutional reform, protection of groundwater, adoption of the integrated catchment management approach and micro-economic reform.

11.2 ALLOCATION AND USE OF GROUNDWATER: A NATIONAL FRAMEWORK FOR IMPROVED GROUNDWATER MANAGEMENT IN AUSTRALIA (1996)¹⁰

This document was prepared by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ). It identifies a range of key reforms, specific to groundwater, but consistent with the Council of Australian Governments (COAG) water reform framework including:

- improved integration of surface and groundwater,
- identification of sustainable yield allocation and use of aquifers,
- establishment of systems to support transferability of groundwater allocations, and
- introducing full cost recovery mechanisms for groundwater.

11.3 NSW STATE GROUNDWATER POLICY FRAMEWORK (1997)¹¹

⁹ National Water Commission, *National Water Initiative*. Available online at <http://www.nwc.gov.au/www/html/117-national-water-initiative.asp>.

¹⁰ ANZECC and ARMCANZ (1996) *Allocation and Use of Groundwater. A National Framework for Improved Groundwater Management in Australia*. Available online at <http://www.environment.gov.au/water/publications/environmental/groundwater/pubs/framework-groundwater.pdf>.

¹¹ Department of Land and Water Conservation, *NSW State Groundwater Quality Protection Policy*. Available online at www.water.nsw.gov.au/ArticleDocuments/34/nsw_state_groundwater_policy_framework_document.pdf.aspx.

This framework aims to achieve efficient and sustainable management of groundwater resources. The framework includes the Groundwater Quality Protection Policy, the Groundwater Quantity Management Draft, and the Groundwater Dependent Ecosystems Policy.

11.4 NSW GROUNDWATER QUALITY PROTECTION POLICY (1998)¹²

This policy is designed to protect groundwater resources against pollution. The management principles outlined in the policy include:

- all groundwater systems should be managed such that their most sensitive use or value is maintained;
- for new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to the groundwater system and the value of the groundwater resource; and
- groundwater ecosystems will be afforded protection.

11.5 NSW GROUNDWATER DEPENDENT ECOSYSTEMS POLICY (2002)¹³

This policy is designed to protect ecosystems that rely on groundwater for survival. Management principles include that groundwater systems should be managed within the sustainable yield of an aquifer system so that the ecological processes and biodiversity of dependent ecosystems are maintain and/or restored.

11.6 AUSTRALIAN AND NEW ZEALAND GUIDELINES FOR FRESH AND MARINE WATER QUALITY (2000)¹⁴

These guidelines establish environmental and human values for different types of waterways and then provide trigger values and methods to ensure that the water quality of the waterway can support these values.

¹² See above.

¹³ Department of Land and Water Conservation, *NSW State Groundwater Dependent Ecosystems*. Available online at www.water.nsw.gov.au/ArticleDocuments/34/groundwater_dependent_ecosystem_policy_300402.pdf.aspx.

¹⁴ ANZECC and ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Available online at http://www.mincos.gov.au/publications/australian_and_new_zealand_guidelines_for_fresh_and_marine_water_quality.

11.7 APPROVED METHODS FOR THE SAMPLING AND ANALYSIS OF WATER POLLUTANTS IN NSW (2004)¹⁵

This document outlines the laboratory methods accredited by the NSW EPA for testing water.

12. WHAT IS A GOOD GROUNDWATER ASSESSMENT?

Groundwater impact assessment involves the collection of a range of information from desktop studies, field investigations and laboratory analyses. The work should be undertaken by a suitably qualified environmental consultant called a **hydrogeologist** using standard and agreed methods. Details of the methods used, quality control, results, interpretation and conclusions should be clearly documented within the groundwater assessment using tables, graphs and figures where appropriate. Note that impacts are often hard to predict, and might not be immediately apparent.

12.1 WHAT SHOULD BE MEASURED?

12.1.1 Basic information

Groundwater Hydrology

Hydrology is the study of the movement, distribution and quality of water through the earth. Detailed investigations of the existing groundwater environment should be undertaken prior to the proposed development, clearly describing:

1. The aquifer systems present in the area, including their nature, extent (vertically and horizontally) and inter-relationships. The interaction between confined and unconfined systems should be clearly defined.
2. The physical characteristics of these aquifers, including **groundwater elevation**, direction of flow, gradient, **permeability** and rates of flow.
3. The chemical characteristics of groundwater, including salinity and trace elements, with reference to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality.¹⁶
4. The connections between groundwater aquifers to surface water features and groundwater dependent ecosystems. Proximity to a disturbance does not always determine impact to the groundwater. The groundwater dependent ecosystem or the surface water feature could be upstream of the site and hence may not be impacted

¹⁵ DEC (2004) *Approved methods for the sampling and analysis of water pollutants in NSW*. Available online at <http://www.environment.nsw.gov.au/resources/water/approvedmethods-water.pdf>.

