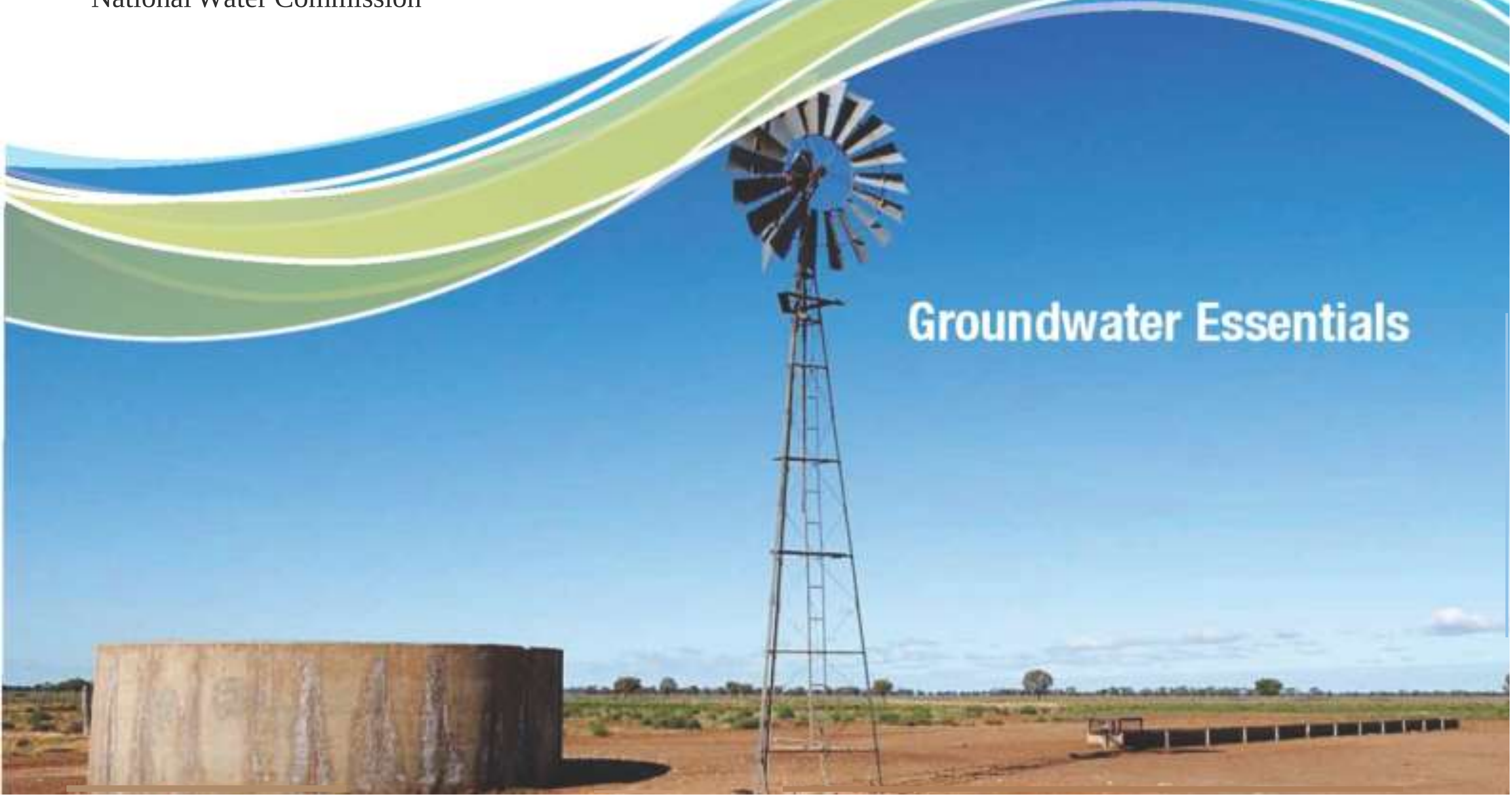
Australian Government

National Water Commission

Groundwater Essentials



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About the National Water Commission

The National Water Commission is responsible for driving progress towards the sustainable management and use of Australia's water resources under our blueprint for water reform - the National Water Initiative (NWI).

Established under the *National Water Commission Act 2004,* the Commission advises the Council of Australian Governments and the Australian Government on national water issues and the progress of the NWI.

The Commission assists governments in implementing the NWI and administers the Australian Government's $250 million Raising National Water Standards Program.

Acknowledgments

The Commission acknowledges the assistance of Arup Pty Ltd, which has developed this booklet on behalf of the Commission.

Foreword

James Cameron
Chief Executive Officer
National Water Commission

March 2012

Groundwater makes up about 17 per cent of Australia's currently accessible water resources and up to 30 per cent of our water consumption in particular regions. However, this valuable resource is neither understood nor managed as well as it needs to be if it is to be sustained.

Continuing water scarcity and climate change are placing pressure on Australia's groundwater reserves and the security of supply. These 'hidden' reserves are increasingly being tapped to supplement surface water supplies. In fact, much of our groundwater is connected to surface water, with consequent impacts on stream flows, aquifer recharge, groundwater–dependent ecosystems, and water quality.

Groundwater quality also requires careful management. Risks include uncontrolled urban and industrial discharges, the cross-contamination of aquifers, and seawater intrusion into heavily used coastal aquifers.

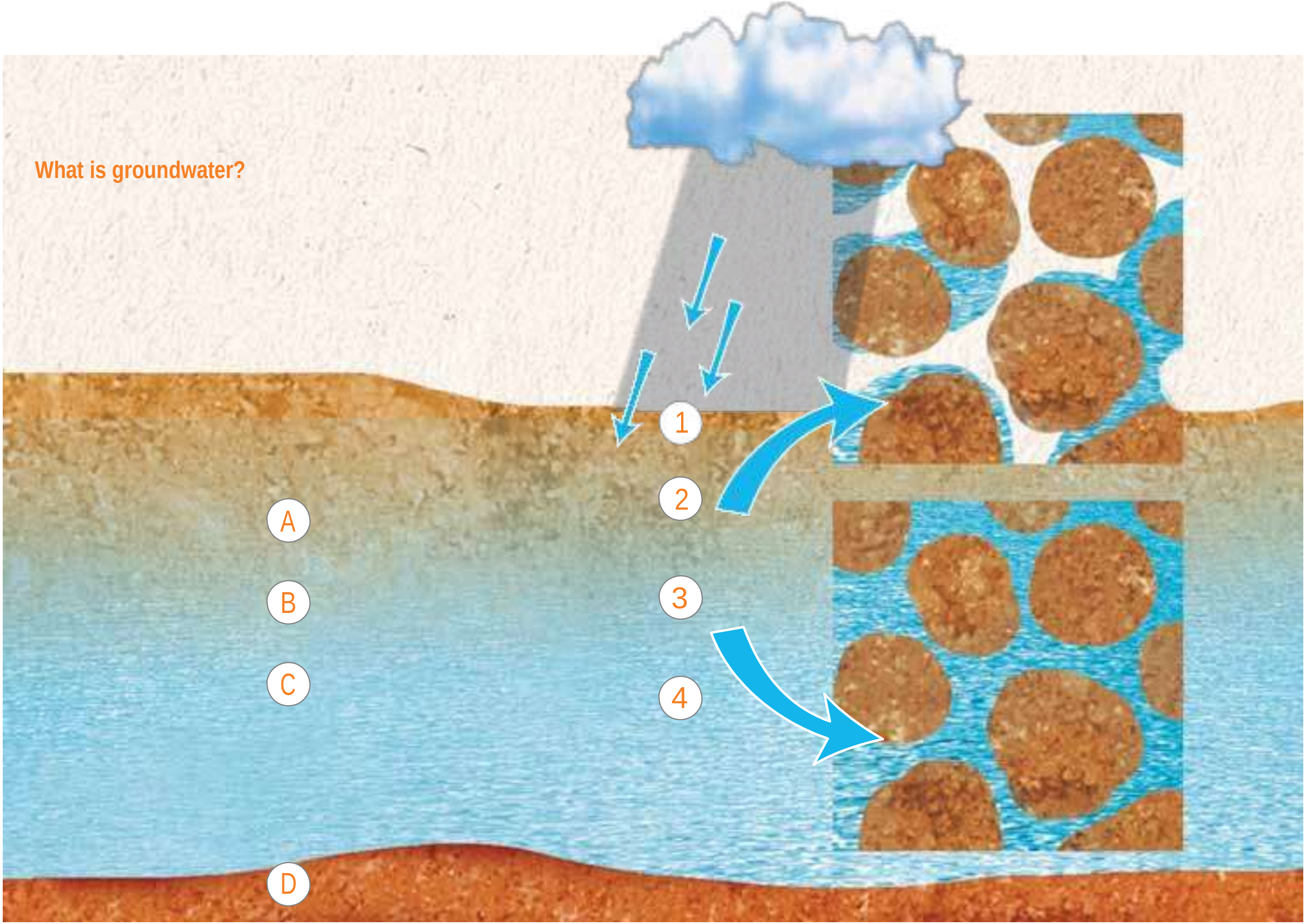
Through the National Groundwater Action Plan, the Commission has funded projects that address groundwater knowledge gaps and reforms agreed under the National Water Initiative (NWI).

This booklet will provide groundwater users with information to help them understand and manage groundwater resources to the best of their ability. The booklet explains groundwater's place in the hydrological cycle, its importance to the country, its various uses, surface/groundwater connectivity and risks to groundwater resources.

Mound Springs in the Great Artesian Basin, SA.
Photo courtesy of GABCC.

Contents

What is groundwater?



What is groundwater?

What is groundwater?

1. Water seepage – not groundwater
2. Pores filled with air and water – not groundwater
3. Water table – boundary
4. Pores filled with water – groundwater

A. Unsaturated zone
B. Water table
C. Saturated zone (groundwater)
D. Impermeable layer

Groundwater is water located in the saturated zone below the earth's surface.

Although it is an integral part of the global water cycle, many people imagine groundwater refers only to lakes or rivers in underground caverns.

Groundwater is actually surface water that has migrated from the surface through the ground and become stored in porous soils and rocks.

Key point

Rocks and soils that hold and transmit usable quantities of water are called aquifers. The top of the saturated portion of ground is known as the watertable.

Typically, the water sits in tiny pores, spaces between the smallest soil or rock particles, or narrow cracks in the rock itself. Only in exceptional cases does water get stored in openings that are many metres across.

Groundwater comes from two primary sources. When it rains, water infiltrates the soil until it reaches the watertable in an aquifer.

Aquifers can also gain water from rivers and streams draining into the ground.

Key point

It is crucial to appreciate the balance between inputs and outputs from groundwater and water quality to achieve sustainable use.

The study of the distribution and movement of groundwater is called hydrogeology.

Why is groundwater so important?

Groundwater is a vital source of water throughout Australia and the world.

It is estimated to make up 98 per cent of the earth's available freshwater. Put another way, groundwater is 60 times as plentiful as freshwater found in all of the earth's lakes and streams combined.

Groundwater is available for use throughout large parts of Australia. In many areas and outback communities, particularly in semi-arid and arid zones, it is the only reliable source of water. Many Indigenous communities, mining operations and remote pastoral properties rely solely on it for their water supply.

Groundwater is a finite resource. It is replenished only when surface water seeps into aquifers (see page 8 for a description of the types of aquifer). This process of aquifer replenishment is called recharge. Aquifers become depleted if groundwater extraction rates exceed recharge rates.

Aquifer depletion affects communities, agriculture and the industries that rely on groundwater supplies. Depleted groundwater reserves can also affect the environment - for example, by reducing river flows that depend on flows from shallow groundwater, or by drying out ecosystems such as some wetlands that depend on groundwater inputs to maintain water levels, known as groundwater–dependent ecosystems.

