SCIENCE AND SOLUTIONS FOR AUSTRALIA

WATER

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Editor: Ian P Prosser

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Foreword

By Megan Clark, CSIRO Chief Executive and Andrew Johnson, Group Executive – Environment, CSIRO

CSIRO is committed to providing scientific advice on the major challenges and opportunities that face Australia. We commend to you this summary of the latest scientific knowledge on the challenges and prospects for managing water resources in Australia.

Australians have always had a strong sense of living in a dry continent, and have a long history of adapting to the extremes of floods and droughts. This has only been heightened in the last decade or so, revealing the vulnerabilities of our water resources and the ecosystems that depend upon them. It is no surprise that our society is increasingly seeking information about the challenges of securing water resources for all users, especially with prospects of growing use of water and changing climate. This book seeks to provide a bridge from the peer-reviewed scientific literature to a broader audience of society while providing the depth of science that this complex issue demands and deserves. The chapters cover the status of Australia's water resources and its future prospects, the many values we hold for water, and how water can be used most effectively to meet the needs of cities, farmers, industries, and the environment. It is important to find a balance between these sometimes conflicting uses and improve their efficiency.

Through the Water for a Healthy Country National Research Flagship, CSIRO is conducting research to help Australia and the world respond to the challenges of providing and sustaining water resources under strongly increasing demand. For more than 50 years, our scientists have been contributing to the growing body of scientific knowledge about water and are now seeking and finding new ways in which Australian communities, industries, and ecosystems, can improve how they use and dispose of water.

We cannot do this important work without the numerous national and international partnerships, collaborations, and networks. We collaborate with Australian and international universities, industry groups, research organisations, government agencies, and governments at every level to undertake excellent science and find and implement practical, scientifically based solutions.

As your national science agency, we will continue to provide scientific input and solutions to the community, industry, and government on understanding and improving the management of our nation's water resources.

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Contents

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Introduction

Bill Young and Ian Prosser

Around the world, access to water has always been a key determinant of how and where human populations have flourished. Australia is no different. Both Indigenous people and European settlers were mainly drawn to those parts of the country with more abundant and reliable water supplies. Thus, in spite of being the driest inhabited continent, 80% of Australia's population inhabits a comparatively well-watered green fringe.

Water is essential to our economy and our way of life and its use has continued to increase due to population growth and expansion of agriculture and other industries. This increase in water use – significantly underpinned by investment in major water infrastructure – has helped fuel Australia's economic growth, but at an environmental cost.

Australia's water use is dominated by irrigated agriculture, industry, and households. The water is extracted from rivers, lakes, and groundwater. Nationally, Australia uses approximately 6% of the available renewable water (surface runoff and groundwater recharge), but use is focussed in a few areas, such as the Murray–Darling Basin and the catchments surrounding capital cities where the resources are fully allocated.

Australia faces challenges of a growing and urbanising population, of growing demand for water for food and fibre production, and of environmental sustainability, particularly in the face of climate change. These are not unique to this country, but, unlike other developed nations, Australia faces the added complications of high rainfall variability and general aridity. The scarcity of water in Australia depends as much on the variation between years as it does on the long-term average. The highly variable climate means proportionally more water has to be stored to provide the same reliability of supply compared with less variable climates. For example, Melbourne's water supply system has 10 times the per capita storage volume of London's water supply system.

In contrast to human populations, Australia's unique flora and fauna are well adapted to high variability in available water. Recognising this dependency on variable water supply is central to ensuring the protection of ecosystems and the services they provide. Australians highly value their rivers and estuaries for tourism, amenity, and commercial and recreational boating and fishing. These values can be considered as services provided by aquatic ecosystems. Other less obvious aquatic ecosystem services include waste treatment, flood mitigation, biodiversity, and weed and pest control. Increasing levels of water use and expansion of water infrastructure have, however, led to worrying levels of environmental degradation in some areas, affecting the provision of these natural services. In addition, many intrinsically valuable environmental assets,

Discussing water, Hillston, New South Wales. Photo: Bill van Aken, CSIRO.

including extensive floodplain wetlands and forests, and iconic species such as the Murray Cod, are in marked decline from water use and other threats such as pests and water quality.

The challenge for Australia is to not only to deal with the present problems, but to prepare for the future. Demand for water will continue to grow, to support a population that is anticipated to increase by at least 50% by 2050. Global demand for food is expected to double, and growth in the mining and industrial sectors will place even greater pressures on water resources. Competing demands will mean that returning over-allocated systems to sustainable levels of use will be even more difficult than at present. Securing reliable urban water supplies – especially for Australia's four major urban areas (Perth, Melbourne, Sydney, and South East Queensland), requires far-sighted planning and billions of dollars of infrastructure investment. To continue to increase agricultural productivity with limited water will require many innovations in policies, technology, and knowledge that enable smarter and more efficient delivery and application of irrigation water.

As well as increasing demands, there are clear signs of decreasing water availability in parts of the country. In South West of Western Australia, climate change observed since the mid 1970s has seen stream flow into Perth's reservoirs more than halved, compared with the earlier long-term average. Research has shown that the unprecedented 1997–2009 drought in south-eastern Australia included a climate-change signal: a signal consistent with climate change predictions for a future of global warming producing lower rainfall in southern Australia. Further research continues to better quantify these signals.

Traditionally, water resource planning and engineering design of major infrastructure, including dams, were guided by measurements of past rainfall, temperature, and river flows. Scientists, engineers, and policy makers now agree that water resource planning and investment should consider multiple plausible climate and hydrology futures, not just historical records. The road ahead is uncertain, but relying only on the rear-view mirror would be negligent.

In the face of increasing demand and dwindling supply in some regions, Australia has the difficult task of balancing the use of water for direct economic benefits against indirect benefits such as environmental water use of water for conservation and the provision of ecosystems services.

There is a water quality dimension, as well as quantity, that needs to be considered for the future. Water quality should be at a level fit for its intended use; pollution of water can prevent or diminish future use and make it harder to meet increased demands on the resource. This is particularly a challenge for groundwater, where over-use of fresh groundwater can lead to salinisation reducing or preventing future use and degrading freshwater ecosystems reliant on the groundwater resource.

Responding to the challenge

Australian Governments have been actively reforming water management in response to the evolving water challenge. Under Australia's constitution, water resources are the responsibility of state and territory governments, but the Australian Government is involved through national competition policy, national and international environment policy, and the management of water resources that cross state borders (mainly the Murray–Darling Basin, Great Artesian Basin, and Lake Eyre Basin), and associated funding programs.

Monoman Creek, Chowilla Floodplain, South Australia during the millennium drought showing dying red gums and a blue green algae bloom. Photo: Ian Overton, CSIRO.


Googong Reservoir, Murrumbidgee catchment, New South Wales. Photo: Greg Heath, CSIRO.

The reforms increasingly treat water as an economic good or service, including formal legal entitlements to access water, which enable entitlements and seasonal allocations of water to be traded among users. Water supply services have been privatised, including in cases where infrastructure is government-owned, and the roles of water supply and regulation of use have been separated. Water prices are changing to reflect the full costs of supply and disposal, including separate charges for separate services.

A second key objective of the reforms is to make water management more environmentally sustainable. Water resources are thought to be over allocated in many parts of Australia, in the sense that the amount of water used, or the way that it is used, has caused socially unacceptable levels of environmental decline. An important milestone in the reform process was the passing of the *Water Act 2007 (Commonwealth)*, which has a focus on achieving sustainable management of the water resources of the Murray–Darling Basin through implementation of a Basin Plan. The Act paves the way for more formal environmental water management by establishing the Commonwealth Environmental Water Holder, which will hold in excess of 1000 GL of water entitlements and associated seasonal allocations to be actively managed for environmental benefit, just as other entitlements are managed for economic uses.

The reforms show that water is becoming an increasingly valuable commodity, and they provide an incentive for greater investment in the technologies and knowledge base required for smarter and more efficient management. In a carbon-constrained world, the large amounts of energy required to pump and desalinate water will increasingly mean the water and energy footprints of economic development will be considered jointly. Opportunities will be sought to reuse and recycle water rather than just using it once and disposing of the wastewater.

Wivenhoe Dam, Brisbane, during a controlled release, October 2010. Photo: Mat Gilfedder, CSIRO.

The role of science and technology

In order to secure water for future generations, Australian governments, industries, and communities will want to understand current and future water availability and explore ways of meeting the demands on these water supplies. They will want to better understand how river systems and groundwater systems respond to a changing climate and to increasing water use, and they will want to be confident that water use will not unduly harm future water supplies through pollution, over-use or environmental degradation. Improvements in ecological understanding, and in understanding the human health and other implications of contaminants in water, can provide vital help in developing water plans and provide safe and reliable water for all uses, including environmental water.

With increasing demands on a limited resource, there are strong incentives for more efficient ways of using water in irrigation, in cities, and for the environment. This will stimulate innovation in ways of providing the same or greater production and service provision using less water. Solutions are likely to include greater efficiency of water use in food production, in mineral processing, and for domestic use, to reduce demand while maintaining outcomes. Other opportunities may emerge from how water is managed for multiple benefits such as through recycling and reuse. New supplies will be sought through more efficient desalination and recycling technologies or through better use of groundwater. In the future, it is likely that the management of dams and rivers will shift from a primary focus on supply for cities or for irrigation, to balancing urban, agricultural, and environmental uses of water. New technologies are emerging with the potential to better understand and manage water resources. For example, ground-based


Woronora Dam, Sydney. Photo: Greg Heath, CSIRO.

radar and satellite-based remote sensing technologies are providing improved measurements of rainfall that will improve forecasting skill across the continent.

The scientist's techniques for employing accurate measurements, experimentation, hypothesis testing, and critical analysis, will assist in making major strategic decisions with confidence, and adapting to unforeseen consequences in the future. For example, new sensors and information technology are allowing early detection and remediation of urban water pollution. Careful monitoring and evaluation can improve the uncertain outcomes of providing water to restore degraded ecosystems. Accurate projections of the impacts of future climate on water resources and future demands on resources will help ensure enduring value from major investments in infrastructure.

Water science and technology has evolved in tandem with the water resource management challenges over the years. Research on aquatic ecosystems directly contributed to policies to tackle over allocation of water resources and return water to the environment. Now research is focussing on predictive ecology, to maximise the ecological benefit from the increasing volumes of water being managed for the environment, just as water supplies for irrigation are being improved to increase food production.

Billions of dollars of expenditure on water infrastructure is occurring now and this level of expenditure is expected to continue into the future, and similar amounts are spent on operating and maintaining water treatment, supply, and wastewater systems. Research that reduces operating costs or delays capital costs can have significant economic value. The well-being of the nation may depend, in future, on the ability to deliver high-quality water supplies to the many competing users. Scientific research continues to find solutions that greatly improve the effectiveness of water supplies and the benefits gained from them for all users.

Current water availability and use

Ian Prosser

Key messages

- Overall, Australia has sufficient water resources to support its current uses, consuming 6% of renewable water resources each year.
- Current use of rainfall and water resources in effect meet the needs of more than 60 million people, through Australia's exports of agricultural produce.
- A very uneven distribution of water resources across Australia and high year-to-year variability means that water resources in some regions are fully or over allocated, while others remain largely undeveloped.
- Australia's arid landscape and high potential evaporation pose challenges from the high demand for water by crops and cities, and large water losses from reservoirs and inland rivers.
- Some water resources are at risk from bushfires and unlicensed uses, which can reduce water availability to licensed users.

A summary of Australia's water resources and their use

A pervasive question is whether Australia has sufficient water resources to meet current and future uses. To answer that question fully, requires considerations of sustainability and likely changes to the resource as a consequence of climate change, but the key starting point is to compare Australia's water resources with the uses placed on them.

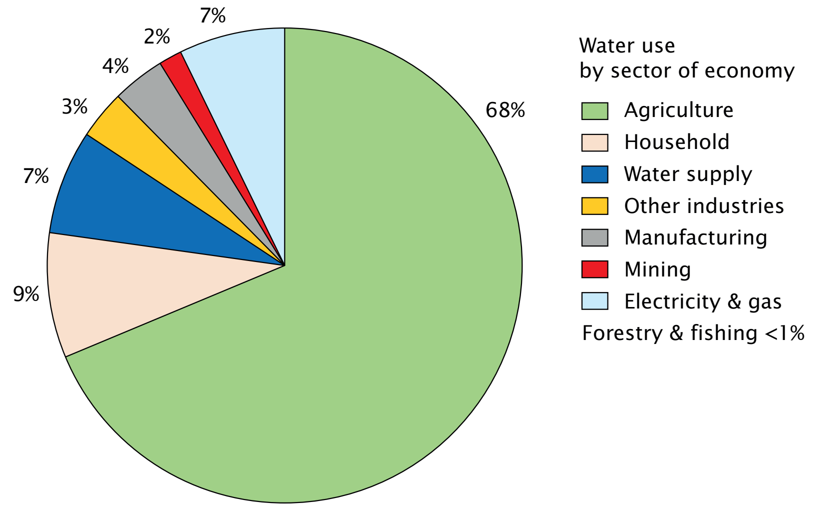
Australia receives an average of 417 mm of rainfall per year (Table 1.1),[1] which adds up to 3 700 000 GL of water per year (a gigalitre is 1×10^9 litres). Rainfall supports Australia's dryland (non-irrigated) agriculture and some domestic water supplies (via rainwater tanks), but is not itself considered a water resource for statutory water management. It is only when rainfall runs off into creeks, rivers, and lakes or recharges groundwater aquifers that it becomes a managed resource.

The sum of runoff and recharge is the total renewable water resource. It can be extracted, stored, managed, regulated, distributed, and used for a range of purposes. On average, only 9% of rainfall in Australia becomes runoff, and approximately 2% percolates through the soil to recharge groundwater (Table 1.1).[2] The rest evaporates back into the atmosphere, mainly through vegetation.

Table 1.1: Water use compared with average total renewable resource.[1, 2, 3]

	Average annual fluxes
Rainfall	3 700 000 GL (417 mm of rainfall)
Runoff	350 000 GL (9% of rainfall)
Groundwater recharge	64 000 GL (2% of rainfall)
Total renewable water resources	414 000 GL (11% of rainfall)
Evapotranspiration	3 286 000 GL (89% of rainfall)
	Average annual fluxes
Total extraction	72 431 GL (17% of renewable resource)
Total consumption	24 449 GL (6% of renewable resource)

Only a small proportion of Australia's renewable water resources is consumed each year. The Australian Bureau of Statistics produces reports on water use every 4 years. Levels of water use in 2008–09 and 2004–05 were reduced by drought across southern Australia so the statistics for 2000–01 are used here to better reflect unrestricted demand for water. In 2000–01, of the total 72 431 GL that was extracted for use, 47 982 GL was returned to rivers, mainly being used for hydroelectric power generation, and 24 449 GL was consumed by industry, households, and agriculture (Table 1.1). Of the water consumed, 68% was used in irrigated agriculture to produce food and fibre, 23% was consumed in various industries, and 9% was taken for household water use (Figure 1.1). It will be interesting to see the next set of statistics on water use because restrictions on use have eased and the population has increased, but people are now more conscious of water conservation.



▸ ***Figure 1.1**: Water consumption by different sectors of the economy for 2000–01. Consumption in the water supply industry is mainly the losses of water that occur in supplying water and providing sewerage services.*[3]

Australia is a generally arid continent but it uses only a low proportion of its water resources compared with other regions of the world (Table 1.2). It is the driest populated continent, and has the lowest proportion of rainfall converted to runoff,[4] giving it slightly less water per unit area than any other region of the world (Table 1.2). However, Australia has by far the lowest population density of any major region, so it has moderately plentiful water resources per person and consumes a smaller percentage of its water resources than other dry regions and the most densely populated regions of the world (Table 1.2).

Table 1.2: Global comparison of water resources and use.[5]

Region	Available water per area	Population density	Available water per capita	Water consumed	Consumption per resource
	ML/ha	People/km²	ML/person/year	10^3GL/year	%
Australia[a]	0.5	2.5	21.3	25	6.0
North America	2.8	20.7	13.4	603	9.9
Central America	11.2	115.7	9.6	23	2.9
Southern America	6.9	21.5	32.2	165	1.3
Western and Central Europe	4.3	107.1	4.0	265	12.6
Eastern Europe	2.5	11.5	21.4	110	2.5
Africa	1.3	32.7	4.0	215	5.5
Middle East	0.8	47.1	1.6	271	56.0
Central Asia	0.6	18.5	3.0	163	62.0
Southern and Eastern Asia	5.5	174.4	3.2	1991	17.1
Oceania and Pacific[b]	1.1	3.3	33.0	26	2.9
World	3.2	50.4	6.4	3832	8.9

[a] *Data from Table 1.1*
[b] *Includes Australia*

Inspecting rice near Yenda, New South Wales. Photo: Greg Heath, CSIRO.

Australia's water resources are in effect used to support more than our domestic population of 22 million people. Water is used in the production of almost all goods and services, and particularly in the production of food and fibre (e.g. cotton). For instance, it takes about 8000 L of water to produce a pair of leather shoes and about 5000 L of water to produce a kilogram of cheese.[6] This principle of water required for production can be applied on a global scale to show that some countries, such as Australia, use more water to produce their exports than is embodied in their imports. Countries with very high population densities and only small areas of arable land tend to be net importers of embodied water because they import much of their food and export manufactured goods that require less water.

Australia exports a majority of its agricultural produce and imports many manufactured goods, using far more water to support domestic consumption and exports than is used to produce the imports. Using the data of the Water Footprint Network,[7] Australia is effectively supporting a population of about 67 million people at our own high levels of consumption.

Much of the water used in agricultural produce is rainfall used in dryland agriculture, not water extracted from rivers and groundwater for irrigation. The two types of water should not be compared directly with each other when examining the water use efficiency of different crops. Irrigation consumes water resources from rivers and groundwater, the use of which competes with other uses, including for the environmental values that rivers, lakes, and estuaries support. By contrast, the rainfall that evaporates through dryland crops would also have evaporated through the natural vegetation cover on the land, or other vegetation covers. Only where dryland agriculture reduces the amount of water flowing into rivers and groundwater (perhaps by storing water in farm dams) does it impact on water resources and other water users.

Putting Australia in a global perspective shows that although it has enough water to meet its needs and to support trade, there have still been recent water shortages. The problems emerge in the very uneven distribution of the water and where it is used.

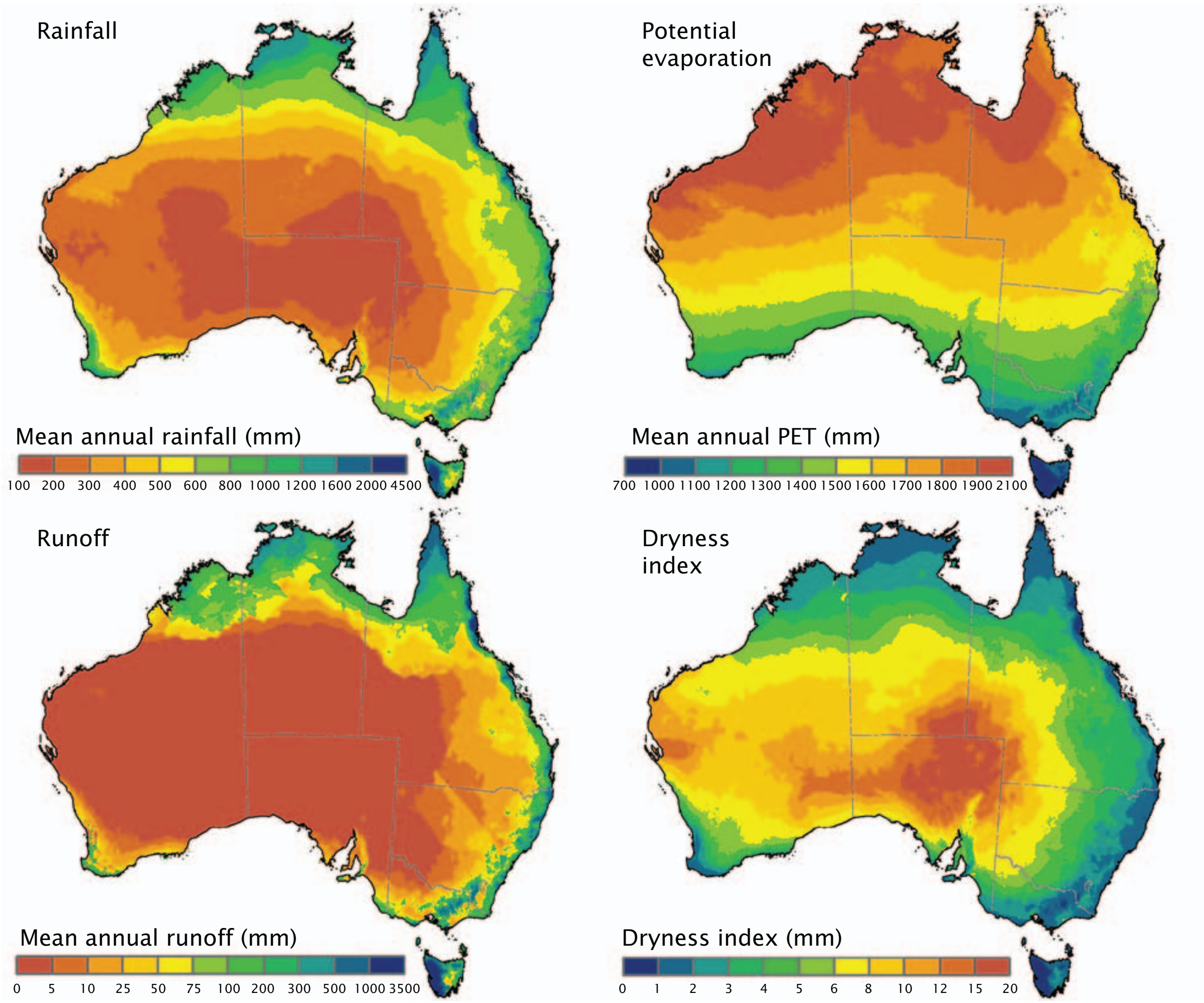
Water resource patterns across Australia

Australia has a thin wet margin and a dry interior. The north, east and south-west coasts and ranges receive moderate to high rainfall while the rest of the continent is dry. A better indicator of the aridity of the continent, though, is the dryness index, which is the ratio of potential evaporation to rainfall (Figure 1.2). Potential evaporation is the amount of evaporation that would occur if an endless supply of water were available, whereas actual evaporation is much lower, because a landscape may be dry for much of the time. If rainfall is insufficient to meet the demand of potential evaporation, the landscape is at least seasonally dry. Where rainfall is greater than potential evaporation, the dryness index is less than 1.0, there is excess water to keep soils moist, excess rainfall becomes runoff and plant growth is not limited by water availability. On a mean annual basis, only western Tasmania, the Australian Alps and the Wet Tropics have a dryness index less than 1.0.

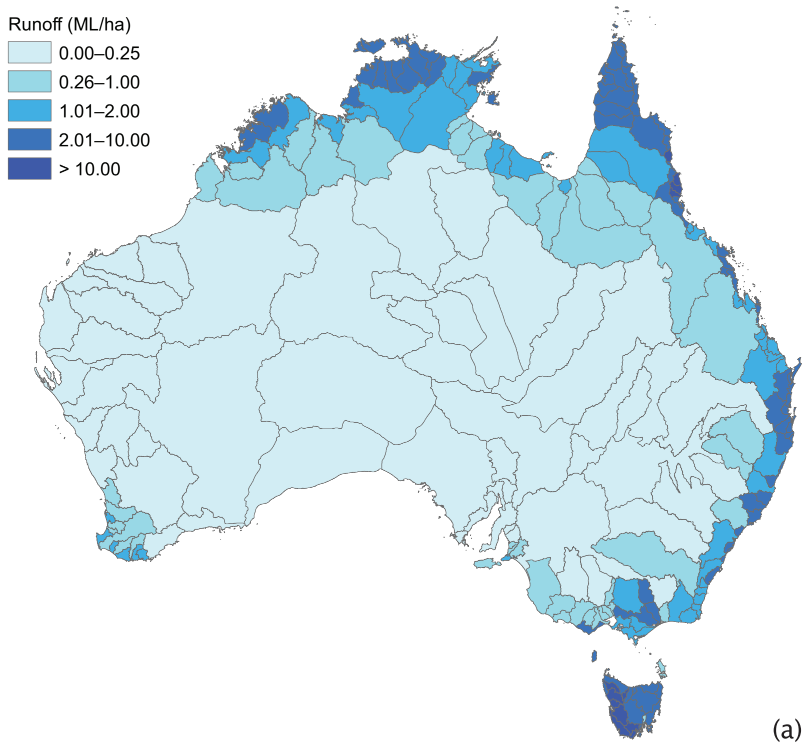
Where the dryness index is greater than 1.0, the landscape is water-limited for at least part of the year and plant growth is limited by water availability. The larger the dryness index, the greater the moisture deficit and the lower the amount of runoff. Most of Australia is water-limited, producing little runoff either seasonally or over the whole year. These annual averages mask strong variations between years, controlled by climate variability. Almost every year, some part of Australia experiences drought, where low rainfall and high potential evaporation cause more intense aridity than normal, and this can persist for several years.

Not only are Australia's water resources concentrated around the coastal rim, so too is its population and water use. Figure 1.3(a) shows how the pattern of runoff is distributed as surface water resources among the 224 river basins in Australia. Figure 1.3(b) shows what proportion of surface water resource is used. Water use is greater than 40% of the surface water available in and around capital cities and across the Murray–Darling Basin. Small coastal rivers tend to have higher rates of use than the larger rivers, showing that intense use is local, close to the coast and does not fully utilise the resources of the larger basins.

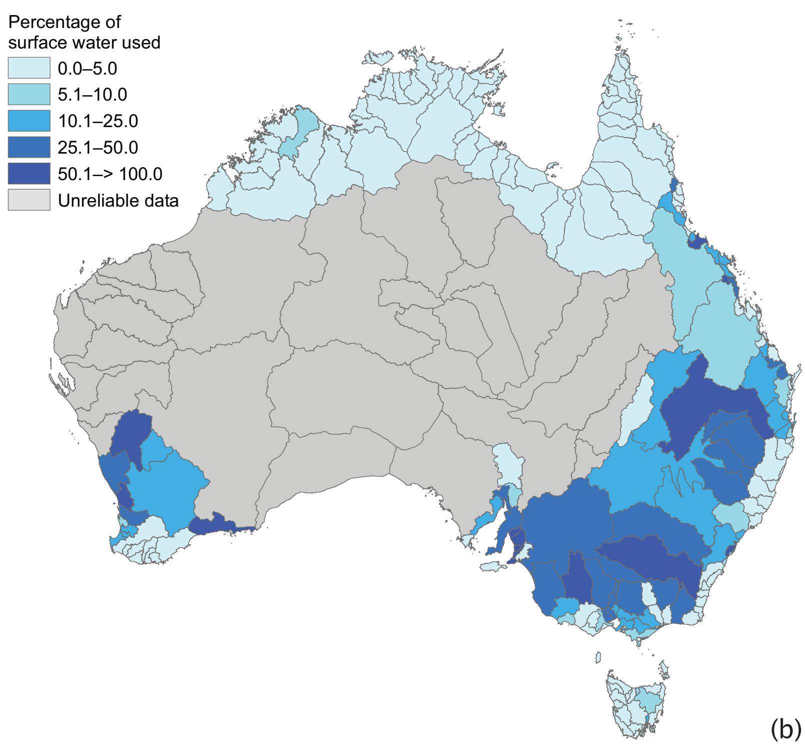
The Murray–Darling Basin is Australia's most developed rural water resource, where 48% of surface water is consumed on average each year, mainly in the southern part of the Basin.[8] This water resource is considered to be over allocated[9,10] in the sense that the high levels of water use have degraded the rivers and wetlands that rely on them (see Chapter 9). Coastal cities largely rely upon small river basins that are fully developed, so water is transferred from neighbouring river basins (e.g. piping water from the Thompson River in Victoria to supply Melbourne or from the Shoalhaven River to supply Sydney). Water use in other coastal areas of Victoria, New South Wales, Queensland, northern Australia, and much of Tasmania is below 10% of runoff. These are areas with potential for further development, although factors other than water availability need to be considered.



