Groundwater

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Key messages

- Groundwater use is increasing and it is the main source of water for much of Australia's dry interior.
- Groundwater shares many of the same sustainability issues as surface water, with the added complication that over-use may not be detected for several decades because of slow renewal and movement of the resource.
- Groundwater resources are strongly connected to surface water supplies, and many of Australia's ecosystems, plants, and animals depend upon groundwater for their survival.
- The sustainable extraction limit of an aquifer is usually much less than the rate of annual recharge, or renewal. Pumping aquifers causes groundwater levels to fall, affecting ecosystems and river discharge, and increasing salinity.

Groundwater use is increasing as surface water resources become fully allocated, and as demand grows for water in drier regions in which groundwater is the predominant resource. Groundwater is ubiquitously found beneath the surface but it is only usable where the water is not too deep, where the rock or soil is permeable, and where it has suitable quality. Much groundwater in Australia is unusable because of its natural salinity.

Groundwater was regarded as a resource to be mined, much like the rocks in which it lies, but it is now generally managed as a renewable resource, recognising that it is recharged from rainfall and discharges into rivers, lakes, the oceans, and through vegetation. Consequently, groundwater management faces many of the same sustainability issues as surface water. Ecosystems depend on the discharging groundwater, and over-extraction of groundwater can lower water tables or the pressure of water, which impacts upon the dependent ecosystems and on other users.

There are added difficulties of groundwater being hidden below the surface and moving slowly so that over-use may take many years to detect. The complex movement and interactions of different layers of water can be hard to detect but they have a direct effect on the sustainable use of the resource, such as by protecting fresh groundwater from being polluted by nearby saline layers. Many groundwater systems are poorly understood, as are their connections to ecosystems, so we do not know the full potential for groundwater in Australia even though pressures on the resource are growing.

Australia's groundwater resources

The amount of water that can be pumped over a reasonable time without causing a well to dry up is called 'groundwater yield'. It is a major factor in determining whether groundwater can be put to beneficial use. Salinity is the other major factor limiting groundwater use. About 30% of Australia's groundwater is potable (containing less than 1500 mg/L of total dissolved solids). The remainder varies from brackish to highly saline, and can be saltier than sea water.

High water yields occur in aquifers where rocks or sediments are highly porous and the pores, or holes, are well connected. Aquifers are often separated by impermeable low water-yielding rocks, termed aquitards, where the pores are small or disconnected, where the rocks effectively act as a barrier to water flow.

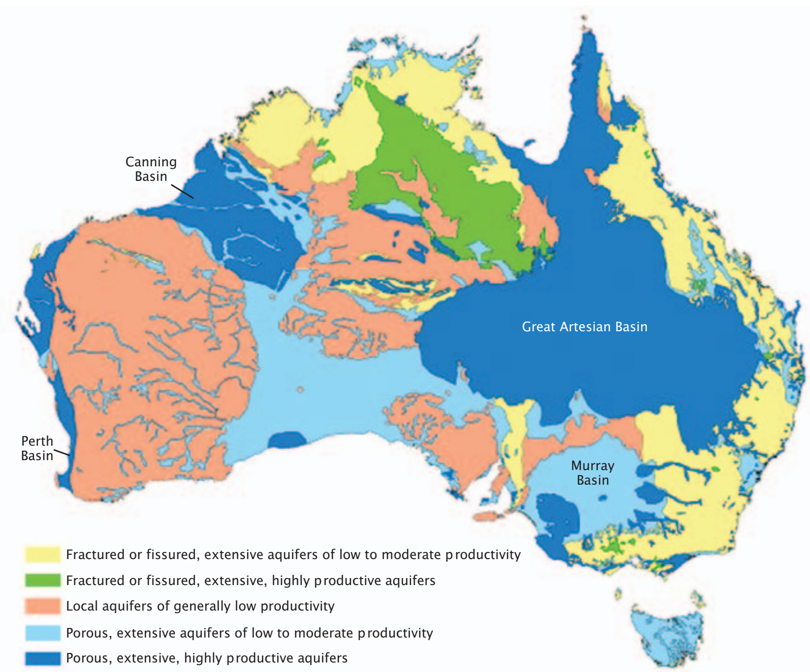


Figure 4.1: The variety of aquifer types and their productivity across Australia. The most productive aquifers are shown in dark blue and green.[1]

The aquifers of Australia's sedimentary basins can cover thousands of square kilometres and contain several layers of variable quality, separated by aquitards. Highly productive basins include the Perth Basin, the Murray–Darling Basin (straddling the South Australia–Victoria border) and the Gippsland Basin in Victoria (Figure 4.1). Where aquifers are confined between aquitards, the water can be held under pressure and flow freely to the surface if penetrated by a bore. These are termed artesian basins, where bores continue to flow without any pumping, the best example of which is the Great Artesian Basin, which provides water to much of Australia's arid interior.