¹⁶ See above.

at all by any aquifer disturbance happening downstream of it. Also, it may not demonstrate the usual directional permeability common in aquifers and hence may not be connected to the disturbance nor to the groundwater stream flow.

Careful consideration should be given to the density and location of groundwater sampling points and sample frequency to ensure potential impacts can be identified. For sampling to be considered adequate, there are many factors which may be taken into account, including:¹⁷

- whether the sampling was carried out using standard protocols;
- whether quality control (procedures to ensure accuracy of data) and quality assurance (effectiveness of quality control procedures) checks have been made;
- whether there is documentation of the analysis procedure, date and location, identity of the analysts and equipment used; and
- whether the reporting of the results is clear, concise, unambiguous and timely.

Regional Setting

Background information about the regional setting should be provided to facilitate groundwater impact assessment including:

1. The character of the catchment, including topography, geology, rainfall and evaporation.
2. A detailed description of surface water bodies in the area, including flow, water quality, current use, location relative to the proposed development site, and reliance of existing users on these sources.
3. A description of groundwater recharge areas, including their location, extent and recharge characteristics, such as speed and intensity.
4. The details of groundwater bores, wells and springs in the area, including depth, source aquifer, yield, water quality, current use, location relative to the proposed development site, well density and reliance of existing users on these sources.
5. The nature, extent and location of groundwater dependent ecosystems in the area, including streams, wetlands and terrestrial vegetation. The sensitivity of these ecosystems to changes in groundwater elevation and groundwater quality is to be assessed.
6. High priority groundwater resources, **embargoed aquifers** and Water Sharing Plan areas under the *Water Management Act 2000* (NSW) should be identified and described.

¹⁷ ANZECC and ARMCANZ (2000) *Australian and New Zealand guidelines for fresh and marine water quality, Chapter 7: Monitoring and assessment*. Available at http://www.mincos.gov.au/__data/assets/pdf_file/0014/316130/wqg-ch7.pdf.

Groundwater Dependent Ecosystems

A detailed assessment of groundwater dependent ecosystems in the vicinity of the proposed development site should be undertaken including:

1. Identification of all groundwater dependent ecosystems in the vicinity of the site. Wetlands, rivers, terrestrial vegetation and karst systems are to be included.
2. Detailed field investigations to clearly define the degree and nature of ecosystem dependence on groundwater.
3. Consideration of the ecological values of the groundwater dependent ecosystems identified, including biodiversity and species assemblages.

12.1.2 Development Proposal Details

Details of the proposal should be provided so that the interaction between the development and groundwater in the vicinity of the site can be clearly defined. This will enable the potential impacts of the development on groundwater to be reasonably predicted.

Description of the Proposal

The development proposal should be outlined in the context of potential groundwater impacts.

1. The proposed development should be described in detail. Works which intersect the groundwater table, including mine pits, underground workings, tailings pits, extraction bores, dewatering bores and monitoring **piezometers**, are to be clearly defined. Works which may impact on groundwater in other ways, such as impervious surfaces, water storages, vegetation removal and the use or storage of chemicals, should also be clearly defined.
2. The site layout throughout the life of the proposed development should be presented. Efforts to avoid interference to surface and groundwater resources should be demonstrated. Impacts of activities with significant potential to affect the groundwater system such as open cut pits, underground workings, tailings dams, and establishment of new production bores should be minimised.
3. Detailed cross sections which show the hydrogeological interactions under different conditions (i.e. wet and dry seasons, high and low level pumping, use or absence of liners, etc.) between the development and surface water bodies, unconfined and confined aquifers and groundwater dependent ecosystems for the life of the development, should be presented.
4. The location, purpose and construction of all proposed bores, including production, dewatering and monitoring bores, should be provided.

Licences

To extract water from rivers or aquifers to use for commercial purposes, a licence is generally needed. As the regulations regarding water licences are complex, licences will only be dealt with briefly in this factsheet. For more information on water access licences, see **Fact Sheet 5.4**.