▲ ***Figure 1.2***: *Rainfall, potential evaporation (PET), runoff, and dryness index across Australia. The dryness index is the ratio of potential evaporation to rainfall. Where the dryness index is less than 1.0, there is on average more rainfall than can be evaporated giving large volumes of runoff. Where dryness index values are greater than 1.0, there is a deficit between rainfall and evaporation potential leaving a dry landscape, with little runoff and the need for irrigation to support vibrant plant growth. Rainfall and potential evaporation data were obtained from Bureau of Meteorology databases and runoff is a CSIRO compilation of modelling and measurements.*



(a)



(b)

▸ ***Figure 1.3***: *(a) Availability of surface water shown as average annual volume of surface water (ML) per hectare of land for each Australian river basin; (b) Percentage of surface water used for each Australian river basin.*[8,11,12] *Arid areas rely mainly upon groundwater and have unreliable data for surface water use.*

Constraints on water use

Even in the fully developed river basins, only about half of the available surface water is consumed over time. This reflects some physical constraints on water resource development and use as well as limits imposed to protect rivers and wetland environments from degradation. Some of these constraints are more extreme in Australia than elsewhere.

As well as very uneven spatial distribution of water resources, the regions with temperate climate (outside of tropical and desert climates) have the highest year-to-year variability of runoff in the world.[13] For example, in the Murray River a dry year produces approximately one-tenth the river flow of a wet year. Typically, the difference in runoff between wet and dry years in Australian temperate climates is twice that of the northern hemisphere temperate regions. This is partly due to a higher rainfall variability in Australia that is amplified in the amount of runoff, and is linked to the strong influence of El Niño and La Niña seasonal weather patterns and the high potential evaporation of Australia.

The high variability of runoff from year to year puts a constraint on the amount of water that can be reliably supplied even with large storages. In the Murray–Darling Basin in the drier years, which have low flow, more than 60% of all water available is used and in nearly one-third of years more than 70% is used (Figure 1.4). After accounting for the need to leave sufficient water in the river to keep supplying users downstream, no further water could be used. In wetter years, large flows coincide with low demand for water because of the good rainfall, so only a small proportion of water is used. When yearly supply is balanced against demand, only about half of the water is used.

Australia's high potential evaporation and variable runoff mean that very large dams are needed to provide a reliable supply of water to cities. More than 23 000 GL/year is lost to evaporation from Australia's major dams, similar to the volume that is used.[14,15] Wivenhoe Dam stores 10 years of supply for Brisbane when it is full, yet the high evaporation and drought up to 2009 meant it

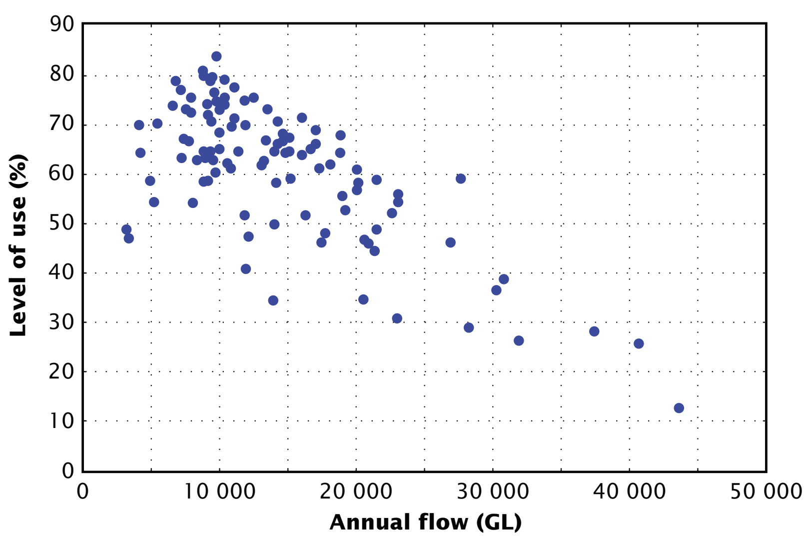


Figure 1.4: *Water used in the Murray–Darling Basin as a percentage of the annual flow at Wentworth. Wentworth is the point of maximum flow in the Basin.[8] In dry years, almost all water is used, while wet years have low levels of use because of both higher supply and lower demand.*

came close to emptying, before rapidly refilling when above average rainfall returned. In large river systems there are also significant losses of river flow as water moves downstream. Across the Murray–Darling Basin there is 28 900 GL/year of runoff on average, but by the junction of the Murray and the Darling Rivers half of this has evaporated or seeped into groundwater.[8] When the sources of water are very distant from the points of use, only a fraction of runoff is usable.

A dry climate means that water use per capita is high. Use in Australian houses is comparable with other cities of the world with similar standards of living, but more water is used outdoors because of the high irrigation demands of gardens and parklands. Domestic water use has decreased in recent years as a result of conservation measures. For example, in cities with hot or dry summers such as Brisbane, Adelaide, and Perth, over 100 kL was consumed per person per year prior to water restrictions and a new focus on water conservation.[16] In European cities with high housing density and low garden watering, use is of the order of 50 kL per person per year. During water restrictions, Brisbane achieved a use of 53 kL per person per year.[16]

A similar situation of high water demand occurs in irrigated agriculture in Australia. The larger the gap between rainfall and potential evapotranspiration, the greater the amount of irrigation water needed to support highly productive agriculture. Some Australian irrigation areas have evaporative demands that are three to eight times greater than the rainfall (Table 1.3).

Table 1.3: Rainfall (P), potential evaporation (Epot), rainfall deficit (Epot-P), and aridity index Epot/P for selected city and irrigation locations.

Location	P[(a)] (mm/year)	Epot[(a)] (mm/year)	Epot-P	Epot/P
Brisbane	1046	1821	775	1.7
Sydney	1156	1624	468	1.4
Melbourne	598	1525	927	3.1
Adelaide	500	1751	1251	3.4
Perth	766	1884	1118	2.4
Ord irrigation	870	2535	1665	2.9
Burdekin	569	2229	1660	3.8
Griffith	401	1808	1407	4.5
Narrabri	635	2023	1388	3.2
Renmark	239	1878	1639	7.7

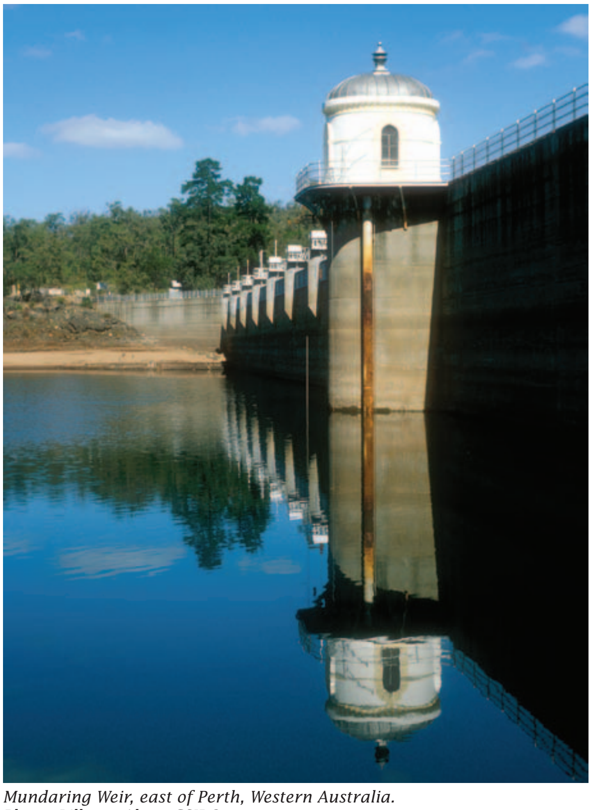
[(a)] *Obtained from Bureau of Meteorology databases*

Australia is similar to other subtropical and arid continental regions such as India, central and east Asia, and western United States of America in requiring irrigation to support the most productive agriculture. In temperate Europe and America and the Wet Tropics, most agricultural production is supported directly by rainfall.[17]

Opportunities for development of water resources

The contrast of high levels of water use in some basins with low levels of use elsewhere raises the prospect of increasing use by transferring water between river basins. The Snowy Mountains scheme transfers 1000 GL/year from the Snowy River into the Murray–Darling Basin.[18] Several smaller transfers take water from the Murray–Darling Basin to augment supplies for Adelaide and Melbourne. More ambitious schemes such as piping water from northern Australia to the Murray–Darling Basin, the Bradfield Scheme[4] or the proposal to augment Perth's dwindling surface water supplies with a canal from the Fitzroy River in the Kimberley region have all been suggested.

The more ambitious schemes have high financial and environmental costs. For example, the cost of building a canal from the Kimberley in northern Australia to augment Perth's supply was at least $20/kL.[19] Shipping using super-tankers would reduce the cost to $7/kL,[19] and the Perth desalination plant supplies water at $1.16/kL.[20] For irrigation water, the lower price and the larger quantities of water required make these schemes even less financially attractive. For example, a typical supply price for irrigation water is around $33/ML (3 cents/kL), more than 30 times lower than the price for urban water. A proposal to transfer water from the Clarence River into the Murray–Darling Basin, would supply 755 GL/year (7% of water use in the Basin) at a capital cost of



Mundaring Weir, east of Perth, Western Australia.
Photo: Bill van Aken, CSIRO.

$656 million and an operating cost of $130/ML (13 cents/kL).[4] More cost-effective solutions have been used to augment urban water supplies, and irrigated agriculture is being developed where there is more water available, such as in northern Tasmania.

There is renewed interest in developing water resources for irrigation in northern Australia to alleviate the pressure on the Murray–Darling Basin. Runoff from the two drainage divisions in the north is nearly eight times that of the Murray–Darling Basin. Although opportunities for water resource development exist in the north, they are not as straightforward as is suggested by the high runoff because some of the limiting factors of Australia's water resources described above are magnified in the north.

Northern Australia has a hot climate, with most rain falling from November to April. Water is in deficit with rainfall less than potential evaporation for 10 months of the year. The annual rainfall deficit is over 1500 mm/year for much of the region, and crop water demands are very high, as is evaporation from storages (Table 1.3). The ratio of dam storage to supply of water would need to be higher than for southern Australia. Much of the runoff occurs as major floods, which can be a hazard rather than a resource, causing extensive inundation of the lowland regions for weeks to months at a time. Northern Australia has fewer locations for large dams because of its open valleys and, aside from the most easterly ranges, the headwater regions are the driest and hottest parts of the catchments.[21]

Groundwater presents the most attractive opportunities for irrigation, with approximately 600 GL/year of groundwater available (Figure 1.5). The Daly, Wiso, and Georgina groundwater provinces in the Northern Territory and north-western Queensland have the greatest potential, although the Daly province is almost fully allocated. The Canning (east of Broome), Ord-Victoria

▲ ***Figure 1.5**: Groundwater resources and prospective use in northern Australia.*[21]


Maroondah Reservoir, near Healesville, Victoria. Photo: Nick Pitsas, CSIRO Publishing.

(east of Kununurra), Pine Creek (south-east of Darwin), McArthur and Great Artesian provinces could each be expected to deliver 10 to 100 GL of groundwater a year.

Water availability is just one factor contributing to irrigation development and is probably not the limiting factor in northern Australia at present. Other factors that need to be considered include suitable land and crops, and access to infrastructure, workforce, and markets.

Risks to water availability and use

The amount of water that is available to licensed users in the future is at risk from external impacts on the resource such as climate change and bushfires, and internal risks created by the way water use is licensed and managed. The main risks that have been identified are:

- climate change (see Chapter 3)
- bushfires
- plantations and other revegetation
- farm dams
- floodplain harvesting
- unlicensed groundwater bores (see Chapter 4)
- double accounting of surface and groundwater (see Chapter 4)
- mining water use (see Chapter 10)
- reduced return flows from irrigation (see Chapter 8).

Bushfires pose a risk to water availability when regenerating forests use more water than the mature forest they are replacing. This effect is most pronounced in the ash forests of south-eastern NSW and Victoria where the trees usually do not survive fire. The density of regrowth can reduce runoff for several decades. The major bushfires in Victoria in 2003 and 2006–07 burnt over a million hectares of forest. Their combined impact on the Murray River (at the confluence with the Ovens River) is expected to be 255 GL/year reduction or approximately 3% of the average annual flow.[22]

Forest plantations and farm dams use significantly larger volumes of water than the agricultural practices that they replace, so their expansion can reduce the amount of runoff in rivers. It is where plantations replace pastures, rather than existing forests, that water use increases significantly.

Floodplain harvesting, unregulated groundwater bores, and mining are direct uses of water that may not have water access entitlements and can impact on users with entitlements to the resource. These activities, together with plantations and farm dams, are termed 'intercepting activities' because they intercept (or use) water that would otherwise have contributed to the formal water resource. Their use is hard to measure, but a national assessment (Table 1.4) indicates that significant volumes of water are involved. Intercepting uses that have been in place for decades are not of concern because their use of water would have been included in assessing how much water was available and distributing that across entitlements. It is the future expansion of intercepting land activities that poses the larger risk because it reduces the amount of water available to those with entitlements. Although the projected future volumes in Table 1.4 are small on a national scale, development is usually focussed in particular valleys, where impacts can be locally significant.[23] Where there are significant impacts from intercepting land uses, a possible solution is to bring the uses into the system of entitlements.

Table 1.4: National assessment of intercepting activities.[23]

Activity	Current water use (GL/year)	Potential additional water use to 2030 (GL/year)
Plantations	2000	62
Farm dams	1600	300
Floodplain harvesting	890 [(a)]	0 [(b)]
Stock and domestic groundwater bores	1100	286

(a) 880 GL of this use occurs in the northern Murray–Darling Basin.
(b) Moratoriums on construction of storages are in place.

Better water information for Australia

With increasing demands on Australia's finite water resources, and concerns about risks to the resources, it is imperative that there is accurate information on availability and use of water. Water is a significant business, community, and ecological asset that deserves the same level of accountability as any other asset. There were few reliable and current sources for water information covering the whole of Australia available for compilation in this book. Statistics were highly variable depending on the period reported or the methods used, adding to uncertainty over the scarcity of water across Australia.

To overcome these problems at a national scale, the Bureau of Meteorology has been mandated to compile, analyse, forecast, and report on water across the country.[10] It estimates that water information is collected by some 200 agencies across Australia, and some of it is hard to access and compile to build a national picture. CSIRO is working with the Bureau of Meteorology to develop technologies for automatic accession, processing, analysis, and reporting of this information. Traditional field measurements of rainfall, river flow, and groundwater level, are being complemented with new satellite remote sensing of hard-to-measure water attributes such as the amount of water evaporating through vegetation or seeping from unlined irrigation canals.

The best opportunities come from combining on-ground measurements and remote sensing in computer models to map and forecast the state of water resources across the country. For example, remote sensing from satellites is being used to estimate rainfall between gauges that are widely spread across the landscape, to measure flows on floodplains, or to measure use of water by crops (Figure 1.6). An example of new seasonal forecasts of river flow is given in Chapter 3.

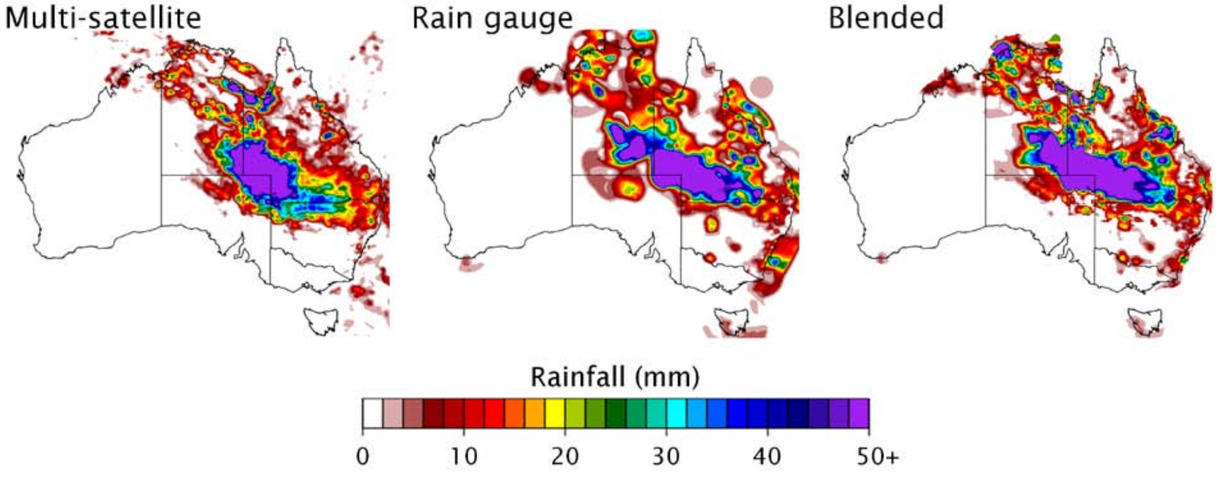
Farm dam near Wallacia, New South Wales. Photo: Greg Heath, CSIRO.

Conclusions

Australia is only partly a dry continent. It is a continent with a thin wet margin, where most of the population lives, but it is also sparsely populated and uses only a small proportion of its water resources. Australia exports much of its agricultural produce and its use of rainfall and water resources is enough to support, in effect, more than 60 million people. There is more than enough water overall to meet the country's needs yet the perception of aridity is real.

Australia's rainfall is notoriously unreliable, and in temperate regions its river flows are the most variable in the world. On top of that, high rates of potential evaporation place large demands on water for the irrigation of crops and household gardens, and results in much water being lost from rivers and dams. Australia has to store very large quantities of water to ensure reliable supplies, and even then some large dams used to supply cities have come close to running dry. The use of water resources is highly concentrated around the large capital cities and in the southern Murray–Darling Basin, which is considered to be over allocated. Future water supplies are at risk from climate change, bushfires, and the way water is licensed for use.

There are opportunities to develop new water resources but these are often, not coincidentally, in places with highly valued aquatic ecosystems, or where there are other factors that limit water use, such as lack of economic opportunity. Questions about the values or benefits obtained from water should be examined before considering whether and how water could be used more effectively.



▲ ***Figure 1.6****: Rainfall estimates for 1 March 2010. From left to right: from a NASA multi-satellite rainfall product; from analysis of rain gauges; and from combining the gauge and satellite rainfall estimates. The rain front shown led to widespread flooding in southern Queensland and northern New South Wales.*

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Water values

Rosalind Bark, Darla Hatton MacDonald, Jeff Connor, Neville Crossman, and Sue Jackson

Key messages

- As a society, Australians value water highly for a range of economic, environmental, social, and cultural benefits, which at times are in conflict with each other.
- Water resources are an input into the production of most goods, and water environments support economic uses such as fisheries, tourism, and recreation.
- Healthy water environments provide valuable ecosystem services such as maintenance of water quality and habitat, and many people intrinsically value and feel highly attached to water-related environments.
- For Indigenous Australians, water is central to culture and identity, as well as livelihood, but these values are poorly understood.
- Increasingly market mechanisms, such as water trading, are used to resolve competing uses, but regulation, community aspirations, and valuation of ecosystem services are also important future drivers.

People value water and water environments for a diverse range of reasons. Water is essential for human life and wellbeing, is critical to food production, and is a part of many manufacturing and industrial processes. Australians have a deep connection with the water environments of rivers, lakes, estuaries, and coasts, which are central to much recreation and tourism, and for Indigenous Australians water environments have a deep spiritual meaning. Perceptions of dryness of the continent have also shaped the Australian 'psyche'.[1]

Many of the values for water are shared, but it is the contested values that are at the heart of conflicts over water, such as determining sustainable levels of use. Large-scale water use inevitably has some impact on water ecosystems, so setting sustainable levels of use inevitably involves weighing up competing values. This chapter outlines the many benefits obtained from water and how they shape the way water is managed in Australia. Although it is convenient to describe separate social, cultural, environmental, and economic values for water, they are in fact closely intertwined.

Mandurah estuary, Western Australia. Photo: Bill van Aken, CSIRO.

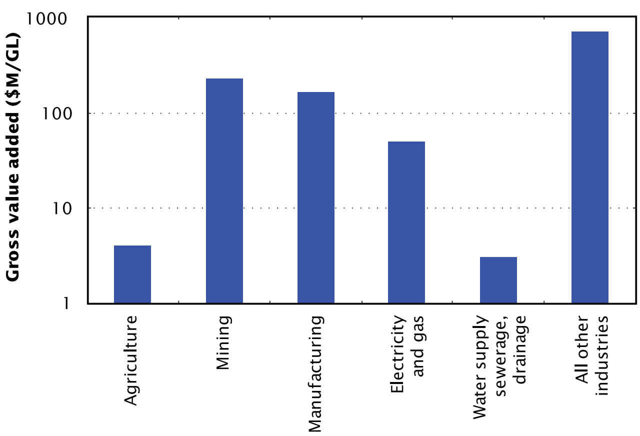
Water has been critical in Australia's history, both in shaping and responding to broader values that have changed over time. Some refer to the period from early European settlement through the first half of the 20th century as the expansionary phase of Australian water resources and the time since then as the maturing phase.[2] In the expansionary phase, the focus was on nation building, and populating rural areas, supported through irrigation. An icon of this phase was the Snowy Mountains Hydroelectric Scheme, the development of which reflected an emphasis at the time on the economic values associated with water.

The maturing phase has been marked by a shift to encompass a broader set of values, which at times compete with each other. These include increasing concerns over the condition of water ecosystems because water use led to degradation of natural environments, sometimes to the detriment of ongoing water use, such as high salinity levels having an impact on irrigated agriculture and town water supplies. At the same time, the economy has grown and become more diverse and settlement has concentrated in the large coastal cities. Decisions like the one to not proceed with dams on the Franklin River in Tasmania and the more recent moves to restore environmental flows in the Murray–Darling Basin reflect this shift in values.

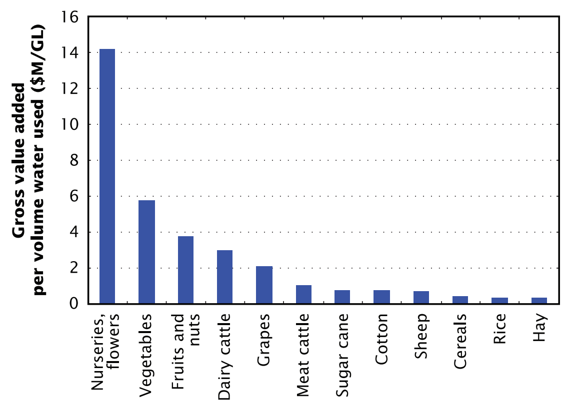
Economic values

Water is used in the production of almost all goods. Water resources are critical for irrigated agriculture, mining, households, and many industries, all of which are substantial users. The largest amount of water use is for irrigated agriculture, producing food and fibres (such as cotton).

The market value of water use can be described using marketplace concepts, such as the gross value added per gigalitre ($/GL) of water used in production (Figure 2.1). The gross value added is the wholesale value of the goods produced minus the operating costs of production (input goods and labour). By this measure, water used in mining and manufacturing produces much higher economic values than water for irrigated agriculture.[3] Within irrigated agriculture, nurseries, vegetables, and fruit have much higher gross value added than dairy and grapes, which in turn are higher than rice and cereals (Figure 2.2). The value added for each agricultural product can vary substantially from year to year as a result of changes in global commodity prices: for instance, the data shown in Figure 2.2 reflect the high price for dairy products in 2008–09.



▲ ***Figure 2.1****: Gross value added per GL of water used by various industries, 2008–2009.[3] Mining, manufacturing, and other industries are high-value economic users of water while irrigated agriculture produces less value per GL of water used.*



▲ ***Figure 2.2****: Gross value added of irrigated agricultural production across Australia for 2008–09. Nurseries, vegetables, fruits, and nuts produce the highest added value from irrigation.[3]*

While the $/GL metric is straightforward, it is not a reliable measure of the true value of water, because water is often a relatively small input cost and it is often not the input that limits production. The metric does not account for capital costs or any change in price that would come from changed production volume. Thus doubling the amount of water made available for manufacturing, for instance, would not produce double the value. Similarly, farm productivity, farm profits and, regional economies would not necessarily benefit from having all irrigation water go to the highest gross value crops. The costs of access to processing plants and the markets for those products needs to be considered, together with the impact on prices of increased production, and the suitability of the land and climate for the crop.

A better indicator of the economic value of a change in water use is the marginal profit added by an additional unit of water used. Those users who can generate the most value from using more water will be the ones that will purchase additional water. Alternatively, they would be the users who would benefit most from future development to make more water available for use.

Running tap, Perth. Photo: Bill van Aken, CSIRO.

Water ecosystems (rivers, lakes, estuaries, and wetlands) support a range of economic activities without water being consumed, including commercial fishing, tourism, and recreation. The economic value of freshwater extends to the coast and inshore marine environment. Some commercial species, such as prawns, rely on freshwater discharges from rivers, and the nutrients they bring, to sustain viable populations. The direct economic value of water environments can be estimated from the commercial value of the markets for tourism and other recreational activities. For example, Moreton Bay in south east Queensland is an estuary and marine area dependent on clean freshwater inflows from the adjacent rivers. Use of Moreton Bay earns $10.5 million per year for the South East Queensland tourism industry, $260 million for the recreational industry and $60.1 million for the commercial fishing industry.[4]

Values of household water use

Good quality water for drinking, washing, and cooking is essential to sustain human life. The values embedded in domestic water go well beyond its cost and quality, as revealed by community reactions to the option of using recycled water for human consumption. Recycling wastewater or storm water is a technically viable and cost-effective solution for urban water supply (see Chapters 6 and 7), but there is significant community resistance to some uses. The closer the use gets to direct human contact, the less acceptable recycled water becomes. It is more acceptable for uses such as toilet flushing and open space irrigation, less acceptable for growing fruit and vegetables, which get eaten directly, and least socially acceptable as water for drinking and personal hygiene.[5] At the heart of the concerns are emotions and perceptions of risk, and the perceived lack of trust in public institutions to be able to provide the highest level of drinking water service all day, everyday, for decades to come, especially in the face of emerging pollutants (see Chapter 5).

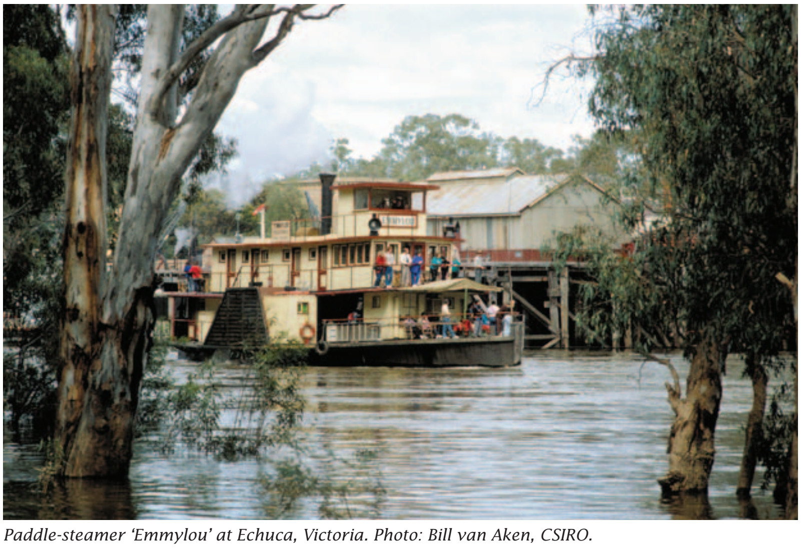
In Australia, up to half of domestic water use is for garden watering, providing the aesthetic and other values of a verdant garden. In recent years, under household water restrictions, surveys showed that people were willing to pay up to twice the price of water at the time to secure reliable supplies of water for their gardens.[6,7] Of course, garden watering does not require potable standards of water quality and alternative sources can be found for the price people are willing to pay.