Very productive aquifers are also found in the alluvial plains of Australia's river systems, and the coastal plains. The sediments in these areas have porous, permeable layers and give good yields of fresh, quality water – up to 0.8 ML/day – at a shallow depth that can be easily pumped.

Analysing a sample of groundwater, Perth. Photo: David McClenaghan, CSIRO.

Much of the Australian continent overlies hard rock geology (areas coloured yellow, green, and pink in Figure 4.1). These areas provide limited groundwater resources, because water can only refill the aquifers through cracks and fractures in the rock. Although groundwater is present, it is only usable where the fractures are connected. The uplands of the Murray–Darling Basin, the Mount Lofty Ranges (including the Adelaide Hills), the Darling Range of the South West of Western Australia and the Sydney Basin would all have high demand for groundwater, but the geology makes them largely unproductive.

Groundwater use

Groundwater use is increasing across Australia but the total use is difficult to estimate. Most groundwater is extracted by individual users and is rarely metered, and only a small fraction is managed through distribution networks. In 2004–05, licences for groundwater use were about 4700 GL/year, or 25% of the total amount of water consumed in Australia.[2,3] Unlicensed use of groundwater – mainly for stock and domestic uses – is estimated to consume an additional 1100 GL/year.[4] The amount of groundwater used is estimated to have almost doubled since the mid 1980s. Increased use of groundwater has been facilitated by recent drilling technologies and cheap submersible pumps that can lift water from considerable depths.

In the drier parts of Australia, groundwater is the predominant water source because surface water resources are so scarce. Perth and Alice Springs, for example, rely on groundwater for about 80 and 100% of their water supply, respectively. When surface water resources become scarce, users turn to groundwater to meet their needs. Declines in surface water availability during the millennium drought in the southern Murray–Darling Basin led to a modest rise in groundwater use (1240 GL in 2000–01 to 1531 GL in 2007–08), but a sharp rise in the proportion of water supplied from groundwater (11% to 37%).[5] Given the reliability of supply and convenience of self supply, the use of groundwater may not return to previous levels, even when surface water availability does.

Groundwater as a renewable resource

Groundwater is recharged, or replenished, over timescales ranging from years to millennia and eventually all recharged water discharges back to the surface (Figure 4.2). Thus, in some ways, groundwater is complementary to surface water – it is a very large reservoir of water that is renewed slowly. The large reservoir effectively smooths annual and even decade to decade variations in rainfall to provide a highly reliable supply of water, provided it is used within limits that do not have unacceptable impacts on storage or ecosystems.

Different types of aquifers have very different reservoir effects. The deep, large sedimentary basins have enormous stores of water equivalent to thousands to millions of years of recharge, although extraction can cause changes to pressure (see below). By contrast, the small alluvial aquifers of river floodplains are renewed in a matter of years and, like dams, the amount stored is much more variable and sensitive to the levels of use.

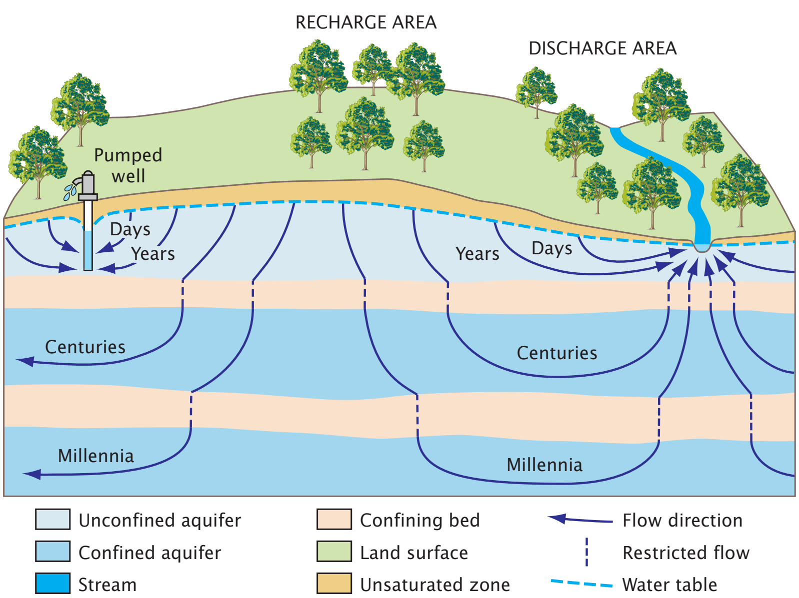
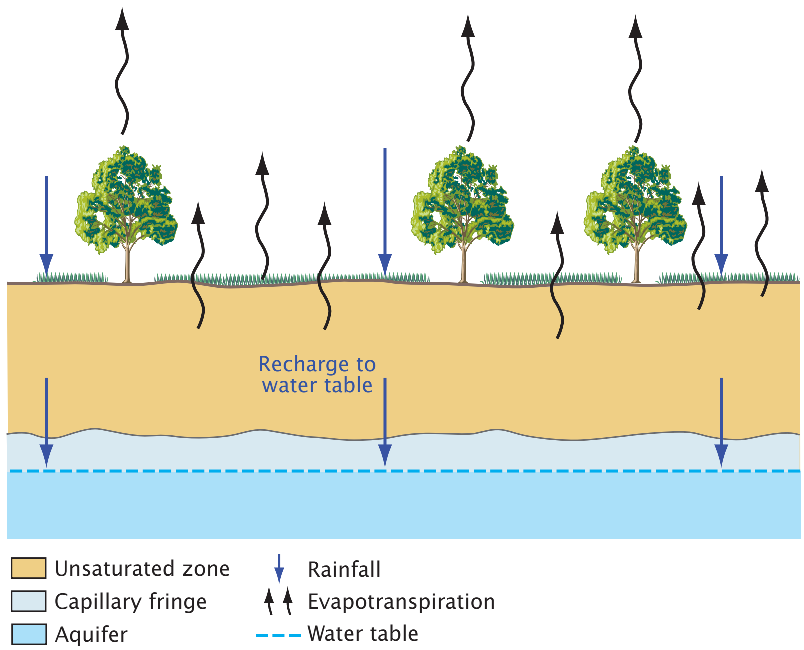