In areas with Water Sharing Plans, the issuing of new water licences and the trading of allocations and licences occurs under the *Water Management Act 2000*.¹⁸ To check if an area has a Water Sharing Plan, see the list on the NSW **Office of Water's** webpage, contact the Office of Water on 1800 353 104 or email **information@water.nsw.gov.au**.

In areas without Water Sharing Plans, the issuing of new water licences and the trading of allocations and licences is governed by the *Water Act 1912*.¹⁹ The circumstances attached to licences granted under this Act are more complex than those under the *Water Management Act*.

A licence is required for:

- taking water from a stream or river via a pump or other work except if a basic landholder right; for household or stock consumption, as a native title right, or as a harvestable right.
- capturing surface water in a farm dam with a larger storage capacity than the calculated **maximum harvestable right** dam capacity for the property, or in a dam located on a river or stream.
- extracting groundwater via any type of bore, well, or groundwater interception scheme except to take water from an aquifer under a basic landholder right.

These licences:

- set out the share of water from a particular source which can be extracted;
- entitles the holder to access water, but is not an approval to build water supply works or to use the water;
- in the case of 'continuing' water access licences (licences granted in perpetuity), allow for the licence and water allocation available under that licence to be traded in whole or part, or to be subdivided, consolidated and changed; and

¹⁸Office of Water, *New Access Licences*. Available at <http://www.water.nsw.gov.au/Water-Licensing/About-licences/New-access-licences/default.aspx>.

¹⁹Office of Water, *Licensing under the Water Act 1912*. Available at <http://www.water.nsw.gov.au/Water-Licensing/About-licences/Water-Act-1912/default.aspx>.

- are listed on a public **Water Access Licence Register**.

Water Balance

Water balance is the total in and out flow of water. A simple way to calculate water balance is by taking the volume of evaporation and runoff from the volume of precipitation.

A detailed water balance addressing potential groundwater impacts should be prepared which:

1. Specifies the water resource requirements of the proposal throughout the life of the development for a range of conditions. Details of the processes which use water and the volumes and quality of water required for each process should be provided. The proposed source of water for each process should also be identified, noting the following:
 - If groundwater is to be extracted from the site, the quality and volume of the water to be extracted and the pumping regime (how long are the pumps going to run continuously, at what rate and when) under different conditions should be predicted.
 - If surface water is retained on site, the capacity of dams should be within the maximum harvestable right for the life of the operations.
 - If water is sourced off site, its volume, quality and sources should be specified. It should be clearly indicated why reuse of water from on site is not an option. If water contamination is limiting reuse on site, it should be clearly indicated why treatment of the water is not an option.
2. Clearly defines the types of water to be generated, managed and disposed of onsite, e.g. waste, saline, contaminated, etc. The quality and quantity of each type of water throughout the life of the development under a range of conditions should be predicted.
3. Provides the location and design of all channels, storage structures, detention basins, and outlet fixtures for the different types of water on site.
4. Indicates whether water is to be applied to the site surface, and if so, identifies water application areas and measures to address unacceptable salt and contaminant accumulations in groundwater across the site.
5. Clearly states whether waste water will need to be disposed of offsite under certain conditions. If offsite disposal of waste water is required, the volumes and quality of the water likely to require disposal, where the water is to be disposed and the method and timing of disposal should be indicated. Justification should be provided for why the site cannot be managed to ensure there is no discharge throughout the

life of the development for a range of conditions. Justification should also be provided for why contaminated waste water cannot be treated and beneficially reused on site. In terms of groundwater, this should justify why groundwater should be extracted without any return to the environment.

6. Indicates if saline or contaminated water is to be treated to allow for onsite reuse or discharge of waste water (of acceptable quality – depending on applicable standards and licence conditions) into receiving surface waters, the volumes to be treated under a range of conditions, the treatment methods to be employed and the predicted quality of the treated water.

12.1.3 Impact Assessment

Hydrogeological Regime

The Applicant must explain potential changes to the existing groundwater regime resulting from the development by:

1. Establishing benchmark, steady-state or undisturbed conditions of the groundwater system on site. See **Appendix 1**.
2. Modelling groundwater responses to groundwater extraction, dewatering and loss of pressure over the life of the development.
3. Predicting changes in the hydraulic properties of the aquifer, including groundwater elevation, flow direction, permeability, gradient and rates of flow, as a result of groundwater extraction, dewatering and pressure decline.
4. Considering potential changes to the area where the aquifer is recharged and the location of creek diversions over rehabilitated areas. Changes to the aquifer recharge area and creek diversions will alter the hydrogeological regime downstream.
5. Evaluating the impact on water supply bores and springs, connected aquifers, surface water bodies and groundwater dependent ecosystems. In terms of protecting water resources, ANZECC and ARMCANZ suggest a three radius approach:²⁰
 - Zone 1: This area corresponds to the area of a groundwater flow system which contributes to water discharge at the monitoring point.
 - Zone 2: The maximum distance a contaminant particle would have travelled if it took 10 years to reach the monitoring site.
 - Zone 3: Corresponds with the regional protection or catchment area.