Environmental water values

As well as the direct economic uses, water-dependent ecosystems provide a myriad of ecosystem services of indirect economic value and they have intrinsic value beyond any economic consideration. Water ecosystems provide services such as processing waste and keeping water clean, or providing biodiversity as genetic capital for future applications (Figure 2.3). Costs for human provision of the services (such as for treatment of water quality) might be much higher if the ecosystem services were not maintained. In this way, a monetary value to people can be placed on the ecosystem services provided. A highly influential analysis of global ecosystem services showed that ecosystems provided at least as much value to the economy as the human production of goods and services,[8] but ecosystems also have benefits beyond their human utility.

Ecosystems can be valued purely for their own sake, or merely from the knowledge of their existence. Individuals express bequest values for ecosystems, wanting to preserve them not just for their own benefit but for the equal benefit of generations to come: a core concept of environmentally sustainable development as first defined.[9] Others have deeply held sense of place and belonging towards water environments such as the Murray River, which has an emotional significance for people throughout Australia. Residents of Perth have developed a sense of attachment towards the many groundwater-fed lakes and wetlands of the city and support the use of water to sustain the wetlands.[10] Further, there is a strong sense of responsibility for the environment and a sense of entitlement to fair and equitable access to the continuing benefits deriving from these environments that extends beyond mere economic value.

Ecosystems may be appreciated purely for the diversity of organisms that they support, placing intrinsic worth on all organisms, including, but not limited to, humans. From this perspective, all ecosystems and species are of value whether they contribute to human wellbeing or not.



Paddle-steamer 'Emmylou' at Echuca, Victoria. Photo: Bill van Aken, CSIRO.

Provisioning Services	
Food:	Ecosystems provide the conditions for growing food such as fish in wild habitats.
Raw materials:	Ecosystems provide materials for construction such as fine timbers.
Fresh water:	Ecosystems provide surface and groundwater.
Medicinal resources:	Many plants are used as traditional medicines and as input for the pharmaceutical industry.
Regulating Services	
Local climate and air quality regulation:	Water and vegetation reduce temperature extremes.
Carbon sequestration and storage:	As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
Moderation of extreme events:	Ecosystems can create buffers against natural hazards such as floods.
Waste-water treatment:	Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.
Erosion prevention:	Vegetation prevents river and foreshore erosion.
Pollination:	Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.
Biological control:	Ecosystems are important for regulating pests and vector borne diseases.
Habitat or Supporting Services	
Habitats for species:	Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.
Maintenance of genetic diversity:	Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial species.
Cultural Services	
Recreation and mental and physical health:	The roles of natural landscapes and green space for maintaining mental and physical health is increasingly being recognised.
Tourism:	Nature tourism provides considerable economic benefits and is a vital source of income for some regions.
Aesthetic appreciation and inspiration for culture, art and design:	Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
Spiritual experience and sense of place:	Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

▲ ***Figure 2.3****: The range of services that water ecosystems may provide for people.*[11]

Legislation that protects species and ecosystems such as the *Australian Environment Protection and Biodiversity Conservation Act 1999*[12] protects species and habitat for their own sake, not because they have economic value per se. The Ramsar Convention is a similar international agreement to protect migratory birds and internationally significant wetlands.[13] Metrics used to value biological diversity in a marine or freshwater aquatic habitat include the number of endangered species, species richness and diversity, and the presence of indicator species.

Australia is fortunate in having many water ecosystems of high intrinsic worth or that are treasured by society, as evidenced by the results of surveys of their use for recreation and tourism, and the increased property values observed in the vicinity of water ecosystems. These include the Kakadu wetlands, Lake Eyre, the Murray and Darling Rivers, Moreton Bay, Port Phillip Bay, and the Swan River; and coastal rivers such as the Daly River, Clarence River, and Thompson River, to name a few. The degradation of rivers and estuaries in recent decades has led to public awareness of the importance of sustaining these environments (see Chapter 9).

There are over 1000 estuaries in Australia, of which 50% are in near pristine condition[14] and there are over 900 wetlands listed as being of national importance, of which 64 are also of international significance.[15] There are 346 species of native fish in Australia, and before their decline, wetlands supported over one million water birds, including plovers, sandpipers, and stints, which migrate seasonally from the Arctic Circle to Asia and then on to Australia and New Zealand.

It is often convenient to express environmental values of water in monetary terms so that their value can be compared directly with economic uses of water. The three main ways to monetise ecosystem values are: through conventional markets, such as the value the water would have if put to economic use; implicit markets, such as the value of an estuary estimated from the increase in nearby residential housing prices; and constructed markets, by eliciting the willingness to pay for improvements to an ecosystem.

More than 60 studies have estimated use and non-use values of the natural capital assets and the ecosystem services these assets supply across the Murray–Darling Basin.[16] For example, the willingness to pay to restore the Coorong and Lower Lakes of the Murray River, is estimated to be $5.8 billion.[17] Interestingly, while such attempts to put an economic price on the intrinsic values of water ecosystems are fraught with uncertainty, the revealed values for the Murray–Darling Basin are of the same magnitude as the $10 billion that is being spent by the Australian Government, with community support, to restore environmental health of the Basin. Support for such levels of government expenditure is another indicator of the importance society places on these ecosystems. Whether that ecological restoration should come at significant cost to irrigation water use, however, is being contested through reactions to the Murray–Darling Basin Plan at the time of writing.

Collecting bush tucker, Kakadu wetlands Northern Territory. © Skyscans.

Indigenous values

Indigenous Australians attach deep spiritual significance to water ecosystems. They believe water to be a sacred and elemental source and symbol of life, which has sustained watershed communities for thousands of years, and governed Indigenous peoples' relationships to each other and country.[18,19]

Indigenous perspectives and values relating to water are not widely understood and have been neglected in water use decisions and water management. There is now more attention being given to Indigenous beliefs, interests, and common-law rights under Native Title. National water policy now recognises the need to include Indigenous people in all activities relating to water planning and management.[20] Indigenous groups have identified water management as one of the most pressing environmental problems they face, alongside climate change. The diversity across Indigenous communities throughout Australia is likely reflected in a diversity of views and opinions about water use and management. Indigenous people express a strong desire to be involved in land and water management in order to fulfil customary obligations to care for their country.

Water is also of value to contemporary Indigenous livelihoods. Indigenous people have rights under the common law to access cultural water sites and to maintain customary use and access of places and the plants and animals that depend on water. Many Indigenous people and communities rely heavily on aquatic resources to supplement their household incomes. Some Indigenous landowners and corporate organisations also have water entitlements and wish to develop water-based enterprises. Indigenous organisations have argued that their people have a right to benefit from the economic use of water and the development of water resources. Greater access to economic opportunities from water could improve the socio-economic position of Indigenous people.

Water policy reform, ratified by the Commonwealth, states and territories in the National Water Initiative, has started to enable some dimensions of Indigenous water values to be recognised,[21] but progress towards including Indigenous values in water planning remains slow.[22]

Resolving conflicts in values

Competing values for water and increasing demands on a fixed resource often result in conflicts over access to water, and trade-offs or compromises between different groups are inevitable. The over-arching challenge of sustainable water use, for example, is to balance the consumption of water with the intrinsic and economic values of maintaining water environments in good condition. The resolution of conflicting values for water in Australia is being achieved through a combination of regulation, planning, and markets.

The increased recognition of the economic importance of water has led to a recent trend towards using market mechanisms to resolve competing uses, particularly in rural areas. Entitlements to access water have been formalised and separated from land titles and can now be bought and sold, as can the annual allocations of water for those entitlements (see Chapter 8). In 2007–08, over 1500 GL of water was traded in the Murray–Darling Basin, mitigating the economic losses as a result of low allocations in that drought year.[23] Water markets are imperfect, because regulations exclude some users (such as the limits on trade from some irrigation districts discussed in Chapter 8), but there are opportunities for further innovations. One example might be to enable irrigators to manage their own reliability of supply by purchasing ongoing storage in a reservoir rather than being given an annual allocation of water. Carry-over rights are a form of this access to storage and are implemented in some systems.

For markets to work well, the price of water should include all costs. Although the price of water has increased to reflect true costs, capital costs are sometimes subsidised by governments and costs to the environment are not always included. In some areas, the price of water has been disaggregated to reflect different aspects of cost, including storage in reservoirs, costs of supply infrastructure, and costs of managing the provision of water. Treating water as an economic commodity is not acceptable in many societies, because it is not always considered ethical to charge people the full cost for an essential and natural resource such as water. The price of water, though, is typically for the provision of services such as safe, reliable, piped water. Bottled water, which is of high quality, refrigerated, and is widely available in a convenient container is priced at a few dollars per litre. Potable and reliably supplied domestic water, piped to your home, is priced at a few dollars per thousand litres, whereas irrigation water, provided in larger quantities and of variable quality and reliability, costs much less than a dollar per thousand litres. In an open market, therefore, the price of water reflects the balance of supply and demand for the service, and its perceived value, not just its cost.

Water plans and regulations are used to ensure that licensed users have equitable and reliable access to water and to ensure protection of water environments. For example, an interim cap on diversions in the Murray–Darling Basin was introduced in 1995 to ensure the reliability of existing entitlements and to halt further ecological degradation of river, wetlands, and floodplains. The limits on use of water in the Murray–Darling Basin are being revised now, through the Murray–Darling Basin Plan, to restore and protect ecosystems.

There is now much more knowledge being generated to better inform water plans. The water requirements of ecosystems are increasingly well understood and can be applied to set limits to use that protect ecosystem values (see Chapter 9). There are also several techniques to include non-market values of water and users of water who do not have entitlements, such as cultural uses of water by Indigenous communities and others. An important first step is to catalogue these broader sets of values, such as poorly appreciated Indigenous water uses, and incorporate them into decision making, and this is a current area of research.

The trade-offs between different levels of water use can be shown in a cost–benefit analysis, where all costs and benefits can be expressed in monetary terms. This can reveal whether a community's overall welfare will be improved as a result of a particular water project or policy decision. Ecosystem services can be included in a cost–benefit analysis to broaden its scope, which is another active area of international research. Where there are non-monetary values, multi-criteria analysis can used to include different social, cultural, and environmental aspirations. Each aspiration is weighted in importance and prospective water plans are scored as to how well they meet these aspirations.

Despite the rapidly improving knowledge and techniques used to value water, they are yet to be fully incorporated in water plans. The National Water Commission observes that many plans still lack any transparent consideration of community values or the needs of the environment and trade-offs between values are rarely shown or used in community consultation.[21] Recent public criticism of the lack of transparency and consultation in the proposed Murray–Darling Basin Plan is a stark example.

A benefit of showing trade-offs between competing values is that it can drive innovation towards finding solutions where both human and environmental benefits are increased. This might be achieved by changing the timing of water use or the way water is supplied down a river. This raises the prospect of optimising the planning and operation of water resources to meet multiple values: an area of research that is growing as the potential cost of conflicts over water use increases. As demand for water grows, the best solution for communities might be to look for more efficient and equitable ways of meeting their needs.

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Water and climate

Francis Chiew and Ian Prosser

Key messages

- Floods, droughts, and climate change are the three most important influences of climate on Australia's water resources.
- Water resources are vulnerable to both climate variability and change; for example, runoff into Perth's reservoirs has declined by 55% since the 1970s and the 1997 to 2009 drought resulted in unprecedented decline in runoff and water use in the southern Murray–Darling Basin.
- Climate change has played a part in recent reductions in rainfall and water resources, however its specific contribution is difficult to quantify.
- Climate change by 2030 is likely to reduce average river flows by 10% to 25% in some regions of southern Australia but further climate change could produce even more profound reductions of water resources in southern Australia.
- The relationships between climate and runoff are now being used to provide more accurate seasonal forecasts of water resources useful for irrigators, dam operators, and environmental managers.

Weather and climate are the primary influences on Australia's water resources. Extreme storms and cyclones produce floods that can rise and fall within hours or that can last for months, while yearly variability in rainfall can produce droughts that may last for a decade or longer. Longer-term climate change increases or decreases average rainfall and evaporation, fundamentally changing the amount of water resources available. This chapter describes the influences of climatic events, variability, and change on water resources through their influence on floods, droughts, and water resources.

'Weather' is the brief, rapidly changing daily and seasonal conditions in the atmosphere, while 'climate' is the average weather experienced over years to decades. 'Climate variability' is the year to year and decade to decade noise or variability around the average climate, while 'climate change' is the longer term change in average conditions over several decades to centuries. The noise of weather and climate variability can occur around a changing average climate, making it difficult to detect long-term trends, especially for rainfall, which, in Australia, is highly variable from year to year.

Yearly variations in rainfall, or changes between centuries are amplified as even greater changes to runoff and river flows, making impacts on water resources one of the greatest concerns about climate change. Annual variations in rainfall are typically amplified as two- to three-times larger variations to annual runoff. So a 10% reduction in rainfall typically leads to a 20 to 30% reduction in runoff.[1] This amplification applies to climate change as well, so small reductions in average rainfall as a result of climate change will lead to two- to three-times larger reductions in water resources.

Weather and climate drivers

Floods, drought, and climate change are all driven by a number of processes in the atmosphere and oceans (Figure 3.1), but the changes are driven at different timescales. The drivers shown in Figure 3.1 interact with each other and influence different parts of the continent to bring local weather and climate. The drivers include circulation patterns in the Pacific Ocean that bring El Niño conditions associated with drought in eastern Australia and La Niña conditions that are associated with floods. The Indian Ocean Dipole is a similar pattern in the Indian Ocean that can bring drought to south-west and south-east Australia, and the Southern Annular Mode is a

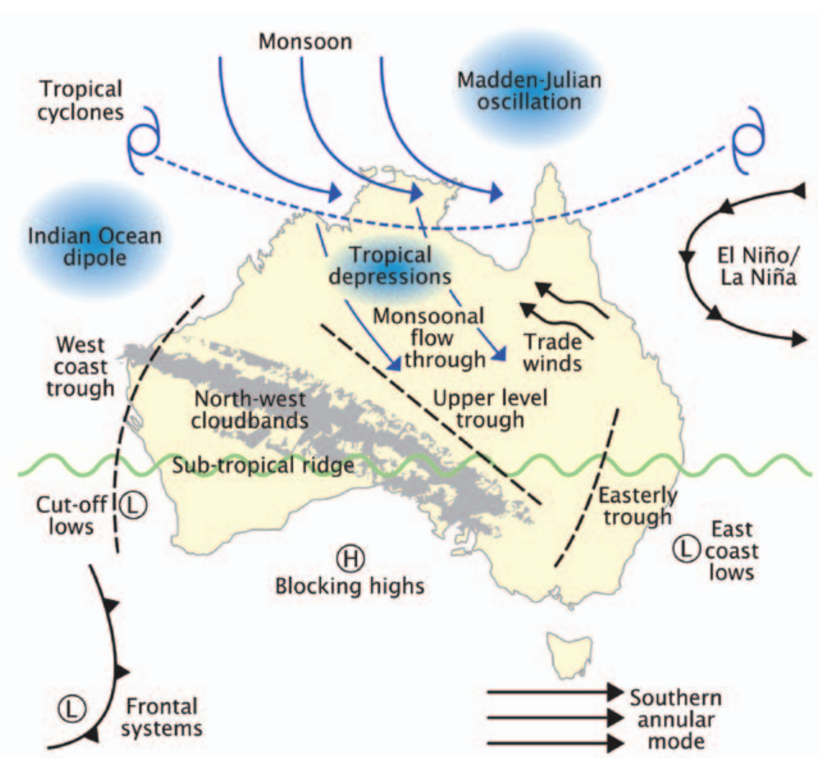
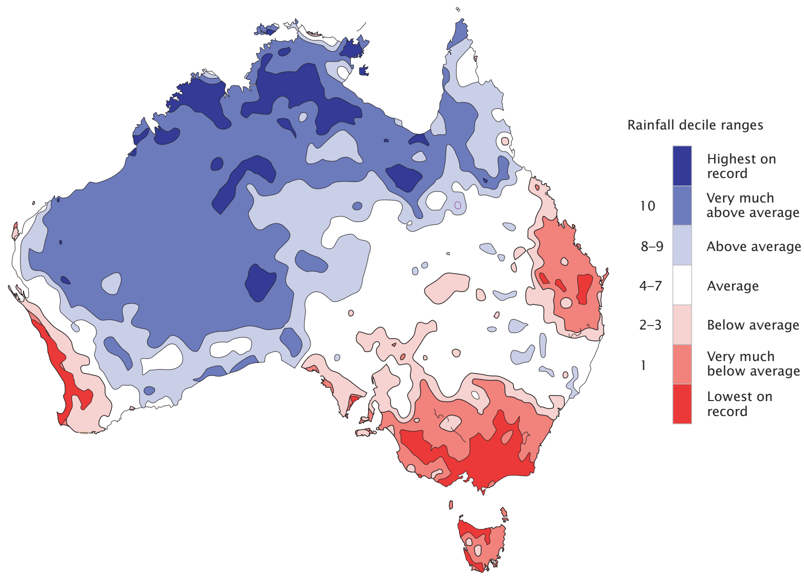


Figure 3.1: The major influences on rainfall (and thus runoff) in Australia.[2] (Reproduced with permission from Australian Bureau of Meteorology. © Commonwealth of Australia.)

▸ ***Figure 3.2***: *Rainfall conditions across Australia from 1 January 1997 to 31 December 2009 relative to the 1900–2009 climate, showing the extreme dry conditions across the south-east, the far south-west of Australia, and south-east Queensland.*[3]



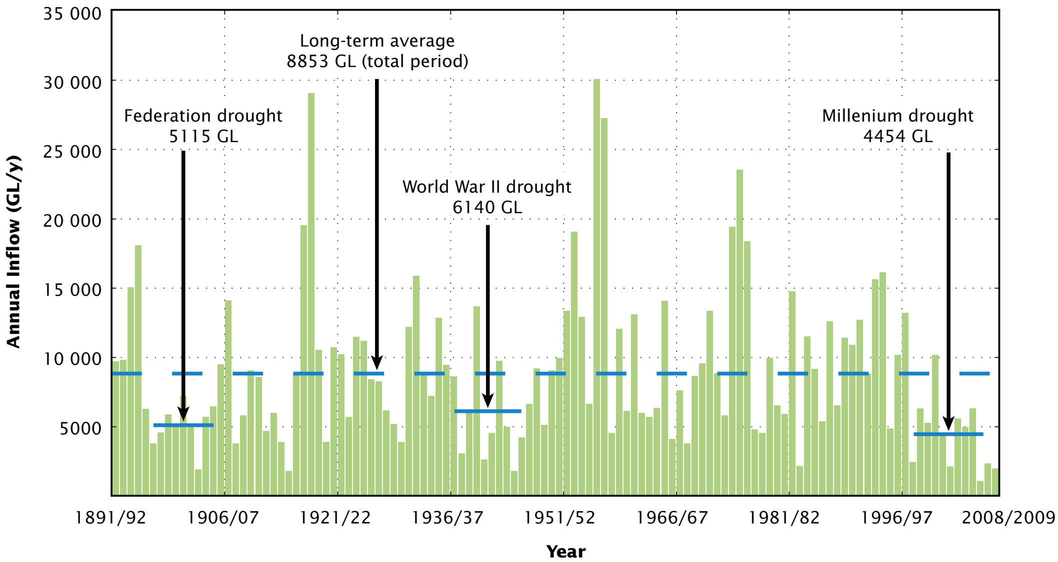
feature of the Southern Ocean that affects weather and climate in southern Australia. Atmospheric patterns such as the monsoon winds and southern ocean frontal systems bring rain, whereas southerly tracks of blocking highs and the subtropical ridge tend to bring dry weather.

Recent drought in southern Australia

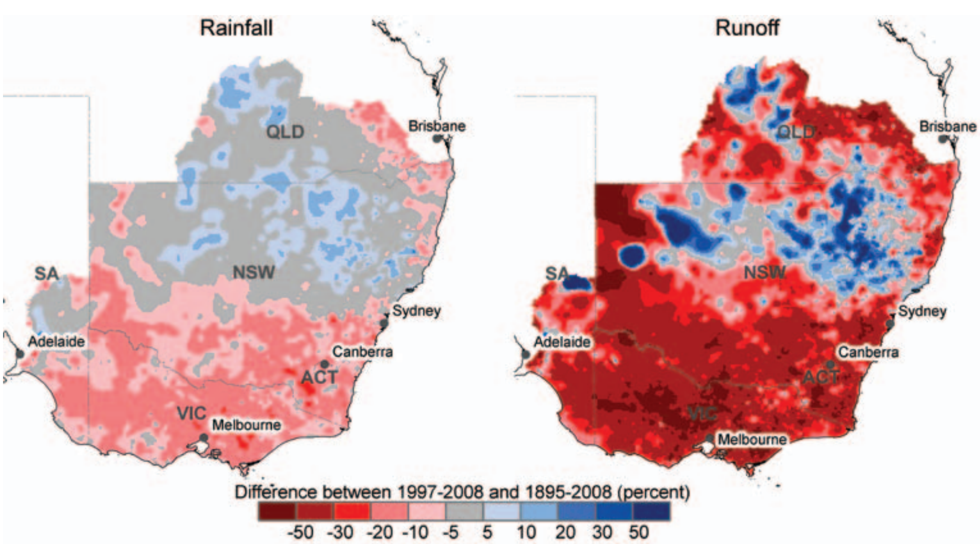
From 1997 to 2009, large areas of southern Australia, in particular the southern Murray–Darling Basin, Victoria, south-west Australia, and South East Queensland experienced prolonged drought, often referred to as the millennium drought (Figure 3.2, Figure 3.3).

The millennium drought in the southern Murray–Darling Basin was unprecedented in the 110 years of reliable rainfall records.[4] It resulted in declining storage levels in reservoirs, several years of severe water restrictions in cities, and years of low water allocations to irrigators in the southern Murray–Darling Basin and elsewhere in Victoria. Water sharing arrangements for the Murray, Murrumbidgee, and Lachlan Rivers were suspended because they were not designed for such extreme conditions.

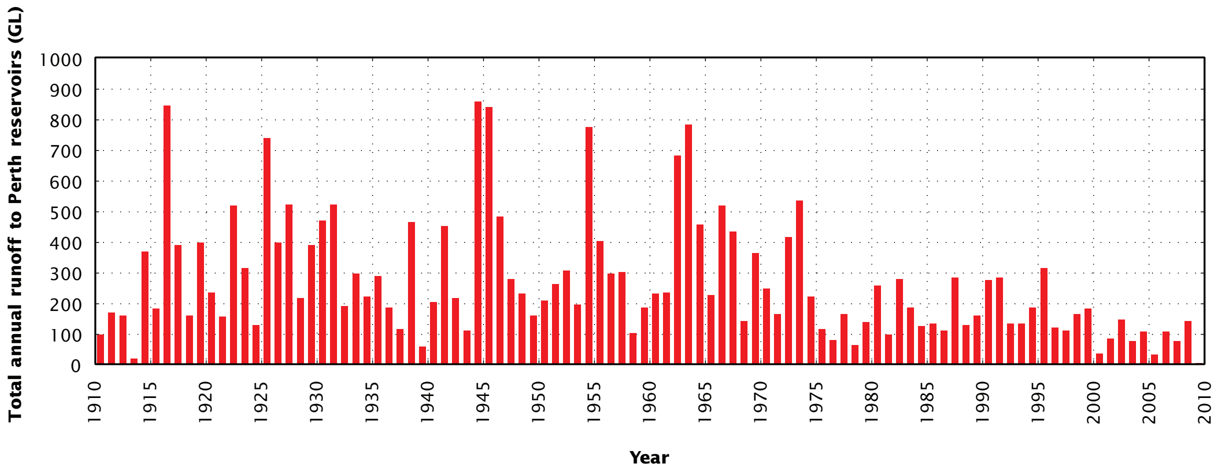
The drought had major environmental impacts.[5] For example, the Lower Lakes of the Murray River fell more than 1 m below previously record low levels, exposing potentially toxic acidic sediments and increasing salinity in the lakes. Across the Murray–Darling Basin, there was either extensive death or stress to river red gums on floodplains, and low river flows led to the isolation of fish communities and a decline in fish breeding. Water use for irrigation fell by 64%[6] and it was the first time that drought had caused a major fall in use for an extended period (see Chapter 8). Most of Australia's water use is in southern Australia, so the drought had a substantial economic, environmental, and social impact.



▲ ***Figure 3.3**: Annual total inflows into the Murray River showing the high year to year and decade to decade variability and the low inflows from 1997 to 2009 and during earlier droughts. (Data provided by the Murray–Darling Basin Authority.)*



▲ ***Figure 3.4**: Percentage difference between recent (1997–2008) rainfall and runoff in south-eastern Australia and the long-term (1895–2008) averages.[8] Although rainfall in Victoria and southern NSW was only 10–30% below average, runoff was 30–60% below average.*

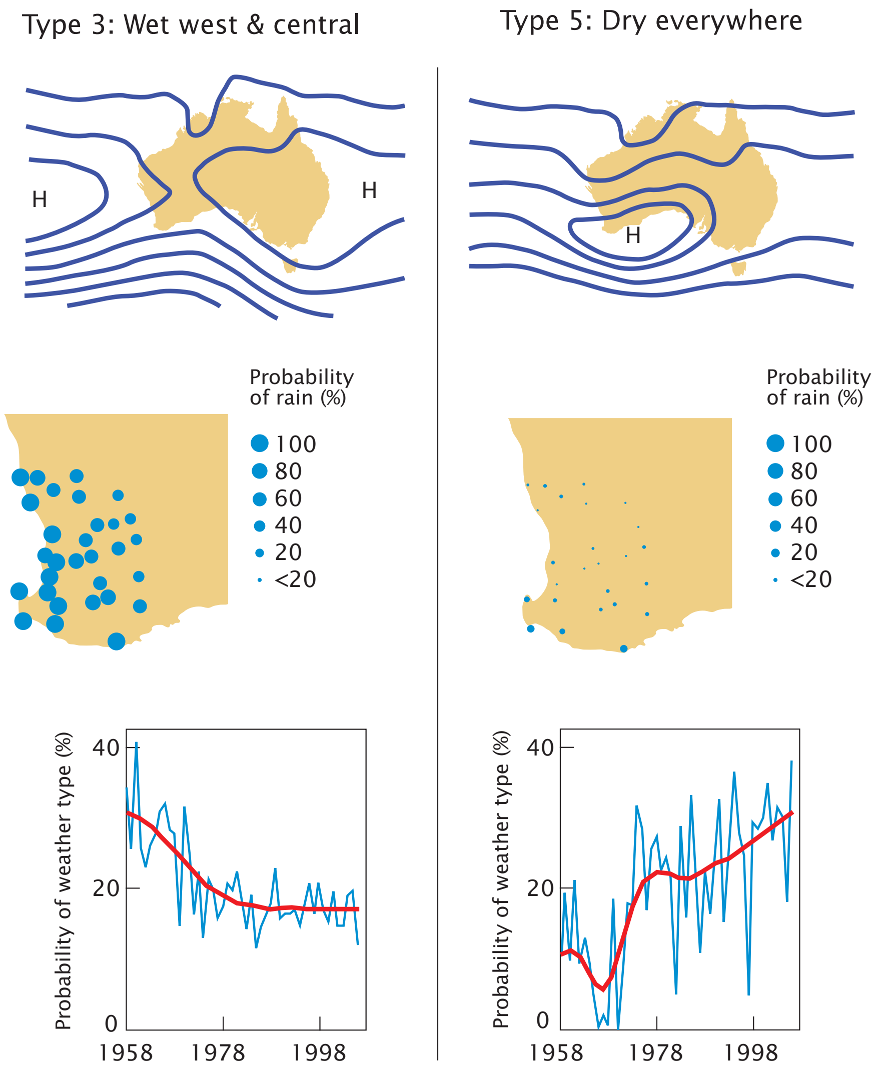


▲ ***Figure 3.5****: Annual series of runoff into Perth reservoirs showing a persistent decline in inflows since the mid-1970s.*[10]

There had been earlier multi-year droughts in the southern Murray–Darling Basin such as the Federation drought of 1895 to 1903 and the depression drought of the late 1930s and early 1940s (Figure 3.3), but none were as severe in terms of reduced runoff as the millennium drought. In places, runoff was less than half of the long-term average, even though average rainfall had decreased by less than 20% (Figure 3.4).[7] The amplification of change from rainfall to runoff was greater than expected from previous droughts. Possible reasons include: a disproportionate rainfall decline in autumn resulting in dry soil at the start of the runoff season; rainfall decline in winter when most of the runoff occurs; the lack of any high rainfall years, which produce disproportionately high runoff; and higher temperatures driving greater evaporation.[3]

In the South West region of Western Australia, the very low rainfall from 1997 to 2009 has been part of a longer 35-year trend of gradually declining rainfall.[9] The average runoff to Perth reservoirs was 338 GL/year before 1975 but from 1975 to 2009 it was only 181 GL/year, or 55% lower than before, as a result of a 16% fall in average annual rainfall (Figure 3.5). The higher runoff years are now nowhere near as high as previously (i.e. since 1975, no annual runoff to Perth reservoirs was above the pre-1975 average). This persistently low runoff led the Western Australian Government to secure additional water supplies for Perth, leading to a greater reliance on groundwater and the opening of Australia's first desalination plant for supply of water to major city (see Chapter 7). Whether the change since the 1970s is a result of global warming or whether it reflects long-term natural variation in climate is discussed below.