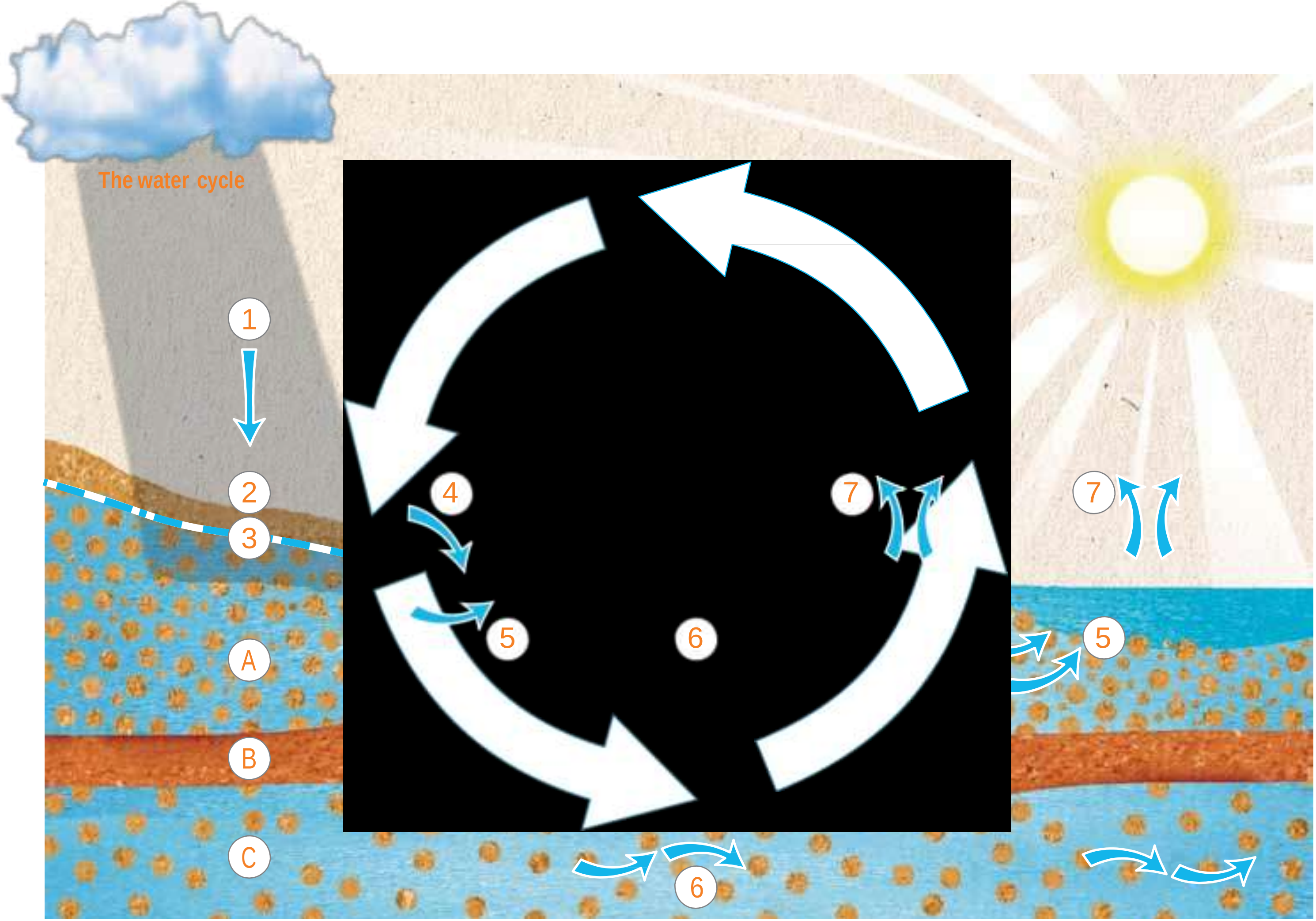
Like rivers and surface water, aquifers and groundwater can become polluted. This affects communities or businesses that rely on clean water supplies. Also, many environments have evolved to tolerate very specific water chemistry, and changing the chemical make-up of groundwater could cause an entire species to die out at a local level.

It is therefore important to minimise or avoid activities that may impair the quality and quantity of groundwater available to humans and the environment.

Did you know?

Groundwater makes up about 17 per cent of Australia's accessible water resources and may account for up to 30 per cent of total water consumption in particular regions.

Left Augmented use of groundwater and surface water
Photo courtesy of NWC


The water cycle
1
2
3
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5
6
7
A
B
C
5
6
7

Groundwater in the water cycle

The water cycle

1. Precipitation
2. Infiltration / recharge
3. Water table
4. Runoff
5. Groundwater discharge
6. Groundwater flow
7. Evaporation
8. Transpiration

A. Unconfined aquifer
B. Impermeable layer
C. Confined aquifer

The water cycle, or hydrological cycle, describes the endless circulation of water between ocean, atmosphere and land. It is a vast, complex process driven by the sun's energy.

Because it can't be seen, groundwater is often forgotten. But it is an important and proportionately large part of the land-based component of the hydrological cycle.

In the cycle, precipitation (rain, sleet or snow) falls on the ground and is either intercepted by plants and transpired or becomes overland flow contributing to the surface water network, or infiltrates the ground.

When surface water percolates slowly down through soil and rock, it eventually reaches a layer that it cannot pass through, where it slowly accumulates and saturates the ground above this layer. The top of the saturated zone is known as the watertable.

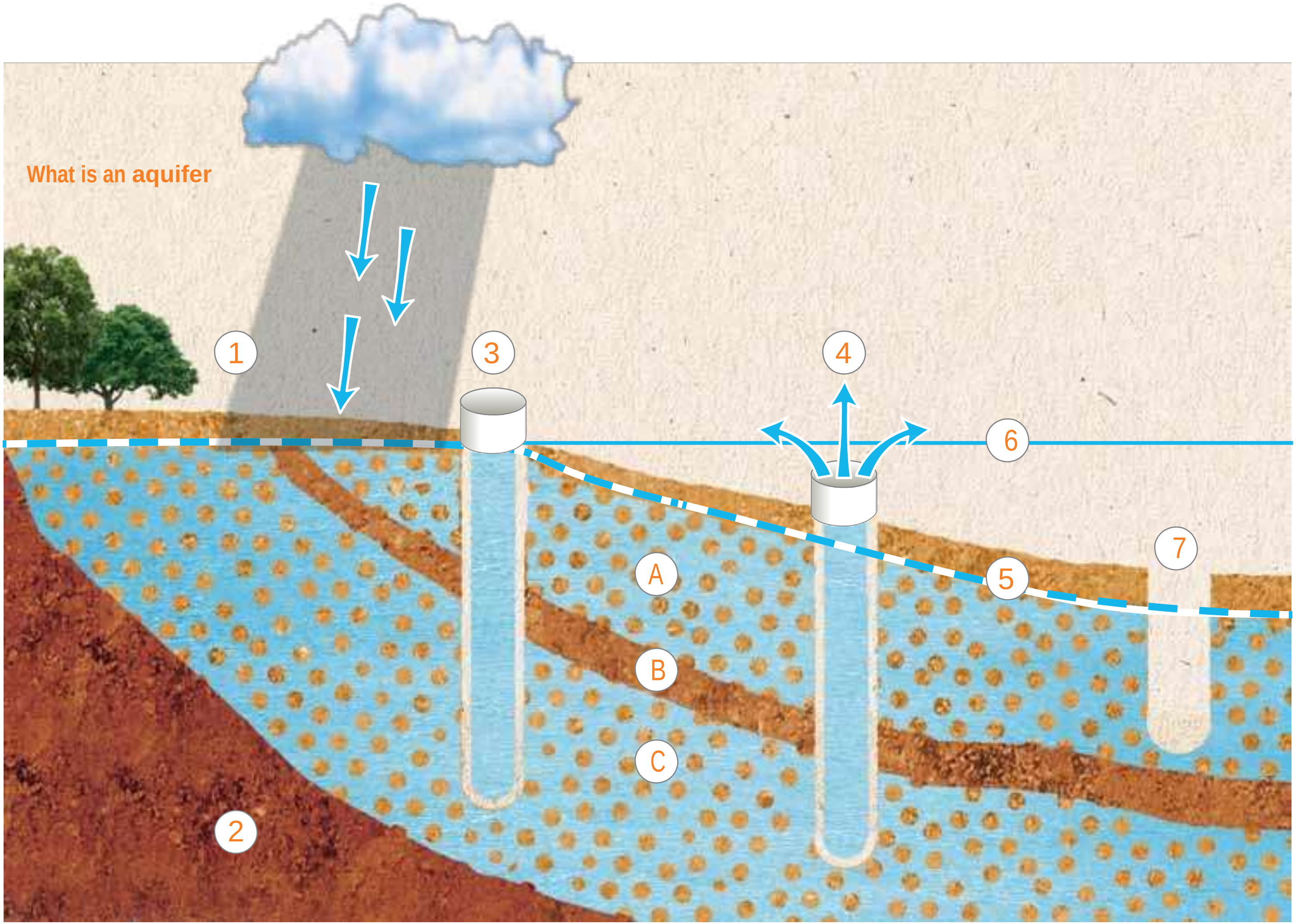
Groundwater usually flows through tiny pores and joints in saturated rock towards natural discharge points such as springs, where the watertable intersects the ground surface. Groundwater will also discharge where the watertable intersects water bodies such as streams, rivers or seas.

Key point

Groundwater forms a long-term storage component of the water cycle, with some groundwater remaining in rocks for millions of years before it naturally discharges or is abstracted.

Did you know?

Groundwater quality can vary considerably from place to place. Laboratory analysis can reveal chemical clues that may be used to trace the source of water that entered the ground, the geological material through which the water passed, and the time it took to do so.


What is an aquifer
1
2
3
4
5
6
7
A
B
C

Understanding groundwater: key concepts

What is an aquifer

1. Recharge
2. Confining bed
3. Artesian borehole
4. Artesian borehole flowing
5. Watertable
6. Piezometric surface
7. Unconfined aquifer well

A. Unconfined aquifer
B. Impermeable layer
C. Confined aquifer

Did you know?

Unconfined aquifers contribute about 60 per cent of groundwater extraction in Australia. A good example is Perth's Gnangara Mound, which supplies 70 per cent of the city's water (see case study page 37).

What is an aquifer?

An aquifer is an underground geological formation which transmits and contains appreciable quantities of groundwater.

Water in the ground travels slowly through pores or fractures, depending on the type of sediment or rock material the aquifer is made of.

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.

There are two main types of aquifers: unconfined and confined.

Unconfined aquifers

Unconfined aquifers are characterised by the absence of a low-permeability (confining) layer above them. Their watertables are typically close to the surface and roughly follow the changes in the land surface (topography).

These aquifers are an important source of groundwater in Australia because of their relative shallowness and hence ease of access.

In low-lying areas, groundwater from these aquifers is often released as natural springs, streams and wetlands.

Confined aquifers

Confined aquifers are permeable rock units deep under the ground and overlain by less permeable layers. Replenishment occurs in areas known as recharge zones where the aquifer is unconfined and which may be a long distance from the confined portion of the aquifer.

Pressure from the recharge zones creates high water pressure in the aquifer beneath the confining layer. Sometimes the pressure is so great that, where there is a break in the confining layer, water will naturally rise and bubble to the surface without the need of a pump. This is called artesian flow.

The watertable in a confined aquifer is called the piezometric surface and does not necessarily follow the land surface

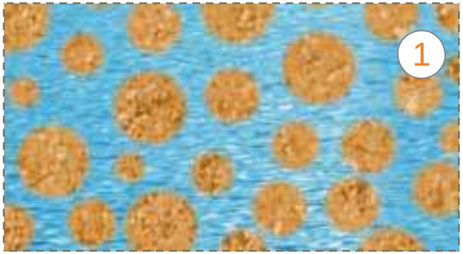
Other types of aquifers

Aquifers can be further categorised by their physical properties - as unconsolidated, sedimentary and fractured rock.

Unconsolidated aquifers

Unconsolidated, or surficial aquifers, consist of mixtures of clays, silts, sands and gravels. They are formed by the deposition of eroded material and found in river valleys, deltas and basins, as well as in lake and wind-formed environments.

These aquifers are commonly used because they are close to the ground's surface and easily accessed. They are a major source of potable groundwater in Australia.