These zones must be decided on a site-by-site basis.

²⁰ ANZECC and ARMCANZ (1995) *National Water Quality Management Strategy: Guidelines for Groundwater Protection in Australia*. Available online at

Subsidence

Subsidence is the collapsing of the ground surface. In severe cases, large holes or landslides may occur as the surface caves in. This can occur when lower layers of soil are washed or mined away. The potential impacts of subsidence should be assessed by:

1. Identifying potential for, and causes of, subsidence due to the proposal, e.g. dewatering, groundwater extraction, blasting.
2. Modelling the nature, extent and magnitude of the expected subsidence impacts for the life of the development. The method used to predict subsidence should be justified. Assumptions and the level of uncertainty in the prediction should be explained.
3. Predicting changes in aquifer hydraulic properties, connectivity and recharge as a result of subsidence. The impact of these changes on water supply bores and springs, surface water bodies and groundwater dependent ecosystems should be assessed. It may be necessary to also evaluate infrastructure that may be impacted by subsidence directly related to changes in the groundwater regime as a result of the development.

Water Availability

The groundwater impact assessment should:

1. Assess the extent to which the proposed development will reduce water availability in the catchment as a result of extraction and dewatering of groundwater.
2. Discuss the impact of reduced water availability on landholders and industries who rely on water supply from the catchment.
3. Evaluate the impact of reduced water availability on surface water bodies and groundwater dependent ecosystems.
4. Assess the impact of any shift in groundwater flow directions. For example, some previously drier areas could get some flooding while some groundwater discharge points could dry up.

Water Pollution

The Applicant should undertake investigations to identify potential sources of water pollution and pathways for pollution of groundwater. In particular by:

1. Predicting the salinity and volume of saline water that will require management over the life of the development. Options for reuse of saline water on site and potential impacts on groundwater quality should be identified, e.g. if saline groundwater is

used for dust suppression or irrigation of rehabilitated areas, the impacts on the quality of shallow groundwater should be considered.

2. Predicting the type and nature of contaminated water that will be generated over the life of the development, including **acid mine drainage**. The potential impacts of contaminated water on the quality of shallow groundwater should be considered.
3. Identifying chemicals to be used, disposed or stored on site, e.g. oils, **extraction agents** and their containment methods. The volumes to be used and potential risks to groundwater from leaking storage tanks and spills on site should be predicted.

Groundwater Dependent Ecosystems

The Environmental Impact Assessment should:

1. Assess the vulnerability of the groundwater dependent ecosystems identified. The study should consider the vulnerability of the ecosystem to over extraction, pollution and other threatening processes.
2. Predict the impacts of the development on the groundwater dependent ecosystems identified for a range of climatic conditions.

Cumulative Impacts

Cumulative impacts are impacts which, whilst otherwise insignificant by themselves, may build up and amplify each other over time. They should be considered by:

1. Determining all cumulative changes to groundwater hydrology and water quality, including the impacts of other developments currently in operation and proposed for the area.
2. Discussing how the proposal will fit within the framework of relevant catchment-wide groundwater management strategies e.g. groundwater sharing plan, town water drought augmentation measures, etc.

12.1.4 Mitigation Measures and Contingency Plans

The groundwater impact assessment should demonstrate that mitigation measures and contingency plans are capable of adequately addressing any risks to groundwater as a result of the development.

Hydrogeological Regime

1. Describe the mitigation measures that will be employed to avoid adverse changes in the hydrogeological regime, e.g. site selection and well design, retention of native vegetation and revegetation, artificial recharge, provision of surface storages with impervious linings, etc.

2. Model the proposed mitigation measures to demonstrate their effectiveness in mitigating impacts. Justify the methods used and assumptions made and indicate the level of uncertainty in the modelling.
3. Specify the contingency plans to be employed in the event that proposed mitigation measures are not effective.