Figure 4.2: Idealised cross-section showing two types of aquifers. An unconfined aquifer below the water table flows into a stream and is also drawn down into a well. Below that, two confined aquifers are renewed over much longer time scales.[6] (Courtesy of the U.S. Geological Survey.)

Diffuse recharge occurs when infiltrating rainfall percolates through the soil, beyond the reach of plant roots, and into the underlying water table (Figure 4.3). Floodwaters also recharge groundwater, especially in parts of northern and inland Australia that are affected by monsoonal rainfall, where vast floodplains are inundated by water. The floodwaters percolate through the soils and into underlying aquifers.

A map of groundwater recharge across Australia consolidated from more than 4400 recharge estimates[7,8] is shown in Figure 4.4. For much of Australia, less than 5 mm of rainfall recharges aquifers per year on average. This is an even lower proportion of total rainfall that becomes surface runoff. Recharge exceeds 30 mm/year in some of the wettest parts of the tropics, along

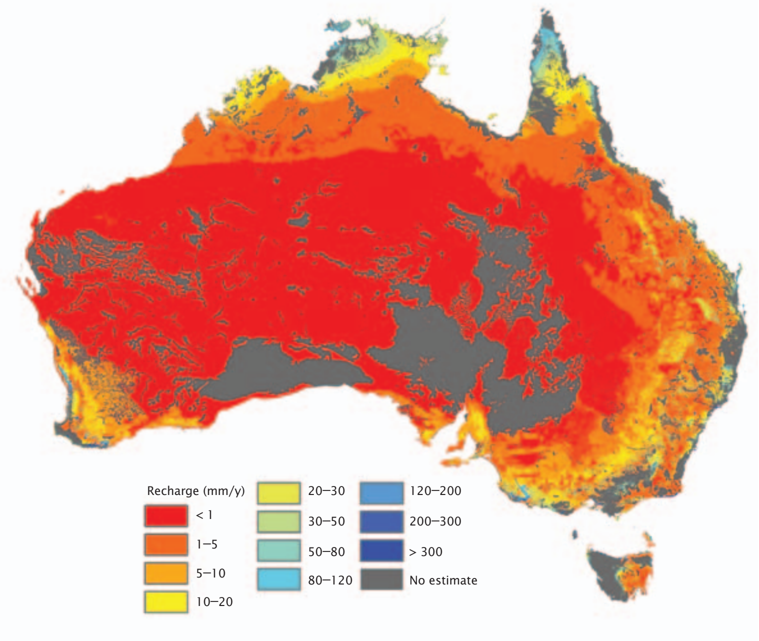


▸ ***Figure 4.3**: Conceptual diagram of water fluxes beneath the land surface to the water table. The amount of rainfall that reaches the water table depends upon rainfall, evaporation through soil and vegetation and the amount of water stored in the soil.*[6]

sandy coastal plains, and in the wetter highlands. Not all of the recharge is usable, because much of it contributes to saline, low yielding or deep aquifers.