The decline in rainfall around Perth has been attributed to changes in weather patterns across south-west Australia (Figure 3.6). Since the 1970s, high pressure systems and associated cold fronts have moved south bringing less rainfall than their previous more northerly track across southern Australia.[11] These changes most strongly affect autumn and winter rainfall and are the same sort of changes predicted to intensify with increasing global temperatures in future.



▲ ***Figure 3.6****: The relationship between two weather patterns and winter rainfall in the South West of Western Australia, showing the changed frequency of the weather patterns as an explanation for why rainfall has declined in the region since the 1970s. In Type 3 weather, high pressure systems and the subtropical ridge occur over the centre of Australia. This weather produces rain over south-west Australia as shown by the blue circles. During Type 5 weather, the high pressure systems occur further south and produce weather that brings very little rainfall to the region. The graphs at the bottom show that since the 1970s the frequency of Type 3 weather has declined and Type 5 weather has increased, explaining the decline in rainfall since that time.*

Floods

At the opposite end of the range of climate variability are floods such as those experienced in 2010 and 2011 across eastern Australia. These were associated with one of the strongest La Niña events on record, the opposite to the El Niño conditions that were associated with drought. During La Niña conditions, the eastern Pacific Ocean is unusually cool as a result of upwelling of deep ocean water, strengthening the easterly trade winds coming to Australia from the western Pacific Ocean. This brings warm moist air over eastern Australia, causing widespread above-average rainfall.

Floods are the most costly natural disaster in Australia. The average direct annual cost of flooding between 1967 and 1999 has been estimated at $314 million.[12] Costs vary widely between flood events (depending on flood volumes and infrastructure affected); for example, the Brisbane floods of 1974 caused $700 million damage at that time, while the damage from the 2011 floods is likely to be in the vicinity of $10 billion in current value. Moderate floods also have several benefits – they infill reservoirs, recharge groundwater, and replenish natural environments (see Chapter 9). These benefits can accrue for several years after the flood has subsided.

The Bureau of Meteorology issues flood warnings based on continuous monitoring and reporting of rainfall and river levels, rainfall forecasts, and hydrological modelling. Floods on small rivers generally have warning periods lasting from several hours to a couple of days. Large regional floods on lowland rivers occur with warning periods of days or weeks as they flow gradually downstream from runoff that is generated in tributaries. The most unpredictable form of flooding is local flash flooding in creeks and small rivers. This type of flooding is caused by locally intense storms that can cause a creek to rise to a major torrent in less than an hour. Flooding in Toowoomba and the Lockyer Valley in January 2011 were examples of flash flooding with tragic consequences.

Statistical analysis of historical floods shows that decades of higher than average rainfall, such as the 1950s to 1970s, can have higher magnitude floods than under average climatic conditions. A flood expected once every 100 years or so on average can be twice as large in these wetter decades than in drier decades.[13] The same could happen with global warming. The warmer ocean temperatures will produce stronger convection and the ability of the air to hold more moisture, which could increase the intensity of storms and cyclones.[14] Climate modelling also shows that extreme rainfall events such as cyclones are likely to be more intense in future, although less frequent,[15] resulting in bigger floods and greater costs from flooding.

Many large dams, such as the Wivenhoe Dam in Brisbane, are managed to store water supplies and to retain some empty storage capacity to absorb and mitigate floodwaters, protecting downstream communities. These two functions may appear in conflict but the level of water to be stored is determined well in advance. Better seasonal forecasts of inflows (see below) offer the prospect of increasing the flood storage volume in dams when the forecasts predict a high probability of flooding.

Brisbane floods, January 2011. Photo: Glenn Walker.

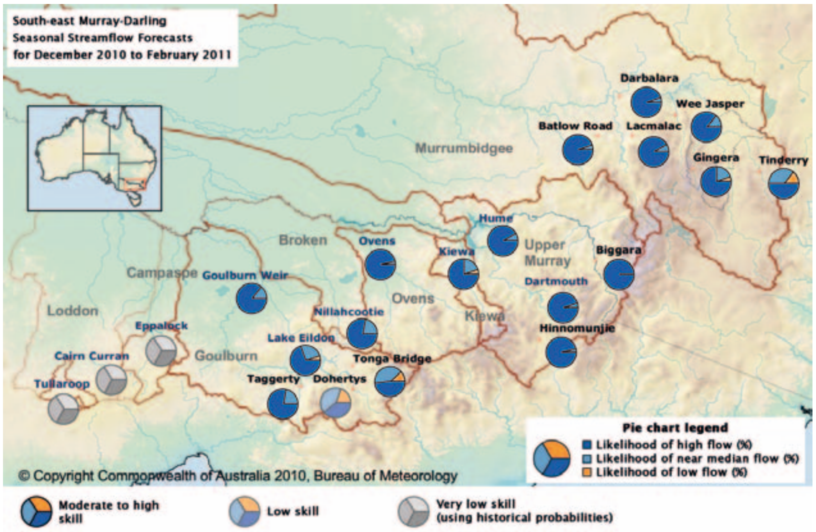
Short-term and seasonal forecasting of river flow

A paradox of Australia's highly variable rainfall and runoff is that it can be predicted several months in advance from the signals of global circulation such as El Niño and La Niña and other indicators. River flows can be forecast several months or seasons ahead using information on the soil moisture in the catchment, and the state of the ocean and atmosphere (e.g. droughts in eastern Australia are often linked to El Niño events in the equatorial Pacific Ocean).[16] Seasonal rainfall and runoff forecasts can help irrigators plan, support trade of water, and make water use more efficient, and help decide when to release water from reservoirs.

The Bureau of Meteorology has been issuing seasonal weather outlooks since the 1990s, and in 2010 it launched a new service on seasonal river flow forecasting.[17] This forecasting system is based on models developed by CSIRO[18] that give probabilistic forecasts of river flow several months ahead, in particular flows to major water storages (e.g. Hume and Dartmouth Dams in the upper Murray; Figure 3.7).

The Bureau of Meteorology is also responsible for issuing flood warnings and is planning to extend its current flood warning service to forecast river flows continuously up to 10 days ahead. The Bureau of Meteorology and CSIRO are jointly developing and testing a modelling system for this purpose combining hydrological and weather prediction models that use real-time data from climate stations, river flow gauging sites, and satellite data.

▸ ***Figure 3.7***: *Seasonal forecast of runoff into the upper catchments of the Murrumbidgee and Murray Rivers issued in December 2010 for the 3-month period from December 2010 to February 2011.*[19] *Dark blue indicates the probability of markedly above average runoff; light blue indicates the probability of average runoff, and orange indicates the probability of markedly below average runoff. The prediction was for high flow across the region as a result of wet catchment conditions and the forecast for continuing La Niña conditions. High flows did persist through the summer.*



Impacts of climate change on river flows

Global temperatures of both the atmosphere and the oceans have been rising since the 1950s, and rising more rapidly than has been recorded in the geological past.[20] Many studies have linked most of the global warming to increasing greenhouse gas emissions.[20,21] There is less certainty whether human-induced increases in temperature are the cause of the decline in rainfall in south-west Australia since the 1970s and the historically unprecedented conditions of the recent millennium drought in south-east Australia. This is because the huge natural variability (or noise) in rainfall from year to year makes it difficult to detect an overall trend. Rainfall is also controlled by regional weather and climate patterns (Figure 3.1), which have a complex relationship with global temperatures.

Climate modelling indicates that the persistent dry conditions in the far south-west and the millennium drought in south-east of Australia are at least in part a result of climate change.[3,11,22] The dry conditions are associated with the shift of storm tracks towards the southern ocean. Climate models indicate that such changes are likely to intensify and become more persistent in future, so the dry conditions experienced are consistent with the trajectories of future climate for those regions.

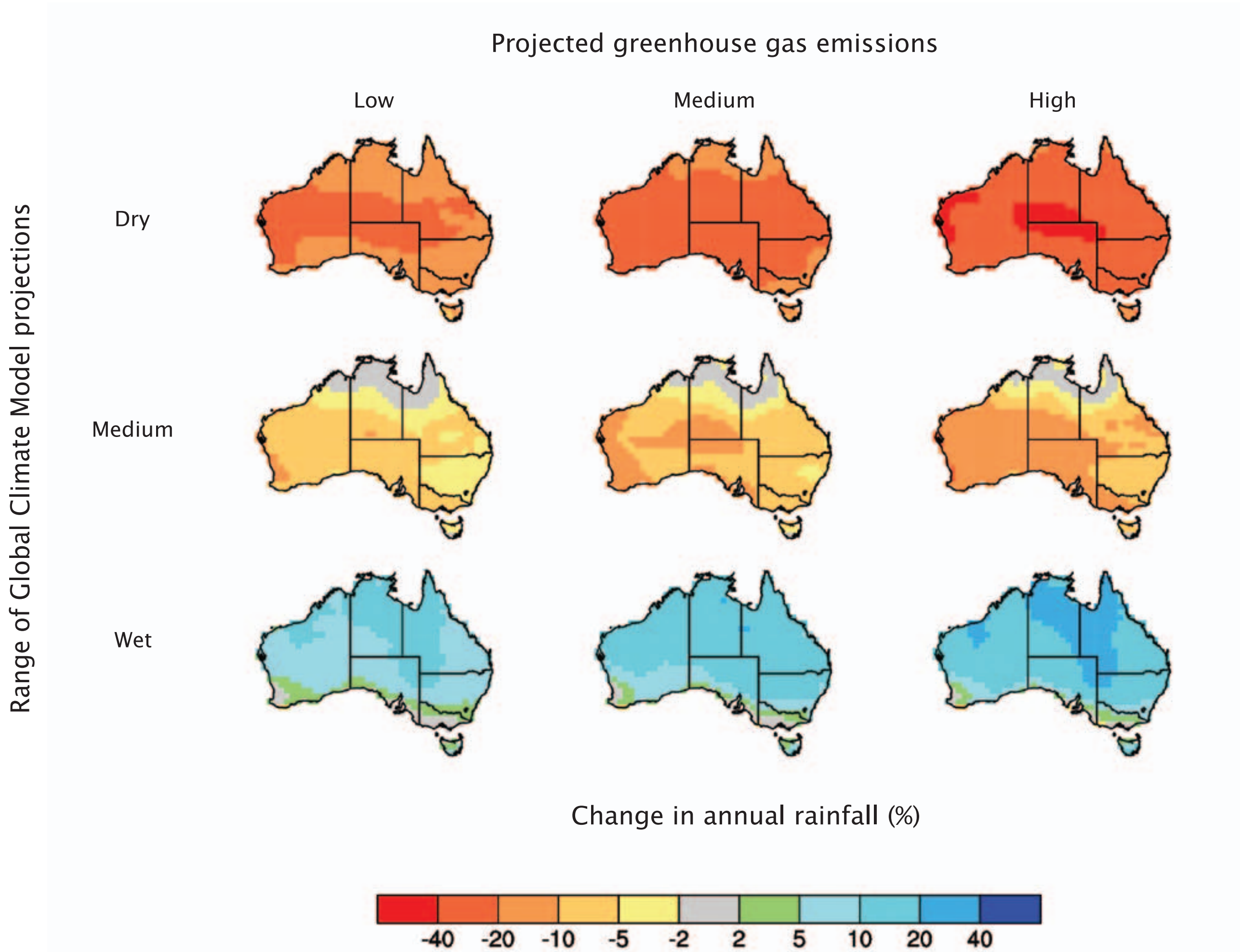
Extended droughts and decades of wetter conditions are also a natural feature of southern Australia's climate. With only a little over a century of measurements, it is hard to establish patterns that span several decades so proxy records from tree rings, corals, and caves are used to describe longer term climate patterns. These proxies are correlated for recent times with the historical measurements of the oceans and atmosphere and then used to extend those records further back in time. At shorter time scales, we know that El Niño and La Niña influence rainfall and runoff[23] and now additional longer decade cycles are being found of increased frequency of El Niño events followed by decades of increased frequency of La Niña events. Decades of high frequency of El Niño events are associated with extended periods of drier-than-average conditions in eastern Australia, such as in the last few decades, and vice versa for wetter than average conditions, such as in the 1950s and 1970s.[24]

It is possible that the millennium drought was a combination of natural variability and climate change and it is only through continued observations in coming years that any long-term trend in rainfall can be confirmed or not, and then, if the connection is evident, be attributed unequivocally to human-induced climate change. Regardless of the cause, though, a decade or more of drier conditions is enough to put water users, including ecosystems, under considerable stress and has tested whether water management is well adapted to such harsh conditions.

Predicting climate change impact on river flows involves three main components. Firstly, global climate models are used to project future climate change. Secondly, the results from these global climate models are 'downscaled' to the region of interest and its weather patterns, and finally, these regional weather patterns are used to run hydrological models to predict future river flows. Global climate models simulate complex global and regional climate systems. The Bureau of Meteorology and CSIRO have combined climate process understanding with global climate model simulations from the Intergovernmental Panel on Climate Change (IPCC)[20] to provide climate projections for Australia.[25] Figure 3.8 is an example of the range of projected changes in average annual rainfall by 2070 relative to 20th century rainfall.

There is a considerable difference in the projected rainfall in each of the maps in Figure 3.8. This is because of two key uncertainties about future climate. The first is the future level of greenhouse gas emissions, which will be determined by future industrial development and mitigation of emissions. The world is currently tracking toward the high end of emissions shown on the right hand column of Figure 3.8. The second uncertainty is how future rainfall in Australia will respond to changes in global temperature. Future rainfall is predicted from global climate models, through changes to conditions in the atmosphere and ocean, such as those shown in Figure 3.1. Figure 3.8 shows the range in projections from the various global climate models used by the IPCC.

Most climate models indicate that southern Australia, where most water is consumed, is on average likely to be drier in the future. The model projections are consistent with the patterns observed during the last decade or so, with a shift of autumn and winter storm tracks towards the South Pole. In northern Australia, the direction of change in average rainfall is uncertain, with as many models predicting a wetter future as a drier future.



▲ ***Figure 3.8****: Projections for percentage change in average annual rainfall in Australia by 2070 relative to 20th century rainfall. Nine projections are shown. The columns of maps show projections for low, medium, and high future greenhouse gas emissions, showing the effects of different amounts of global warming. The rows of maps show the range of projections from different global climate models. The top row shows the drier model results, the middle row is the mid-range of results and the bottom row shows the wetter projections of average annual rainfall from the models.*[26]

Global climate models produce results at a very coarse spatial resolution. Victoria is typically represented by less than five grid cells in a global climate model and Tasmania is equivalent in area to a single grid cell. Although driven by global circulation patterns, rainfall and river flows are regional phenomena influenced by local topography, proximity to the coast, and local weather patterns. For regional and catchment hydrological modelling, the global climate model simulations need to be scaled down to catchment-scale rainfall and other climate variables.[27]

Dynamic downscaling models are fine-scale climate models nested inside the coarse-scale global climate models. They are able to represent fine-scale topography, vegetation, and weather patterns to produce more detailed patterns of rainfall and other climate variables. Figure 3.9 shows a dynamic downscaling example used for hydrological modelling in the CSIRO Tasmania Sustainable Yields project.

Statistical downscaling models statistically relate regional patterns of rainfall and other climate variables to its large-scale drivers in the atmosphere or oceans. Statistical relationships are built between regional rainfall observations and the larger scale properties of the atmosphere. These are then used to predict future regional rainfall under the changed atmospheric conditions of human-induced climate change. Figure 3.6 is an example of statistical downscaling, showing how rainfall across south-west Australia is related to larger scale patterns of atmospheric circulation.

The results from climate downscaling are used to run hydrological models to predict future catchment runoff and river flows.[29,30] Changes to the average annual runoff (and hence river flow) for a 1ºC global warming (median warming by 2030 relative to 1990) across Australia have been modelled (Figure 3.10, Table 3.1). The considerable range in runoff projections is mainly because of uncertainty of future rainfall under a changed climate. In the far south-west and south-east, a large majority of the climate models project a drier future and this translates to runoff declines of 25% in the south-west and 10% in southern Murray–Darling Basin and Victoria for a 1ºC global warming in the median projection. The hydrological models also simulate changes to other flow characteristics, such as the variability of reservoir inflows and floods and low flows. The low flows and loss of connectivity in the more frequent long dry periods in the future will affect aquatic ecosystems[5] and may exacerbate water quality problems. Larger changes than those shown are predicted to occur beyond 2030 as climate change continues (Figure 3.11); for example, if there is 2ºC or more of global warming, which now seems highly likely.[20,21]

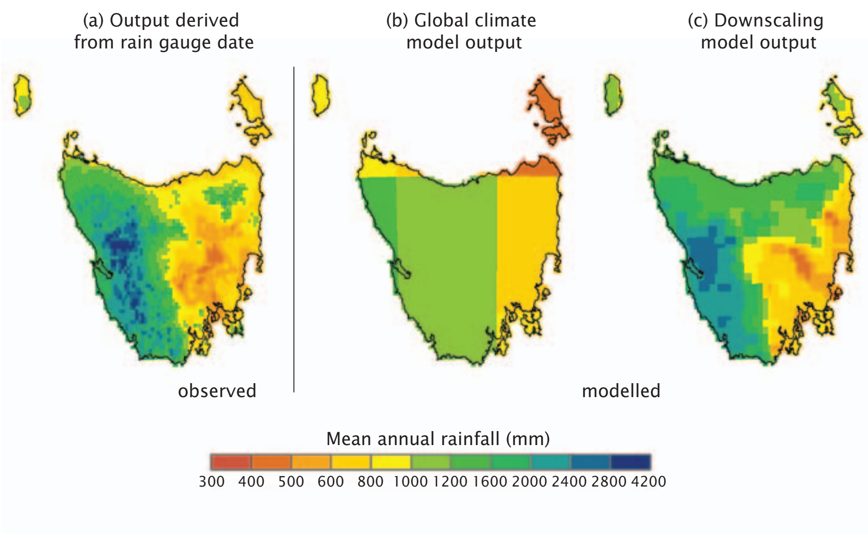
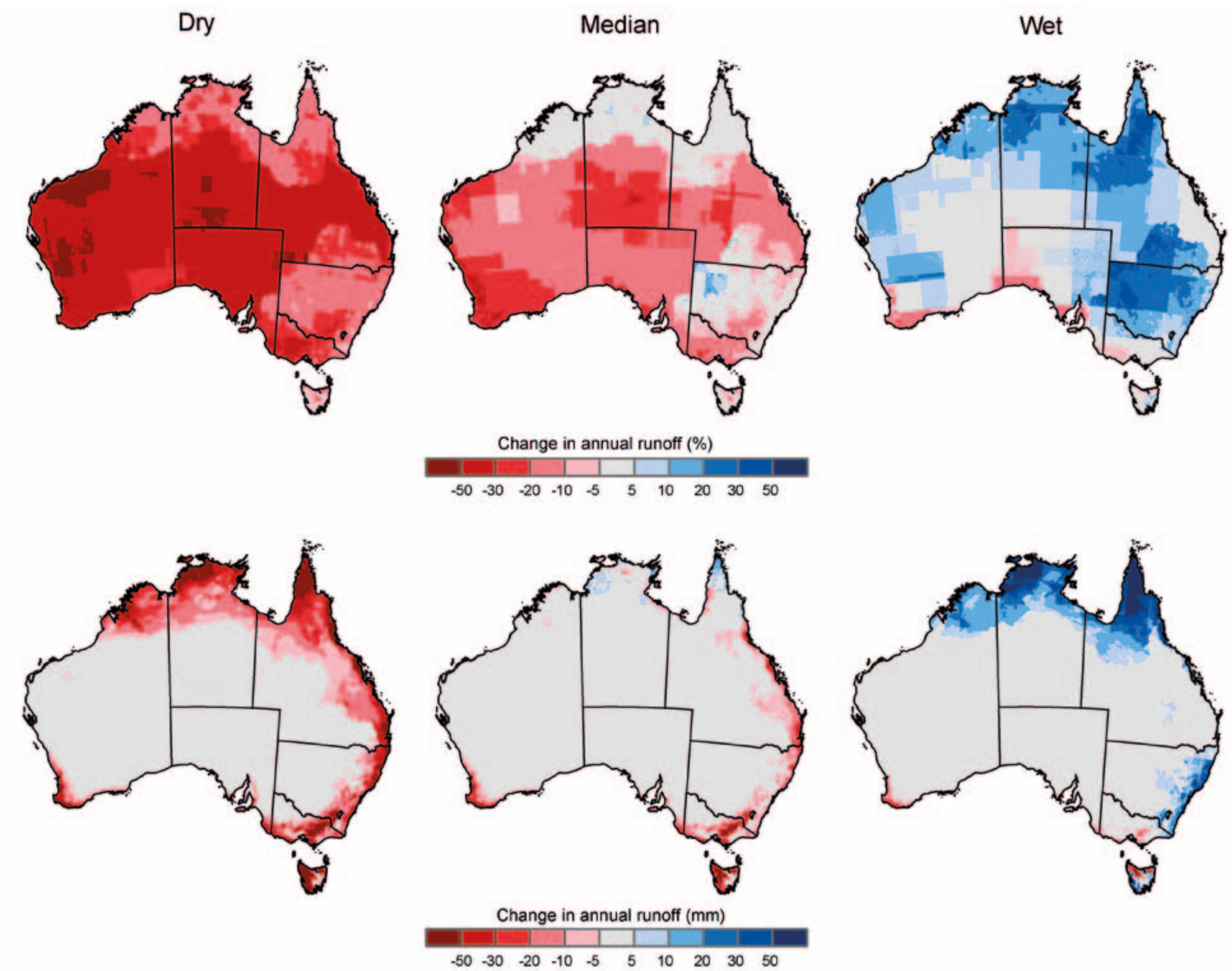


***Figure 3.9**: An example of the need to downscale rainfall from global climate models. (a) The observed patterns of rainfall across Tasmania. (b) A global climate model prediction of rainfall that portrays only the coarsest patterns. (c) Rainfall downscaled from the global climate model using a regional climate model that represents the topography and other influences on regional rainfall, producing patterns similar to those observed across Tasmania.*[28]



▲ ***Figure 3.10****: Change in average annual runoff for 1°C of global warming (~2030 relative to ~1990) across Australia. The top row shows percentage change in runoff and the bottom row shows change in runoff depth (mm). The median, dry and wet extremes of the range of climate projections are shown.*[28,29,31,32]

Table 3.1: Projected changes to average annual runoff for a 1°C global warming from Figure 3.10.

Region	**Modelled changes in average annual runoff (%)**		
	Dry extreme	Median projection	Wet extreme
North-east Australia	−15	−1	+20
North-west Australia	−18	0	+16
South West of Western Australia	−37	−25	−12
Tasmania	−6	−3	0
Northern Murray–Darling Basin	−15	−5	+12
Southern Murray–Darling Basin and Victoria	−20	−10	+1

Although climate change is likely to reduce average rainfall and runoff in southern Australia, the climate will still be experienced largely as floods and droughts. The interactions between climate change, floods, and droughts are illustrated in Figure 3.11 for the southern Murray–Darling Basin and Victoria. A useful indicator for the use of water resources is the 10-year average of runoff. Large dams are able to buffer water supplies against the year to year variations in runoff and provide reliable supplies. However, they are unable to maintain supplies if there is a long drought with low runoff, as was seen in the millennium drought. Similarly, ecosystems have evolved to cope with floods and droughts, but a decade of drought in addition to other pressures can place them under stress.

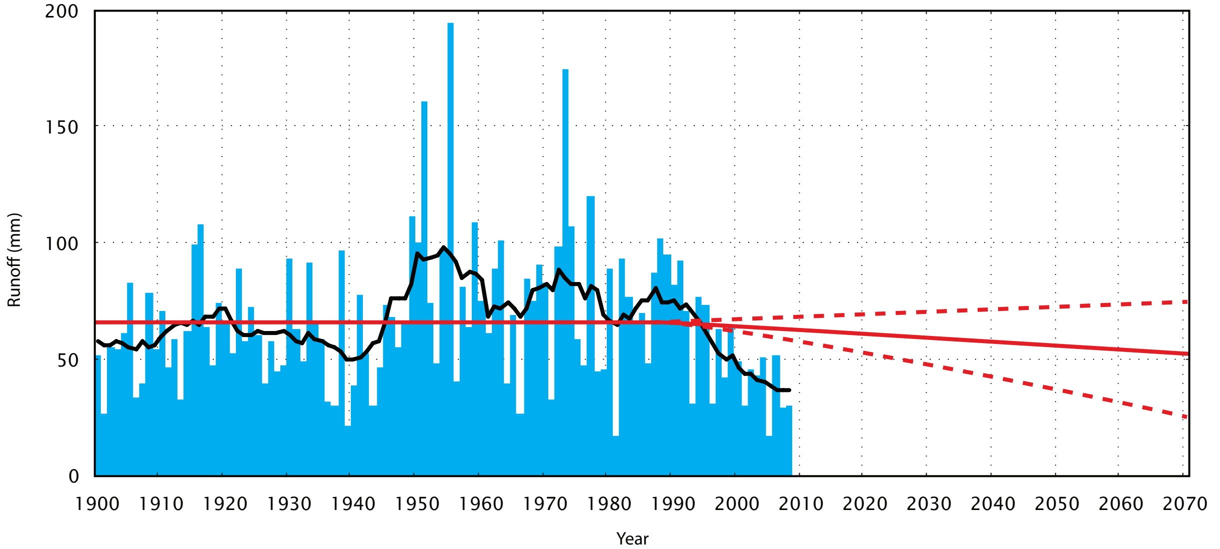
Figure 3.11 shows that the impact of climate change on runoff by 2030 is small relative to the year to year and decadal variability in runoff, where flood years can have 10 times the runoff of drought years. The climate in 2030 will still be one that produces floods and droughts, but with a lower average annual runoff: the droughts may be more intense and the floods less frequent. Projecting out to 2050 and 2070, more profound changes to average runoff are possible, with the prospect that the average runoff could be similar to that experienced in the decade of the millennium drought. Floods and droughts would still be superimposed on that, giving periods of very severe droughts in future. The experience of the millennium drought suggest that such a large reduction in average runoff and more severe droughts on top of that would have severe impacts on water use and on river ecosystems.