Subsidence

1. Describe the mitigation measures that will be employed to minimise the potential impacts of subsidence e.g. controlled pumping rates, pumping schedules and frequency, re-injection of fluids back to aquifers, etc.
2. Model the proposed mitigation measures to demonstrate their effectiveness in mitigating subsidence. Justify the methods used and assumptions made and indicate the level of uncertainty in the modelling.
3. Specify the contingency plans to be employed in the event that proposed mitigation measures are not effective in mitigating subsidence.

Water Availability

1. Identify measures that will be employed to reduce the development's use of groundwater e.g. dust suppressant additives, storage pond design to minimise evaporative losses, water treatment, recycling and reuse.
2. Provide a plan for the diversion of groundwater around the active area of the site and indicate the volume of groundwater to be harvested for use on site.
3. Outline contingency arrangements to compensate water users, including the environment, which may be affected by the proposed development.
4. Provide remediation plans for the rehabilitation of aquifers if there is any anticipated adverse impact on the beneficial use of the aquifer system or groundwater dependent ecosystems as a result of the development.

Water Pollution

1. Describe how the different types of waste water to be generated by the development will be managed and treated, based on a hierarchy of:
 - Minimising the generation of waste water.
 - Capturing all contaminated water, including stormwater, on the site.
 - Reusing/recycling waste water.
 - Treating any unavoidable discharge from the site to meet specified water quality requirements.
2. Describe management procedures that will be adopted to prevent pollution of groundwater by saline water and stormwater runoff from sources on site such as

acid generating stockpiles, e.g. stormwater diversion and capture, lining of storage areas, desalination of saline water and **neutralisation** of acidic water.

3. Outline pollution control measures relating to the storage of chemicals and accidental spills, e.g. **bunded** tank storage areas, staff training in the use of proper chemicals and the amounts required, use of chemical spill kits. Identify appropriate disposal methods for these chemicals.

Cumulative Impacts

1. Describe mitigation measures proposed to minimise cumulative impacts, e.g. locations of pits and groundwater extraction bores, limits on extraction rates, barrier walls.
2. Demonstrate collaboration with nearby developments and a commitment from all parties to address cumulative impacts as soon as they are detected.
3. Ensure funds are available and accessible for rehabilitation, remediation, compensation and/or augmentation of groundwater when necessary. These could take the form of bonds, for example.

12.1.5 Post Closure Management

Some developments will cease operations after a period of time, e.g. a mine will cease operations once the resource has been extracted. These developments may require management post closure under s 76 of the *POEO Act* as a condition of a licence, to ensure there are no ongoing impacts to the environment, e.g. **acid mine drainage** from abandoned underground workings. An applicant may be required to put forward financial assurance that the management will be carried out. If they fail to carry through with their plan, this money will be lost.

The EIA should detail the applicant's commitment to management of the site post closure. Management should include rehabilitation of the site and monitoring of potential ongoing impacts. The EIA should:

1. State the objectives of site rehabilitation, as agreed in consultation with the community, e.g. potable use of groundwater.
2. Clearly indicate the lifespan of the project and the anticipated state of the landscape and natural resources when the project is terminated or decommissioned.
3. Clearly describe the proposed approach for progressive rehabilitation of the site during operations and provide details of the final model of the region. Include illustrations of progressive rehabilitation. Show the location and

configuration of **voids**, surface drainage of the landscape and groundwater recharge areas.

4. Clearly indicate who is responsible for and who is in charge of clean up. Document that clean-up will be undertaken whatever the circumstances that have led to the closure of the project, especially in case of early termination or change of ownership.
5. Predict the impacts of the final landform and final voids on the hydrogeological regime. Consider potential alteration to the long term recovered water table. Use suitable testing methods to predict the hydraulic properties of materials used to backfill dug out sections as part of the rehabilitation. Model how the final voids will interact with groundwater during the recovery process and for at least 100 years post closure. Consider whether the final voids will cause groundwater to discharge and evaporate.
6. Predict the impacts of the final landform and final voids on groundwater, ground stability, and void water quality for at least 100 years post mining. Test backfill materials to predict the long term quality of groundwater, considering salt mobilisation and the acid forming potential of these materials. Predict the quality of water in the final voids based on groundwater quality, inflow rates and evaporation.
7. Compare alternative configurations and engineering designs for the final voids using 100 year model impact predictions. Demonstrate that the selected configuration will have minimal impact on the hydrogeological regime and quality of ground and void water.
8. Outline treatment and remediation approaches to be employed to meet rehabilitation objectives, e.g. desalination or neutralisation of void water, stabilisation and capping of contaminated **spoils**.
9. Engage the community in planning for and deciding the best use of the site post project and how to achieve that goal.
10. Provide details of ongoing management of the site in a site management plan. The plan is to include a rigorous monitoring and reporting program to inspire confidence in the community that the site is safe for the purposes agreed in consultation, e.g. recreational activities such as swimming.