Different types of aquifers

1. Unconsolidated aquifer
   (well sorted sand)
2. Fractured rock aquifer
   (fractures in granite)
3. Sedimentary rock aquifer
   (caverns in limestone)

Did you know?

The Great Artesian Basin (GAB) of central Australia is an example of a confined aquifer.

The GAB stores an estimated 64 900 million megalitres (ML) of water - enough to fill Sydney Harbour 130 000 times. The Basin contains water that seeped into the ground up to 2 million years ago.

The GAB covers 22 per cent of the continent, including parts of Queensland, New South Wales, the Northern Territory and South Australia.

Fractured rock aquifers

These aquifers occur in igneous (e.g. basalt or granite) and metamorphosed (e.g. marble) hard rocks that have been subjected to disturbance, deformation, or weathering. Water may move through and be stored in the joints, bedding plains, faults and zones of weathering present in the rock formations.

These aquifers are found over wide areas, but they store far less groundwater per cubic metre than other aquifers. Yields from them are difficult to predict and are frequently low.

Sedimentary rock aquifers

Sedimentary aquifers occur in older, consolidated sediments that have formed into rocks, including porous sandstones and other fractured or weathered conglomerate rock formations.

Water may move through and be stored in the tiny spaces between unconsolidated particles, or in joints, bedding planes and zones of weathering. These aquifers are often found in large, continuous sedimentary basins that range from tens to hundreds of metres thick.

Because of their size and porosity, they contain the largest overall quantity of groundwater of all other aquifer types, although their water may be of poorer quality and difficult to access due to its relative depth. They are less susceptible to variations in rainfall (drought) and impacts of surface water pollution.

Despite their limitations, they provide clean water and are of critical importance over much of inland Australia.

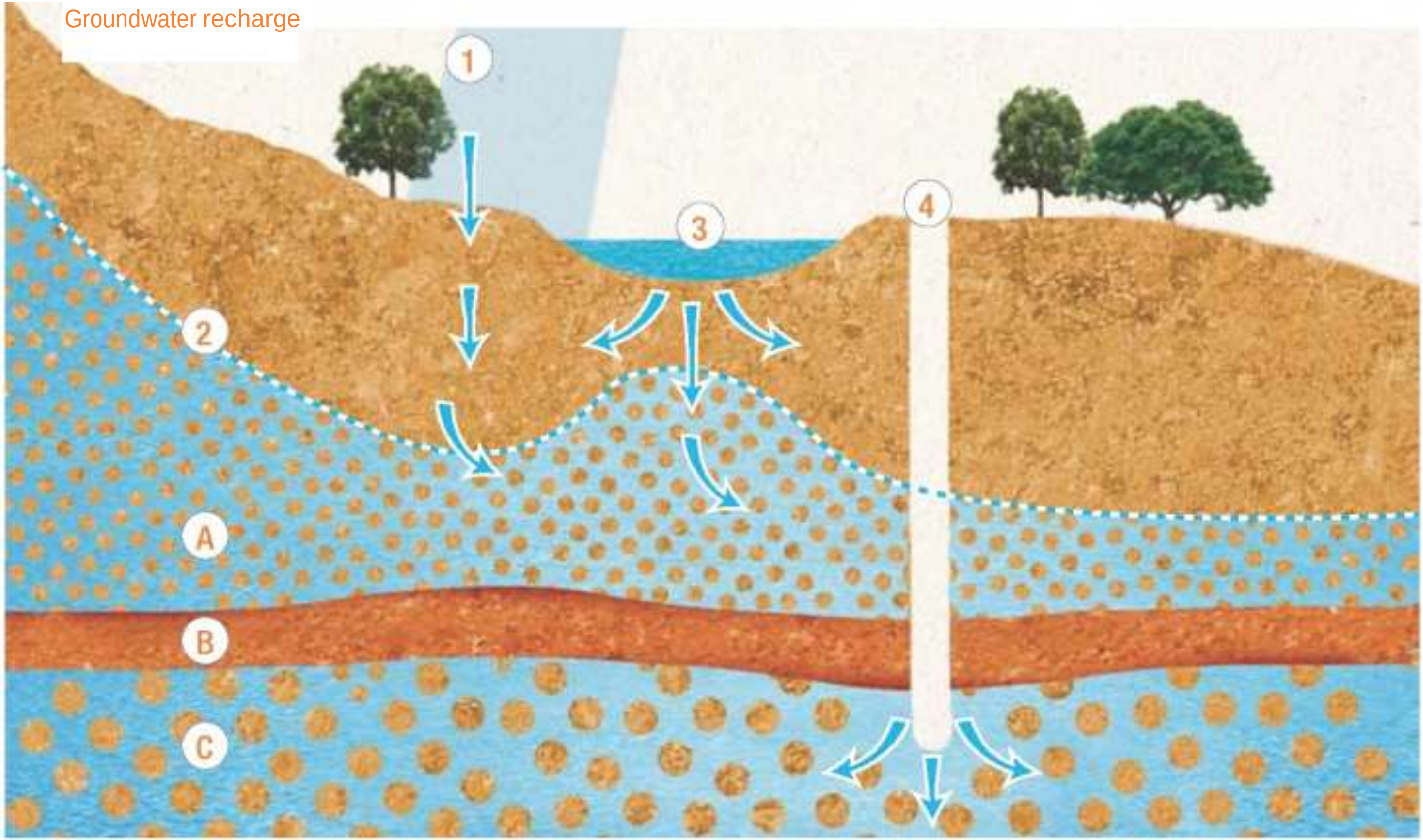
Key concept: Fossil water

Fossil water forms where aquifers have been essentially cut off from recharge for thousands or even millions of years. In some cases, recharge rates are so slow they are measured in geological time.

Fossil water can be abstracted and exploited but, unlike other groundwater, it is not replenished. Its usage can be compared to that of any other non-renewable mineral resource such as oil, coal or copper. That is why abstraction of fossil water is referred to as groundwater mining.

The use of fossil groundwater, however, is increasing in some of Australia's arid areas.

Groundwater recharge



Groundwater recharge

1. Precipitation
2. Watertable
3. Stream / river
4. Managed aquifer recharge well

A. Unconfined aquifer
B. Impermeable layer
C. Confined aquifer

Groundwater recharge

Recharge is the replenishment of water to a groundwater system from the ground surface. It can occur naturally or artificially.

Infiltration of rainfall beneath the land surface and its movement to the watertable is a widespread form of natural recharge.

Aquifers can also be recharged from surface water infiltrating the ground from water bodies such as rivers, creeks, dams and wetlands.

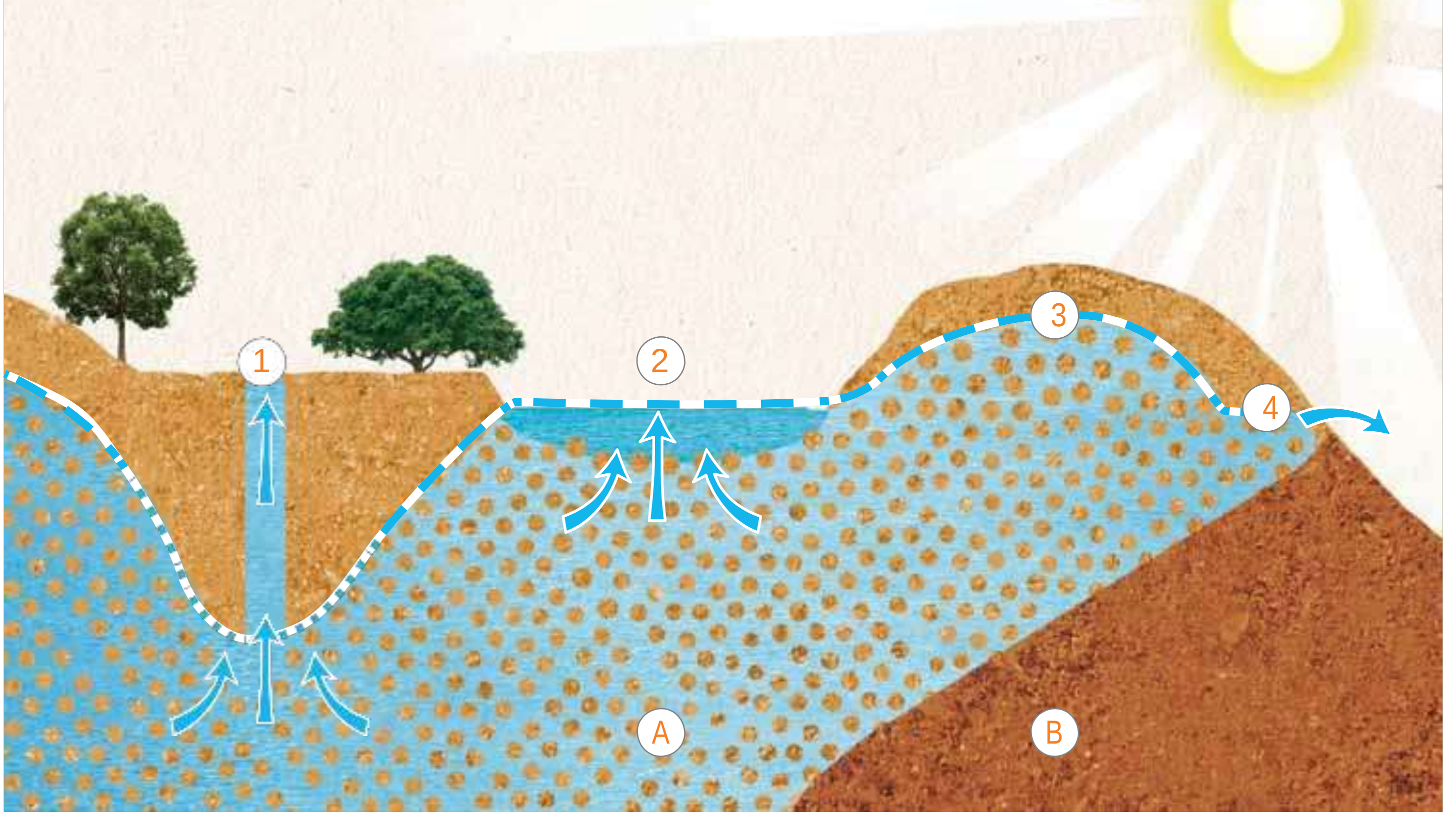
It is possible to artificially recharge an aquifer for subsequent recovery or environmental benefit. This is often referred to as managed aquifer recharge (MAR) or aquifer storage and recovery (ASR). In urban areas, MAR can be used to store desalinated seawater, recycled water, stormwater and even mains water, reducing transportation costs and water lost to evaporation. See page 40 for an example of an Australian ASR project.

Key point

Managers need to know recharge volumes and the rate at which water is transmitted through the aquifer to avoid overextraction.

Even if the amount of groundwater being pumped from an aquifer is less than its recharge, localised impacts may occur if pumping exceeds the rate at which water can be transmitted through the aquifer from recharge areas.

Groundwater discharge



Groundwater discharge

1. Pumping well
2. Stream / river
3. Watertable
4. Spring

A. Aquifer
B. Impermeable rock

Key point

As part of integrated water resource management, it is important to plan for and manage surface water and groundwater systems as one connected entity.

Groundwater discharge

Discharge is the process by which water leaves an aquifer. For unconfined aquifers, groundwater generally flows from recharge areas on higher ground to low-lying discharge areas.

Groundwater can discharge from an aquifer in a number of ways. Where the flow from an aquifer is slow and spread over a large area, it discharges by seepage; where it is localised and rapid, it discharges through a spring. Groundwater can discharge directly into streams, rivers, lakes and wetlands where they intersect the groundwater table.

A river may receive water from an aquifer through its bed - a process that may not be visible. Discharges to rivers account for most of the flow from aquifers. In drought, groundwater maintains surface water supplies for human use.

Groundwater is intricately connected with surface water through recharge and discharge and commonly affects the volume and quality of rivers, lakes and wetlands. When aquifers exceed their storage capacity, excess water flows to surface water bodies.

Groundwater–surface water connectivity

Although it is not always apparent, many rivers, dams, lakes and wetlands are directly or indirectly connected with groundwater in aquifers.