Water management and planning in a changing climate

As well as reducing runoff, a warmer climate could increase potential evaporation and hence increase the demand for water in irrigated agriculture, cities, and for use by wetlands and other water-dependent ecosystems. Evaporation though, like runoff, has a complex relationship with global warming and is influenced by other factors such as wind speeds and cloud cover. Thus climate change could not only reduce water availability in these regions but could further increase the gap between water supply and demand. Essentially, climate change intensifies the water scarcity challenge facing cities and rural catchments and intensifies the challenge of achieving environmentally sustainable levels of usage.

Water managers and policy makers in Australia are developing and updating plans to cope with a variable and changing water future. Most capital cities are investing in additional water supply infrastructure to meet the needs of growing populations. Some cities are moving away from their traditional reliance on catchment runoff and groundwater, because these sources are most sensitive to climate change and drought. Instead they are diversifying by investing in desalination plants and water reuse. Water demand per capita is reducing as a result of water use efficiencies, water-sensitive urban design, and water conservation by communities (see Chapter 6). In rural areas, the increased use of water markets, improvements in irrigation efficiency (see Chapter 8), and return of water to degraded ecosystems (see Chapter 9) are all improvements in water management that will also make water management more adaptable to climate change and variability.

It should not be assumed that under conditions of climate change all users of water, including the environment, will bear the reductions in runoff equally. In the highly managed rivers of the Murray–Darling Basin, and city water supplies, flows in the river are largely determined by the operation of dams in accordance with water plans. These river operations and plans are designed to provide reliable supplies, buffering users against a drop in runoff during dry years and storing more water during wet years to compensate. The plans also tend to pass on impacts of reduced flows to regions downstream. They were not designed to deal with long-term reductions in runoff due to climate change. Under the plans, long-term reductions in runoff would be largely borne by the environment and downstream regions.[33] In the Murrumbidgee River system, the median climate projection for 2030 predicts a 9% reduction in runoff, which under the existing water sharing plan would reduce water supply to irrigation districts by only 2%, whereas outflows to the Murray River would reduce by 17% and water for the major wetlands would reduce by over 30%. New arrangements would be needed to share the impacts of climate change more evenly while still providing reliable supplies to water users.



▲ ***Figure 3.11**: Annual runoff across the southern Murray–Darling Basin and Victoria (blue bars) and the moving average of the previous 10 years runoff (black line) showing large year to year and decade to decade variability in runoff. The long-term average runoff from 1895 to 2008 (red line), is projected forward using the median climate change projection for mean annual runoff (1990 to 2070). The two dashed lines are the dry and wet extremes of projected average runoff under climate change.[33] By 2030 the change in average annual runoff is small compared to the variability in runoff, but by 2070 the average runoff could be as low as that experienced in some of the worst historical droughts.*

Dried-out lagoon on old station property at Big Bend, South Australia. Photo: Greg Rinder, CSIRO.

Advances in climate and hydrological sciences and modelling tools can be used to guide water management and planning in a changing climate. The predictions of future water availability are improving as more data become available and the science progresses, but the range of possible future runoff is likely to remain large. Water plans at present are almost exclusively based upon historical rainfall, runoff, and groundwater recharge measurements[34] because these data provide some confidence for assessing water resources and they encompass a range of historical conditions. However, the prospect of climate change and the experience of the millennium drought suggest that relying on history alone is insufficient. Formal risk management techniques can incorporate several future scenarios and the high uncertainties associated with them. These approaches can show how impacts from climate change would be shared among users and give certainty over how plans will be adapted to deal with new conditions if they emerge. Water planning can be made more effective by ongoing research to better understand climate, its relationship to water resources, and consequent impacts on water users and ecosystems.

Conclusions

Relatively small changes in rainfall are amplified to much larger changes in runoff and groundwater recharge, which make Australia's water resources the most variable in the world. Water management is highly adapted to this variability, but the millennium drought in south-east Australia and the sharp drop in runoff in the South West of Western Australia since 1975 have tested the effectiveness of these adaptations. New measures are being introduced such as urban water supplies that are less dependent on runoff and the return of water to the environment to make it more sustainable. Climate change is occurring on top of that variability and in southern Australia it is likely to further reduce water resources. For the moderate climate change predicted to occur by 2030, the adaptation to droughts and floods can be effective, because the worst consequences are likely to be more intense droughts and less frequent but more intense floods. For further climate change, projected to occur by 2050 or 2070, the conditions of the millennium drought might become the average future water availability, which would have profound consequences for the way water is used and for ecosystems. The understanding of how climate influences water can help make water management more adaptable, such as through improved seasonal forecasts, and it can help communities plan how they will respond to reduced water availability in future.

Further reading

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Groundwater

Andrew Herczeg

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.

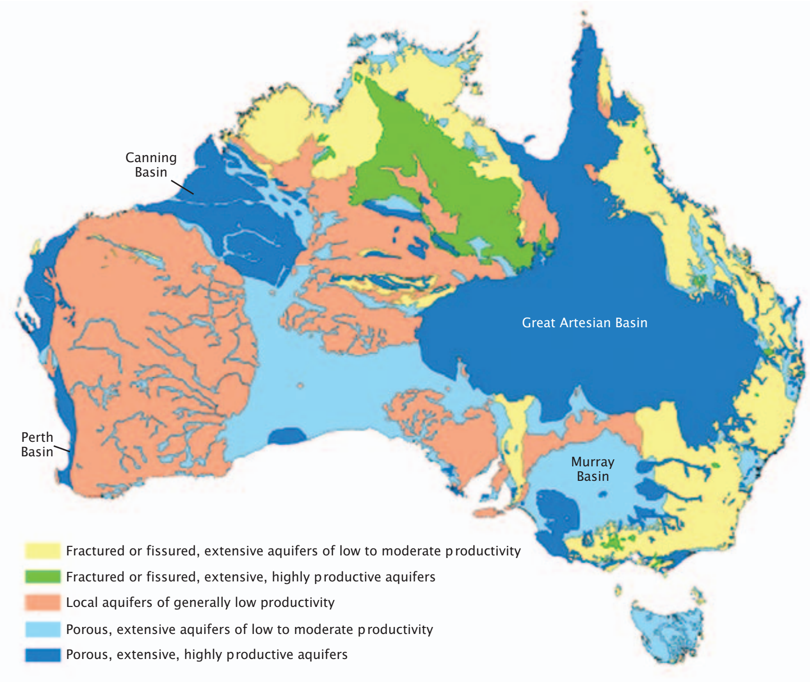
Groundwater was regarded as a resource to be mined, much like the rocks in which it lies, but it is now generally managed as a renewable resource, recognising that it is recharged from rainfall and discharges into rivers, lakes, the oceans, and through vegetation. Consequently, groundwater management 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.

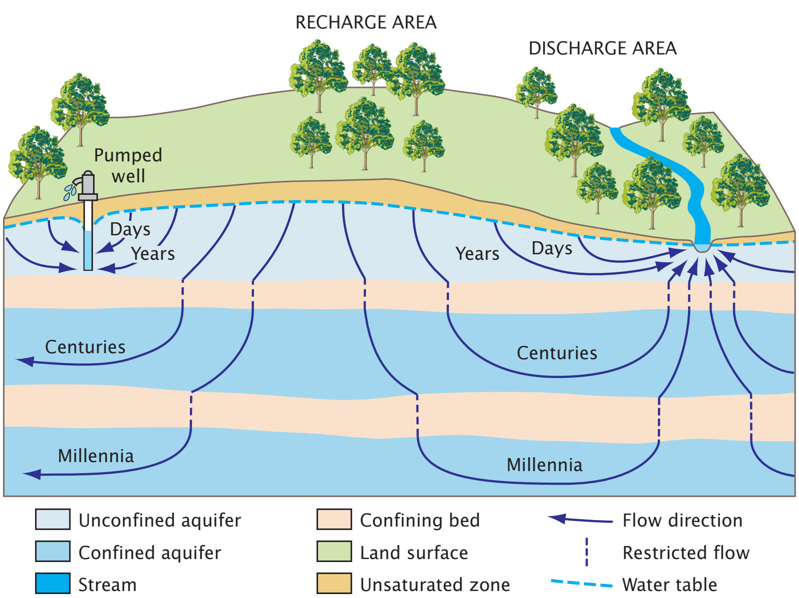
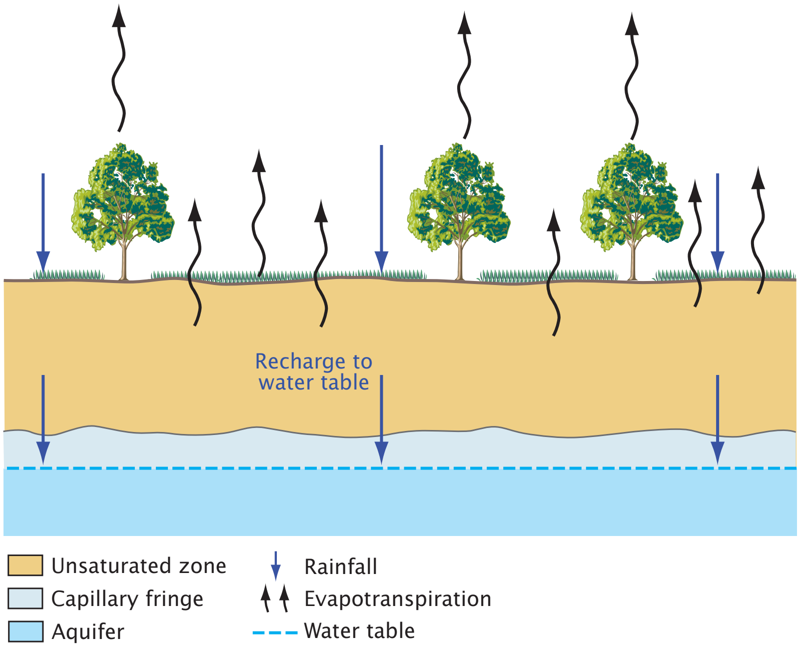


Figure 4.2*: Idealised cross-section showing two types of aquifers. An unconfined aquifer below the water table flows into a stream and is also drawn down into a well. Below that, two confined aquifers are renewed over much longer time scales.[6] (Courtesy of the U.S. Geological Survey.)*

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

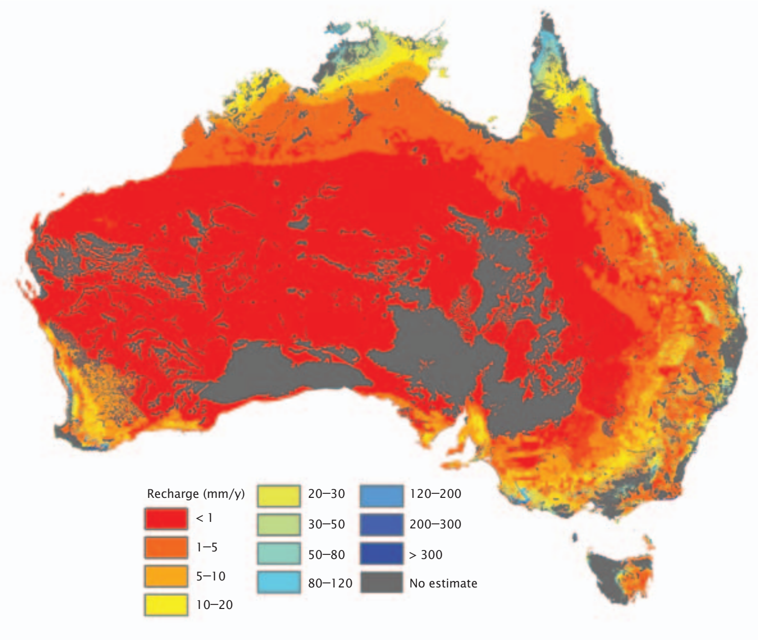


Figure 4.4: Groundwater recharge rates across Australia, showing very low values throughout much of the interior (less than 1 mm/year). These are approximate estimates of recharge based upon extrapolation from limited measurements.[8]

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

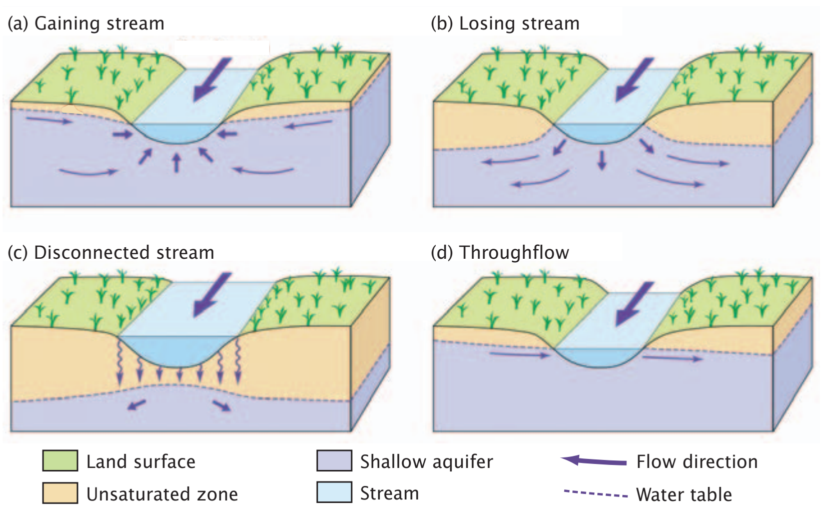
Permanent wetland supported by groundwater inflow. Photo: Bill van Aken, CSIRO.

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.)*



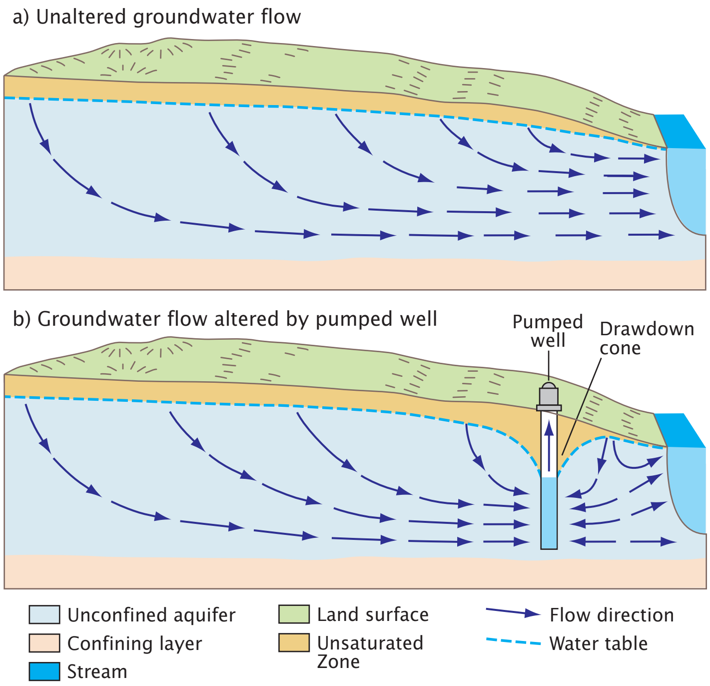


Figure 4.6: Comparison between an unaltered groundwater flow system (a) and a system with a pumped well installed near a stream (b). Water withdrawal from the pump becomes another component of total discharge, intercepting groundwater that would otherwise discharge to the stream.[6] *(Courtesy of the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

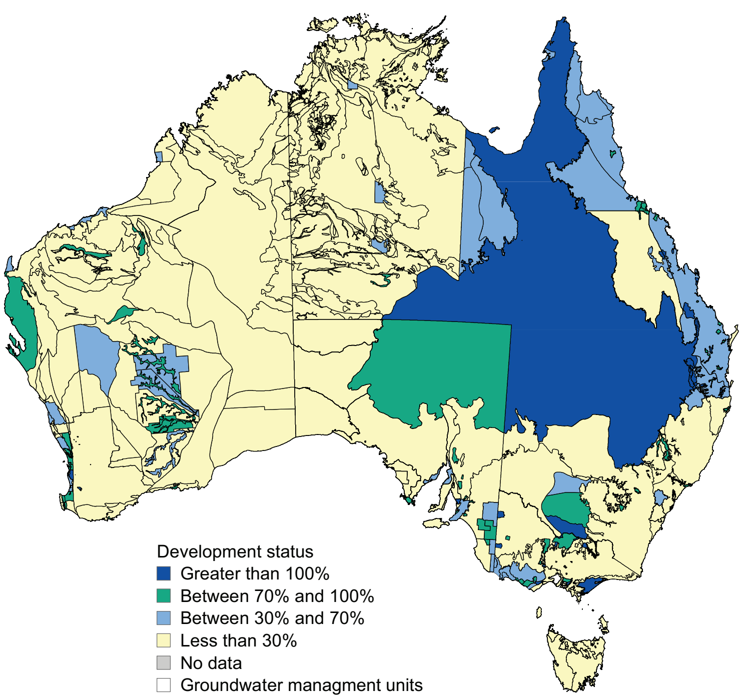
A subtle form of groundwater dependence is that of trees which can persist for long periods without rainfall in the dry season or extended drought, such as red gums across the drier regions. Most vegetation thrives where a high level of soil moisture is available close to the land surface. If soil conditions 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.)*

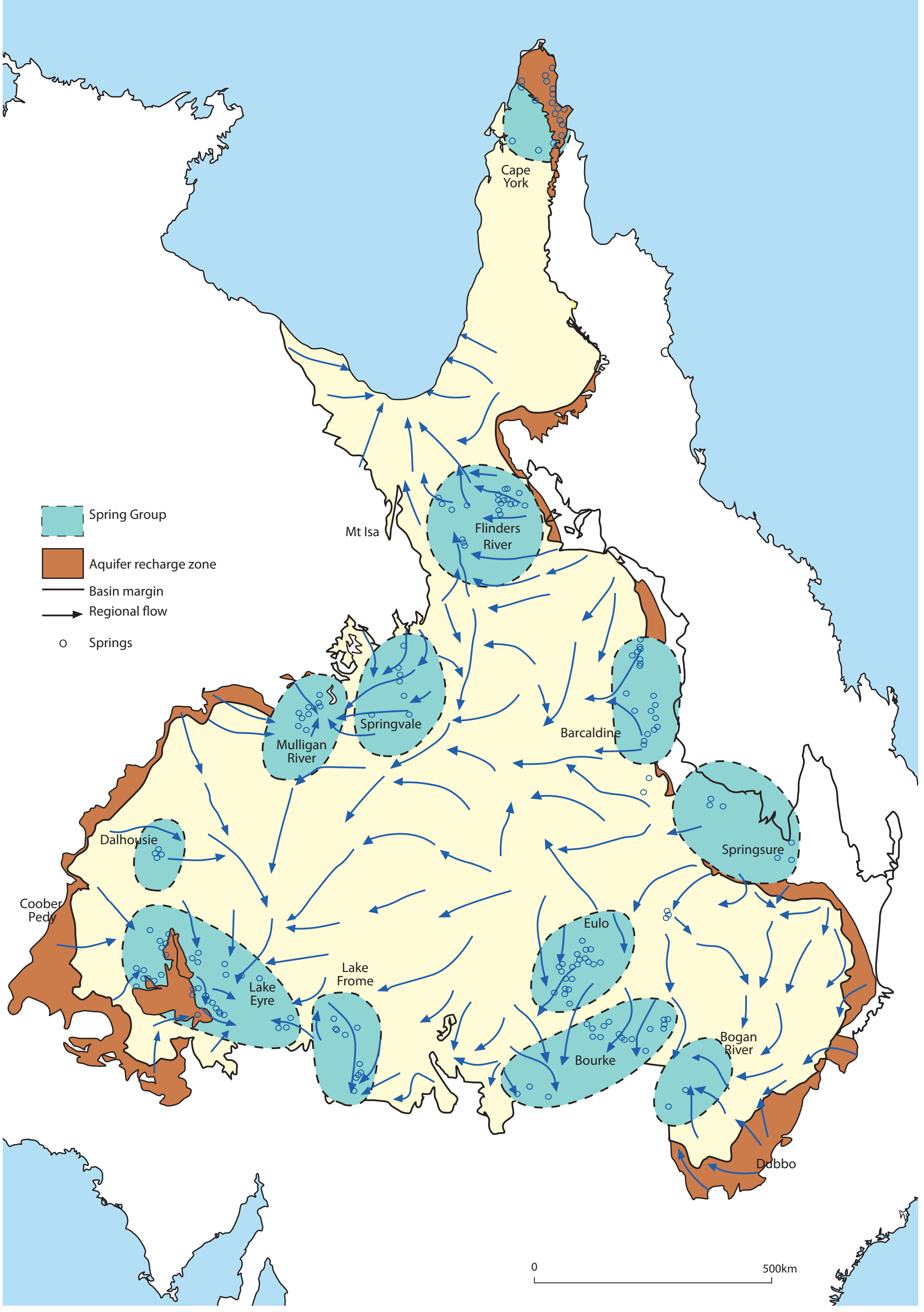
It is useful as a reference point to express the sustainable rate of extraction as a percentage of recharge. As a simple rule of thumb extraction should not exceed 50–70% of recharge without very careful assessment. This precaution is required because rates of recharge are highly uncertain and the actual 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.

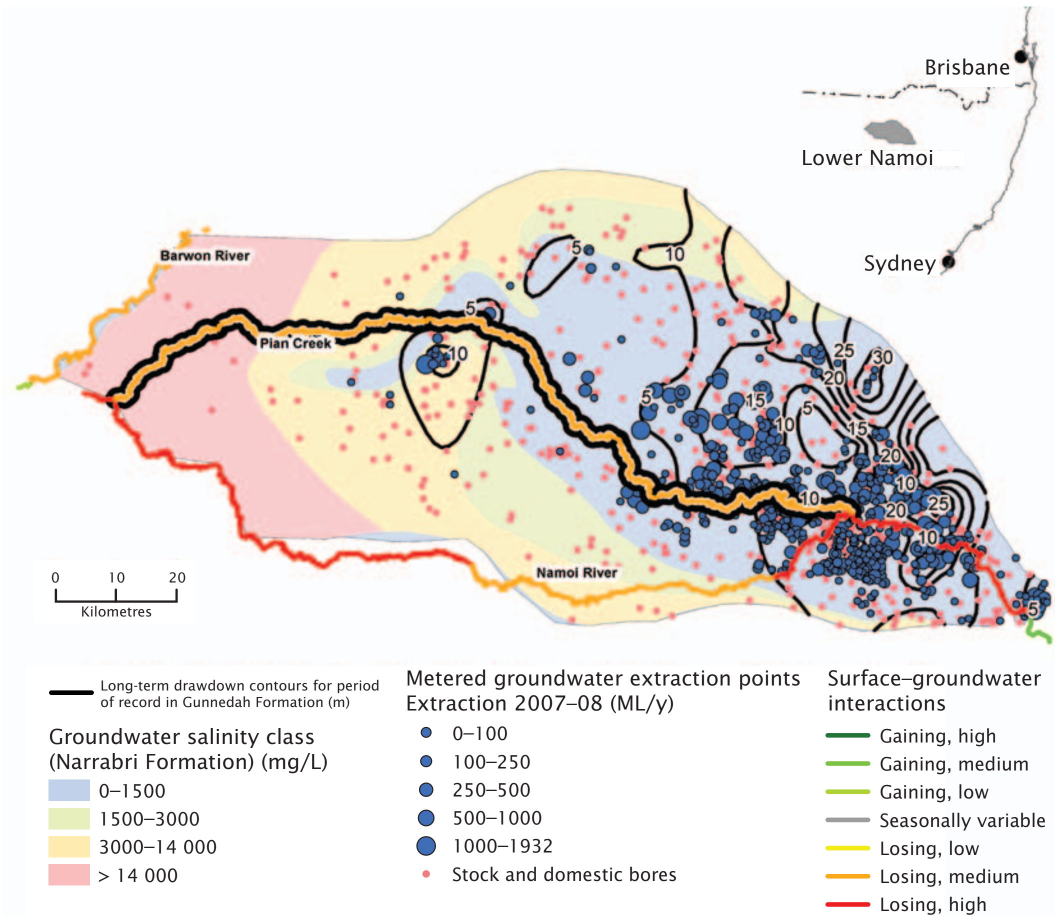
The Great Artesian Basin is a good example of the consequences of over-use. It is one of the world's largest continuous groundwater systems (Figure 4.8) and supports hundreds of springs and wetlands, many of which are listed as significant by the Ramsar Convention on Wetlands of International Importance. 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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Water quality

Simon Apte and Graeme Batley

Key messages

- Strict water quality controls are in place to protect human health and aquatic ecosystems from chemical, and biological pollutants.
- In general, control of pollutants at their source is more effective than remediation because of their persistence in the environment and concentration through the food chain.
- Elevated levels of salinity, nutrients, metals, pathogens, and organic contaminants (e.g. pesticides) are the main causes of poor water quality in Australia. Pollutants are derived from a wide range of sources including agriculture, industry, and urban areas.
- Sediment layers at the bottom of waterways are a major sink for nutrients and contaminants, which can be released into waters and become toxic under certain conditions.
- New contaminants, for example pharmaceuticals, are continually emerging and much monitoring and research is focussed on detecting their presence and toxicity in aquatic environments.

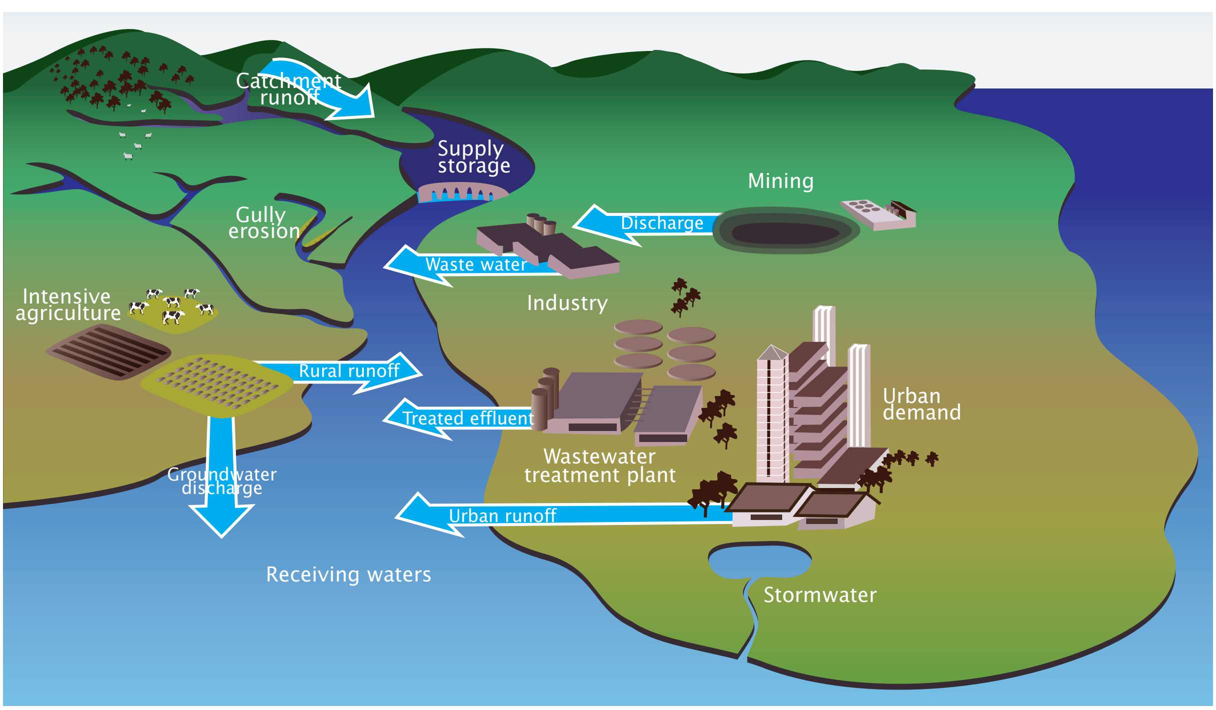
It is not only the quantity of water that matters, but the quality of the water has to be maintained for it to be useful. Maintaining supplies of potable quality water for human health is of paramount concern, either through water treatment or the protection of sources such as the largely pristine water supply catchments that provide for much of Sydney, Melbourne and Perth. Pollutants such as metals and pathogens may also enter the food chain, so the quality of irrigated water and that of fisheries have long been of concern. Poor quality irrigation and stock water can also reduce agricultural productivity. Finally, natural organisms are quite sensitive to some contaminants, so to conserve aquatic ecosystems the highest water quality needs to be maintained. For example, the pollution criteria for copper in the Australia and New Zealand water quality guidelines[1] is 0.0013 mg/L for freshwater ecosystems, compared with 2 mg/L for drinking water.