It is important to know the amount of recharge, as it (not the volume of water stored) determines the maximum level of renewable resource. However, recharge is notoriously difficult to measure or estimate. In the long term, diffuse recharge is the amount of rainfall that is not lost to evaporation and runoff. Potential evaporation exceeds rainfall across much of Australia, but, during sporadic wet periods and large storms, rainfall exceeds evaporation and recharge occurs. Recharge is often calculated from the difference between rainfall and evaporation rates, but it only takes small errors in either of these large terms (measured in hundreds of millimetres) for there to be very large errors in the recharge estimate (which is just a few millimetres per year). A more reliable method uses soil measurements of the chloride ions that accumulate during evaporation of rainfall. The difficulty with this technique is how to scale up those measurements to represent the whole aquifer across a range of soils, rocks, and vegetation. Alternatively, the age of groundwater can be measured using chemical and isotopic techniques, which, combined with data on the aquifer's volume, can be used to estimate recharge rate. But these techniques are very sensitive to assumptions about leakage from aquifers and the sources of recharge. The best estimates are obtained by combining multiple techniques in a single groundwater model to best reconcile recharge estimates to the different sources of information.

Eventually, all of the water recharging a groundwater system is discharged. Groundwater can discharge directly into the ocean, rivers, lakes, and springs. In areas with shallow water tables, it can also discharge back to the atmosphere via evaporation through vegetation and the



◂ ***Figure 4.4****: Groundwater recharge rates across Australia, showing very low values throughout much of the interior (less than 1 mm/year). These are approximate estimates of recharge based upon extrapolation from limited measurements.*[8]

soil. Discharge occurs in many subtle ways and it too is hard to measure it directly. In general, discharge balances recharge over the long term; however, this may not be true for groundwater aged over tens of thousands of years in very large aquifers where discharge rates reflect recharge under past climates and not the current rate. Discharge of groundwater is a key component maintaining many ecosystems, including keeping trees alive in times of soil water stress.

Groundwater to surface water connections

Surface water and groundwater are strongly connected – particularly alluvial aquifers adjacent to rivers and the aquifers that support lakes. Many rivers flow long after runoff from tributaries has receded, because flow is maintained from groundwater discharge. The Daly River in the Northern Territory, for example, receives virtually no runoff during the three driest months of the year, but groundwater discharge lets it flows all year round. Except in the wettest parts of Australia, a good indicator that a river is maintained by groundwater discharge is that it flows throughout the year.

The connections between groundwater and rivers mean that the use of one resource can have negative impacts on the other. Rivers can be termed as 'gaining', 'losing', 'disconnected' or 'throughflow', depending on the interactions between groundwater and the river (Figure 4.5). In a gaining river reach, groundwater pumping may eventually reduce river flows by the amount pumped (Figure 4.6), because this water would have otherwise discharged to the river.[9] In a losing river reach, groundwater pumping can draw down the water table and induce additional recharge

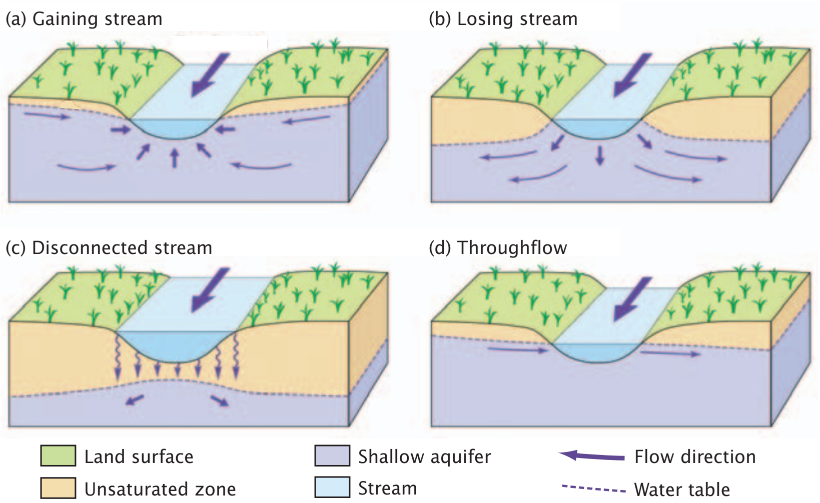
Permanent wetland supported by groundwater inflow. Photo: Bill van Aken, CSIRO.

from the river. When groundwater and rivers are managed as separate resources these interactions are neglected, leading to overestimates of the amount of water that can be used – a problem known as double accounting.

The low gradients and low flow rates through aquifers can cause considerable time lags before the consequences of pumping are realised. For example, the recent expansion of groundwater use in many alluvial aquifers will not be experienced for several decades in some cases.

Groundwater contributions to streams can be estimated from dry season discharge, but more recent methods use a combination of chemical and isotopic properties of streams to reveal the groundwater source. This provides a relatively easy and accurate way to estimate the location and amount of groundwater discharge. Water losses from 'losing rivers' to groundwater are far harder to estimate.

