Chapter 6
Groundwater in Australia: Occurrence and Management Issues

Steve Barnett, Nikki Harrington, Peter Cook, and Craig T. Simmons

Abstract Groundwater is one of Australia's most important natural resources and is the only source of water available for many regions, supplying urban areas, agriculture, industry and mining developments. The economic value to the economy is estimated to be $A34 billion. Groundwater also sustains ecosystems, through baseflow discharges to surface water and artesian spring discharges.

Groundwater is found in both sedimentary and fractured rock aquifers, with most groundwater extraction occurring from the higher yielding sedimentary aquifers including unconsolidated Quaternary alluvial sediments, consolidated sandstones and limestones in large sedimentary basins. Low salinity groundwater is generally found in higher rainfall areas around the southern coastal areas. In the arid interior, high evaporation results in salinities up to 100,000 mg/L. Deeper confined aquifers may contain older low salinity groundwaters recharged thousands of years ago.

Groundwater resources have been rapidly developed over the past 40 years. Current extraction is about 5000 GL/year with 70% used for irrigation whereas in France, 60% of the total extraction of 34,000 GL/year was used for public water supplies. Early management intervention has resulted in only 2% of Australia's management areas being over-exploited.

Future challenges for groundwater management in Australia include potential impacts of climate change, impacts of mining and declining government funding.

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6.1 Introduction

Australia is the driest inhabited continent on Earth with low rainfall, high evaporation and very limited surface water resources. Consequently, groundwater is one of Australia's most important natural resources and is the only reliable and cost-effective source of water available for 60% of the continent's total area, supplying urban areas, agriculture, industry and mining developments. It often plays a crucial role in sustaining ecosystems, through baseflow discharges to surface water and artesian spring discharges. Groundwater provides more than 30% of Australia's total water consumption and generates national economic activity worth $A34 billion a year across agriculture, mining, industry and water supplies in rural cities and towns (Marsden Jacob Associates, 2012).

This chapter provides an overview of Australia's groundwater resources and traces the history of their development. Section 6.2 provides details of groundwater resources in Australia, Sect. 6.3 discusses groundwater use, whilst Section 6.4 examines groundwater management issues, including the need for more timely policy responses (as will be explored in more detail in later chapters in this book). Section 6.5 briefly outlines future challenges.

6.2 Groundwater Resources in Australia

Australia lies between latitudes 10° and 44°S, and is covered by several climatic zones ranging from tropical with summer rainfall in the north, to temperate with winter rainfall in the south. Most of the interior has an arid climate, with some areas receiving less than 100 mm median annual rainfall and experiencing annual evaporation of more than 4000 mm. The rainfall averages 465 mm and results in a runoff of only 57 mm because of the high evaporation. The seasonal distribution of rainfall varies greatly over the continent which is generally of low relief. The tropical areas of northern Australia have high summer rainfall because of monsoonal conditions. Elsewhere higher rainfall due to topographic effects mainly occurs along the Great Dividing Range which runs parallel to the east coast, and in the south-western and south-eastern parts. These areas of higher rainfall are also where most of the highly urbanised population of 23.4 million resides. Figure 6.1 presents Australia's average annual rainfall, which in comparison by volume, represents only 1% of the annual rainfall falling on France.

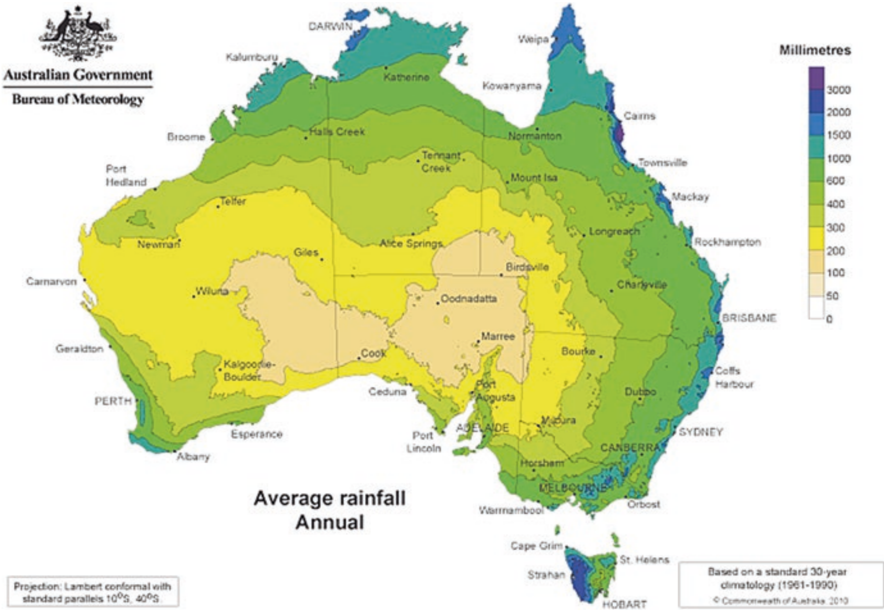

Fig. 6.1 Average annual rainfall of Australia

Although groundwater is found in both sedimentary and fractured rock aquifers, most groundwater extraction occurs from the higher yielding sedimentary aquifers which cover about 65% of the continent. Shallow unconsolidated alluvial sediments contain good quality groundwater in the higher rainfall highland areas along the eastern coastline, however further inland in drier areas, these sediments contain more saline groundwater due to lower rainfall and higher evaporation.