12.2 DESIGN OF MONITORING PROGRAMS

A comprehensive groundwater monitoring program should be undertaken to test the predictions made in the impact assessment and to detect environmental impacts during the development's operation. In recognition of the potentially long lag times between the

action and the impact, a monitoring program should run over a suitable timeframe. The program should include the following:

1. Installation of an extensive network of groundwater piezometers across the site, in the area surrounding the site and at all properties located near (i.e. in Zone 1) the site which use groundwater. Location of piezometers should be representative of all confined and unconfined aquifers potentially impacted by the development's operations. Design of the piezometers should depend on characteristics of the aquifer being monitored.
2. Daily monitoring of groundwater levels (preferably at the same time each day) to assess impacts of any activity around the bores e.g. loss or decrease in groundwater pressure. Recording of water level data should include consideration of weather conditions that might affect water levels.
3. Regular sampling and analysis of groundwater from piezometers on site and off site to monitor the impact of the development's operations on groundwater quality. The analytical suite should include a broad range of parameters relevant to the purpose of the sampling regime.
4. A program for communicating and timely reporting of results of water quality analysis to both government and the community.
5. A plan of action to quickly address any detection of abnormal water quality parameters.
6. A program of monitoring and maintaining clean and contaminated water diversions, lined water storages and chemical storage areas.
7. Preparation of a water balance report periodically or as required, e.g. quarterly reports for a mine, clearly indicating the volumes of groundwater dewatered and extracted for use on site.
8. The construction of piezometers in rehabilitated spoils located within pits (where applicable) to monitor void/spoils water level recovery and water quality.

Impact assessment criteria should be established prior to development to facilitate the assessment of monitoring data. The criteria should set a series of benchmarks against which impacts can be measured.

Reporting and assessment of the monitoring data should be undertaken as soon as it is collected and validated. The validation process should include quality control procedures, cross referencing, double checking and peer review.

Detailed technical information should be made simple and easy to understand through user friendly language so it can be made available to the public. It is also helpful to present concise summaries.

The assessment should include clear correlation of collected data and contextual significance (time, space, regional and scale importance, etc). Figures should include graphical plotting of data, identification of trend lines and calculation of statistics. Departures from predicted or previous data trends should be clearly identified and explained. Annual reports should be prepared and issued to all relevant parties. Depending on the sensitivity of information, it could be released to interested community groups or individuals.

Where environmental impacts are detected, contingency plans (a multi-tiered approach is recommended), which may involve ceasing work, modifying operations, rehabilitation of affected areas or compensation of affected parties, should be instigated immediately.

For more general information on the design of monitoring programs, see the EDO **Technical Fact Sheet on Water Quality Assessment**.

12.3 HOW TO MONITOR GROUNDWATER

Assessment of the hydrogeology of a site is essential to keep track of impacts to the environment and may also be a requirement of an Environmental Impact Assessment. Groundwater monitoring requires the installation of groundwater monitoring bores (or wells) using a drilling rig (if necessary) if no suitable existing wells can be used for monitoring.

Groundwater monitoring bores should be installed by a licenced driller under the supervision of a suitably qualified hydrogeologist. All groundwater monitoring bores must be licenced through the NSW Office of Water prior to installation. The drilling technique used (for example, auger drilling, push tubes, rotary air drilling, rotary mud drilling and cable tool drilling) should be specific to the geology and the sampling requirements.

Groundwater monitoring bores should be constructed specific to the hydrogeology of the area and in accordance with the document *Minimum Construction Requirements for Water Bores in Australia*.²¹ The depth of the bore, the length and positioning of the well

²¹ National Minimum Bore Specifications Committee (2003) *Minimum construction requirements for water bores in Australia*. Available online at <http://www.iah.org.au/pdfs/mcrwba.pdf>.

screen, and the positioning of seals to prevent the downward migration of groundwater through the bore, will be determined by the hydrogeology at that location.

The locations and numbers of monitoring bores will depend on the size, nature, dynamics and configuration of what is being assessed. However, at least three **triangulated** monitoring bores are required to determine the groundwater flow direction and hydraulic gradient if not previously known from existing groundwater records of the area.