Streams, rivers, lakes, and groundwater naturally contain chemical and biological constituents. Natural waters contain essential nutrients of phosphorus, nitrogen, cations and trace metals and biological constituents, such as algae, which are essential requirements for fish and invertebrates. The physical properties of water, including its temperature and the degree of light penetration, also influence aquatic organisms. Water released into rivers from the depths of large dams can be so cold and deprived of oxygen as to be lethal to organisms for tens of kilometres downstream. Consequently, dam release valves have been re-engineered to take water from higher up in the dam.

Native ecosystems have become adapted to an enormous range of natural water quality across Australia, from the clear waters of rainforest streams to the naturally turbid waters of Cooper Creek in western Queensland or the hypersaline lakes of the arid regions. It is the changes to natural water quality, through the pollution of water, which threatens human health and other life. Pollution can result from changes in the naturally occurring concentration of some components in waters, such as when nutrient levels become too high and trigger the toxic growth of algae, or when oxygen levels become too low. Of course, pollution also occurs from manufactured constituents, such as pharmaceuticals, which are not normally found in water.

Managing pollutants in a river basin or groundwater system involves several steps.[2] The first is to define the uses and environmental values of water and risks to them from pollution. Then the sources of pollution and transport pathways should be identified. In large catchments with multiple land uses, there can be many possible sources, and for chemical and biological pollutants, the pollutants can be transformed as they pass through the environment. For example, herbicides can degrade into harmless constituents, so they may only be pollutants close to the source. Targets for improved water quality are then set, along with management actions to achieve them. Monitoring of water quality is used to identify new pollution risks and to help evaluate the effectiveness of the management strategies.

Water quality from point source pollution has improved in recent decades as a result of strong regulations that control pollution at its source from industrial plants, hospitals, sewage treatment



▲ ***Figure 5.1****: There are many potential sources and pathways of pollutants to waterbodies.*

plants, and mine sites. Diffuse pollution of waters from catchment land use is much harder to tackle, and poses the most extensive pollution problems today. Salt, nitrogen, phosphorus, and suspended sediment are diffuse pollutants resulting from a wide range of agricultural and urban land uses that have degraded water quality across much of Australia. There are many possible sources of these pollutants in each catchment (Figure 5.1), making them hard to control. Being natural constituents of water, the levels required to prevent ecological damage are hard to determine and highly variable, although much progress has been made.

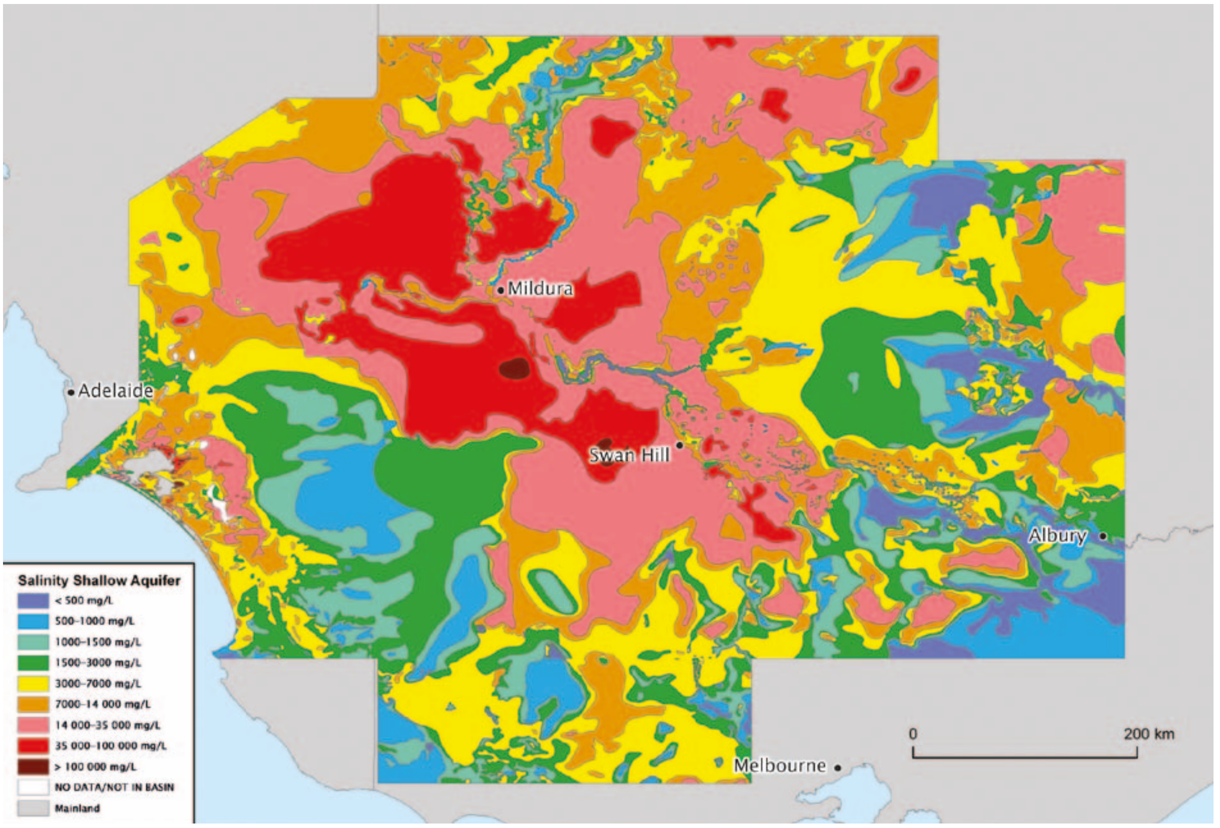
Salinity

Land use-induced increases in salinity affect about one-third of rivers in agricultural regions and cost about $3.5 billion a year in lost production and treatment.[3,4] Salinity has an impact on the potable use of water, including supplies for Adelaide obtained from the Murray River, and the use of water for irrigation and stock (Table 5.1). Although most adult Australian fish can tolerate salinity, juvenile fish (such as Murray cod), are particularly sensitive to salt.[5]

Table 5.1 Indicative salt concentrations above which agricultural production or quality of use declines. Sea water has a concentration of about 30 000 mg/L.

Water use	Salt concentration (mg/L)
Drinking water	500
Irrigation of fruit and vegetables	500–1500
Irrigated pastures	800–3000
Dairy cattle	3000
Sheep	6000

The ultimate source of salt is from rainfall, which contains small amounts of ocean spray, even far inland. The salt accumulates deep in soil over many millennia, especially in regions where rainfall is fairly low (300 to 600 mm/year). Geochemical and isotopic evidence is unequivocal that the source of salt is from marine aerosols and rainfall, even though some rocks were deposited under the sea. That salt is being mobilised and transported to rivers with the rise in groundwater levels under current land use regimes. Under the natural cover of forest and woodland there was very little groundwater recharge (0.1% to 1–2% of the annual rainfall) and correspondingly little discharge of groundwater into rivers. Clearing of trees reduced evaporation, increased recharge up to 10 times, causing groundwater levels to rise. This mobilised the salt stored in soils and



▲ ***Figure 5.2***: *Map of groundwater salinity in the shallow aquifers of the Murray Basin, south-east Australia. Large areas of very saline groundwater in the central Murray Basin leak slowly into the Murray River.*[6]

increased its discharge into rivers. Salinity is also a result of rising saline water tables under irrigation areas and mining can directly discharge saline water into rivers. Much of the salinity in the lower Murray River comes from naturally saline groundwater that has risen in level as a result of clearing of the mallee woodlands and introduction of irrigation (Figure 5.2).

Salinity loads in rivers can be reduced by revegetation of catchments and promoting pastures with deep roots that use more water, but very large areas need to be revegetated.[5] Salt interception schemes are used to pump highly saline groundwater or surface drainage waters into evaporation or storage basins, preventing them from reaching rivers,[7] and improved irrigation practices reduce the recharge of saline groundwater. Maintaining discharges of freshwater from tributaries is also important for providing dilution of saline groundwater, so there is a salinity management imperative for the maintenance of environmental flows in the Murray–Darling Basin. Salinity management has also employed a cap and trade system, as proposed for carbon, as a means to allow new uses of water while preventing any increase in salt pollution, such as to control salt loads from mining in the Hunter River catchment NSW.[8]

A paradox of salinity is that, although it is a symptom of a dry continent, it expresses itself more in wet years. Much has been achieved in recent years in revegetation, drainage, and salt interception to alleviate salinity, but the millennium drought provided a reprieve through lower recharge. It was during the relatively wet early 1970s when the salinity problem began to manifest over large areas, and the exceptional rainfall and flooding in eastern Australia in 2010–11 is being carefully monitored to assess whether salinity returns as a result of rises in water tables and the drainage of salt from floodplains that have been dry for over a decade.

Blue-green algae in Chaffey Reservoir near Tamworth, New South Wales. Photo: Brad Sherman, CSIRO.

Algal blooms

Algae are a natural and essential component of water ecosystems. They photosynthesise, providing food for animals and include phytoplankton, cyanobacteria, diatoms and seaweed. However, many rivers, lakes, and coastal waters have become enriched in nitrogen and phosphorus – a process known as eutrophication – as a result of agriculture and urban discharges. Eutrophication leads to the overly rapid growth of algae (algal blooms) and the predominance of blue-green algae, which can excrete toxins that are hazardous to animals and people if they are consumed, inhaled, or contact the skin. Equally rapid decomposition of the blooms consumes dissolved oxygen in the water, leading to fish kills.

An increased frequency and consequences of algal blooms in the 1980s and 1990s stimulated a concerted effort to better understand their causes and to reduce their occurrence. It was revealed that, although rivers have chronically high levels of nitrogen and phosphorus, it is the local conditions of light, turbidity, and water stratification that are important triggers of algal blooms.[9] Many of Australia’s river pools and reservoirs become stratified under warm conditions with low inflows. The bottom layer of water and sediments becomes oxygen deficient, changing the chemistry of the sediment, causing phosphorus and nitrogen to dissolve into the water, and stimulating algal blooms.[10] Turbid waters are more prone to toxic algal blooms because the toxic algae float and out-compete algae deeper in the water that receive even less light.

It became clear that managing the local conditions was more effective in the short term than reducing the runoff of sediment, nitrogen, and phosphorus, even though that helps in the longer term. Environmental flows can be used to flush and dilute nutrients and algae and reduce periods of low or no flow. In reservoirs prone to algal blooms, water is now mechanically stirred to increase oxygen and reduce stratification,[10] and in urban areas the treatment of sewage and reductions in stormwater runoff reduce nutrient loads. Alternatively, phosphorus can be removed from waterbodies, using products such as Phoslock™, which is a clay that has been modified to bind phosphorus tightly so that it is not released, even under anoxic conditions.[11]

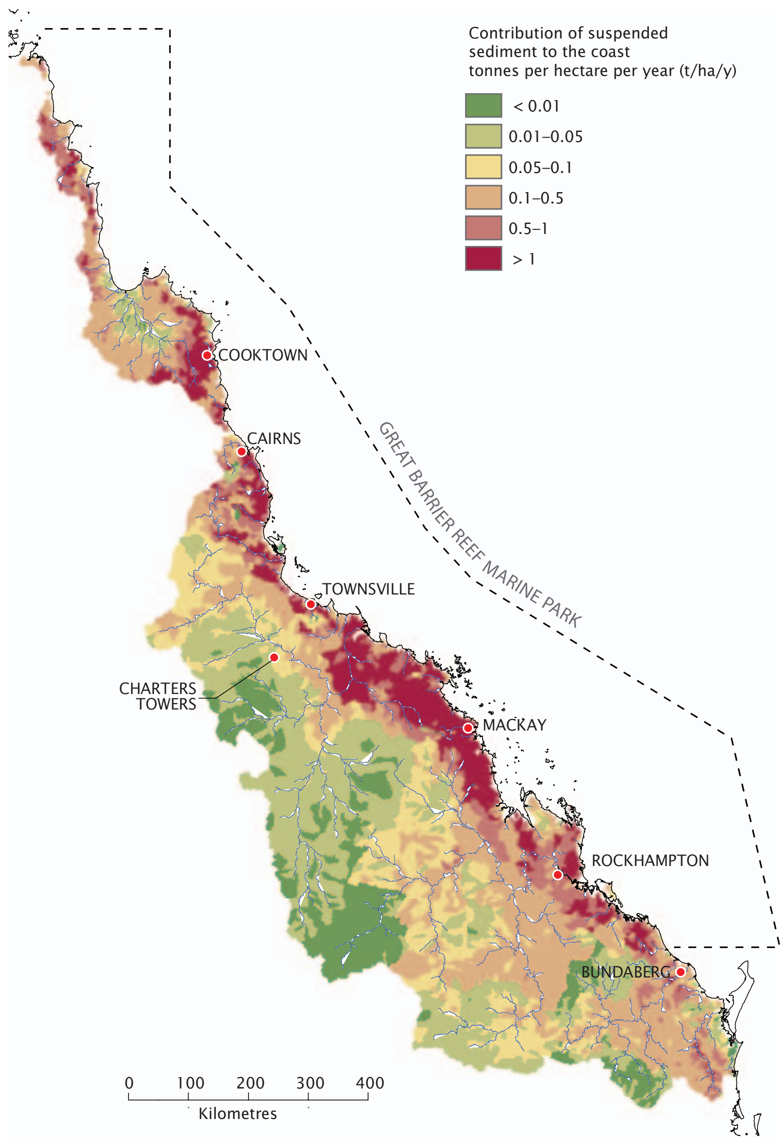
Sediments

A peculiarity of Australia is the very low natural loads of sediment and nutrients in rivers, as a result of its extreme geological stability. The clearing of native vegetation and the development of agricultural land uses changed that, increasing the loads of sediment by 10 to 50 times – particularly in the years immediately following clearing.[4,12] Sediment is relatively easy to remove in town water supplies, but it can have significant ecological impacts. Sediment is transported during storms and is deposited as flows wane. The deposits can smother the bed, covering more suitable habitats, and killing plants and other organisms. The deposited sediments may re-suspend, causing high turbidity, or metals and nutrients contained in the sediment can be released into the water under some conditions. Metals contained in sediment can concentrate in the food chain when sediment is consumed by organisms such as worms, shellfish, and small crustaceans.

Sediment is an ideal example of a pollutant with diverse sources. Sediment erodes from all landscapes, but not uniformly. Typically about 70–80% of the sediment reaching estuaries is derived from just 20% of the upstream catchment area.[13] Thus, catchment management to control sediment pollution can be targeted at these hotspots once they are identified by catchment sediment modelling (Figure 5.3). Further targeting can occur by identifying the erosion processes that are responsible. Agricultural land is the obvious source of erosion, but tracing of sediment sources using the chemical composition of sediment has revealed that accelerated erosion of riverbanks and gullies is responsible for up to 90% of the total sediment yield from a catchment.[12,14] By identifying the source of sediment, management can be much more effectively targeted to the precise sources. The most effective means of reducing erosion is to restore adequate vegetation cover by rehabilitating degraded riparian zones or improving farming practices.

Recycled water complex at Bolivar, South Australia. Photo: Greg Rinder, CSIRO.

Remediation of polluted sediments may be required if biological communities are severely impacted. Remediation of contaminated sites can simply involve dredging and licensed disposal of contaminated sediments, excavation and incineration on-site, capping of affected areas with barrier materials that prevent water infiltration and transport of contaminants, or the application of sophisticated clean-up technologies that use chemical procedures (e.g. oxidation or reduction) to destroy or extract the contaminants. Bioremediation, using microbes to degrade the pollutants, can be used for some contaminants. Two of the biggest sediment remediation activities in Australia are currently underway at Homebush Bay in Sydney Harbour (the source of historical dioxin contamination), and Newcastle Harbour, where oil and metal contamination levels are high.



▸ ***Figure 5.3**: Results of catchment sediment modelling for the catchments draining to the Great Barrier Reef. The model shows which of the more than 5000 sub-catchments contribute the most sediment to the coast. Catchments close to the coast and with intensive land use are predicted to be the highest contributors because sediment from inland catchments is trapped before reaching the coast or those catchments have a lower erosion rate as a result of less rainfall and less intense land use.*[13]

Estuaries and coastal waters

It is the combined impacts of sediment, eutrophication, and other pollutants that have had major impacts on estuaries and coastal waters including the inshore areas of the Great Barrier Reef.[15] Increased nutrient inputs, particularly nitrogen combined with increased turbidity, have led to growth of algae on seagrass beds or on corals, resulting in decline of seagrass and corals and the predominance of algae. High turbidity from re-suspension of sediments reduces light levels, thus favouring algae over seagrass and coral. Examples of seagrass bed decline include Port Phillip Bay, Moreton Bay, and the coastal waters around Adelaide and Perth. Seagrasses are an important food source and a nursery for fish and prawns. When seagrass is lost, the underlying sediments are exposed and move under currents, making for slow recovery. It has taken up to 20 years in other parts of the world for seagrass meadows to regrow once suitable conditions were re-established.

Recovery of seagrass beds requires a combination of reducing sediment and nutrient inputs and restoring seagrass. Sources of nitrogen in coastal waters near Adelaide include a wastewater treatment plant, discharge from major industries, and stormwater runoff. Large-scale recovery of seagrass meadows along Adelaide's coast will require intervention, by providing appropriate settlement substrates for seedlings, transplanting of mature stock, or the harvesting and planting of germinated seedlings. Similar management controls would be needed to restore seagrasses in Perth and Moreton Bay.

Organic chemicals and pesticides

More than 20 000 human-made industrial and household chemicals are used routinely in Australia. These can enter waterways as runoff, through deposition from the air, or by direct discharge of treated wastewaters from sewerage plants and industry. Industrial discharges are usually licensed to protect the environment, and can include organic as well as chemical contaminants. Because of the sheer number of substances, it is not practical to set water quality guidelines for all of them. Guidelines are in place for organic chemicals that are discharged in high volumes or are particularly toxic.

Chemicals found in waterways include pesticides, herbicides, antifouling paints, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons. Commercial fishing in Sydney Harbour is currently banned due to the build-up of toxic organochlorine chemicals in fish and prawns. These contaminants originate from former industrial sites, are leached from contaminated soils, or are deposited in the Harbour through eroded sediments. From the sediments, they accumulate in the tissues of the aquatic organisms.

Pesticides can be broadly grouped into chemicals used to control weeds, insects and fungi (i.e. herbicides, insecticides, and fungicides). In common with most developed countries, Australia continues to be a large user. Pesticides find their way into waterways either as spray drift or in

Aerial spraying, Virginia, South Australia. Photo: Greg Rinder, CSIRO.

runoff. In some cases, they are even used to control water weeds. As well as targeting unwanted weeds and pests, these chemicals are also a hazard to aquatic organisms, even at very low concentrations. Residues from the use of now-banned compounds such as DDT, chlordane, and dieldrin are remarkably persistent and can still be found in both water and sediments.

Reducing the pollution from pesticides and other chemicals can be achieved in three ways: replacing them with less persistent chemicals; recycling or storing water onsite to prevent discharge into waterways; and reducing use through new agricultural and industrial practices. The original persistent pesticides have now been replaced by ones that degrade more rapidly after performing their desired function. Glyphosate (or 'Roundup™') is now the most common herbicide in Australia and degrades within a few days.

Historically, the cotton industry was one of the biggest users of pesticides, and was associated with numerous fish kills from the use of endosulfan (a pesticide that is toxic at parts per trillion concentrations) but all three treatment mechanisms have greatly reduced the risks. Endosulfan is gradually being replaced by the less persistent chlorpyrifos and cypermethrin, and water used in cotton growing is now retained on the farm, although there is still risk from aerial spray drift. The use of genetically modified strains of cotton, commercially available in Australia since 1996,[16] have reduced insecticide use by as much as 80% compared with conventional cotton.[17] These new varieties contain proteins from a soil bacterium that confer insecticidal properties to the whole plant.

Pathogens

Pathogens are disease-causing organisms that end up in waters due to the discharge of sewage effluents or as diffuse inputs from animal wastes. They comprise a wide range of living microorganisms including bacteria, viruses, and protozoa. Very stringent regulations apply to ensure that drinking water supplies are adequately treated and are free from microbial contamination.[18] These include managing pathogen sources and pathways of transport within the catchment, and multiple treatments (see future urban water supplies chapter). For instance, animal wastes from grazing livestock can represent a significant source of pathogens to water reservoirs, which is why many of Australia's urban water supply catchments have strict land use restrictions and largely retain natural vegetation cover, thereby maintaining very high water quality.

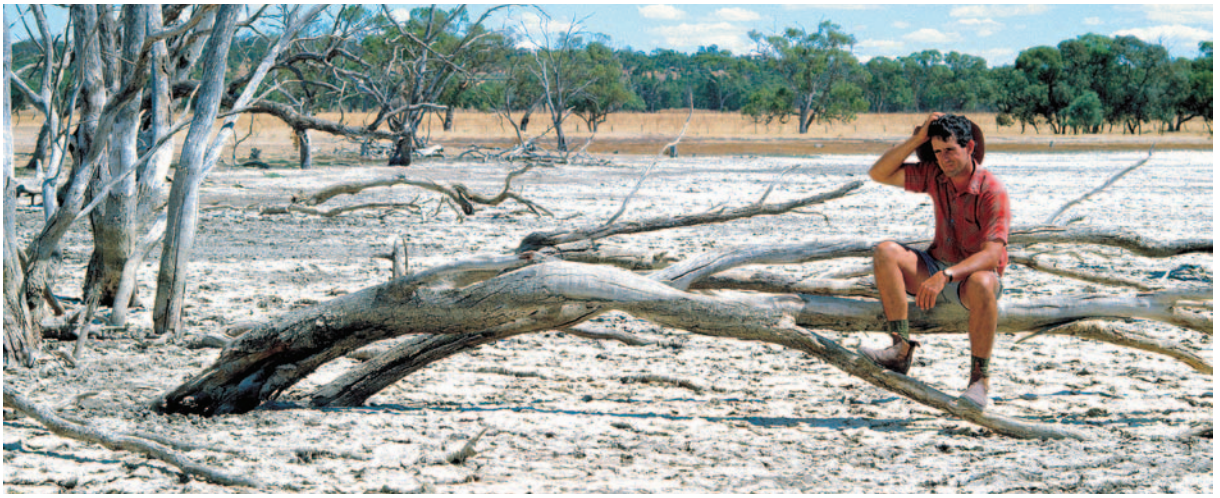
Because there is a very wide range of potential pathogens, routine analysis of each pathogen is not feasible, so indicators such as fecal matter are used to monitor microbial water quality. Currently, microbial tests are slow to perform and at best take 15–24 hours because they rely on culturing the bacteria. This leaves a delay before contamination can be managed. A major goal, therefore, is to develop rapid analytical techniques for pathogens and indicator organisms to enable a more rapid response. This could be most useful for applications in potable recycling.

Metal contaminants

Metal contamination from point sources include mining and mineral processing activities, as well as from specific industries with metal-containing wastes, such as fly ash from coal combustion. Many Australian examples are largely associated with historical contaminations, when regulatory controls were poor or non-existent. Examples include the lead/zinc smelter at Lake Macquarie (New South Wales), lead smelting at Port Pirie (South Australia), zinc refining in Hobart (Tasmania), and copper mining and processing near the King River and Macquarie Harbour in western Tasmania.[19] These extreme cases had serious impacts on aquatic ecosystems. In addition, metals accumulated to alarmingly high concentrations in some organisms. For example, in the 1970s, oysters from the Derwent River in Tasmania were grossly contaminated with zinc discharged from a local smelter and were unfit for human consumption.[20] Metals, unlike most organic contaminants, are persistent and do not break down with time, so prevention at source is preferable to remediation, which can be both very expensive and slow.

Active mining sites in many areas of Australia contribute low concentrations of metals such as copper, lead, zinc, nickel, and uranium to local waters, but such releases now have to meet strict regulatory control and only in extreme cases do concentrations exceed water quality guidelines. Typically mining wastes are retained in sealed tailings dams and are not discharged to the environment.

Urban and residential areas are diffuse sources of trace concentrations of metals (parts per billion levels) to waters, which can lead to a complex mixture of contaminants. For instance, stormwater runoff from roads carries zinc from tyres and copper from brake linings. Dissolved zinc is borne by rainwater washing galvanised metal roofs and quantities of dissolved copper


Rising groundwater tables affecting salinity, Griffith, New South Wales. Photo: Bill van Aken, CSIRO.

originate from the slow leaching of water pipes. Many metals are essential nutrients for humans and aquatic organisms, particularly copper (Cu), cobalt, zinc, and iron. Although organisms are reasonably tolerant of higher than normal iron concentrations, excesses of the other metals can be quite toxic even at part per billion concentrations. Metal toxicity is largely associated with certain chemical forms of the elements: in particular, the free metal cations (e.g. Cu^{2+}).[21] Analyses that determine only the bioavailable and potentially toxic fractions of metal contaminants are now being used to better specify the risks to ecosystem health and ensures that industry is not subjected to unnecessarily strict discharge controls.

Acid sulfate soils

The polluting effects of acid sulfate soils were realised when fish kills and fish disease (e.g. red spot ulceration) were observed. Acid sulfate materials are found naturally and typically form under waterlogging of organic sediment (such as mangrove mud), which causes iron sulfides to form. Left undisturbed, these soils are harmless, but when excavated or drained, the sulfides within the soil react with the oxygen in the air to form sulfuric acid. The acid can dissolve metals such as aluminium and, if discharged to rivers and estuaries, the combination of metals and acidity can kill plants and animals, contaminate drinking water and food such as oysters, and corrode concrete and steel.

Acid-forming soils can be found at many coastal locations and are particularly prevalent in northern New South Wales and Queensland, associated with organic mangrove sediments. The millennium drought exacerbated the problem of acid sulfate soils in the Lower Lakes and wetlands along the Murray River, where the drop in water levels exposed sulfidic materials. Acid formation was mitigated by careful management of water levels and the addition of lime to some rivers and creeks that drain into the Lower Lakes. Recent re-flooding of the acid materials seems to have occurred without harmful acid discharge.

Groundwater contamination

Groundwater contamination occurs through accidental spills and other unintended releases of chemicals, which move downwards through soils into underlying groundwater. It can pollute drinking water supplies, irrigation water, and ecosystems, where groundwater discharges to surface waterbodies. The slow movement and lack of mixing and dilution in groundwater can preserve high concentrations of pollutants for decades and at distances well away from the initial source so, again, prevention is the most effective management option.

Groundwater pollutants include organic liquids such as petroleum fuels and industrial solvents (e.g. perchloroethene, which was used for many years by the dry-cleaning industry and in plastics manufacturing). Petroleum fuels are less-dense than water so they float on the groundwater table. Some solvents are denser than water and sink below the water table towards the base of aquifer systems. Both types of organic liquids slowly dissolve into groundwater over decades to centuries.

Remediation of groundwater pollution can be achieved by biodegradation; for example, by using bacteria that can consume organic contaminants such as benzene, but they require the correct chemical conditions – such as an abundance of oxygen, nitrate or sulfate. Establishing an artificial barrier across the leading edge of a pollution plume can reduce contaminant transport. Such barriers are expensive to install, but low ongoing costs make them financially attractive. Permeable reactive barriers allow some throughflow of water but contain active ingredients that can degrade or immobilise contaminants.[22]

Removal of service station fuel tanks which can leak into groundwater, Perth, Western Australia. Photo: Bill van Aken, CSIRO.

Monitoring water quality in Lake Wivenhoe, Brisbane, Queensland. Photo: CSIRO.