Aquifers in large sedimentary basins contain considerable volumes of groundwater in consolidated sandstones and limestones. Aeolian sediments and karstic limestones also form significant aquifers.

Figure 6.2 illustrates the major groundwater resources in Australia which include:

- the Great Artesian Basin, which covers one fifth of the continent;
- the major alluvial aquifers of the Murray–Darling Basin, which support Australia's major food bowl;
- the Perth Basin, which supplies much of Perth's water demands;
- the Canning Basin in northern Western Australia;
- the Daly River Basin of the Northern Territory; and
- the Otway Basin aquifers of south-east South Australia and south-west Victoria.

Fractured rock aquifers are prevalent throughout much of the Great Dividing Range of eastern Australia, Tasmania, the Mt Lofty and Flinders Ranges in South Australia, and the ancient hills and ranges of Western Australia and the Northern Territory (Fig. 6.2). Given the variability of water-bearing joints and fractures in these aquifers, well yields and salinities can vary greatly over short distances.

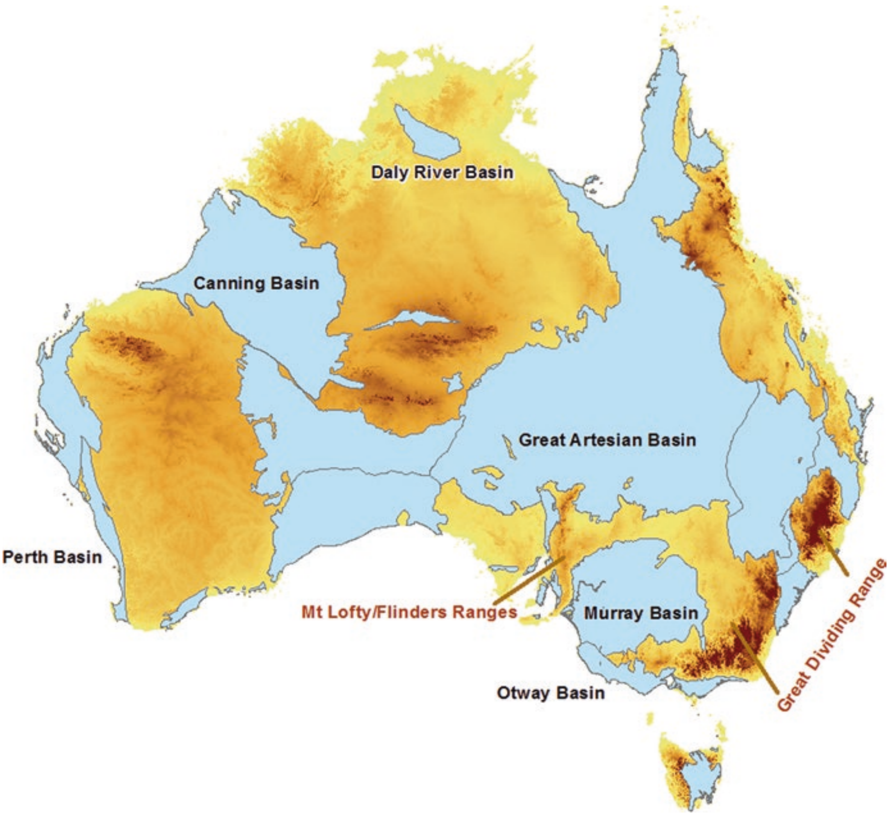

Fig. 6.2 Major groundwater resources of Australia

Typically, better quality groundwater is found in regions with higher rainfall where recharge to the aquifers can occur more readily. Sandstone, quartzite, siltstone and basalt aquifers tend to be productive because the joints and fractures are open and permeable, whereas in metamorphic and intrusive igneous rock aquifers, they are poorly developed or infilled by clayey weathered material.

A number of ecosystems that rely on groundwater discharge or access to groundwater, occur in a wide range of forms throughout Australia (Clifton, Cossens, & McAuley, 2007). There are three main types of these groundwater-dependent ecosystems (GDEs);

- ecosystems reliant on the surface expression of groundwater such as springs and wetlands
- ecosystems reliant on access to subsurface groundwater, for example vegetation that accesses groundwater through roots, drawing on moisture derived from the watertable
- aquifer and cave ecosystems that occur within the aquifer itself and support stygofauna

As the water requirements of GDEs must be taken into account in most groundwater management plans in Australia, a key advance has been the commissioning of a web-based GDE atlas for Australia (http://www.bom.gov.au/water/groundwater/gde/map.shtml). This atlas displays ecological and hydrogeological information on GDEs across Australia, collated from a number of sources, including published research and remote sensing data.