▸ ***Figure 4.5****: The types of connection between groundwater and streams. In a gaining stream, the water table is higher than the stream, and the stream gains groundwater. If the water table is below the stream, the stream loses water to the aquifer. In extreme cases, the stream is disconnected if the water table is below the bottom of a stream, but the water table still receives water from seepage through the stream bed. In a throughflow system, groundwater passes across the stream.[6] (Courtesy of the U.S. Geological Survey.)*



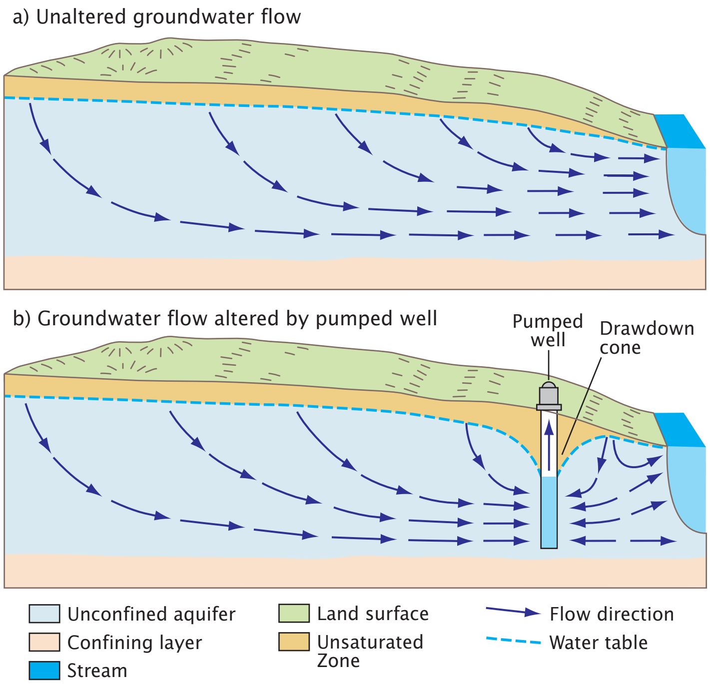


__Figure 4.6__: Comparison between an unaltered groundwater flow system (a) and a system with a pumped well installed near a stream (b). Water withdrawal from the pump becomes another component of total discharge, intercepting groundwater that would otherwise discharge to the stream.[6] (Courtesy of the U.S. Geological Survey.)

Groundwater-dependent ecosystems

Because many rivers, lakes, and wetlands are supported by groundwater, their associated ecosystems, plant, and animal species depend on groundwater discharge to survive. Australian examples include lowland forests, fauna in northern rivers such as the Daly River in the Northern Territory, springs and wetlands in the Great Artesian Basin, floodplain red gum forests near the Murray River, refuge pools in ephemeral rivers, and lakes of the Perth Basin.[10]

Some marine organisms rely on marine discharge of groundwater to support their habitats. Aquifers also contain distinctive, diverse communities of microorganisms known as stygofauna, which include bacteria that metabolise some contaminants.

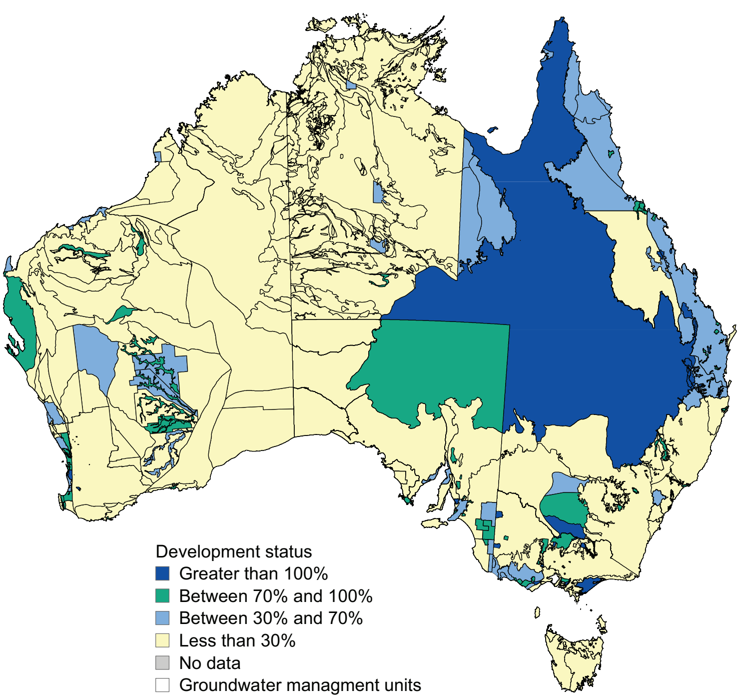
A subtle form of groundwater dependence is that of trees which can persist for long periods without rainfall in the dry season or extended drought, such as red gums across the drier regions. Most vegetation thrives where a high level of soil moisture is available close to the land surface. If soil conditions become dry and salinity levels become high, trees survive by sending tap roots to the water table and lift water from great depth.