Care should be taken during the construction of groundwater monitoring bores to ensure that confined aquifers do not become linked to other aquifers through the length of the well, as this may result in cross contamination of groundwater between aquifers and the creation of an unnatural hydrogeological regime.

12.3.1 Water Level Monitoring

Monitoring groundwater levels before, during and after construction is an important component of a groundwater impact assessment. Water level monitoring will indicate whether there has been any impact on groundwater levels due to the development, e.g. due to dewatering or extraction of groundwater.

Groundwater level is measured with a purpose-built tape and meter and measured from a reference point at the top of the bore casing and calibrated to sea level. To assess the hydraulic gradient, water level monitoring at three monitoring bores constructed in the same aquifer should be undertaken on the same day. Monitoring at three points across the site allows triangulation of water levels and determination of groundwater flow direction.

12.3.2 Rising and Falling Head Tests²²

Permeability is assessed using rising and/or falling head tests. Rising head tests are carried out by removing a quantity of water from within the **bore casing** and then measuring the water level recovery at specific intervals.

Falling head tests are conducted by adding a quantity of water to the bore and measuring the decline of the water level over time. The results of rising and falling head tests are visualised using graphs.

²² Sydney Coastal Councils Group and Groundwater Working Group (2005) *Sydney Regional Groundwater Management Handbook, A Guide for Local Government*.

To create a decline in water level in larger bores, extended periods of high volume pumping at different rates may be required to accurately determine permeability. Once the water level within the well shows no further decline in water, the pumping is stopped and the recovery of the water level is measured over time. Less permeable aquifers take a longer time for the water level to return to its undisturbed level.

12.3.3 Modelling Findings²³

Groundwater models are useful for predicting impacts on the regional groundwater. They are usually used for:

1. water resource assessment: evaluating recharge, discharge and aquifer storage processes,
2. allocation policies: determining sustainable levels of water which may be extracted without causing long term, serious and/or irreversible impacts to the aquifer,
3. assisting decision making: by predicting impacts of alternative courses of action, and
4. assessment of alternative policies.

Modelling is generally carried out using computer programs. There are several stages to the modelling process, including data collection, software selection, calibrating, designing and testing against measured/observed data to identify and fix errors. A sensitivity analysis may also be required to determine unavoidable errors due to uncertainty. The models then must be peer reviewed to ensure their accuracy.

²³ Office of Water, *Groundwater Modelling*. Available online at <http://www.water.nsw.gov.au/Water-management/Modelling/Groundwater/Groundwater/default.aspx>.

APPENDIX 1: TYPICAL MODEL DATA REQUIREMENTS AND SOURCES

From: Murray-Darling Basin Commission (2000) *Groundwater Flow Modelling Guideline*, pg 31, [http://www2.mdbc.gov.au/__data/page/127/model_guide.pdf].

Data Type	Data Sources	Documentation/Presentation
<p>Hydrogeological Framework</p> <ul style="list-style-type: none"> · Physical system (geology, stratigraphy, lithology, topography, surface drainage) · Aquifer extent, boundary types, elevations, thickness, confining beds, bedrock configuration · Aquifer hydraulic and storage parameters and spatial variability (hydraulic conductivity, transmissivity, anisotropy, specific yield, storage coefficient, porosity) · Borehole locations, infrastructure 	<ul style="list-style-type: none"> · Maps of (hydro)geology · Topographical maps showing surface drainage features, and other data to specify drainage geometry (extent & elevation) · Reports of previous work, including drilling programmes, pumping tests and analyses, geophysical studies, hydrology, etc. · Bore construction and lithological logs, cross-sections, bore completion reports · Journal and conference papers, student theses · State agency databases, private company reports and databases 	<ul style="list-style-type: none"> · Common and standard coordinate systems and elevation datum to be used and quality assured · Extent and thickness of geological units, and identification of aquifer units · Contours on the base elevation and thickness of aquifer units · Maps and sections of aquifer units and parameters, identifying significant areas of permeable and impermeable unit outcrop to identify recharge areas · Degree of hydraulic connection between surface drainage and groundwater systems, and between different aquifer units · Groundwater dependent ecosystem areas that rely on aquifer storage or discharge (eg. Phreatophytic vegetation, lakes, permanent streams)
<p>Hydrological Stresses</p> <ul style="list-style-type: none"> · Sources and sinks, and data to quantify their effect on flows and aquifer levels · Natural recharge and discharge areas, rates, patterns and durations · Stream-aquifer interaction · Abstraction, injection and drainage features and processes · Land uses, irrigation, evapotranspiration, vegetation 	<ul style="list-style-type: none"> · Rainfall and evaporation · Stream flow and stage · Groundwater level data for pumping and observation bores · Abstractions from groundwater and surface water, including licensed volumes and estimates of unlicensed amounts · Areas irrigated, crop types and areal distribution · Projections of growth in demand for water and discharge of wastewater · Groundwater and surface water quality · State agency databases, private company reports and databases, some landholder records 	<ul style="list-style-type: none"> · Usually monthly time series data is the bare minimum requirement; daily data is often required · The data is required to specify the time/date, the location, the value and the unit of measurement · For groundwater level data, it is important to know whether abstraction was occurring at the time of the measurements · Presentation of contours of groundwater level at various dates, and hydrographs of time series data · Abstraction data is notorious for its poor quality, and yet this data is critical to the development of good quality models · Land use data (especially area irrigated) is often unreliable.