6.3 Groundwater Use

6.3.1 Historical Development of Groundwater

It is probable that groundwater has been used in Australia by aborigines for thousands of years according to the artefact evidence found adjacent to shallow wells and springs in several locations (AWRC, 1975). Although the first European settlements in the late eighteenth century were located according to the availability of surface water, shallow hand dug wells were also used when surface water was unavailable during drought, or of unsuitable quality due to contamination. As settlement spread from the well-watered coast into the more arid interior, the value of groundwater for providing reliable water supplies was realised. In 1857, the state of Victoria initiated the first known investigation into groundwater resources, and in 1871, an artesian well was drilled to a depth of 52 m near Perth in Western Australia (AWRC, 1975).

Development of the iconic Great Artesian Basin (GAB) began with the first well drilled in 1879 in north-western New South Wales. Similar wells were drilled in adjacent states over the next few years and by 1910, over 1500 artesian wells had been drilled throughout the GAB. Since then, over 30,000 wells have been drilled which have been essential for the expansion of the pastoral industry into the dry interior of Australia. This has resulted in declining pressure levels and in response, an extensive program has been undertaken to restore pressure levels by capping uncontrolled flowing wells (see Chap. 7).

After World War 2, the increased use of the rapid rotary drilling technique and downhole geophysical logging tools that could detect permeable layers, allowed more thorough investigations of groundwater resources. Demand for groundwater increased in the 1950s and 1960s to support agricultural development in the following regions;

- Lachlan Valley – alluvial sediments in tributary valleys of the Murray Basin in New South Wales
- Burdekin Delta – alluvial sediments deposited by the Burdekin River in northern Queensland
- Northern Adelaide Plains – Tertiary limestones of the St Vincent Basin in South Australia
- Western Port Basin – Tertiary sands, limestones and volcanics bordering the coastline in Victoria

During this period of rapid expansion in the 1970s and 1980s, a lack of resourcing for the management and monitoring of a number of groundwater systems in Australia, and occasionally some political interference, led to too many licences being issued and agricultural users being granted allocations in excess of the sustainable extraction limits (over-allocation) and in some cases, the volumes of groundwater extracted are also above the sustainable extraction limits (overuse) (NWC, 2012). These issues ae discussed in more detail in later chapters (see Chaps. 7 and 14).

In recognition of the huge task of assessing Australia's water resources, the Australian Water Resources Council was formed in 1962 by the federal and state governments (now no longer in existence). This led to a significant increase in investment into the investigation of major groundwater resources which continued through the 1980s and 1990s. Since 2000, the focus has been mainly on the monitoring and management of the known groundwater resources where groundwater extractions for irrigation purposes have generally stabilised.

6.3.2 Groundwater Usage

As detailed above, Australia has witnessed a rapid development of groundwater resources use over the past 40 years. Accurate statistics on groundwater abstraction and use in Australia has been difficult to obtain in the past due to limited monitoring infrastructure and inconsistencies in water accounting methods. However in recent years, more consistent national reporting procedures required by the National Water Initiative (see Chap. 7) has resulted in more accurate estimates.

For the 2015/16 water use year, an estimated 5000 GL was extracted, which represents about 63% of the total volume of entitlements (BoM, 2016). These volumes amount to approximately 30% of Australia's total water consumption. By contrast, the total consumption in France is about 34,000 GL/year. Because of the drier climate and smaller population in Australia, 70% of groundwater extraction is for irrigation whereas in France, 60% of extraction is for public water supplies. The mining industry in Australia is estimated to extract an additional 1500 GL/year. Figure 6.3 shows the regions of Australia and their dependence on groundwater.

The salinity of Australia's groundwater resources varies widely and is a major factor controlling groundwater use and development. In unconfined aquifers, low salinity groundwater which can be used for human consumption is generally found in higher rainfall areas around the northern and eastern coasts, as well as the south-eastern and south-western portions of the continent. In deeper confined aquifers, older low salinity groundwaters recharged thousands of years ago (possibly during wetter climates than that experienced today), may be found beneath arid areas after travelling along long flow paths e.g. in the Great Artesian and Murray-Darling Basins. These 'ancient' resources, sometimes over one million years old in the Great Artesian Basin, provide essential supplies for towns, livestock and irrigation. Over large areas of the arid interior where evaporation considerably exceeds rain-