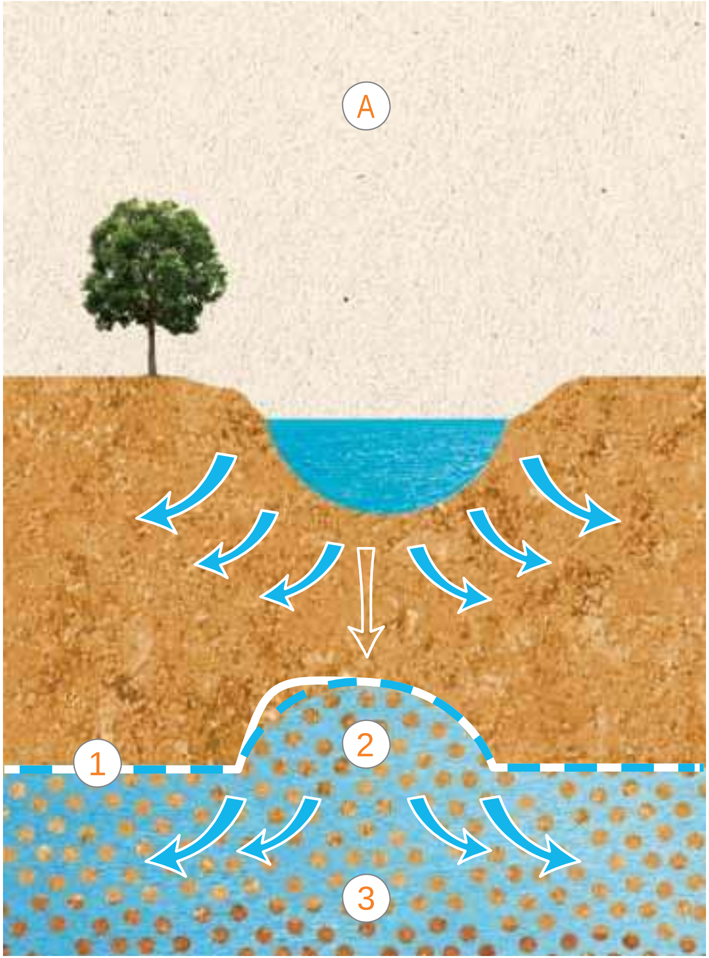
Examples of these connections include:

+ groundwater that discharges and becomes base flow of streams and rivers
+ streams and rivers that infiltrate the ground and recharge aquifers
+ groundwater extraction that reduces groundwater discharge to streams and rivers, possibly many kilometres away.

Managing connected systems

Historically, groundwater and surface water systems have been managed separately in Australia. This has contributed to overallocation of water resources in some areas.

The impacts of groundwater extraction on stream flows can be very rapid in some systems but may take decades in others. In these cases, historical overuse of groundwater will cause surface stream flows to continue declining for many years, even after groundwater extractions have been reduced.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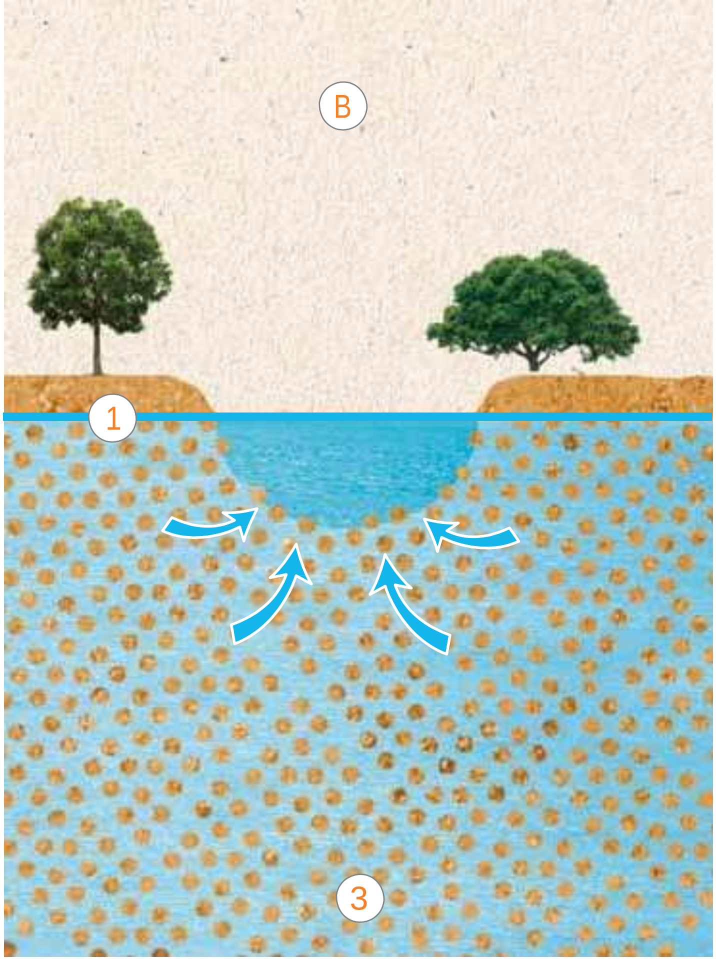
B
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3

Groundwater surface water connectivity

1. Watertable
2. Recharge mound
3. Groundwater

A. Losing stream
B. Gaining stream

Key point

Managing connected systems is complex, as it can take some time for the effects of management changes in one area to become evident in another.

Groundwater–dependent ecosystems

Many ecosystems in Australia rely on groundwater to survive.

Some are completely groundwater–dependent, while others rely on groundwater for part of the time, such as during the dry season in northern Australia. Groundwater can also provide base flows to rivers and creeks on which ecosystems depend.

The water regimes and water quality of groundwater–dependent ecosystems are changing because of competing human use and other land management factors. Human-induced changes in groundwater regimes can pose a significant threat to groundwater–dependent ecosystems, unless action is taken to maintain adequate groundwater discharge.

Above Mound Springs in the Great Artesian Basin, SA.
Photo courtesy of GABCC.

Types of groundwater–dependent ecosystems

In Australia, groundwater–dependent ecosystems can be divided into the following categories:

+ terrestrial vegetation that relies on shallow groundwater
+ groundwater-fed wetlands such as paperbark swamp forests and mound springs ecosystems
+ river base flow that relies on groundwater discharge from aquifers
+ aquifer and cave ecosystems where life exists independent of sunlight
+ terrestrial fauna, both native and introduced, that rely on groundwater discharge for drinking water (e.g. natural springs)
+ estuarine and near-shore marine systems, such as some coastal mangroves, salt marshes and sea grass beds, which rely on the submarine discharge of groundwater.

Left Spoonbills in northern Australia
Photo courtesy of NWC

Case study: Karst environments in Tasmania

Karst formations are shaped by the dissolution of carbonate bedrocks (usually limestone, dolomite or marble). This geological process occurs over many thousands of years and results in unusual surface and subsurface features, including sinkholes, vertical shafts, disappearing streams, large springs and complex underground cave systems.

Aquatic ecosystems in karstic cave environments support specialised fauna that are often distinct from that of surface waters.

Species that live solely in these environments have developed curious features, including the degeneration or loss of eyes and body pigment, elongated antennae and legs, and enhanced sensory structures.

Case study: Mound springs in the Great Artesian Basin

The Great Artesian Basin is the source of many artesian springs, some of which form mound springs that sustain groundwater–dependent ecosystems.

The mound springs provide habitat for a wide range of species, including fish, invertebrates and aquatic plants, and are unique to the Basin.

Key point

Changes in groundwater quantity and quality can severely affect groundwater– dependent ecosystems, some of which may have evolved to tolerate very specific water conditions. The changes can lead to changes in the competitive advantage that allows other species to inhabit an ecosystem, at the cost of losing the local species.

Extraction and use of groundwater by humans

Humans have extracted groundwater for centuries, and it continues to provide the primary water supply for many settlements around the world.

Key point

Without access to clean and reliable groundwater, many parts of the world, including parts of Australia, would be uninhabitable.

Groundwater use in Australia

Australia's reliance on groundwater supplies has increased in recent decades because of growing competition for surface water resources combined with frequent periods of drought, which rapidly deplete surface water supplies.

Water for towns, industry and agriculture can be sourced from both surface water and groundwater. In some areas, surface water is the primary resource, and water users will rely on groundwater only when surface water is temporarily unavailable. In some regional areas and major cities, particularly in arid and semi-arid Australia, groundwater is the only reliable source of fresh water.

Agricultural

Throughout Australia, groundwater is used to irrigate crops and pasture, provide water for stock and increase agricultural productivity.

Urban and domestic

Groundwater provides reliable town water to many communities, particularly those in rural and remote areas. Individual urban households and community facilities may also use groundwater for irrigation.

Industry and mining

Many large-scale mining projects and much of the petroleum production industry across the arid zone are wholly dependent on groundwater.

Key point

With Australia facing a future of continued climate variability and increased population growth, groundwater use is likely to increase.

Case study: Groundwater use in Western Australia

Groundwater is Western Australia's most important source of water, providing two-thirds of the state's water needs.

It is a major source of scheme water supplies and privately drawn supplies for agriculture, industry and pastoral use, and is also tapped by household bores for watering gardens.

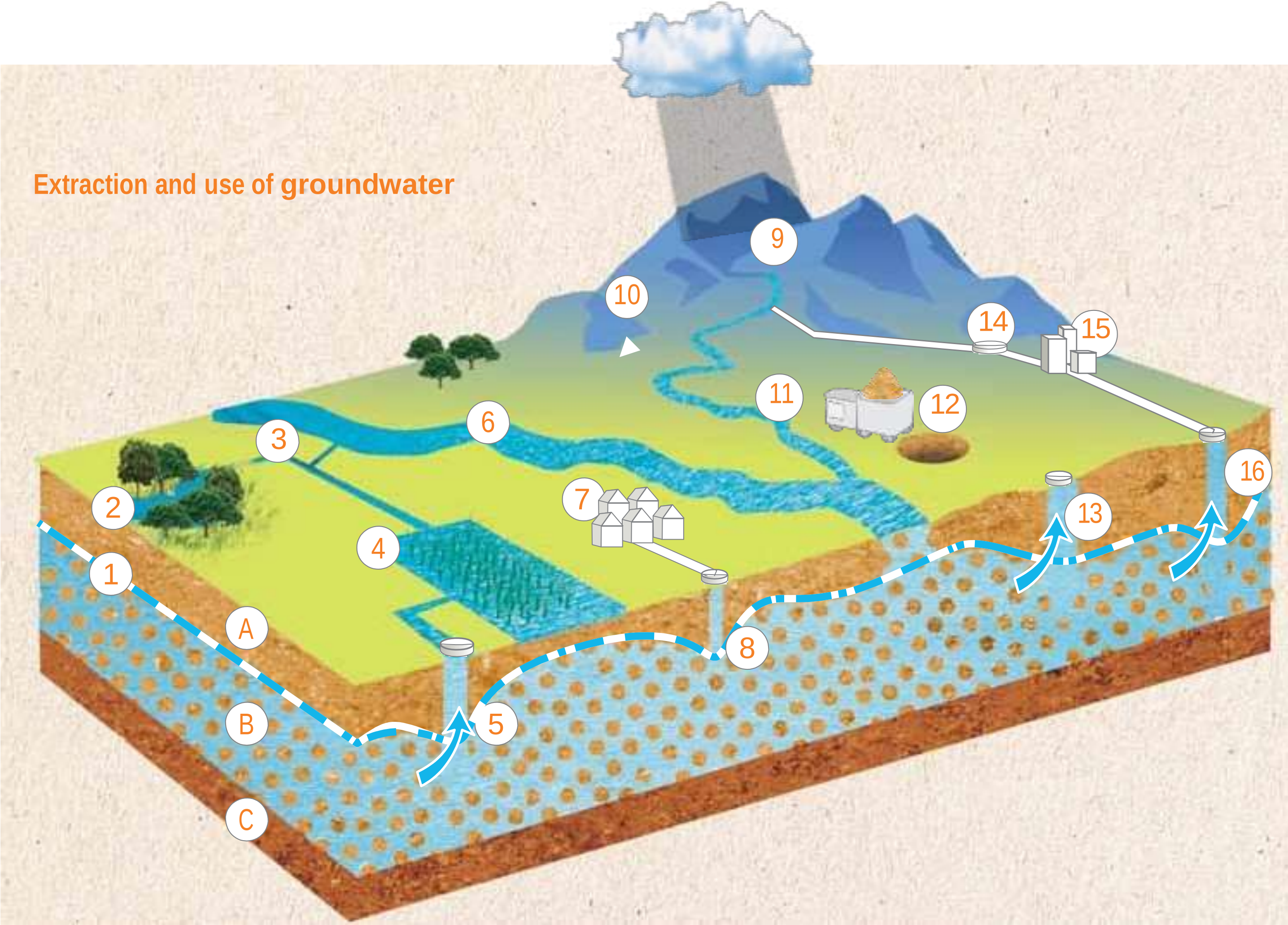
Case study: Charleville's water supply

Charleville, a rural town 660 km west of Brisbane, in south-central Queensland, often experiences long periods of low rainfall.