GLOSSARY

Acid generating stockpiles – heaps of waste usually from mining operations containing substances such as sulphides and chlorides which can turn water acidic.

Acid mine drainage – groundwater which has turned acidic after coming into contact with contaminants, usually iron sulphide) from mines.

Analyte – a component in a substance, the amount of which is determined through an analysis.

Aquifer – an underground layer of permeable rock or unconsolidated materials which stores and/or transmits water, such as to wells and springs.

Aquatic – things that are in or of the water.

Bore – a cylindrical shaped hole drilled to make a well in a confined aquifer.

Bore casing – a pipe designed to fit tightly in a bore, to prevent leakage of water into the surrounding soil.

Bunded – material confined by a bund. A bund is a raised border to contain liquid within a specified area.

Confined aquifer - contains groundwater under pressure. This pressure comes from the weight of overlying materials and hydraulic gradient. Confined aquifers have an upper confining layer and a lower confining layer. Because the groundwater in confined, the aquifer is under pressure and the water will rise to a level (known as the potentiometric surface) above the upper confining layer if a pathway exists (such as when a bore intersects the aquifer). Confined aquifers are not recharged directly by vertical infiltration but need to be connected to an unconfined area so that recharge can occur.

Dewatering – removal by pumping of groundwater that flows, for example, into mines, as a result of the hydraulic gradient.

Embargoed aquifers – the Minister for the Department of Primary Industries may place an embargo on an aquifer, preventing the approval of developments or applications that seek to use the water.

Extraction agent – a substance which can be used to ease the extraction of another material.

Groundwater elevation – the distance above sea level of the top of the water table. This is calculated by measuring the height of the ground surface and subtracting the distance to the top of the water table, measured in a well or bore.

Hydraulic gradient - the difference in groundwater level or pressure between two points. Generally, groundwater flows from high to low water levels.

Hydrogeology – area of geology that deals with the distribution and movement of groundwater in rocks and soils.

Impervious – unable to be penetrated.

Karst – landscape shaped by the dissolution of rock e.g. limestone or dolomite. Permeability in karst systems is very high as water flows through large caverns or underground rivers which have been formed by the action of slightly acidic water.

Maximum Harvestable Right – Landholders have the right to capture 10% of the average regional yearly runoff for their property and use it for any purpose under the *Water Management Act*. The maximum harvestable right for any property may be calculated from the **Permitted Unlicensed Dam Size**.

Neutralisation – a chemical process which changes acidic or basic substances to a neutral pH (i.e. 7 on the pH scale).

Piezometer – a well with a small diameter used to measure the hydraulic pressure of groundwater in aquifers, which is usually measured as water surface elevation and represents the energy at the bottom of the piezometer.

Permeability – the rate at which water is able to penetrate rocks or soil. The size of the pores between particles in rock or soil influences its permeability.

Riparian – of a river bank. Riparian vegetation is the vegetation on river banks, between the river and surrounding landscape.

Screen - a screen is a special form of bore liner which is surrounded by gravel and allows the flow of water from the aquifer into the monitoring bore.

Spoil – mounds of excavated earth and/or rock.

Terrestrial – things that are of the land.

Triangulated – aligned for triangulation. Triangulation is a process to locate an unknown point using the locations of two known points and a chosen angle to form a triangle. The unknown point forms the third corner of a triangle.

Unconfined aquifer – an aquifer which does not have impermeable material above it. Unconfined aquifers usually occur near the earth's surface, making them easily recharged but more at risk of contamination.

Voids – empty spaces between material.

Water table – the upper surface of groundwater.

Waterlogged – oversupplied with water.

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