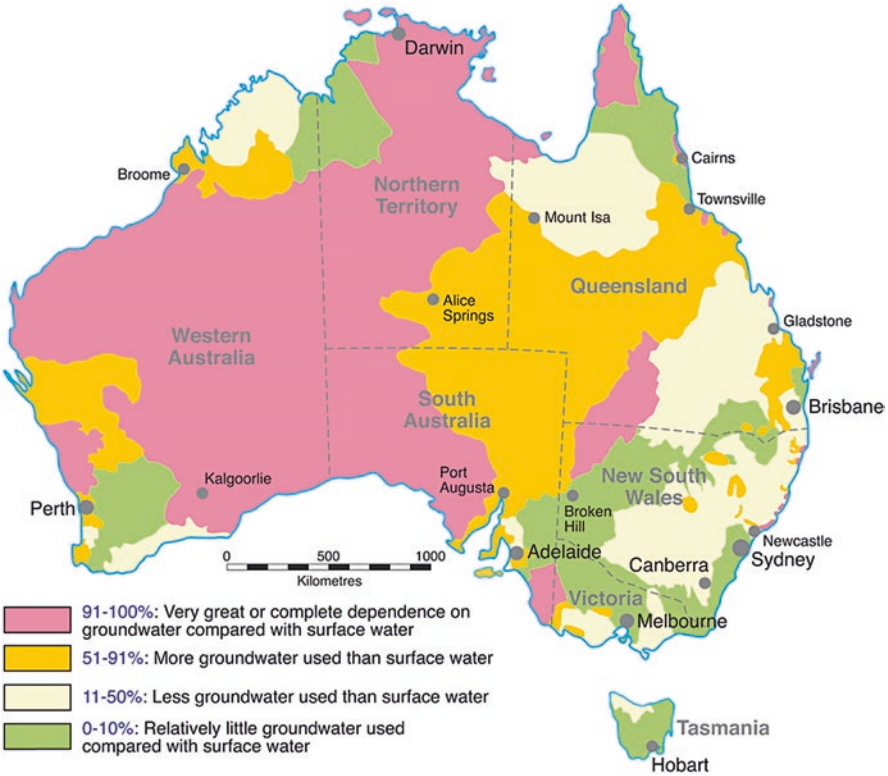

Fig. 6.3 Dependence on groundwater in Australia

fall, high salinities occur that are too high for drinking or agricultural purposes. However, the gold mining industry in Western Australia uses highly saline groundwater over 200,000 mg/L sourced from Tertiary palaeochannels for mineral processing.

6.4 Groundwater Management Issues

6.4.1 Overallocation and Overuse of Groundwater

The impacts of groundwater overuse are well documented (unacceptable decline in groundwater levels which could lead to loss of access to groundwater by users and ecosystems, increased infrastructure and pumping costs, seawater intrusion; and increased salinity of aquifers through inter-aquifer leakage).

The National Water Initiative (which is explained in more detail in Chap. 7) committed the States to address these issues. In 2016, there were 288 groundwater management areas (GMAs) throughout Australia. Of these, 136 GMAs had volumetric limits for extraction, with 25% of these classified as over-allocated, but more importantly, only 2% considered overused. While some of the GMAs that do not have volumetric limits could be considered 'at risk' or 'over-allocated', the management plans generally have rules that keep extractions at sustainable levels (BoM, 2016). Despite the uncertainties in determining extraction volumes in some GMAs, it can be concluded that over-extraction is not a widespread problem in Australia, although there may be localised issues in some areas.

6.4.2 Impacts of Groundwater Extraction on Surface-Water Systems

Groundwater and surface water are often connected. They are part of the one hydrologic cycle, and surface water resources can be significantly impacted by groundwater abstraction. Groundwater recharge can also be impacted by surface-water extraction or river regulation. Although hydrologists and hydrogeologists have long recognised the interconnection between surface-water and groundwater resources, and a study found that in some of Australia's more heavily developed catchments, reductions in baseflow to rivers and streams have caused reductions in surface water flows or complete drying out of streams (Evans, 2007). The impact of groundwater abstraction on surface-water systems has only been translated into policy and management to a limited extent so far (see Chap. 8).

The time lag from the commencement of groundwater pumping until the impact on a surface-water system is realised, can vary from days to decades or longer. Historically, groundwater and surface-water resources have been managed separately, however when increases in demand and low rainfall levels caused regulators to cap the use of many surface water resources, this had the unintentional result of shifting the extraction to nearby groundwater resources.

One of the best examples of this was in the Murray–Darling Basin, where there is usually a close hydraulic connection between the streams and the underlying alluvial aquifers. In 2008, groundwater use represented 16% of total water use in the Basin, and it was expected that this could increase to over 25% by 2030 under the prevailing water management arrangements that restrict surface water use. It was estimated that 25% of the groundwater use would eventually be sourced directly from induced streamflow leakage (CSIRO, 2008). The development of the Murray–Darling Basin Plan is Australia's most prominent example of government intervention to achieve effective conjunctive management of surface-water and groundwater resources (see Chap. 8).

6.4.3 Groundwater-Dependent Ecosystems

As mentioned earlier in this chapter, groundwater-dependent ecosystems (GDEs) occur in a wide range of forms throughout Australia. A great deal of progress has been made in the identification of GDEs. In 2007, a practical tool was developed to assist in the identification of GDEs and the management of their environmental water requirements (Clifton et al., 2007). This toolbox was updated in 2011 to include an assessment framework and assessment tools (Richardson et al., 2011a, 2011b).