Despite its proximity to the Warrego River, Charleville has been dependent on groundwater for its water supply since the 1880s.

Left Blue Lake, which serves as the water supply for Mount Gambier, is fed almost entirely from a limestone aquifer. Photo courtesy of CSIRO

Extraction and use of groundwater



Extraction and use of groundwater

1. Watertable
2. Groundwater dependent ecosystem (GDE)
3. Diversion canal
4. Irrigated agriculture
5. Agricultural supply well
6. River
7. Urban use
8. Urban supply well
9. Spring
10. Runoff
11. Stream
12. Mine
13. Mining water extraction
14. Water treatment plant
15. Industrial use
16. Industrial supply well

A. Unsaturated zone
B. Saturated zone
C. Impermeable layer

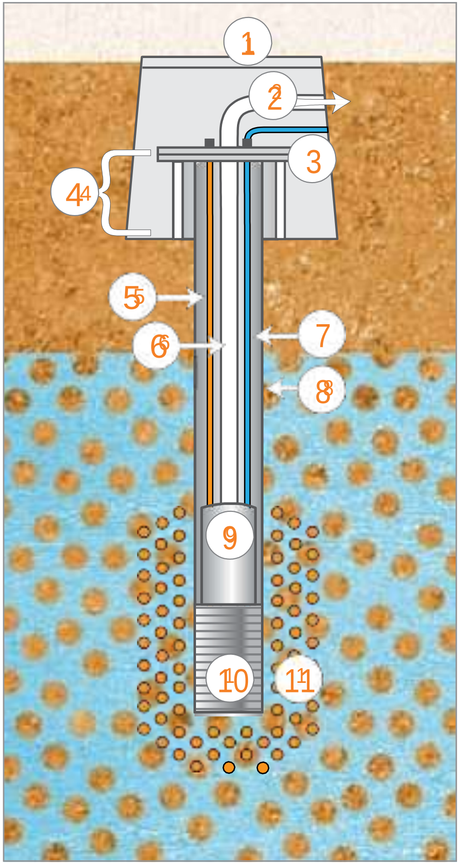
Groundwater extraction: wells and bores

In Australia, groundwater is typically extracted via a bore or well. It may also be extracted when water is sourced from natural groundwater-fed springs, rivers and lakes.

A bore is a pipe or open hole in the ground that intersects saturated ground and fills with groundwater. In most cases, a pump is needed to bring water to the surface - although some groundwater can flow to the surface naturally. This happens when a bore intersects aquifers that are overlain by thick, very low permeability layers, which keep the groundwater under enough pressure to force it to the surface (artesian groundwater).

Wells were traditionally constructed by manual digging, driving or piling. Today - depending on the ground conditions - a drill rig, rotary drill or auger is used to build most bores.

Bores can be sunk to varying depths, depending on the aquifer to be tapped, the type of rock and the desired water yield.



Bore components

1. Manhole cover
2. Delivery pipe
3. Seal
4. Headworks / Borecap
5. Access point (dip tube)
6. Rising Main
7. Power cable
8. Casing
9. Submersable pump
10. Screen
11. Gravel pack

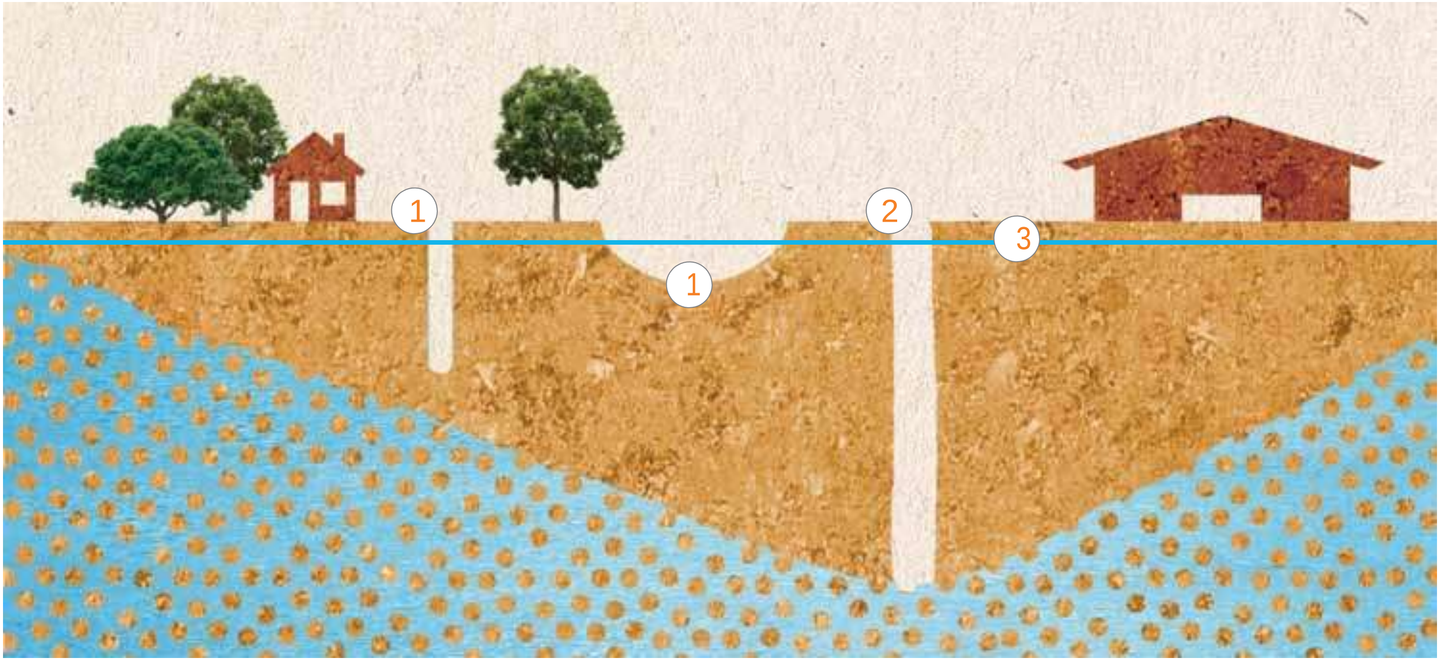
Key concept: Cone of depression

The pumping of groundwater lowers the watertable immediately around the bore, causing a dimple, called the cone of depression, to form in the watertable around the well.

The cone of depression grows larger as the pumping rate is increased but once pumping stops the watertable will eventually return to its original shape, although the water quality may have changed.

Cone of depression

1. Stream and well run dry due to overpumping of industrial well
2. Large industrial abstraction
3. Original watertable



Bore construction

Bore construction can be complex and hazardous. Generally, the deeper the well and the harder the rock, the more expensive a bore is to construct.

Aquifer yield can vary considerably with depth. Accurate information should be sought - usually from a local groundwater expert - on the specific location of a potential bore site before construction.

Bores should always be placed away from potential contamination sources and either be located on locally high ground or have correctly sealed headworks to prevent surface runoff and other pollutants entering the supply.

Construction should always be carried out to approved standards, requiring a professional and qualified driller using correctly maintained equipment.

Left Groundwater monitoring station, Condamine river catchment, Darling Downs, Qld.
Photo courtesy of MDBA

Did you know?

Extraction of water from a bore lowers the water level in the aquifer around it. Water levels will drop in other bores supplied by the aquifer, reducing the rate at which water can be extracted.

Generally, closely spaced bores, together with high extraction rates, cause the greatest water-level interference. It is therefore important that the regulating authorities and neighbouring bore owners are consulted to ensure the location of a new bore minimises interference on surrounding bores.

State and territory government water plans take this into account when allocating water extraction licences.

Operation and maintenance of bores

Correct operating and maintenance procedures - often dictated by abstraction licence conditions and government guidelines - ensure a bore operates sustainably and minimises the impact on the aquifer and nearby groundwater users.

Information on bore operation and maintenance and licence requirements is available from rural water authorities or state government departments. At a minimum, bore owners and operators should:

+ regularly monitor bore water depth for evidence of overextraction
+ regularly test water quality, especially for salinity and contaminants of concern
+ maintain pumps in accordance with the manufacturer's instructions
+ keep detailed records of bore performance (groundwater levels and abstraction rates) to track long-term changes.

Bore decommissioning

If a bore is damaged beyond repair or is no longer needed, it must be decommissioned in accordance with state regulations.

A decommissioned bore is typically backfilled with grout, from its base up to ground level.

Decommissioning ensures the bore does not provide a pathway for contaminants to enter the aquifer or move between aquifers if there is more than one layer.

Key concept: Disinfection

Disinfection of a new bore protects against naturally occurring iron bacteria.

These bacteria excrete iron, causing encrustation on the bore surface that can greatly reduce the efficiency of bore water extraction.

A driller can disinfect the bore with a mild chlorine solution, which may need to be periodically reapplied.

Challenges to the sustainable management of groundwater

In Australia, groundwater benefits a wide range of people and environments. But there are a number of threats to the sustainability of this natural resource, which are compounded by a lack of understanding of it.

This section presents some of the key challenges facing groundwater management in Australia.

Key point

Failure to address the range of challenges to the sustainable management of groundwater in Australia could result in irreversible degradation of this vital resource. Degradation may, in turn, lead to long-term detrimental impacts on industries, communities and environments that rely on groundwater.

Knowledge of groundwater

The hydrogeology and management of Australia's groundwater resources are just beginning to be understood. The fact that every aquifer is different makes it more difficult to form a clear picture of their character and extent.

All levels of government are now making concerted efforts to better understand the resource and manage it proactively.

A number of programs being funded aim to:

+ improve the skills of groundwater managers and users
+ improve our knowledge of the resource
+ quantify how groundwater systems function and are affected by extraction
+ determine sustainable extraction regimes for surface and groundwater systems.

Overallocation and overuse

Groundwater is often seen as a resource that can be drawn on when surface water is scarce. However, it is not an infinite resource, and its connectivity with surface water means we must take care to use both groundwater and surface water supplies sustainably.

Overextraction can cause groundwater salinisation, resource depletion and saltwater intrusion, and disturb the balanced interaction between surface water and groundwater.

Because of an historical lack of understanding and a shortfall in resourcing to manage, measure and monitor groundwater, too many licences have been issued (i.e. overallocated) in some areas. In some cases, this has led to the unsustainable extraction of groundwater (i.e. overuse).

Poor management practice has been exacerbated by:

+ failure to meter licensed groundwater usage in many parts of Australia
+ groundwater being provided free or under price
+ management plans failing to recognise the connectivity of groundwater and surface water.

Increasing demand

Demand on groundwater resources continues to increase in Australia. This is due to:

+ development and growth pressures
+ the perceived need to diversify water resources to complement existing supply
+ frequent drought, which increases pressure on surface water resources.

Key point

Poor quality and polluted groundwater can seriously threaten the health and viability of communities, agricultural operations and the environment. Once polluted, aquifers can be very difficult to restore.

Threats to groundwater quality

Land management practices can create diffuse or point sources of groundwater contamination, or alter natural groundwater recharge and flow paths.