Emerging contaminants

New chemicals are introduced continually, but only a small proportion of them are routinely monitored in water. The release of emerging chemical or microbial contaminants may have gone unrecognised for long periods until new, more-sensitive analytical detection methods were developed. Studies in the United States of America and Europe show that a broad range of chemicals found in residential, industrial, and agricultural wastewaters commonly occur as mixtures at low concentrations in rivers and streams. The chemicals detected include human and veterinary drugs, natural and synthetic hormones, detergent metabolites, plasticisers, insecticides, and fire retardants. Similar results are now being found in Australia. The presence and significance of such contaminants is particularly pertinent to water recycling.

Low levels of certain pharmaceuticals in the environment could affect aquatic life through patient use of prescription and non-prescription medicines, especially if there is little degradation or removal during sewage treatment. Veterinary chemicals may enter waterbodies through animal excreta and farm runoff. Dilution can reduce the concentration of these contaminants to below levels of concern, but the problem is exacerbated by Australia's low discharge rivers and streams.

Much recent effort has focussed on organic contaminants, which can disrupt animal reproduction or growth by modulating, mimicking, or interfering with hormones. These compounds are called endocrine disrupting chemicals. They include hormones created in the body, synthetic hormones (such as those manufactured for birth control), and industrial/commercial compounds that can have some hormonal function (such as alkylphenols, pesticides, pharmaceuticals, and phthalates). Natural estrogen is excreted from the female body in a deactivated form, but, during the process of sewage treatment, chemical changes occur that restore estrogen to its original chemical form and biological activity. A major challenge in this area is to understand how very dilute mixtures of bioactive contaminants interact with living organisms, and how interactions between contaminants may magnify biological effects.

Nanomaterials represent a new class of contaminants. They have an extremely varied composition and, because of their small size, may possess chemical and physical properties that are unlike their equivalent macro-sized forms. There is a good deal of research activity in Australia and overseas dedicated to evaluating the potential impact of these new materials on aquatic environments and to determine if they require their own water and sediment quality guidelines.

Further reading

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Urban water sustainability

Alan Gregory and Murray Hall

Key messages

- An extra 10 to 20 million people could be living in Australian cities by 2050, requiring more water supplies, more wastewater disposal, and greater energy use to provide these services.
- The increasing demands for water, energy, and other resources in cities are leading to new approaches to urban water as part of broader urban sustainability and liveability.
- There is considerable potential to improve urban sustainability by recovering water, energy, carbon, and nutrients from wastewater and reusing them in the city and as fertiliser for food production.

Growing cities and the need for sustainability

The world's population in the 21st century will become predominantly urban. Half of the world's population is already living in cities and this proportion will increase to about 70% by 2050 (Figure 6.1). Nearly all of the expected growth in the world's population will occur in urban areas by 2050.[1]

Demand for urban water supplies will grow across the world and Australia is no different. Australia is already highly urbanised, with almost 90% of the population living in cities, but in the next 50 years 10 to 20 million extra people will live in Australian cities.[2] The capital cities alone will need to accommodate an additional 10.5 million people by 2056[2] – the equivalent of the current population of Sydney, Melbourne, Perth, and Adelaide. Not only will more water be needed to supply this population, but more sewage will be produced and treated, and more urban stormwater will be generated from the additional roofs, roads, and paved areas. The impacts of these discharges on the valued rivers, estuaries, coasts, and groundwater systems surrounding our cities is already significant, and this level of urban growth will place waterways under increasing pressure.

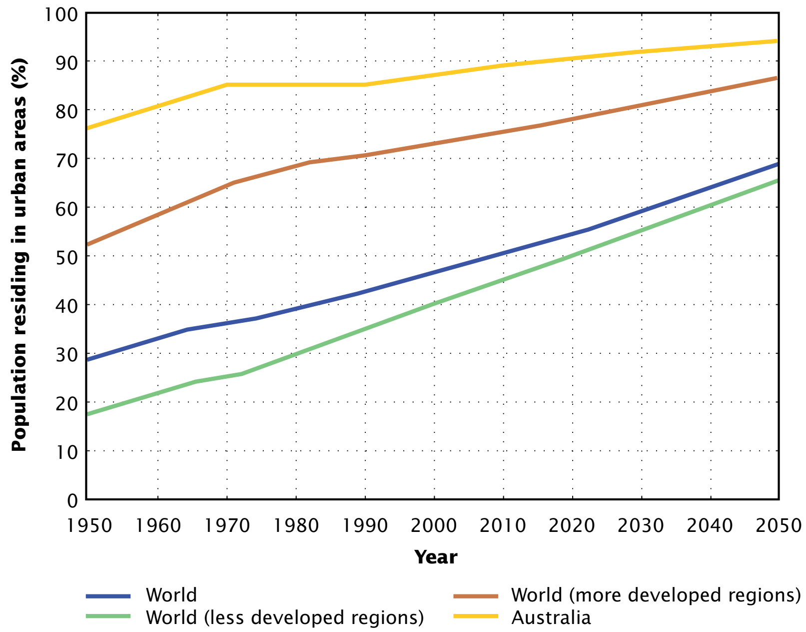
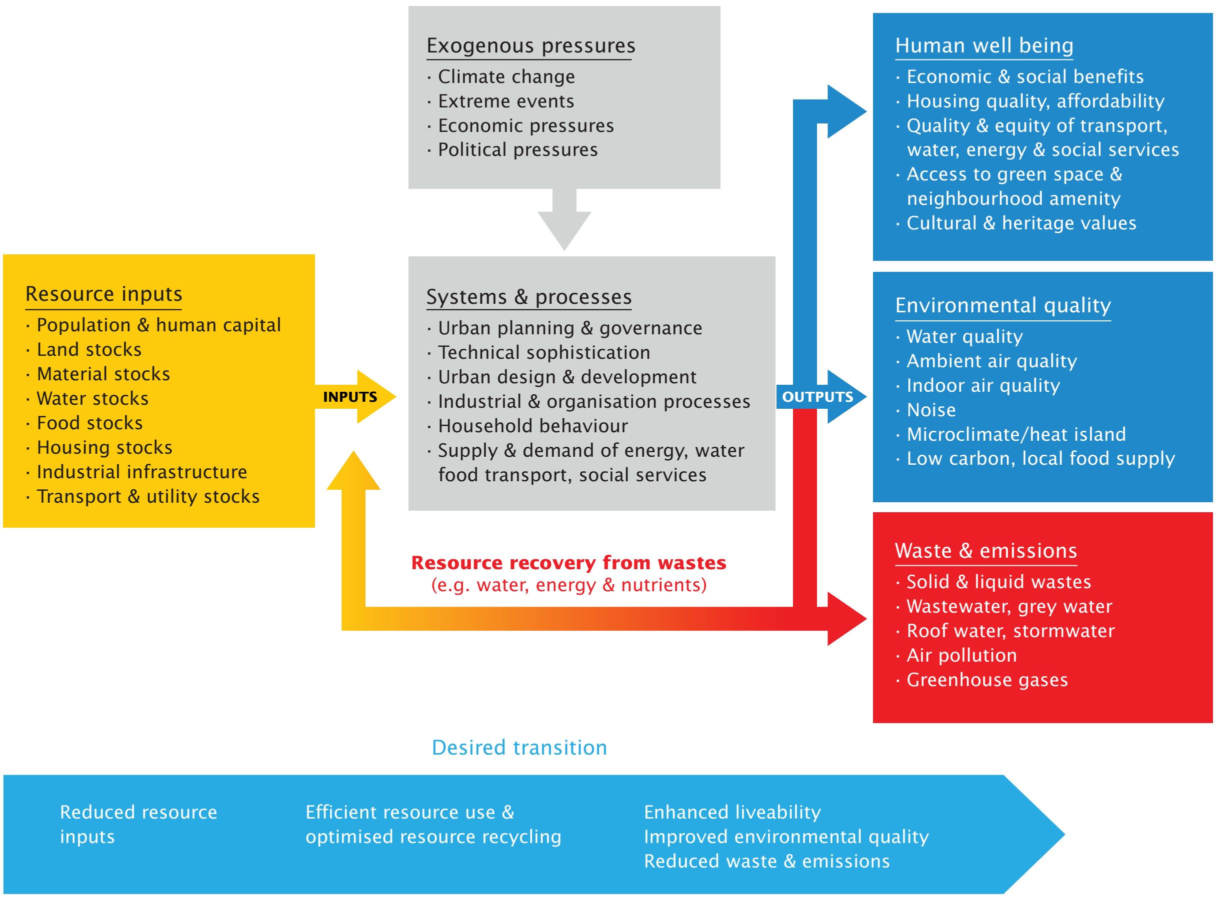


Figure 6.1: The percentage of global population living in urban areas is increasing especially in less developed regions. Australia already has a highly urbanised population but it too will become more urbanised.[1]

The strong growth of cities and the emergence of mega cities raises questions about their future sustainability, and the way water is managed is central to these concerns. Urban water systems have evolved into large, highly engineered systems in which water is imported from surrounding catchments and aquifers, distributed through extensive pipeline networks, and used just once. Most of the used water is then collected in large sewerage systems, treated to remove contaminants and nutrients, and discharged back to rivers and the sea. These systems provide reliable clean water for residents and industry, and they protect public health, but there are concerns that water systems could be much more efficient, rather than just importing more water, disposing of more wastewater and removing more stormwater. They will need to more efficiently use local sources of water as populations grow, water resources become fully allocated, and climate change reduces the supply of water from catchments and aquifers.

The International Water Association argues that the objectives of urban water management should expand to contribute to the development of more liveable and sustainable cities.[3] Urban water systems do not exist and operate in isolation: they have many linkages to other systems within a city and its surrounding regions. For example, population growth and urban density influences water demand, and water use influences wastewater generation and energy use for treatment and transport. Urban design influences stormwater generation and flows, which in turn influences flood risk and water quality. Green space and open water in cities can reduce extreme temperatures, perhaps using more water, but requiring less energy for cooling. There are other direct and indirect connections, some of which will be discussed further in this chapter.

'Urban metabolism' is a useful metaphor to visualise the city as a system, rather like a living organism (Figure 6.2).[4] Resource inputs, such as water, are translated through a series of connected urban systems and processes into a range of human wellbeing and liveability outcomes, and, in this process, waste streams are generated, which can impact on the local and surrounding natural environment. The system can be made more efficient by improving the benefits from the resources, such as by reusing them or recycling resources, and reducing impacts on the environment. Resources can potentially be recovered from these wastes to reduce the need for new inputs. By changing the urban system and processes within a city, including the way we design and manage water systems, the 'metabolic efficiency' of a city can be enhanced.



▲ ***Figure 6.2***: *Cities from an urban metabolism perspective: consuming resources, processing them to produce wellbeing, and producing waste products.*[5]

An example of the potential for greater efficiency in urban water use is shown in Figure 6.3. Depending on each city's outdoor water use, up to 75% of water supplied becomes sewage effluent, which could be recycled to offset input of additional water. Urban stormwater is an additional resource that often exceeds the volumes of mains water, but except for Perth, less than 3% of urban stormwater is harvested. Perth recycles an estimated 80% of stormwater for irrigation reuse following recharge to aquifers. Until recently, all household water use was of potable quality even though up to half was used for garden watering and less than a third is used in the kitchen or bathroom.

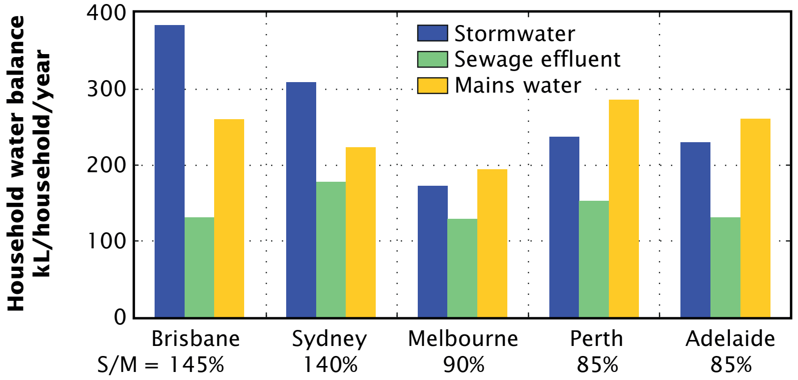


Figure 6.3: Water balances per household in Australia's five largest cities. Much mains water ends up as sewage effluent, and stormwater is an even larger waste stream that can exceed the volumes of mains water. S/M refers to stormwater volumes as a percentage of mains water supply.[6]

This chapter examines how urban water management can respond to the challenges of sustainability. Chapter 7 explores in more detail the options for augmenting supplies in Australian cities to meet the growing demand for water.

Managing demand

Households use 70–80% of total urban consumption, so, historically, water use tended to rise in line with population. However, since the early 1990s, per capita water use has declined in most cities as a result of greater water use efficiency in households and industry, higher prices for water, and changing urban design such as increasing multi-unit housing and smaller sizes of household blocks. Figure 6.4 demonstrates the effect of this trend in Sydney, where total water use today is the equivalent of demand in the early 1970s, despite an additional 1.2 million residents.

Consumers do not require a specific volume of water: they want the services that water provides such as clean clothes, pleasant landscapes, or waste removal, in addition to safe water for drinking, cooking, and bathing. These services can be provided while using less water through better system design, technology efficiency, or changed behaviour.

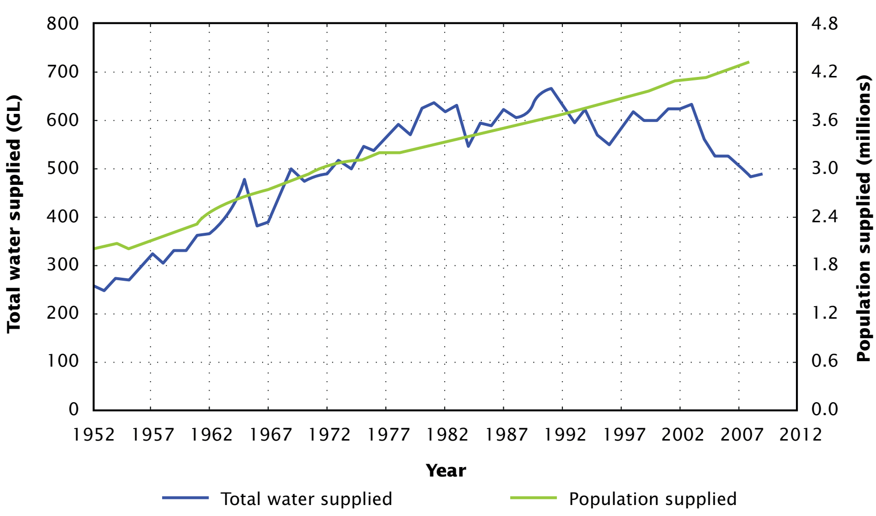


Figure 6.4: Long-term trend in Sydney water supply. Water supply used to grow in line with population, but reduced per capita consumption since 1992 enabled more people to be supported from the same total supply.[7]

Efficient water use delays the need for expensive augmentation of supplies, such as from new dams or desalination plants. Reducing per capita use is invariably less expensive than sourcing, processing, and supplying more water. Demand management can also reduce per capita wastewater flows, providing additional capacity in existing sewers to cater for population growth.

Strategies to reduce demand include adoption of appliances that are more water-efficient such as shower nozzles, dishwashers, and washing machines. Garden water use efficiency has improved through the use of drought tolerant species, more efficient irrigation systems, and education on garden watering. For many purposes, drinking water could be substituted by water sourced from rainwater, stormwater, or recycling. The water supply system can also be made more efficient by reducing distribution losses through leakage control and pressure management, using less water to provide the same service.

A prominent Australian example is the potable water savings of 85 GL/year achieved in Sydney over the last decade from sustained demand management and water recycling strategies (Figure 6.5). These water use reductions equate to the volumes that can be provided by the recently constructed Sydney desalination plant, or 15% of annual supply to Sydney.

During the millennium drought in the southern capitals, restrictions were imposed to reduce household water use as supplies dwindled. The most extreme reductions occurred in South East Queensland where the average per person residential consumption dropped from 300 to 130 L/person/day in response to dam storages dropping below 20%. Historically, water restrictions have been an effective temporary response to drought. The longer term use of restrictions required

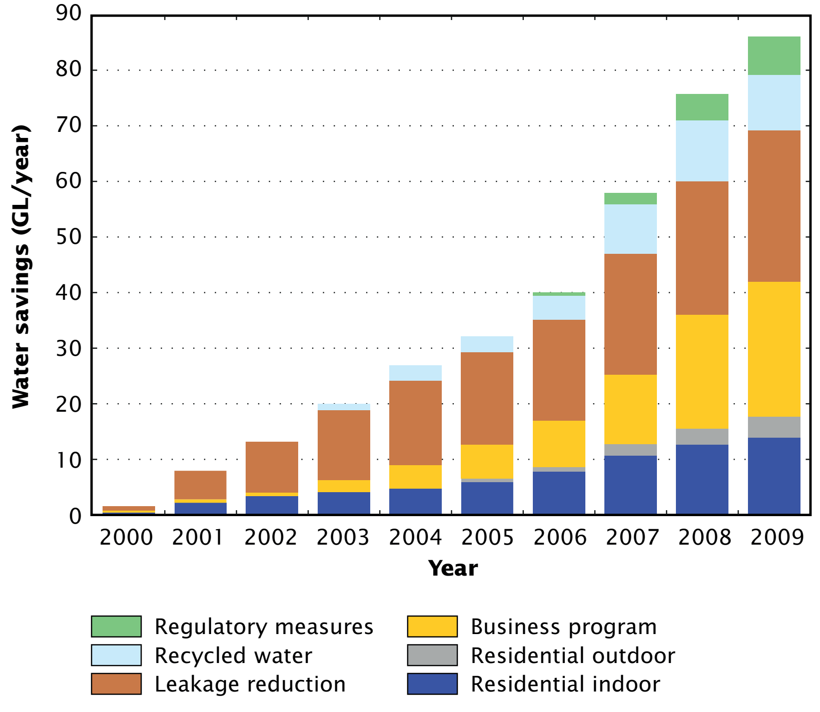


Figure 6.5: Water saving measures in Sydney, which have made savings equivalent to 15% of supply.[8] *(Adapted from Sydney Water Corporation 2010.)*

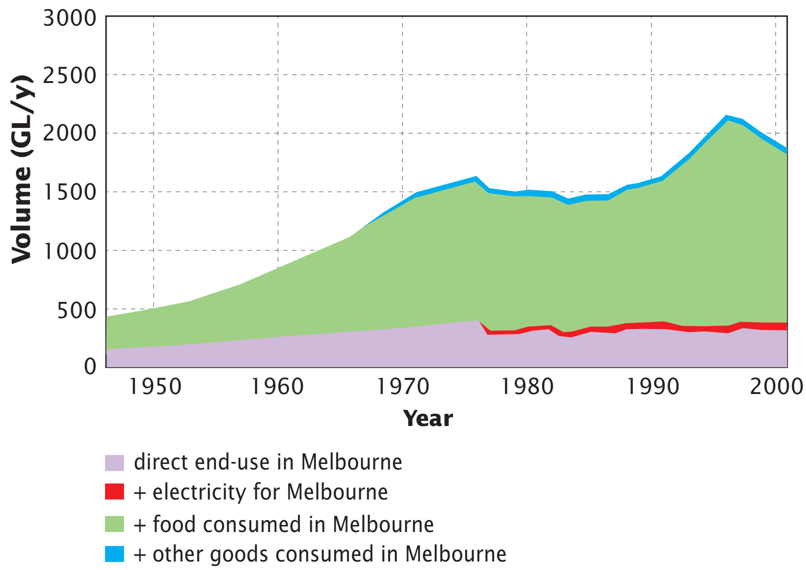
during the millennium drought highlighted the impact on some services such as the quality of parks and gardens, and the detrimental effects on landscape and garden industries. The drought and associated restrictions did galvanise community action on water conservation through lower water use appliances, use of rainwater tanks, and improved garden design. Since restrictions were lifted, water use has increased slightly,[9] indicating that there has probably been a permanent change in behaviour that will not see a return to pre-restriction levels of water use.

The density and design of housing will influence residential water use, particularly outdoor water consumption, in the future. In some Australian cities, backyard irrigation is almost half of total household water use. A recent study in Melbourne found that adopting a more compact city design could reduce residential water consumption by 100 GL/year by 2045, compared with more traditional low density urban expansion.[10] Higher housing density brings other benefits of reduced transport and energy costs and is thus a part of urban planning in most cities.

There has been considerable debate over the potential for water pricing to be used as a mechanism to moderate demand.[11,12] Many utilities charge higher prices for water above a basic supply charge, but the prices do not change over time with the scarcity of water. The price for high rates of domestic consumption could be increased during drought as an alternative to water restrictions.[13] This would work if demand was sensitive to price, but there is conflicting evidence for that at present. It also requires effective price signals, which are lacking when only a small part of the cost is variable, when the costs are paid 3 months in arrears, and when costs are shared equally across multi-unit apartments.

The water effectively consumed by a city includes not just the water directly supplied but the water used in rural areas to produce food and fibre for city residents and to generate the city's electricity. The fact that the produce from irrigated agriculture is predominantly consumed in cities is often forgotten in polarised conflicts between urban and rural communities. For example, the amount of water used to produce food, fibre, and electricity consumed in Melbourne is

Low water use shower head. Photo: CSIRO.



▸ ***Figure 6.6****: Total effective consumption of water in Melbourne includes not just the direct supply of water to the city but also the water consumed to produce electricity, food, and other goods consumed in the city.*[10]

approximately four times the water directly used by city residents and businesses, and has grown faster than direct water use (Figure 6.6). A further significant share of water use is to produce exports, which provide earnings to offset imports that are a large part of consumption of all Australians.

Water and energy

To provide water and wastewater services requires energy for treatment and pumping, and the dominant forms of current energy generation require large volumes of water. The choices made about urban design, water, and energy use, and the sources of both water and energy will influence the future sustainability of cities.

The recent growth in desalination and water recycling has put a focus on energy use in water supply. Direct energy use for the provision of water services in 2007 represented only about 0.2% of total city energy use (about 7 Petajoules (PJ)/ year).[14] By comparison, residential hot water heating uses 46 PJ/year, nearly seven times the amount used to supply water.[14] Even more energy is used in association with commercial and industrial uses of water, mainly for heating and transport processes.[15]

A breakdown of energy consumption by water utilities for 2006–07 (a year that precedes desalination and large-scale reuse), shows that each of the major cities differ substantially in their energy use because of differences in topography or system configuration (Figure 6.7). Figure 6.7 clearly shows the energy penalty associated with pumping, where both Sydney and Adelaide were transferring bulk water over long distances to maintain supplies during drought. Water is very heavy at 1 tonne for every kilolitre. Sourcing water close to its end use has definite energy benefits.

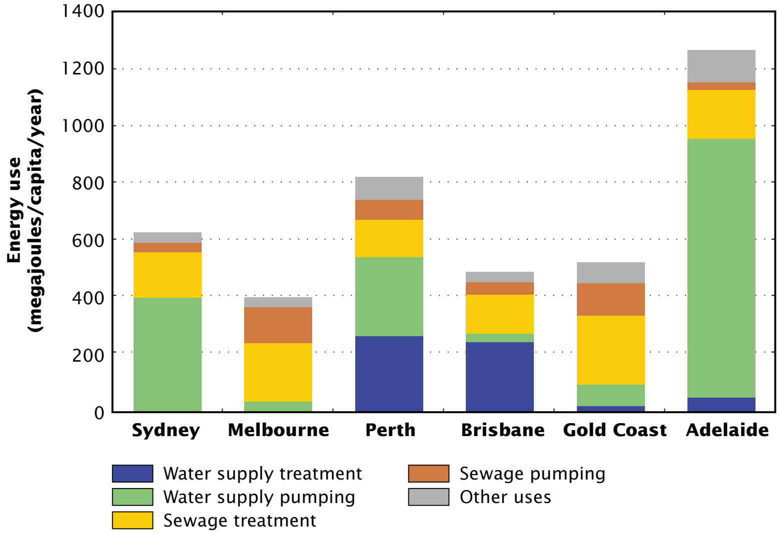


Figure 6.7: Energy use for water and wastewater services differs markedly among cities (2006–07) depending upon the type and location of their supplies and the location of sewage disposal.[14]

Unfortunately, future water supplies are likely to use more energy. Until recent times, most of Australia's coastal cities were supplied by water fed by gravity from inland dams. Future supplies will have to rely upon piping water over catchment divides or will interconnect systems across regional water grids or entail desalination plants and recycled water schemes, all of which use more energy. A 25% population growth by 2030 is anticipated to increase energy use by water utilities to twice that of 2006–07 levels.[14] Even decentralised supplies, such as rainwater tanks, stormwater harvesting, and local wastewater recycling, can be more energy intensive than existing supplies if poorly designed or maintained.

The largest energy use associated with water though is in heating of water in homes, commercial, and industrial applications, and there are opportunities to reduce this use. Water heating accounts for about 25% of all residential energy use[16] but it could be halved through water-efficient appliances and more efficient water heaters.[14] Even greater energy benefits may be gained in industry, where reductions in steam and hot water losses, reduced pumping in manufacturing, and cooling result in significant energy savings.

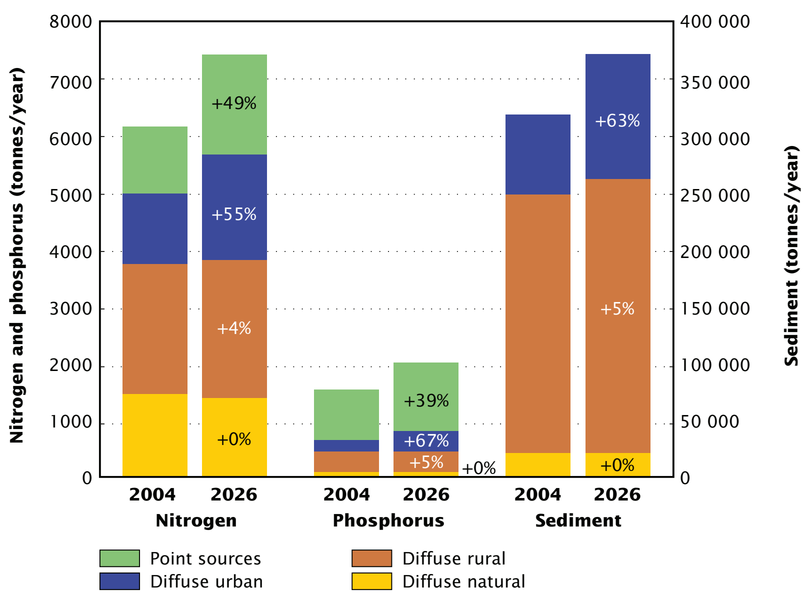
There are growing international efforts to reduce greenhouse gas emissions from water use for environmental and economic reasons. Large and increasing energy use combined with rising energy costs provide strong business incentives for water utilities to reduce their energy use. Measures being pursued by Australian utilities include optimising system operations to minimise energy use, generating renewable energy through installing mini-hydro systems in pipeline networks, recovering biogas during wastewater treatment, sequestering carbon through tree farms and woodlots, or offsetting by purchasing renewable energy.[17]

Reducing wastewater and stormwater impacts

The growth of cities will produce an equivalent increase in the amount of human waste that needs to be managed and increased stormwater runoff. Most rivers, estuaries, coastlines, and groundwater systems close to cities and towns have suffered environmental impacts from various forms of pollution. The waterways and coasts are among the most heavily used and valued, placing pressures on water managers to reduce the impacts of stormwater and sewage.

From a wastewater management perspective, the removal of nutrients such as phosphorus and nitrogen contained in human waste is the primary focus for current and future sewage treatment. Strengthening regulation of industrial and commercial pollution at its source over the last 20 years in Australian cities means that the discharge of other contaminants to sewer systems is strictly controlled to avoid waterway pollution. Since the early 1990s, the gradual adoption of load-based environmental regulation across Australia has resulted in upgrade to sewage treatment plants, which use advanced biological treatment processes to improve effluent discharge quality into receiving waters.