6.4.4 Effect of Climate Change on Availability and Quality of Groundwater Resources

Over the past few decades, large areas of Australia have experienced a drier climate and reductions in surface water resources, causing increasing pressure on groundwater resources. Analysis of the climate over the past 80 years shows warming over most of Australia (except in the inland north-west); increasing rainfall over northern, central and north-western Australia; and decreasing rainfall in eastern, south-eastern and south-western Australia (Barron et al., 2011). From 1997 to 2009, large areas of southern Australia, particularly the southern Murray–Darling Basin, experienced the prolonged millennium drought which was the most severe drought in the 110 years of recorded rainfall history.

The south-west region of Western Australia has experienced a longer trend of gradually declining rainfall than the rest of the country. The average runoff to Perth reservoirs between 1975 and 2009 was 55% lower than prior to 1975, a result of a 16% fall in average annual rainfall. This led to the development of additional water supplies for Perth, resulting in a greater reliance on groundwater and commissioning of the first desalination plant to supply an Australian city (Bates, Chandler, Charles, & Campbell, 2010).

Most global climate models predict that southern Australia is likely to be drier in the future, which has significant implications for the future availability of groundwater resources. This is because variability in groundwater recharge can be two to four times greater than rainfall variability, with the effect of this being particularly obvious in areas of low recharge (Barron et al., 2011). Predictions of future changes in recharge have been made using 16 global climate models and these results have been scaled according to three global warming scenarios (low, medium and high) for both 2030 and 2050 (Barron et al., 2011). These predictions resulted in decreases in diffuse recharge across most of the west, centre and south-east of Australia, and increases across northern Australia. As well as reducing the availability of water resources, a drier and warmer climate may increase the demand for water resources from irrigated agriculture, cities, wetlands and other water-dependent ecosystems.

Hence, climate change intensifies the water scarcity challenge facing cities and rural catchments alike, but given the uncertainties in how and when the climate will change, an adaptive and flexible groundwater management approach is important to deal with these changes, together with comprehensive monitoring of the condition of the groundwater resources.

6.4.5 Impacts of Mining on Groundwater Systems

The mining sector is a large industrial user of water that is growing rapidly. Mining (including mineral, coal, petroleum and gas extraction) and quarrying tend to have a high gross value added per gigalitre of water consumed compared with agricultural uses. Despite an exponential increase in production, reported water use by the mining industry has historically been relatively steady, consuming within the range of 500–600 GL (Prosser, Wolf, & Littleboy, 2011). It is believed that the stable trend is due to improvements in water use efficiency in the mining industry, but also possibly to under-reporting of water use. Most water used for mining is in arid or semi-arid regions where water is scarce and often saline and there are few competing users. In these regions, the mining industry provides its own infrastructure, so water provisions tend to be part of the mining development approval process and are not always counted as a licenced extraction under a water management plan with other users.

There are exceptions to this, for example in the states of New South Wales and Victoria (and in Groundwater Management Areas in other states), all extraction for mining falls under the water planning process and requires a water access entitlement. Because mining is increasingly occurring in systems that are already developed for agriculture, the competition for resources and the potential impacts on existing water users is becoming more controversial.

A boom in coal seam gas (CSG) developments in Queensland and New South Wales presents major challenges in understanding and managing impacts of mining on other water users and the environment (Comino, Tan, & George, 2014). New technology to extract methane from deep lying coal beds has led to unprecedented CSG production in areas previously considered to be economically non-viable. Here, the gas extracted from coal seams is cooled and compressed to produce liquefied natural gas, which is ideal for export. Over 1000 gas production wells are in operation, requiring a peak extraction of about 95 GL to lower groundwater pressures which will allow the gas to be released from the coal deposits (DNRM, 2016).

Some key water management challenges in the current coal seam gas boom are (a) the effect of depressurisation on surrounding aquifers, (b) the likelihood and impacts of inter-aquifer leakage caused by aquifer depressurisation and hydraulic fracturing, and (c) chemical processes affecting the quality and safe disposal of the released water (Prosser et al., 2011). In Queensland, there are concerns over possible interactions of the CSG developments with usable aquifers (eg the Great Artesian Basin) which can occur above or below the coal seams. The locations of the potential development areas is shown in Fig. 6.4.