Poor groundwater quality can affect a range of environmental, social and economic values. For example, low-grade extracted groundwater that is disposed of to waterways and wetlands used by the pastoral community would indirectly affect agricultural and horticultural productivity, as well as causing environmental damage.

When it is a key component of a community's or household's drinking water, poor-quality groundwater can also pose risks to human health.

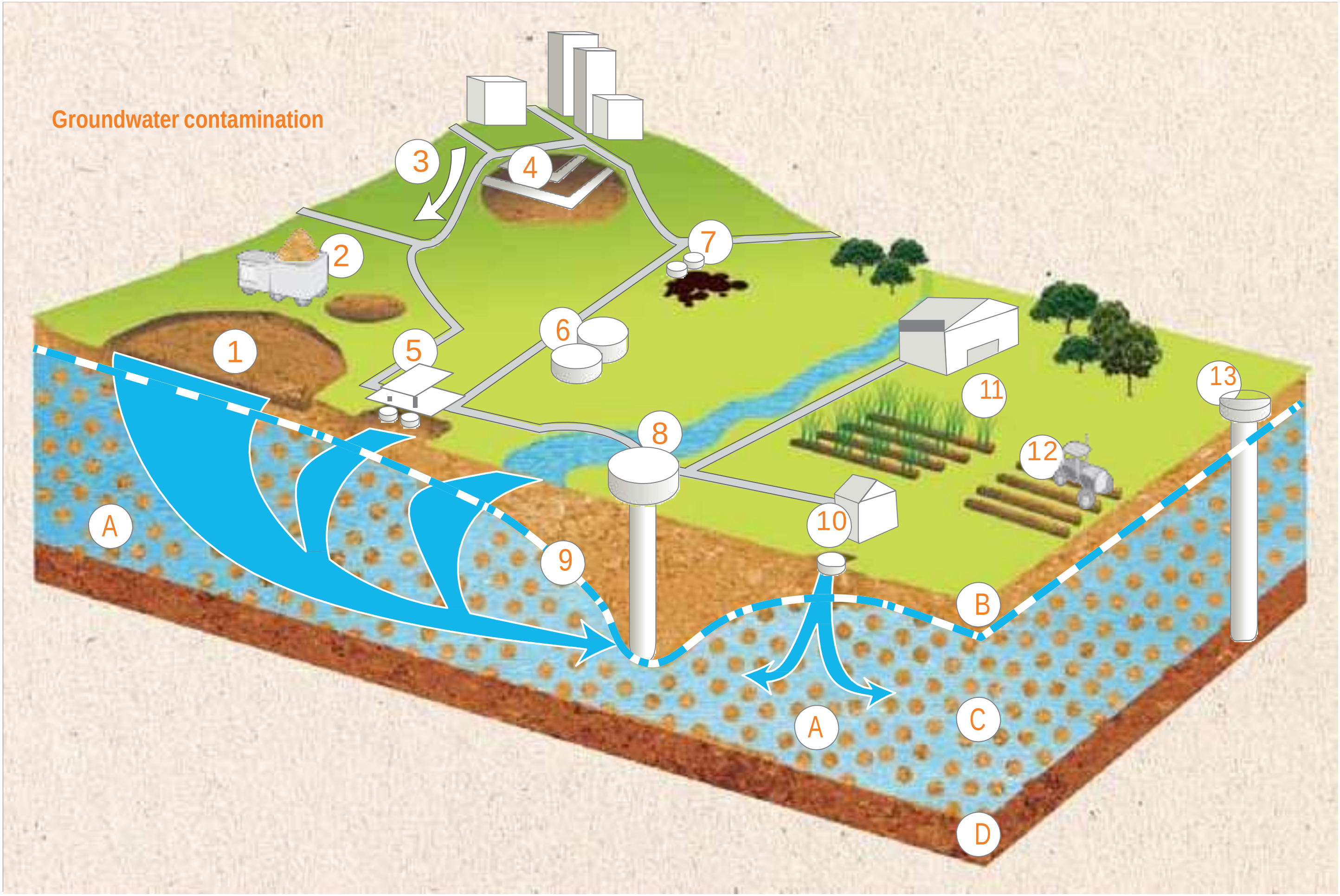
Inter-aquifer contamination

Some management activities can pose a risk that aquifers with good water quality will be polluted by water leaking from aquifers of poor water quality.

+ Groundwater bores may intersect and connect multiple confined aquifers of varying water quality.
+ Extraction of water from a good-quality aquifer creates a pressure gradient into it. Water from an adjacent aquifer, which may be of poor quality, can seep in if it is only partially confined from the extracted aquifer.
+ Hydraulic fracturing may connect aquifers of varying water quality.

Risks of inter-aquifer contamination can be minimised by:

+ monitoring aquifers to detect problems early
+ using appropriate (e.g. strong, non-corrosive) materials in the construction of bores.
+ ensuring operations avoid mixing aquifers of varying water quality
+ maintaining bores while they are active
+ decommissioning bores in the appropriate manner; and
+ using licensed drillers who employ proper standards.


Groundwater contamination
1
2
3
4
5
6
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8
9
10
11
12
13
A
A
B
C
D

Groundwater contamination

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

Contamination

Groundwater is vulnerable to contamination from a range of activities. These include:

+ industrial discharges and processes
+ agricultural practices
+ land-use changes
+ mining practices
+ oil and gas extraction
+ landfill.

Above Transparent borehole sampling tube (bailer) showing layer of fuel oil contamination floating on top of groundwater. Kwinana, WA.
Photo courtesy of CSIRO

Unconfined aquifers are most at risk of pollution. They can be contaminated by:

+ point sources such as landfills, leaking petrol stations or localised chemical spills
+ diffuse sources such as agricultural fertiliser use or polluted runoff from urban areas.

Groundwater pollutants are varied. They include:

+ detergents
+ excessive nutrients (e.g. phosphates and nitrogen)
+ heavy metals such as lead
+ industrial solvents
+ microbiological contaminants from sewage and effluent
+ pesticides
+ petroleum fuels.

Salinity

When the salt content of groundwater reaches certain thresholds it becomes unsuitable for some uses. Saline water can damage soil, be unpalatable to drink and affect the growth of crops and pasture.

Irrigation practices, inappropriate disposal of wastewater and land clearing can all increase groundwater salinity. Saline groundwater can also result if extraction from aquifers is greater than the rate of natural recharge. This draws saline groundwater into aquifer zones that previously contained only fresh water.

Groundwater can be the source of dissolved salts that cause saline-affected land. Dryland salinity occurs when a saline watertable close to ground level evaporates and leaves salts at and near the soil surface.

Clockwise from top left

Saline stream near Quairading, WA, 1989.

Trees killed by high salinity and rising groundwater near Hanwood, NSW, 2001.

Saline build-up on the dry bed of the Brukunga Pyrites Mine tailings dam, east of Adelaide, in the Mount Lofty Ranges, SA, 1992.

Photos courtesy of CSIRO

Seawater intrusion

Fresh groundwater stored in coastal aquifers is an important resource for many urban, agricultural and industrial activities.

Dependency on groundwater has increased on Australia's coastal fringe due to rapid population growth combined with frequent periods of drought.

Excessive extraction of groundwater in coastal settings causes the salinisation of aquifers because freshwater drawn from them is more rapidly replaced by seawater than by freshwater recharge.

Seawater intrusion can have major impacts on the water quality of aquifers, rivers and estuaries, as well as floodplain and wetland ecosystems. In some cases, the damage caused can be reversed but, in many cases, it is irreversible.

Treatment and disposal of extracted groundwater

Poor quality groundwater may be extracted from aquifers, for example to prevent salinity in rising water tables from entering rivers, or to depressurise an aquifer so it will release natural gas. The treatment and disposal of this water presents a management challenge.

Difficulty of remediation

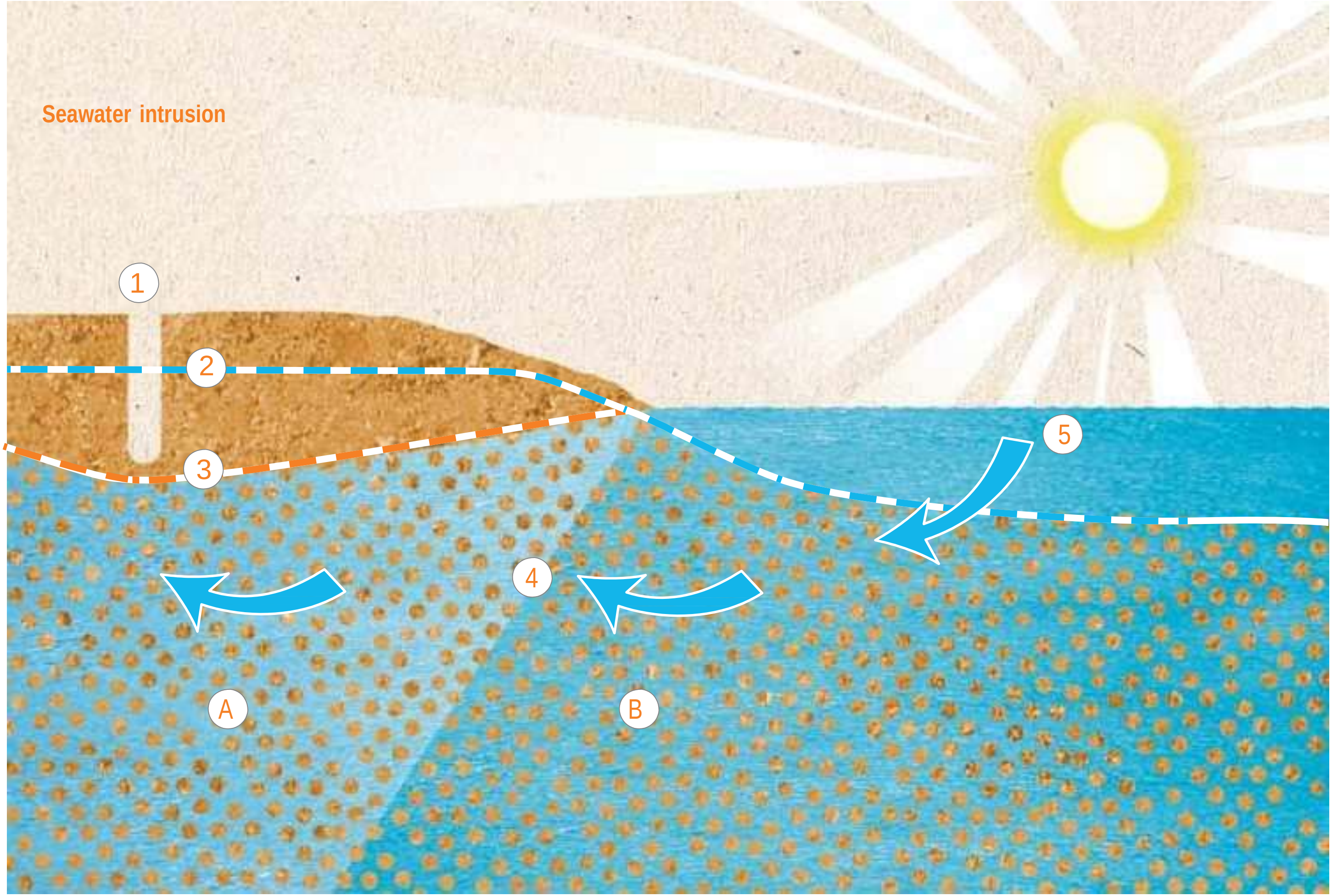
Remediation of groundwater (removal of pollutants and contaminants) is difficult and time-consuming. This is normally due to the complex and unique dynamic of groundwater movement in each system.

Extensive study is usually needed to develop a management strategy and remediation can be expensive. That is why it is almost always preferable to minimise or avoid activities and practices that degrade groundwater quality.

Different remedial techniques can be used to improve groundwater quality. For example, extraction licences may need to be acquired and then retired (surrendered) to limit extraction from overexploited aquifers. Expensive extraction and treatment systems that directly remove dissolved groundwater pollutants can also be used.