Ecosystems may be entirely or partly dependent on groundwater, and their needs are a key part of determining sustainable groundwater extraction rates. The extent and nature of groundwater-dependent ecosystems are only now being mapped across Australia. A variety of techniques is used to estimate groundwater fluxes, but assessing how an ecosystem will respond to reduced discharge or lower water tables is a bigger challenge, involving ecological and hydrological assessments (see Chapter 9).

Sustainable groundwater extraction

The recharge rate of the aquifer is the absolute maximum amount of groundwater that could be used sustainably, but, in reality, only a fraction of the recharge can be used in the long-term or without impacts. This is because any extraction of groundwater can alter recharge, reduce discharge elsewhere, lower water levels or change the flow paths and water pressure through an aquifer. These changes may affect other users of the resource, including groundwater dependent ecosystems.

Extraction of groundwater will be sustainable if water use can be maintained long into the future by recharge and if use has no unacceptable impacts on other users (including surface water users) or the environment. Determination of sustainable yield is always a compromise between different demands for the resource as any extraction will have some impacts. Regulators can sometimes decide to allow mining of fossil groundwater reservoirs in remote areas as part of a fixed-term mining development, or consciously enable greater exploitation of groundwater during times of limited surface water supply.



▸ ***Figure 4.7***: *Australia's major aquifer systems have been developed to varying degrees.*[11] *The development status shown is the level of use compared to the estimated long-term level of use that could be sustained. (Source: National Land and Water Resources Audit. Department of the Environment, Water, Heritage and the Arts.)*

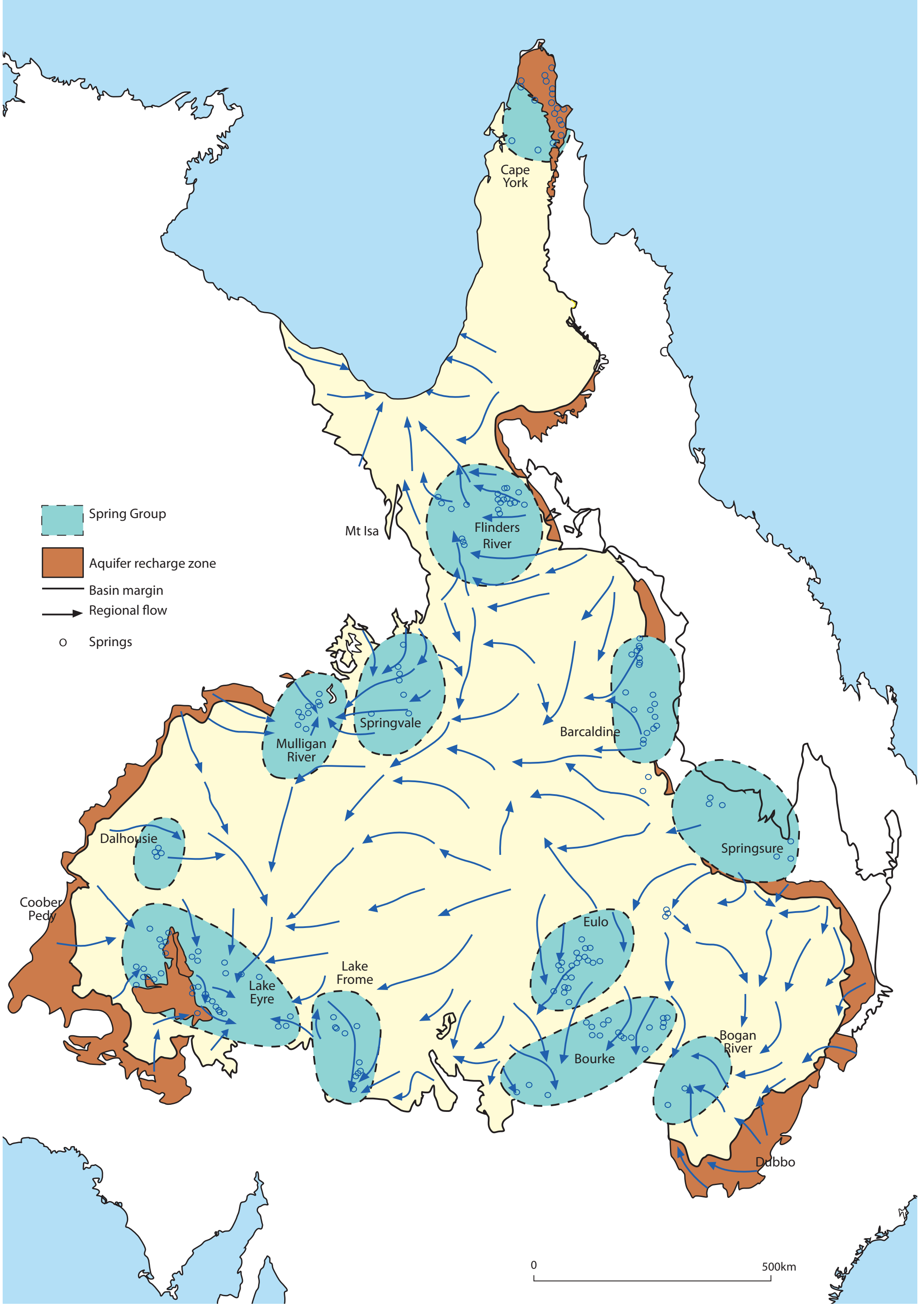
It is useful as a reference point to express the sustainable rate of extraction as a percentage of recharge. As a simple rule of thumb extraction should not exceed 50–70% of recharge without very careful assessment. This precaution is required because rates of recharge are highly uncertain and the actual rate may be lower than estimated. The sustainable level of use may also be a lower fraction of recharge than first thought when local hydrogeology, induced salinity, or impacts on groundwater dependent ecosystems are considered. The National Land and Water Resources Audit[11] (Figure 4.7) and the CSIRO's Murray–Darling Sustainable Yields project[12] have revealed several highly stressed Australian groundwater systems.