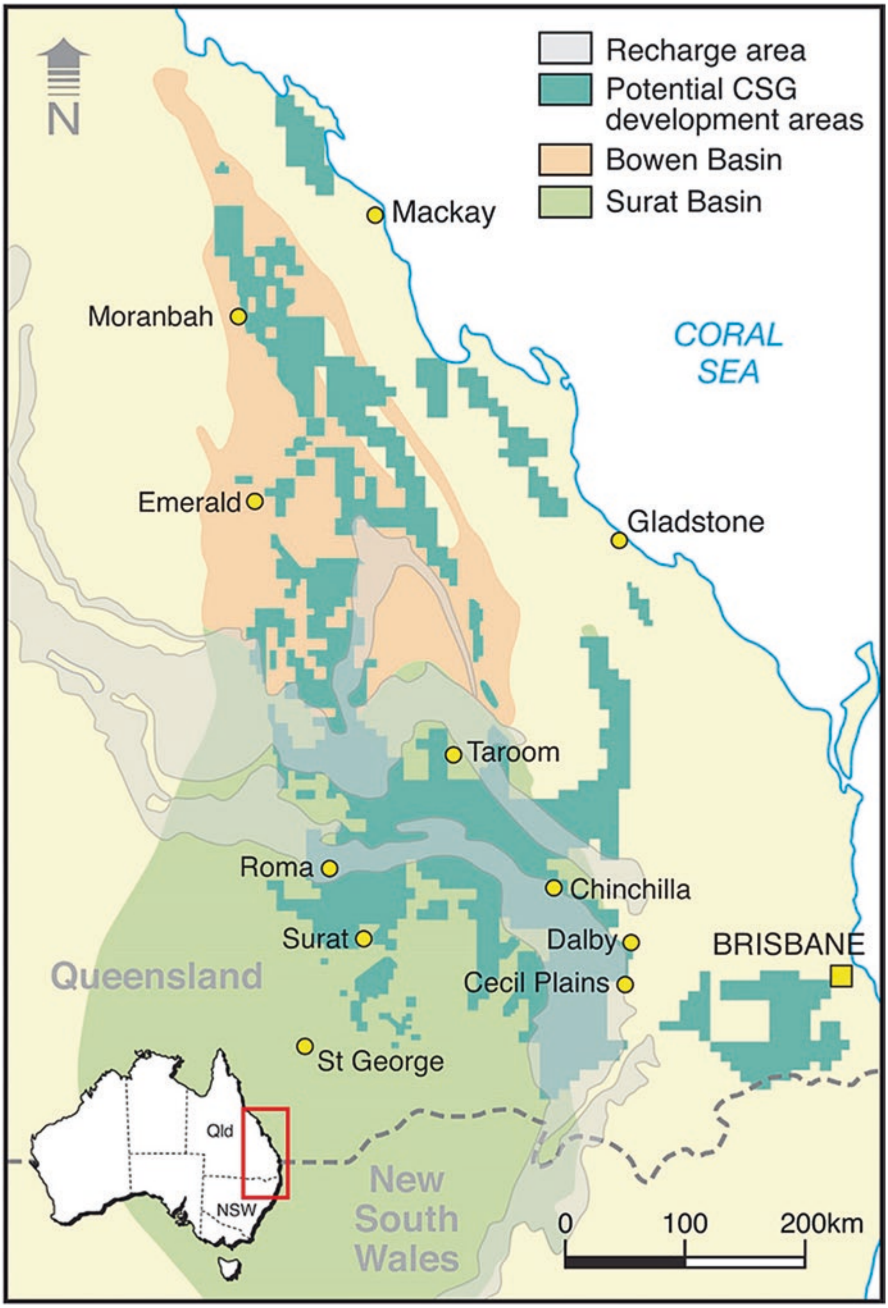

Fig. 6.4 Potential coal seam gas developments in Queensland

An overarching issue for the management of water resources around coal seam gas and mining developments in general is the uncertainty about the cumulative regional impacts of multiple developments on groundwater levels and pressures, and inter-aquifer leakage. Groundwater flow velocities are slow in many of the basins of interest, and any unforeseen consequences of the mining process can take decades or centuries to become apparent. Groundwater models are often desirable in this kind of analysis and these require a good characterisation of basin geology and how it controls groundwater pressures, flows, and quality (Prosser et al., 2011).

6.4.6 Seawater Intrusion

Seawater intrusion is the landward encroachment of seawater into fresh coastal aquifers in response to hydrological changes, such as groundwater extraction, reductions in groundwater recharge and sea level rise. The threat of seawater intrusion has been enhanced in Australia by an increased use of coastal groundwater, caused by increasing populations of coastal areas, and below-average rainfall (Werner, 2010).

One recent study by Geoscience Australia and the National Centre for Groundwater Research and Training, undertook a national-scale assessment of the vulnerability of coastal aquifers to seawater intrusion (Ivkovic et al., 2012). The study identified the coastal groundwater resources that are most vulnerable to seawater intrusion, including future consequences of over-extraction, sea-level rise, and climate change. The risk of seawater intrusion has been identified to be greatest in Queensland, although smaller but significant areas of Victoria, South Australia and Western Australia have also been identified as being at risk (Ivkovic et al., 2012). To date, targeted investigations into seawater intrusion to support water management have been mostly limited to the high value groundwater resources in the agricultural areas of Queensland, and high-value aquifers used for urban water supplies.

6.4.7 Salinisation of Land and Groundwater Resources

Groundwater salinity and land salinisation are major Australian natural resource management issues. Salts originating mainly from deposits of oceanic salt from rain and wind, are naturally distributed across the Australian landscape and have been concentrated in soil water through high evaporation rates and transpiration by plants for thousands of years. Salinisation of land and water resources occurs when comprehensive changes in land-use following European settlement changes the water balance and mobilises the naturally occurring salt. These land use changes involve dryland management systems (dryland salinity) and irrigation systems (irrigation salinity).