Above Laboratory for testing groundwater quality.
Photo courtesy of Geoscience Australia

Seawater intrusion



Seawater intrusion

1. Abstraction borehole
2. Original watertable
3. Lowered watertable
4. Transition zone, mixture of fresh and salt water
5. Recharge

A. Freshwater

B. Seawater

Case study: Botany, NSW

The groundwater beneath the Botany Industrial Park and nearby areas became contaminated by chemical compounds, commonly known as chlorinated hydrocarbons. This was caused by more than a century of industrial operations in the area, before the implementation of strict government-regulated environmental controls. The natural groundwater flow beneath the industrial park is in a south-westerly direction towards Botany Bay, and it moves about 110 to 150 metres a year. Groundwater plumes of different contaminants varying in concentrations and depths are present in the area between the park and Botany Bay.

Orica, a global chemical and materials supplier, is now responsible for managing the contamination and has established the Botany Groundwater Cleanup Project. The project aims to intercept the contaminated groundwater to prevent it entering Botany Bay and to treat it to a usable standard.

A $167 million plant now treats contaminated groundwater and provides water for reuse. In 2007, the plant became fully operational and treated groundwater at an average rate of more than 5 ML a day. The plant was designed to operate for 30 years.

Groundwater management in Australia

Science to underpin sustainability

A major challenge to managing groundwater sustainably is poor understanding of the connectivity of groundwater to surface water systems and dependent environments. The existing and possible future demands for human use are often poorly understood. Development of robust and effective management practices requires this detailed understanding of groundwater systems.

Groundwater management plans

States and territories apply environmental, resource and water management policies to manage groundwater. Groundwater management can be refined at a local level, where a greater and more detailed knowledge of individual aquifers can be incorporated into management practices.

Detailed management plans aim to strike a balance between water availability, people's water uses and the water needs of the natural environment. They also provide the means to control groundwater pollution and overuse in those areas.

Groundwater management plans are normally developed only for areas with well-used groundwater resources, i.e. those with high-quality water and yields that are economically viable to extract. The complexity and detail in a management plan reflect the level of economic or environmental value associated with the resource.

Below Sign near Lyrup, South Australia in 2005. Test wells and floating flags have been installed in the Renmark to Border LAP Area to display the effect of irrigation in developing perched water tables where a Blanchetown Clay layer exists. A floating flag indicates the level of the water table. Photo courtesy of MDBA

Case study: National Centre for Groundwater Research and Training

The National Centre for Groundwater Research and Training aims to produce a new generation of skilled groundwater scientists and policy makers who will develop the knowledge and practices vital to the ongoing sustainable management of our groundwater resources.

The Australian Research Council and the National Water Commission jointly funded the establishment of the centre, which will train postgraduate and postdoctoral scientists in advanced hydrogeological and related sciences. The centre will also improve knowledge of policy and management issues confronting water managers.

To implement plans, users are allocated permits or licences to extract groundwater at specified rates from specified locations and depths. Permit conditions may require the user to collect groundwater monitoring data (e.g. extraction rates, groundwater levels or groundwater quality), or to build the bore so as not to degrade the resource unnecessarily.

Below In attempting to control salinity levels near Loxton in South Australia groundwater is pumped into evaporation ponds. Image was taken in October 2008.
Photo courtesy of MDBA

Key point

Some areas lack groundwater management plans because there is no economic or environmental incentive to develop them, i.e. there is no usable groundwater resource. The balance between water availability and the environmental need is maintained naturally and there is no need for resource management.

Developing a water management plan

Western Australia has initiated a multi-agency approach to address the impacts, management and cost of a number of land-use and land management strategies aimed at increasing recharge to the Gnangara Mound.

The Gnangara Sustainability Strategy (GSS) aims to assist the development of a statutory water management plan for the Gnangara groundwater areas.

The draft GSS was released for public comment in July 2009. Sixty-two submissions comprising well over 1000 individual comments from the public were received.

In the light of issues raised during public consultation, the WA Government is now considering a final GSS.

Meanwhile, a new water management plan for the Gnangara groundwater areas will address some short-term options for water allocation on the mound.

Case study: Gnangara Mound, WA

Australia's largest urban subsurface freshwater resource, the Gnangara Mound, is under stress from increasing extraction demand and diminishing recharge rates. Bounded by the Swan River to the south and Gingin Brook to the north, the mound extends inland to the Darling Fault.

It supplies about 70 per cent of the greater Perth metropolitan area's water requirements and supports a horticultural industry valued at more than $100 million annually. It also provides water to the Goldfields Agricultural Supply Scheme, supplying towns in regional areas and Kalgoorlie-Boulder.

A threatened resource

With groundwater levels declining across most of the mound, the sustainability of supply will need careful management. Since the mid-1990s the rate of decline has increased. This is due to:

+ reduced recharge to groundwater resulting from the significant reduction in average annual rainfall since the mid-1970s

+ increased abstraction of groundwater for public municipal water supply and private and industrial use.

Long-term weather predictions indicate that below-average rainfall is likely to continue for the foreseeable future, with a possibility of greater decreases.

Changes in land uses have exacerbated the recharge problem. Extensive pine plantations and increased density of native woodland reduce the amount of rainfall infiltration available to recharge the mound.

Groundwater extraction from the Gnangara Mound has more than doubled over the past 20 years. However, there is a limit to the amount that can be sustainably extracted. Groundwater management initiatives are being developed to ensure the mound continues to contribute to the sustainable socioeconomic development of the region. The development of a statutory water management plan will enable the adoption of more robust management arrangements for the mound.

Key reforms, programs and initiatives to improve groundwater management

Groundwater and the National Water Initiative

Between 2004 and 2006, all Australian governments signed the National Water Initiative (NWI), which calls for a 'whole of water cycle' approach to water management and aims to improve groundwater management. The NWI has committed all governments:

+ to improve knowledge of groundwater–surface water connectivity by managing connected systems as one integrated resource
+ to return all currently overallocated or overused systems to sustainable levels of extraction
+ to improve understanding of sustainable extraction rates and regimes, and to develop common approaches to achieving sustainability
+ to develop a better understanding of the relationship between groundwater resources and groundwater–dependent ecosystems

To progress the groundwater reforms agreed under the NWI, the Australian Government established the $82 million National Groundwater Action Plan. Under the plan, the National Water Commission is investing in projects to improve knowledge, understanding, planning and management of Australia's groundwater resources at all levels.

State and territory arrangements

Each state and territory has its own management arrangements for promoting the sustainable and efficient use of groundwater resources. It is always advisable to contact the relevant government department for guidance and advice on local management practices.

New South Wales - NSW Office of Water

Victoria - Department of Sustainability and Environment

Queensland - Department of Environment and Resource Management

Western Australia - Department of Water South

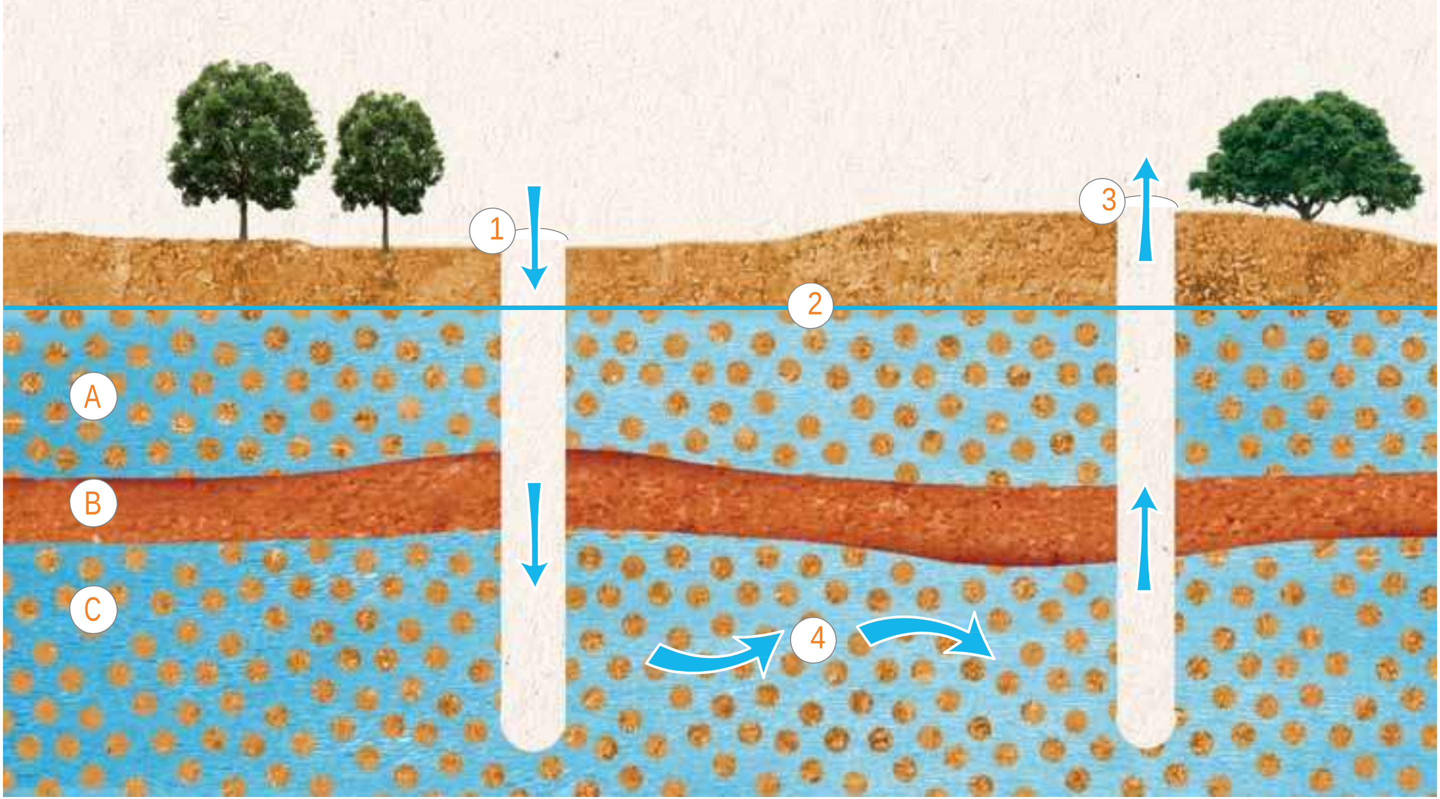
Australia - Department for Water Tasmania -

Department of Primary Industries, Parks, Water and Environment

Australian Capital Territory - Department of the Environment, Climate Change, Energy and Water

Northern Territory - Department of Natural Resources, Environment, the Arts and Sport

Aquifer storage and recovery



Emerging challenges and opportunities: the future of groundwater

Aquifer storage and recovery

1. Injection bore
2. Watertable
3. Abstraction bore
4. Groundwater flow

A. Unconfined aquifer
B. Impermeable layer
C. Confined aquifer, where water is stored

Sustainable levels of extraction

The NWI requires the return of all currently overallocated and overused surface and groundwater systems to environmentally sustainable levels of extraction. It also requires other less stressed systems to be maintained at environmentally sustainable levels.

The National Water Commission supports the development of national guidelines for water planning and management - particularly the clarification of the meaning of 'sustainable levels of extraction' and other key concepts.

Aquifer storage and recovery

Aquifer storage and recovery (ASR) is the re-injection of water into an aquifer for later recovery and use. Developed for municipal, industrial and agricultural use, ASR is becoming more common in rural and urban areas in Australia.

While it is sometimes technically challenging, ASR has the potential to provide many benefits for improved water management practices in Australia.

Where is provides adequate and useful storage, ASR will probably be preferred to large reservoirs and dams, which have lower water storage efficiencies and greater environmental and social impacts.

Water reuse in Alice Springs, NT

The Water Reuse in the Alice project recycles and stores up to 600 ML annually of treated wastewater in an underground aquifer. The water is then reused by Arid Zone Research Institute horticulture projects.

Case study: Great Artesian Basin Sustainability Initiative

Until the 1950s, artesian water came to the surface under natural pressure and was allowed to flow uncontrolled into open drains for distribution to stock. Up to 95 per cent of this water was wasted through evaporation and seepage.