Aquifers typically have hundreds to thousands of wells. Extraction from each well will create a drawdown halo around each well (Figure 4.2); the extent and severity of the drawdown depends upon the rate of pumping and local hydrogeology. Extraction can also induce vertical leakage between aquifers. This may cause saline water to enter from adjacent poor quality aquifers, or extraction from coastal aquifers can result in sea water intrusion as the aquifer's water levels fall below sea level, as has occurred in Perth.

It may take several decades for the water table or water pressure response to spread across the whole aquifer, so consequences of pumping may not be detected until long after its use has been established. Eventually, a new lower water level will be reached where recharge is balanced with extraction and discharge. This lower water level will have a lower discharge to rivers and lakes, and may be low enough to dry the wells of other users.

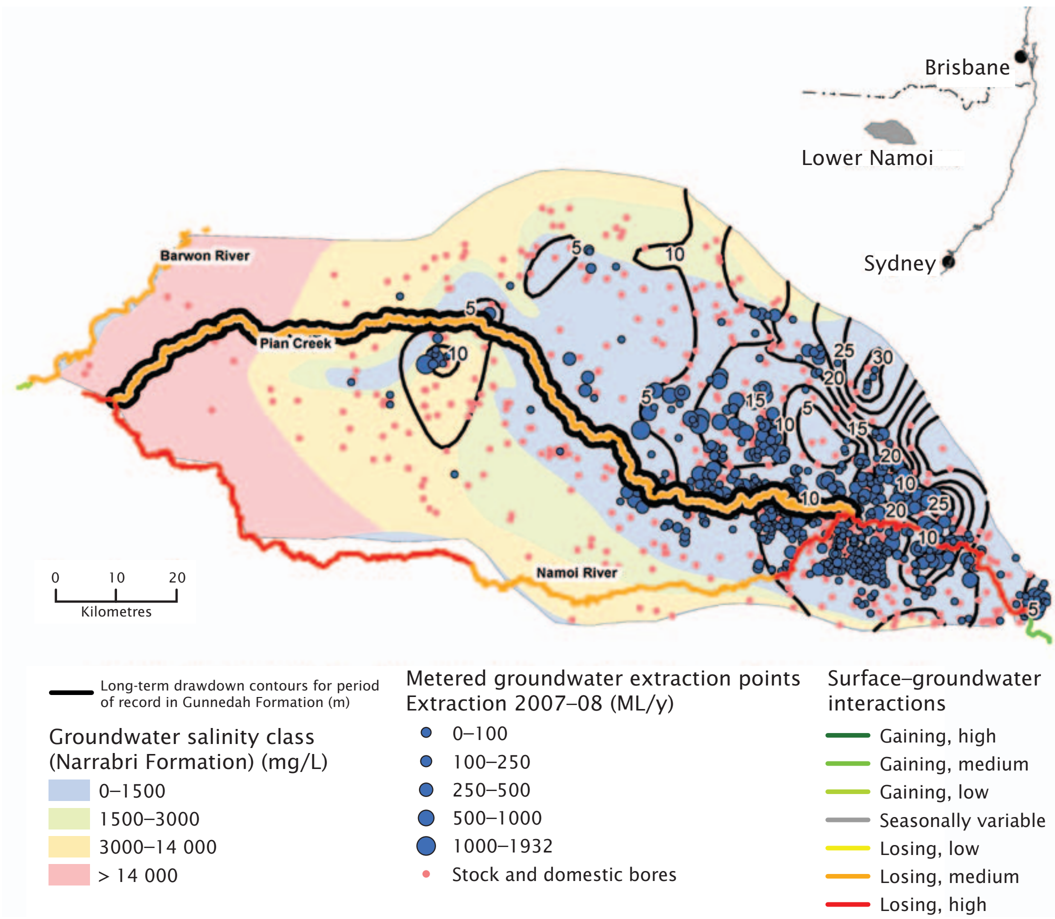
The Great Artesian Basin is a good example of the consequences of over-use. It is one of the world's largest continuous groundwater systems (Figure 4.8) and supports hundreds of springs and wetlands, many of which are listed as significant by the Ramsar Convention on Wetlands of International Importance. The typical age of water as it discharges is 1 to 2 million years, having travelled up to 1500 km from recharge areas. Thousands of wells have been drilled into the Basin's highly productive confined aquifers, and many have been left to flow, lowering aquifer pressure and encouraging feral animals and weeds that otherwise would not have an available water supply. A program of well capping is restoring pressure to the system to enable sustainable use and maintenance of dependent ecosystems. Most of the 500 GL/year used from the Great Artesian Basin is for stock watering, but there are new demands from the mining and resource sector – particularly from companies seeking to develop the abundant coal seam gas resources in Queensland's Surat and Bowen Basins, which may have an impact on existing users (see Chapter 10).