Dryland salinity occurs when European farming practices replaced deep-rooted native vegetation with shallow-rooted annual crops and pastures, resulting in a dramatic increase in groundwater recharge rates which can cause the watertable to rise, bringing salts into the root zones of plants and even to the surface where evaporation concentration occurs, impacting upon vegetation and rural infrastructure including buildings, roads and pipes. Increased recharge can also increase hydraulic gradients towards surface-water bodies which can increase the flow of saline groundwater into rivers and streams, thereby increasing river salinity. The National Land and Water Resources Audit defined the distribution and impacts of dryland salinity across Australia, with an estimation of 5.7 million hectares being affected or having a high potential for the development of dryland salinity (National Land and Water Resources Audit, 2001). The National Dryland Salinity Program which operated between 1993 and 2004, invested $40 million on research and development into the causes, costs, consequences, solutions and management of dryland salinity in Australia.

Since this audit, the previously discussed millennium drought from 1997 to 2009 affected large areas of southern Australia, reducing recharge and causing widespread declines in watertable levels which has reduced the risk of dryland salinity in many areas. It remains to be seen whether the predicted drying impacts of climate change will also reduce the risk of expansion of the current areas of dryland salinity.

Irrigation salinity (or recycling) occurs when groundwater is extracted from a shallow aquifer and is applied to a crop by irrigation, and as water is drawn up through the root system, most of the dissolved salt is not taken up by the plant and accumulates in the root zone. This salt then percolates back down into the shallow aquifer during subsequent irrigation applications or from rainfall recharge, resulting in increasing groundwater salinity over time due to the recycling of the irrigation drainage water.

6.5 Future Challenges

Australia has made good progress with water reform over the past decade or so. From a groundwater perspective, this included advances in groundwater science, education, management and policy reform (NWC, 2014). However, the process of water reform in Australia has now stalled. In 2007, the National Groundwater Action Plan was initiated with a $105 million investment from the federal government administered by the National Water Commission. This plan, which was the centrepiece of government investment in groundwater in Australia, terminated in 2012 with no continuation or replacement on the agenda.

Attention to groundwater and groundwater management from policy makers is deteriorating at an alarming rate, especially at a time when there are many groundwater related matters of national importance described previously (such as coal seam gas) that must be dealt with. Australia's future will increasingly depend on groundwater. It is expected that climate change and a potential doubling of the population in the next 50 years will be important future drivers of demand which will place further stress on already stretched groundwater resources (Simmons, 2016). The reform journey must continue if the many challenges are going to be overcome. But in order for this to occur, problematic institutional legacy and funding issues must be addressed (as discussed in other chapters in this book). The universal "hydro-illogical cycle" (Wilhite, 2012), whereby political attention and funding rains down during droughts but evaporates when water in plentiful, is being implemented in Australia.

National water reform must continue with the clear understanding that droughts are a fundamental component of the Australian climate. Recognising the need for an integrated, whole-of-water-cycle approach for effective water resources management, groundwater will be a critical part of any water reform strategy. An enduring, assertive, proactive, non-partisan approach to water reform in Australia is urgently needed which rejects short-term political and drought-driven interventions. The benefits for current and future generations will be enormous. The need for such reforms are discussed in later book chapters. For present purposes, this section will now focus on two emerging responses, namely managed aquifer recharge and general resourcing and education, that are otherwise not covered in detail in the remaining book chapters.

6.5.1 Managed Aquifer Recharge

Increasing pressure on water resources from climate change, population growth and increasing urbanisation means that Australia needs to diversify water sources to meet demand. Managed aquifer recharge (MAR) is a less established but growing alternative available to water resource managers. MAR is the purposeful recharge of water to aquifers through mechanisms such as injection wells, infiltration basins and galleries from sources such as rainwater, stormwater, reclaimed water, mains water and water from other aquifers. The recovered water may then be used for drinking water supplies, industrial water or irrigation, with the appropriate levels of pre-treatment before recharge and post-treatment on recovery. Figure 6.5. presents a simple MAR operation.

Managed aquifer recharge can also be used to benefit the environment by leaving the stored water in the aquifer to sustain groundwater-dependent ecosystems or provide a barrier against seawater intrusion. The advantages of MAR are; it is less expensive than dam construction and uses far less land area, it minimises evaporation losses, and can make use of the natural attenuation properties of aquifer materials.