The uncontrolled flow of water from bores and open bore drains in the Great Artesian Basin (GAB) reduced the pressure of the confined aquifer and threatened the health of important groundwater–dependent ecosystems and farmers' continued access to artesian water.

Under the Great Artesian Basin Sustainability Initiative, the Australian Government is investing about $140 million over 15 years (1999–2014) to repair uncontrolled artesian bores and replace open bore drains with piped water reticulation systems so that wasteful use of GAB water is a thing of the past.

Mining

Mining extracts valuable geological materials from the earth. This includes fossil fuels, such as coal and gas, rare minerals and metals, and bulk raw materials such as sands and gravels.

The mining industry offers substantial benefits to Australian society but, if it is not managed appropriately, its processes risk affecting the quality and quantity of groundwater resources.

Below Seepage of acidified water from tailings dam at the Renison Tin Mine in western Tasmania 1993.
Photo courtesy of CSIRO

Mining activities that can affect the quality of groundwater include:

+ the construction of shafts and tunnels that intersect and connect groundwater systems
+ the oxidation of certain minerals, which can cause acidic groundwater to develop and induce other contaminants to dissolve
+ storage of tailings or other materials that leach contaminants into groundwater
+ increased interception of groundwater
+ disposal of saline and contaminated wastewater produced in the mining process by allowing it to infiltrate into the ground.

Mining activities that can affect the quantity of groundwater include:

+ the deliberate lowering of groundwater tables by pumping, to permit the safe and efficient removal of materials
+ extraction of groundwater for use in mining processes.

As with any industrial or commercial process that may affect groundwater or the wider environment, mining activities are regulated, managed and assessed by state governments.

Case study: Coal seam gas

Coal seam gas (CSG) is an emerging energy resource in Australia. Development is concentrated mostly throughout central Queensland, with the remainder in New South Wales.

The potential impacts of CSG developments, particularly the cumulative effects of adjacent projects, need to be better understood and assessed. This is to manage and minimise:

+ reduced flow and water storage in non-target groundwater (and potentially, surface water) systems caused by connectivity with the dewatered coal seam
+ contamination of groundwater systems through the introduction of chemicals sometimes used in hydraulic fracturing
+ contamination of shallow groundwater systems or surface waters following the disposal of low-grade CSG water.

As with any large extractive industry, the impacts of CSG projects are investigated and assessed by each project proponent, who must define measures to minimise or negate them. As part of the planning process, project proponents must make their assessment available for public review, and usually have strict and binding conditions imposed on them by the state government.

Left Gas fired power station at Dalby, QLD. Natural gas is taken from local underground coal seams to power the power station. Image taken in 2009.
Photo courtesy of MDBA

Geothermal power generation

Geothermal energy - the heat contained within the earth - can be used to generate renewable electricity with little to no green-house gas emissions. This is done in one of two ways:

+ traditional hydrothermal projects, which use naturally occurring hot water or steam circulating through permeable rock
+ enhanced geothermal systems (EGS), which artificially circulate fluid through naturally occurring hot dry rocks (usually higher than 200°C) that may be many kilometres below the earth's surface.

Geothermal technology has the potential to affect groundwater by connecting previously unconnected aquifers. Additionally, geothermal power generation plants may use water for cooling, which increases demand and pressure on existing water resources.

A general lack of traditional hydrothermal resources and the relative infancy of EGS technology mean geothermal power generation is not yet well developed in Australia. However, a number of EGS pilot projects are underway.

Geothermal energy

1. Electricity production, building heating and cooling, desalinisation, industrial heating, etc.
2. Heat exchanger
3. Production well
4. Injection well

A. Insulating layer

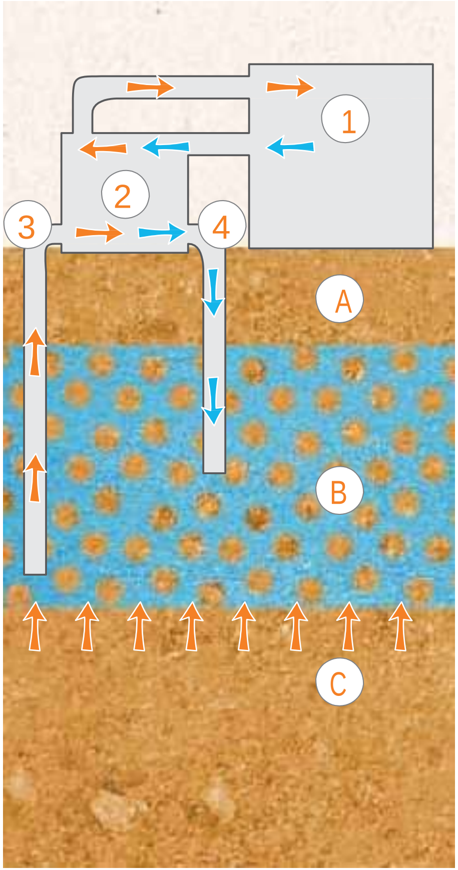
B. Hot sedimentary aquifer

C. Heat source

Example: Birdsville geothermal power station

A geothermal power plant has been periodically in operation at Birdsville, Qld, since 1992.

The plant uses a bore that produces water from the Great Artesian Basin at 98°C to generate about 80 kW net, supplying about 30 per cent of the plant output. The remainder is fuelled by diesel and liquefied petroleum gas.



Glossary

aquifer Rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit quantities of water to wells and springs.

aquifer storage and recovery The injection of water into an aquifer for subsequent recovery of recharged water from the same aquifer.

artesian When the piezometric surface of a confined aquifer is above ground. An open artesian well or bore will spurt water from the ground.

artesian bore A bore which intersects an aquifer and in which the water level rises above the natural ground level due to the hydrostatic pressure acting on groundwater without mechanical assistance.

base flow 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.

cap A limit on the volume of water that can be taken from a waterway, catchment, basin or aquifer, or a seal on the top of a bore or well to prevent the loss of water in artesian conditions.

confined aquifer An aquifer overlain by a confining layer of significantly lower permeability in which groundwater is under greater pressure than that of the atmosphere.

confining 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).

consumptive pool The amount of water that can be made available for consumptive use in a water system under the rules of the relevant water plan.

consumptive use The use of water, including for irrigation, industry, urban and stock and domestic use.

contaminant Biological or chemical substance or entity not normally present in a system, or an unusually high concentration of a naturally occurring substance capable of producing an adverse effect in a biological system, seriously affecting its structure or function.

discharge Water that moves from a groundwater body to the ground surface or surface water body (e.g. a river or lake).

diversion See extraction.

ecosystem A community of organisms and the non-living environment, all interacting as a unit.

entitlement holder The owner (holder) of 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.

environmentally sustainable level of extraction (or take) The level of water extraction from a particular system which, if exceeded, would compromise important environmental assets and the productive base of the resource.

extraction The removal of water for use from waterways or aquifers (including storages) by pumping or gravity channels.

extraction rate The rate in terms of unit volume per unit time at which water is drawn from a surface or groundwater system.

filtration Removal of particulate matter in water by passage through porous media.

formation A unit in stratigraphy defining a succession of rocks of the same type.

gigalitre (GL) 1 billion (1 000 000 000) litres, or 1 km^2 of water 1 metre deep.

groundwater Water occurring naturally below ground level (whether in an aquifer or other low permeability material), or water occurring at a place below ground that has been pumped, diverted or released to that place for storage there. This does not include water held in underground tanks, pipes or other works.

groundwater–dependent ecosystem Ecosystems that rely on groundwater - typically the natural discharge of groundwater - for their existence and health.

groundwater management unit An hydraulically connected groundwater system that is defined and recognised by Australian state and territory agencies. This definition allows for management of the groundwater resource at an appropriate scale, at which resource issues and intensity of use can be incorporated into groundwater management practices.

groundwater recharge Replenishment of groundwater by natural infiltration of surface water (precipitation, runoff), or artificially via infiltration lakes or injection.

groundwater system See water system.

groundwater use See water use.

hydrogeology The study of groundwater, including flow in aquifers, groundwater resource evaluation, and the chemistry of water–rock interaction.

hydrostatic pressure The pressure which is exerted on a portion of a column of fluid (such as water) as a result of the weight of the fluid above it.

infiltration The process of water entering the soil through its surface. The downward movement of water into the soil profile.

inflow Surface water runoff and deep drainage to groundwater (groundwater recharge) and transfers into the water system (both surface and groundwater) for a defined area.

managed aquifer recharge A term applied to all forms of intentional recharge enhancement, for the purpose of reuse or environmental benefit.

megalitre 1 million litres.

overallocation Where the total volume of water licensed to be extracted by entitlement holders at a given time exceeds the environmentally sustainable level of extraction for that system.

overuse Where the total volume of water extracted for consumptive use exceeds the environmentally sustainable level of extraction. Overuse may arise in systems that are overallocated or where the planned allocation is exceeded.

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.

piezometric surface A theoretical surface representing the total head of groundwater in an aquifer. It is defined by the level that water would rise to in a well.

porosity The proportion of the volume of rock consisting of pores, usually expressed as a percentage of the total rock or soil mass.

runoff Rainfall that does not infiltrate the ground or evaporate to the atmosphere. This water flows down a slope and enters surface water systems.

saline groundwater Groundwater that exceeds a salinity of 3500mg/l of sodium chloride.

salinity The measure of salt in surface water or groundwater, or the landscape.

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.

spring A naturally occurring discharge of groundwater flowing out of the ground, often forming a small stream or pool of water. Typically, it represents the point at which the watertable intersects ground level.

stratigraphy The study of stratified (layered) rocks and their history.

surface water Water that flows over land and in watercourses or artificial channels and can be captured, stored and supplemented from dams and reservoirs.

sustainable diversion limit An environmentally sustainable limit on the amount of water that can be taken from a system.

sustainable yield The level of water extraction from a particular system that, if exceeded, would compromise the productive base of the resource and important environmental assets or ecosystem functions.

unconfined aquifer An aquifer in which there are no confining beds between the saturated zone and the ground surface, so the watertable can fluctuate.

unsaturated zone The zone in soils and rocks occurring above the watertable, where there is some air within the pore spaces.

water access 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.

water allocation The specific volume of water allocated to water access entitlements in a given season, defined according to rules established in the relevant water plan.

water plan Statutory plans for surface water and/or groundwater systems developed in consultation with relevant stakeholders on the basis of available scientific and socioeconomic assessment to provide resource security for users and secure ecological outcomes.

water system A system that is hydrologically connected and described at the level desired for management purposes (e.g. subcatchment, catchment, basin or drainage division, or groundwater management unit, subaquifer, aquifer, groundwater basin).

watertable The upper surface of a body of groundwater occurring in an unconfined aquifer. At the watertable, pore water pressure equals atmospheric pressure.

water use The volume of water diverted from a stream, extracted from groundwater or transferred to another area for use. It is not representative of 'on farm' or 'town' use. It represents the volume taken from the environment

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

Where to go for more information

National Water Commission
www.nwc.gov.au

National Centre for Groundwater Research and Training
www.groundwater.com.au

Department of Sustainability, Environment, Water, Population and Communities
www.environment.gov.au

CSIRO
www.csiro.au

Geoscience Australia
www.ga.gov.au/groundwater

The Groundwater Foundation
www.groundwater.org

International Association of Hydrogeologists
www.iah.org

Murray-Darling Basin Authority
www.mdba.gov.au

United States Geological Survey
water.usgs.gov

Australian Capital Territory, Department of Environment, Climate Change, Energy and Water
www.environment.act.gov.au

Northern Territory, Department of Natural Resources, Environment, The Arts and Sports
www.nt.gov.au/nreta/water

New South Wales Office of Water
www.water.nsw.gov.au

Queensland Department of Environment and Resource Management
www.derm.qld.gov.au

South Australian Department for Water
www.waterforgood.sa.gov.au

Tasmanian Department of Primary Industries, Parks, Water and Environment
www.dpiw.tas.gov.au

Victorian Department of Sustainability and Environment
www.dse.vic.gov.au

Western Australian Department of Water
www.water.wa.gov.au