The Namoi region of northern New South Wales (Figure 4.9) has one of the most intensely exploited groundwater resources in Australia. It is a stressed system in which it was realised too late that rates of groundwater pumping were too high. Approximately 250 GL/year (2004–05) are used from the Namoi, equivalent to half the estimated annual extraction from the entire Great Artesian Basin. High levels of groundwater use over small areas in the Namoi region have lowered groundwater levels by several metres, and the alluvial aquifers now essentially receive most of their recharge from the losing streams in the area. The Murray–Darling Basin Sustainable Yields



▲ ***Figure 4.8**: The Great Artesian Basin stretches from the Gulf of Carpentaria across much of western Queensland to the north western part of the Murray–Darling Basin, and into the Northern Territory and South Australia. This map shows the general direction of groundwater flow (arrows) and main areas of groundwater springs. The main recharge zones are on the western slopes of the Great Dividing Range and some recharge occurs on the western margin.[13] (Source: ABARES.)*

project[14] suggests that groundwater use in the Namoi exceeds recharge; the water balance shows that increased groundwater use corresponds almost entirely to induced leakage from streams, reducing access to river water in dry times and increasing salinity and land subsidence caused by the declining groundwater levels.



▲ ***Figure 4.9****: An example of a report card assessment of the Lower Namoi region of New South Wales, showing distribution of wells, salinity and assessment of losing (to groundwater) streams and gaining (from groundwater) streams.[13] Groundwater levels are falling in the east and salinity of groundwater is rising in the west. The Namoi River loses water to groundwater, and Plan Creek gains water from discharging groundwater.*

Conclusions

Many aquifers with high historical rates of use are showing symptoms of over-use, such as falling water tables and lower aquifer pressures and subsequent impacts on future use, groundwater salinity, river flows, and ecosystems. The level of over-use was not recognised for decades because of the lags inherent in large, flat, and slow moving groundwater systems. Remediation of these systems is expensive and difficult because salinity and ecological damage are hard to reverse, and because of the historical expectation of reliable water supplies. Inadvertent impacts of recent strong growth in groundwater use have not been felt yet and, given that the consequences of present use are in many cases still to be felt, some caution should be exercised around future groundwater development, by putting effective risk assessment and management processes in place.

Groundwater systems are hard to understand, being hidden below the surface and involving complex geological patterns. The principles are well understood, but applying those to characterise the unique situation of each aquifer is fraught with difficulty. To properly understand a groundwater aquifer relies on information about aquifer dimensions, structure, and permeability, as well as the timescales of recharge, discharge, and groundwater flow. It requires many bore holes

Blue Lake, Mount Gambier, South Australia, fed by groundwater. Photo: Bill van Aken, CSIRO.

to be drilled and pump tests to be undertaken. Laboratory analyses of the chemical and isotopic properties of groundwater provide a complementary picture of an aquifer's history, and new remote sensing techniques to map salinity and water content are emerging. All of the information can be interpreted and integrated in detailed groundwater models, where predictions can be made of the consequence of current and future extraction.

The best groundwater assessments come from a combination of all these techniques, and research is continually improving their accuracy, but detailed groundwater assessment is expensive and time-consuming and cannot be undertaken for all aquifers. A risk assessment approach is appropriate, where the level of investigation is matched against the possible consequences of use. For large aquifers with little prospect of use, reconnaissance assessments and local experience are appropriate levels of assessment. As the rate of use starts to approach a reasonable proportion of the rate of recharge, and where other users and environmental impacts need to be considered, more detailed assessments are required. The challenge is to ensure that additional investigations and regulations keep pace with growing use. Groundwater monitoring and adaptive management complement thorough planning by detecting and responding to early symptoms of over-use. A better understanding of groundwater would lead to less precaution needing to be applied to future use, or less frequent occurrence of the impacts of over-use.

Further reading

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