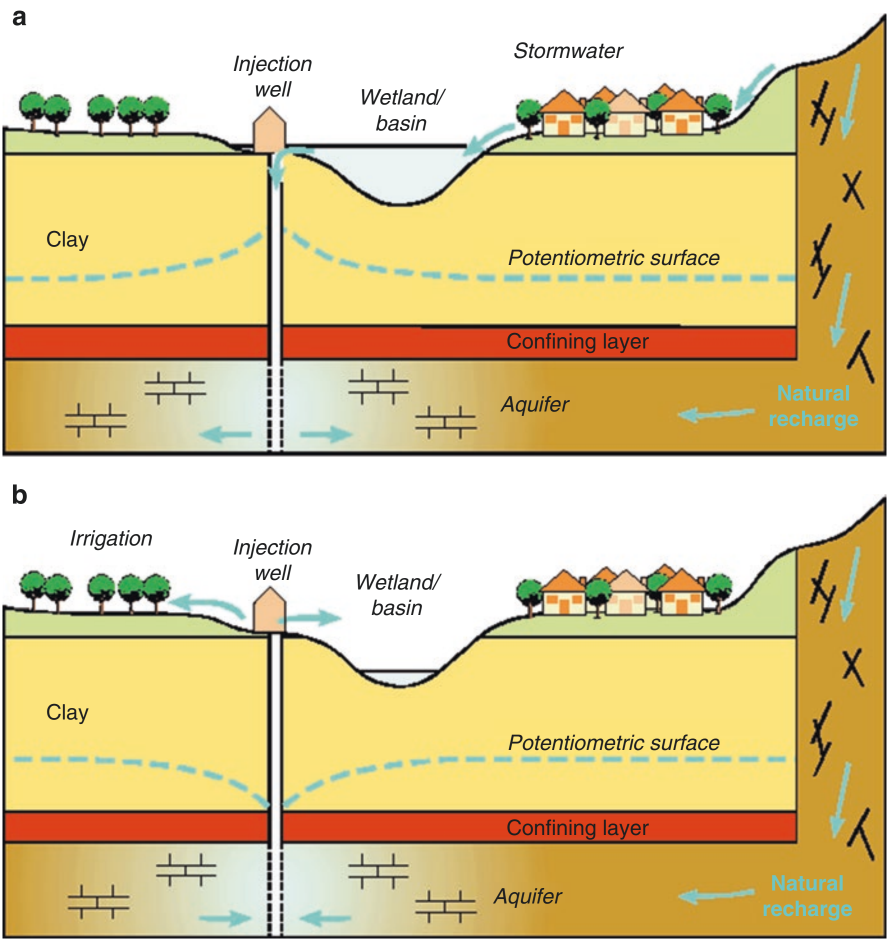

Fig. 6.5 Managed aquifer recharge (**a**) injection in winter (**b**) extraction in summer

A comprehensive overview of managed aquifer recharge is provided by Dillon, Pavelic, Page, Beringen, and Ward (2009). The occurrence and diversity of managed aquifer recharge in Australia has increased in recent years. In 2016, five states had operational managed aquifer recharge projects which contributed 410 GL/year to water supplies across Queensland, South Australia, Western Australia and the Northern Territory. The Western Australian Water Corporation has completed a trial of injecting more than 2.5 GL of highly treated recycled water into a deep confined aquifer over 3 years and it has been estimated that by 2023, groundwater replenishment of 28 GL/year could be achieved during winter for subsequent extraction during the dry summer months for potable supplies.

Currently growth in MAR in Australia is soundly based and is expected to make a greater contribution than sea water desalination in the longer term due to lower costs. However, there are some potential issues that need to be recognised and managed in the development of managed aquifer recharge schemes. These include water entitlement issues in water management plans (who owns the water), ensuring appropriate treatment of the source water (normally stormwater or recycled water) to prevent any risk to human health and the environment, including rendering an aquifer unsuitable for certain beneficial uses (e.g. drinking or irrigation), and also to prevent changes to water quality or aquifer permeability. The National Water Quality Management Strategy provides a framework for ensuring that managed aquifer recharge projects protect human and environmental health. Specific guidelines for managed aquifer recharge were developed in 2009 and form part of the Australian guidelines for water recycling along with other relevant guidelines for end uses of recycled water (NRMMC, EPHC and NHMRC, 2009).

6.5.2 Declining Resources for Understanding and Managing Groundwater

Because most states have not determinedly pursued full cost recovery of management costs from water users (despite being required as part of the National Water Initiative, see Chap. 7), funding available for the management and monitoring of groundwater resources is declining. This trend will increase the risk of inadequate monitoring being carried out, lead to a general decline in capacity and capability in management agencies, and the non-replacement of ageing monitoring infrastructure (Simmons, 2016).

In addition to addressing this decline in resources, a range of additional educational options to enhance better understanding and management of groundwater include;

- continuing to raise the profile and awareness of groundwater issues in Australia to politicians, policy makers and water users to combat ignorance and misunderstanding.
- building a national groundwater policy and planning forum where groundwater policy makers, managers, industry and scientists work together to define and solve important groundwater policy, management and technical issues.
- integrating all of the essential interdisciplinary subjects that relate to hydrogeology such as climate science, ecology, socioeconomics, public policy and law.
- quantifying and reducing uncertainty in analyses and explaining confidence levels to policy makers.

6.6 Conclusion

Australia's future will increasingly depend on groundwater due to the impacts of climate change and a growing population. Australia has made good progress with groundwater science, education, management, and policy reform, however there are many challenges ahead. Awareness of the importance of groundwater needs to be raised amongst politicians and policy makers so that current complacency and the resultant decline in budgets and resources within groundwater management agencies does not compromise their capability to address these issues in the future.

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