Despite these gains, total sewage volumes and nutrient loads will increase over the coming decades because of population growth. Additional measures will be required to constrain nutrient loads to environmentally sustainable levels. The cost of additional treatment to further reduce nutrient concentrations is relatively expensive and energy intensive – a significant problem for fast-growing regions such as South East Queensland which have sensitive aquatic ecosystems. Figure 6.8 shows that the expected increase in phosphorus, nitrogen, and sediment loads to Moreton Bay over the coming decades will be predominantly from point sources such as sewage effluent and diffuse urban sources such as stormwater runoff.



▸ ***Figure 6.8**: Predicted increases in nitrogen, phosphorus and sediment loads to Moreton Bay over the next 20 years showing that urban sources will soon dominate nitrogen loads.*[18]

Diffuse pollution from stormwater runoff remains a significant problem for cities. Stormwater typically contains litter, sediment, vegetation, nutrients, chemicals, pesticides, metals, and bacteria. Stormwater can also be contaminated with bacteria and nutrients from sewage overflows and animal faeces after rain. Urbanisation increases the volume of and speed of runoff, helping entrain more pollutants and impacting on receiving waterbodies and riparian vegetation.

Water sensitive urban design is an increasingly adopted approach to urban development to minimise the impacts of urbanisation and improve the liveability of cities. It recognises that the way we design buildings, landscapes, and public infrastructure can incorporate water design features that enhance public amenity, cool surfaces and the surrounding air, capture and store stormwater for recycling, improve water quality outcomes in waterways, and protect local biodiversity.

Examples of these approaches include the use of stormwater retention and storage ponds, managed aquifer recharge, constructed wetlands, bio-filtration beds, grassed swales, permeable paving and roadways, and the increased use of water features in public spaces.

Resource recovery

It may be possible to reduce the export of wastewater from a city in a way that recovers resources and substitutes them for inputs into the city. Treated wastewater can be used as a recycled water source for a city, but it can also be a valuable source for nitrogen and phosphorus fertiliser to grow food and fibre, and be a source of energy while reducing greenhouse gas emissions from the treatment process. In essence, some of the inputs and outputs to a city could be internalised into its metabolism, making it more efficient and sustainable.

Growing global populations require increased food and fibre production and increased demand for fertilisers. In Australia, fertiliser use has increased seven fold over the last 40 years.[19] All phosphorus-based fertilisers are sourced from phosphate rock, and it is predicted that high- grade phosphate rock will become depleted over the coming century and lower grade resources will be used instead. Production and energy costs will be greater for these resources and they present other problems such as potential contamination with heavy metals.[20] An alternative source for phosphorus could be to recover it from treated wastewater.

Similarly for nitrogen, fertilisers are produced using a very energy-intensive process and then nitrogen is removed during wastewater treatment at a high energy cost. Tertiary wastewater treatment processes can also generate and emit nitrous oxide to the atmosphere: a very potent greenhouse gas. Again there could be many benefits of recovering nitrogen from wastewater as an alternative source of nitrogen fertiliser.

Human waste contributes about 80% of the nitrogen and phosphorus in domestic sewage. The world's population excrete about 25 million tonnes of nitrogen per annum and about 4.4 million tonnes of phosphorus. This is the equivalent of about 17% of the total worldwide production of nitrogen fertiliser and about 22% of that for phosphorus. The amount of nitrogen and phosphorus in agricultural wastes is at least as large, so nutrient recovery from these sources has the potential to supply a significant fraction of the total worldwide fertiliser demand and contribute to more sustainable food production.

Because urban populations provide a concentrated source of nutrient flows in wastewater, sewage treatment plants are an ideal focus for resource recovery in a city. Recent innovations in nutrient recovery from wastewater streams highlight the potential to produce struvite (a slow-release fertiliser of magnesium, ammonium, and phosphate).[21] Commercial application of this technology is progressing in sewage treatment plants in Canada and the United States of America. Vacuum stripping of ammonia is a new technique and simulation studies on the impact of the ammonia recovery process indicate a reduction in greenhouse gas emissions of between 25% and 48%, compared with current advanced biological treatment.[22]

Table 6.1 illustrates the approximate potential value of methane, ammonia, and phosphorus in Melbourne's sewage, based on 2008 prices for these resources. Methane can be used as an energy source to make the treatment plant a net source of energy. The value of water contained in the sewage would be many times the value of the resources. The challenge is to develop and adopt technologies to realise this value in a cost-effective way while protecting environments from pollution.

Table 6.1: Estimate of annual quantities and values of methane, ammonia, and phosphorus available from Melbourne's sewage.[23]

	Yearly (tonnes)	Value ($/year)
Methane	93 200	$30 million
Ammonia	22 500	$22.5 million
Phosphorus	3660	$12 million

Melbourne CBD, Yarra River and urban parkland.
Photo: Robert Kerton, CSIRO.

Domestic rainwater tank. Photo: CSIRO.

One way to realise the potential of resource recovery is to separate black water (toilet wastewater) at its source. Current sewers collect black water and grey water flows. However, black water contributes about 20% of residential sewage discharges but contains some 90% of the nitrogen and 60% of the phosphorus discharged.[24] Black water separation would concentrate the flows of nutrients and carbon in sewage to enable purpose-built energy and nutrient recovery treatment processes. The remaining grey water sewage flows would be significantly lower in nutrients, greatly reducing the need for tertiary treatment based on nitrogen removal, thereby reducing energy use and facilitating simpler and safer grey water recycling (Figure 6.9).

Black water separation is easier to implement in new developments, but a transition to such a system may also be possible in existing areas of a city as wastewater infrastructure and housing stock is renewed over time. The economics of such a transition are complex but should consider the value of all the components and resource flows beyond simply the cost of sewage treatment. Black water separation requires additional collection pipelines (possibly within the existing sewer), as well as a resource recovery treatment processes – both significant investments. These could be offset by new income from the fertilisers and energy produced, a new water source from recycled grey water, lower capacity required for sewage treatment plants, and lower pollutant discharges to the environment.

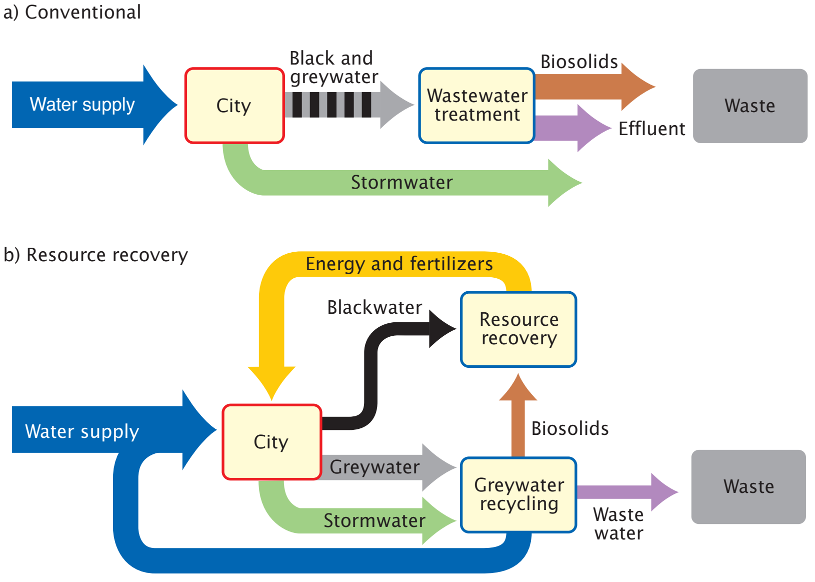


Figure 6.9: A conventional urban water system compared with one designed to recover resources from black water and recycle grey water.

Transitioning to a sustainable urban water system

Today, society has the advanced technologies and the economic capacity that allow us to manufacture clean drinking water or water fit for other purposes from virtually any source of water, wastewater, or stormwater. Technologies are emerging that will enable more effective recovery of resources from wastewater, that will provide real-time management of water quality and water use, and optimise integrated water system operation for a range of environmental, public health, and service quality outcomes.

Across the globe, water managers are grappling with the challenge of how to use these technologies to evolve to more sustainable water systems. The first step is to define a new vision for urban water management in light of 21st century challenges. With significant input from the Australian water sector, the International Water Association recently endorsed a set of principles that describe the water related characteristics to which cities can aspire. These principles include:[3]

- Liveable and sustainable cities that have a compact footprint and use green urban design and green space to cool cities and provide low-impact transport corridors.
- Cities that generate water, energy, and nutrient by-products in a way that is carbon neutral and recognises resource connections with surrounding regions.
- In addition to public health and water security, recognise the role that water provides for urban ecosystems, waterways, and a green city.
- A greater choice of water services and ones that bear the full environmental and social cost of these choices. Choices that are informed by improved access to useful and accurate information about costs and benefits and their own resource usage.
- City planning that integrates water, energy, and urban design at all scales to enhance sustainability benefits.

The expanded contribution to more liveable, sustainable cities is appropriate where broader social, public health, and environmental benefits and costs are defined or where there is a willingness by water consumers or other urban beneficiaries to pay for the outcomes.[12] This highlights the challenge of effectively valuing the wider social and environmental benefits and costs of alternative water servicing approaches. All major cities in Australia have progressed towards pricing based on the recovery of direct capital and operating costs, although governments have directly subsidised some recent large water projects.[12] The inclusion of indirect costs and benefits or externalities into water prices has generally been limited to cases where these costs are internalised through regulation.

A shift from conventional to more integrated water, wastewater, and stormwater systems often requires an increased level of involvement from the community due to the increasingly decentralised nature of these systems. Recent research highlights the benefits from engaging and educating the community in order to identify acceptable management and ownership of water sensitive systems and overcome the sometimes poor understanding of water sensitive urban design and inappropriate uses of non-potable water sources. Some plans for potable recycling of water, such as in Toowoomba, have been defeated as a result of the lack of community acceptance.

Conclusions

Over the past 100 years the water sector has expanded its range of functions, evolving from water delivery to wastewater, drainage, and pollution control functions. It has also begun to recover energy and capture nutrients in bio-solids and to implement water-sensitive urban design. Climate change, limited and decreasing catchment water supplies, and the relatively high cost of manufactured water will continue to place pressure on water services, just as waterway health and rising treatment costs will continue to place pressure on wastewater services. Large price increases have already been foreshadowed, but it is perhaps only by considering the full range of values gained from water that the sector will evolve towards sustainability.

Further reading

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Future urban water supplies

Stewart Burn

Key messages

- Australia's largest cities are forecast to require 1150 GL/year (or 73%) above the current supply of 1505 GL/year by 2050. In addition, current supplies will probably reduce as a result of climate change, requiring additional augmentation.
- Desalination is the most adopted technology to date, providing 484 to 674 GL/year of additional water. There is potential for major improvements in the efficiency and cost of desalination.
- Other potential water sources include rainwater tanks, capturing and reusing stormwater, and indirect potable recycling – all of which have their particular strengths and weaknesses.
- Traditionally, financial and technical considerations were emphasised when exploring new water supply options; now, consideration is also being given to social acceptability, and environmental costs and benefits. There will be different solutions to new supplies for each city, given their very different situations.

The need to augment urban water supplies

As outlined in the preceding chapter, 10–20 million extra people will be living in Australian cities in 50 years time. Population growth will create a demand for an additional 1150 GL or 73% of water by 2056 (Figure 7.1).[1] In the past, large dams were built to meet that growing demand but recently other options have been considered and used, such as desalination plants, recycling, stormwater harvesting, and rainwater tanks. This chapter explores the merits and prospects of these options as new methods of supplying water.

Growth in demand for water was accommodated until recently by reducing per capita use (see Chapter 6). By 2001–02, each capital city's water consumption had grown close to, or exceeded, its reliable supply from surface or groundwater sources (Figure 7.2), and the millennium drought in southern Australia revealed the vulnerability of existing supplies. Augmentation of water supply became critical, and most states built desalination plants (Table 7.1).[2] Desalination has the advantage of not being dependent on variable catchment runoff or groundwater recharge, which was a critical consideration during the drought.

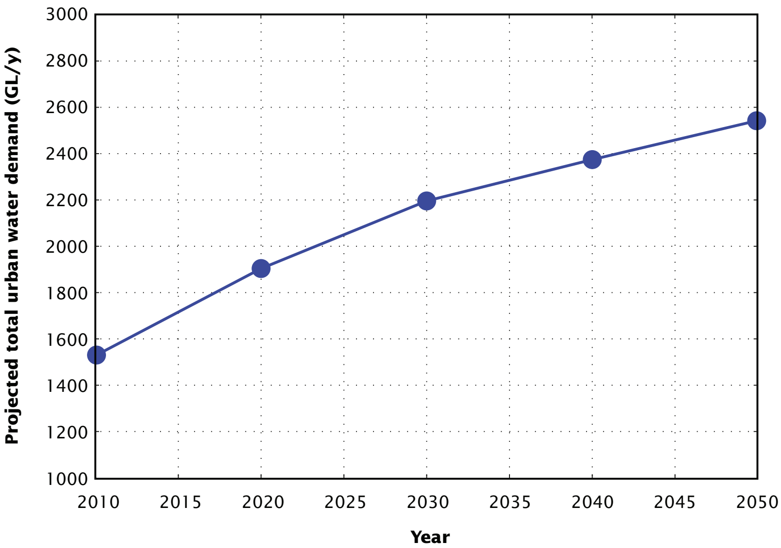


Figure 7.1: The projected total water demand in Australia's major cities (the sum of demands in Canberra, Perth, Adelaide, Sydney, South East Queensland and Melbourne) as a result of growing population.[1]

Climate change in southern Australia is predicted to reduce the long-term yield of dams and groundwater systems (see Chapter 2). In Melbourne, for example, the predicted reduction in surface water inflows to urban water storages is 10% by 2020 and 20% by 2050.[3] Higher temperatures and reduced precipitation could also increase urban water demand because cities use about 30–40% of residential water for irrigating domestic gardens and public parks. More water tends to be used when the weather is warm and dry (e.g. in evaporative cooling and swimming pools). Based on studies in Melbourne[3] and Sydney[4], the increase in urban demand due to climate change will be 1% in 2020 and 5% in 2050. This is a small increase compared with the expected reduction in surface water inflows, but the growing demand and dwindling supplies will produce a widening gap, requiring new supplies.

The recent national investment in 484 GL of desalination capacity (expandable to 674 GL) will suffice in most cities until approximately 2026 (Table 7.2). Beyond 2026, new sources of water will be needed in some cities, giving a 15-year opportunity to undertake new solutions. For inland cities and towns, desalination is not feasible and other options, including the purchase of irrigation entitlements, are needed. Canberra is currently augmenting supplies with stormwater harvesting and an enlarged dam.

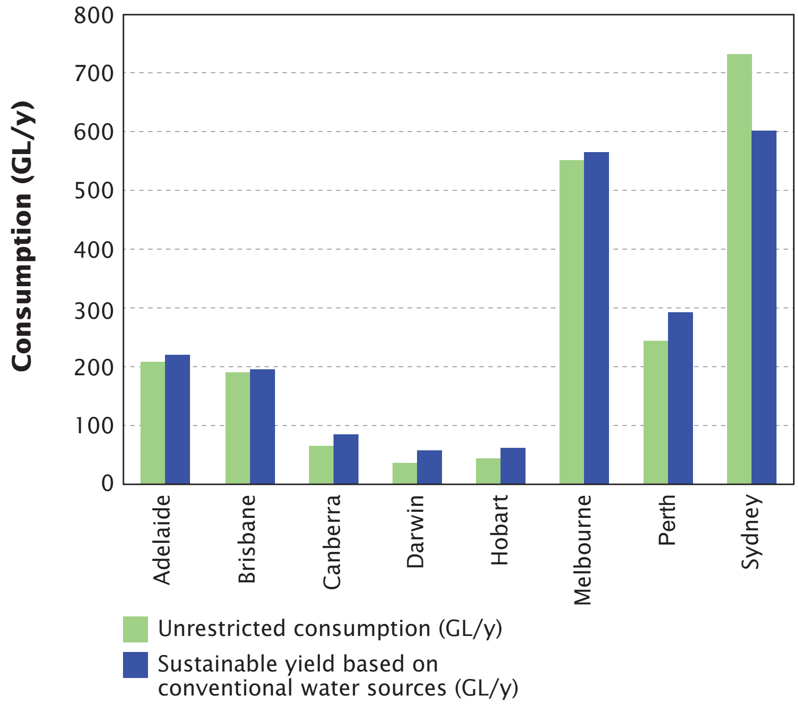


Figure 7.2: Comparison of 2001–02 unrestricted consumption and sustainable yield based on conventional surface and groundwater sources in Australian major cities, showing that consumption had grown to the limit of sustainable yield of the supplies.[2]

Table 7.1: Current desalination capacity installed (or being built) and total proposed capacity in Australia's capital cities.[1]

City	Current capacity – gigalitres	Maximum proposed capacity – gigalitres	Maximum desalination compared with consumption 2008–9
Adelaide	100	100	73%
Brisbane and SEQ	49	49	22%
Canberra	0	0	0%
Darwin	0	0	0%
Hobart	0	0	0%
Melbourne	150	200	42%
Perth	95	145	38%
Sydney	90	180	18%
Total	**484**	**674**	

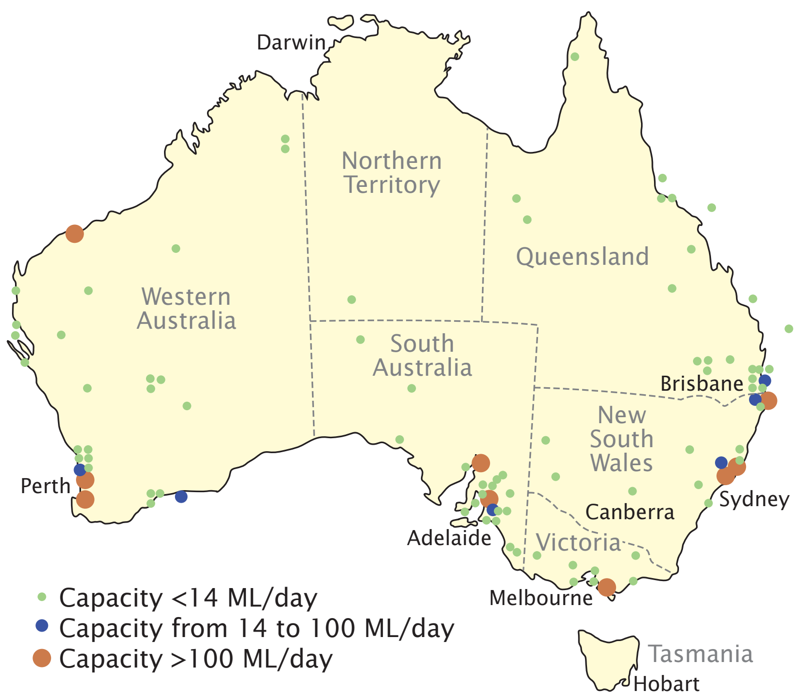
Desalination plant at Kwinana, Western Australia. Photo: Western Australian Water Corporation.

Table 7.2: Predicted water availability (in GL/year) in 2026 for Australia's capital cities.[5,6,7,8,9]

	Current yield	2026 yield with climate change	Current desalination capacity	Total capacity (2026)	Urban water consumption 2009	Predicted consumption in 2026	Predicted surplus (deficit) 2026
Adelaide	216	194	100	294	138	176	**118**
Brisbane and SEQ	476	428	49	477	223	499	**–22**
Canberra	104	80	0	80	46	75	**5**
Darwin	42	38	0	38	37	55	**–17**
Hobart	803	723	0	723	40	40	**683**
Melbourne	555	500	150	650	360	516	**134**
Perth	256	230	95	325	250	285	**38**
Sydney	603	543	90	633	492	619	**14**

Desalination

Australia has a long history of water desalination. Initial drivers were the need for potable water from the sea, or from brackish groundwater in the case of arid and remote communities (Figure 7.3). Early applications of desalination were all small-scale plants deploying a range of technologies. Australia's six largest coastal cities all now have desalination plants in place or under construction to ensure reliable water supply (Figure 7.3). These plants use reverse osmosis because it has a proven history of use and has low energy and capital costs compared with other available desalination technologies.



▸ ***Figure 7.3**: Location and size of desalination activities across Australia.*[10]

Reverse osmosis (Figure 7.4) uses a membrane to filter and remove salt ions, large molecules, bacteria, and disease-causing pathogens from sea water by applying pressure to the water on the input side of a semi-permeable membrane. The salt is retained on the pressurised side of the membrane and pure water passes to the other.

Reverse osmosis has a number of shortcomings. Although the membrane is impervious to salt, it can let through chemicals such as pesticides and herbicides, so for potable water it still requires a pure source. Reverse osmosis removes all the naturally occurring salts to give un-buffered water that is deficient in calcium and other essential minerals, so to ensure that it is appropriate to drink these are added back into the water.

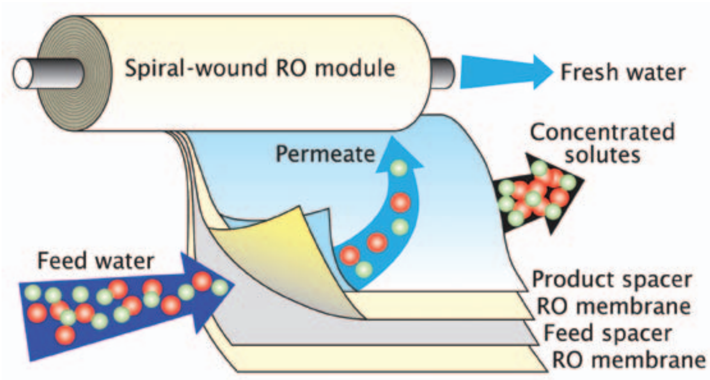


Figure 7.4: Schematic of the reverse osmosis (RO) process.[11] (Adapted from nanoh2o.com.)

Reverse osmosis is also relatively inefficient – all the input water must be chemically pre-treated and filtered even though a large proportion of the input is returned to the ocean as a concentrated brine stream. In the Perth plant, this brine is equivalent to 60–65% of the input water stream. Reverse osmosis also uses significant amounts of electricity to pressurise the input water (for example, the highly efficient Perth plant uses power equivalent to that for 27 000 homes).

It is expected that the existing trend to use reverse osmosis for urban and industrial water desalination will continue. Research is examining ways to make the process more efficient and reduce the amount of energy needed. A range of emerging technologies increase efficiency by either pre-treating water, reducing membrane fouling, improving the throughput of water and rejection of pollutants, or reducing the pressure at which the systems operate.

Pre-treatment is essential to prevent fouling of membranes for at least half of the major reverse osmosis seawater desalination plants installed around the world. Inorganic salts, colloidal and particulate matter, organic compounds and microorganisms present in the feed water reduce membrane efficiency and lifespan. The main pre-treatment used is coagulation. However, coagulation only removes some pollutants and can produce small flocculants that penetrate and block membrane pores. New coagulants formulated for a number of water sources aim to greatly improve flocculent size, capture more pollutants, reduce membrane fouling, and can be easily washed from membranes.[12] Technologies are also being developed to allow membrane surfaces to be treated with sugars that have excellent anti-fouling properties.

Several emerging technologies have the potential to improve the efficiency of reverse osmosis, for example polymer membranes (Figure 7.5), but it may be decades before some of these are mature enough for widespread application. These technologies could also be applied to water recycling and the treatment of industrial waste streams, enabling water reuse.

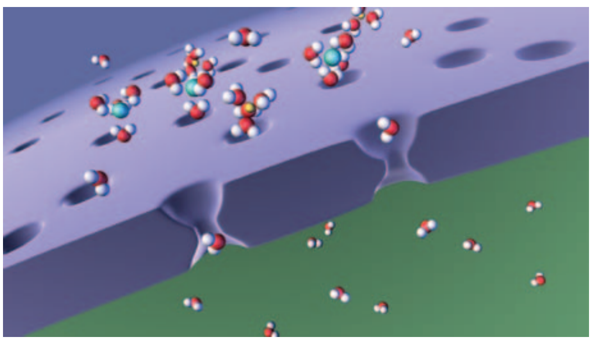
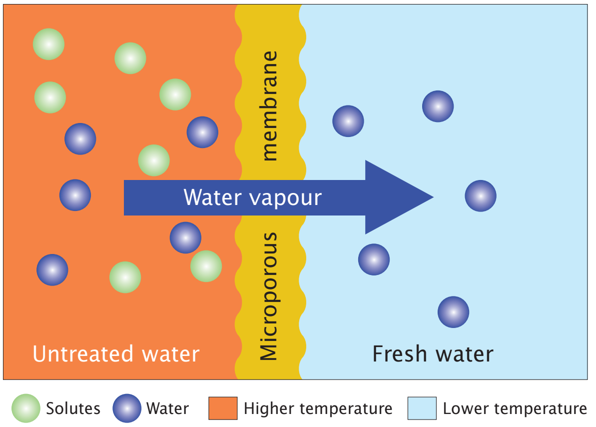


Figure 7.5: Schematic of a new polymer membrane which uses microscopically small hour-glass pores to allow water molecules to pass through the membrane while larger salt ions and other molecules are unable to pass through. The polymer mimics the shape of micropores found in nature.

Carbon nanotechnology can possibly be used to produce membranes that are effectively forests of microscopic tubes. It is claimed that these tubes offer an almost frictionless flow of water while retaining salt. They also have the potential for low membrane fouling, enabling simple regeneration of the membrane. Membranes with permeability that is significantly higher than conventional materials are being examined for desalination performance.[13,14]



▸ ***Figure 7.6***: *Schematic showing water vapour passing through a membrane from the high temperature to low temperature compartments in the membrane distillation process.*

Membrane distillation (Figure 7.6) is a thermal process, which uses any low-quality heat source, to enable water vapour to pass through a specialised membrane leaving pollutants in the remaining liquid. Membrane distillation works at atmospheric pressure and recovers up to 80% of clean water relative to 40% for reverse osmosis. Current limitations are a low throughput and membrane fouling.[15] Alternatively, a combination of permeation and evaporation ('pervaporation') can be used to pass water through a polymer membrane with evaporation on the far side of the membrane providing a pressure difference to maintain flow. This technique has potential to be very efficient but it is limited at present by low flow rates.[16,17] Electrodialysis is a low-pressure, direct current electrical process for removing salts from brackish water that is showing potential for treating highly saline waste water. It does not remove pathogens effectively, but the resultant water is considered suitable for irrigation and can be produced at an operation cost of $100/ML – considerably lower than for potable supplies.

Rainwater tanks

Urban households are increasingly adopting rainwater tanks as a water source. Rainwater tanks were traditionally used in rural areas that did not have a reticulated supply, but their use has proliferated in cities in response to government policies to reduce demand on centralised water supplies (Figure 7.7). From 1994 to 2010, the number of capital city households that use a rainwater tank has more than doubled, increasing from 407 000 to 1 030 000.[18,19] Urban rainwater tanks are mainly used for garden watering and toilet flushing, which are a large component of domestic water use. Capture and use of rainwater moderates peak stormwater runoff and reduces discharge of nutrients to rivers and estuaries. Rainwater is not permitted to be used as a potable supply in some cities because the water is untreated and could be contaminated by metals, organic matter, and microorganisms.

It is expected that the number of urban rainwater tanks will continue to increase because most jurisdictions have mandated installation of water-saving features for new buildings. Rainwater tanks are one way of meeting this requirement (e.g. the Development Regulations in South Australia require all new houses and units to have connection to an additional water source to supplement mains water).

How effective rainwater tanks are as a new supply of water depends on how much they reduce demand on centralised supplies and how much energy they use. Water billing data from South East Queensland shows an average water saving of 30 kL/household/year from rainwater tanks (approximately one-tenth of domestic supply), while tank modelling showed a saving of 46 kL/household/year could be achieved from internal usage.[20] Savings depend upon how well households use the water, the design of the system, and seasonal rainfall.

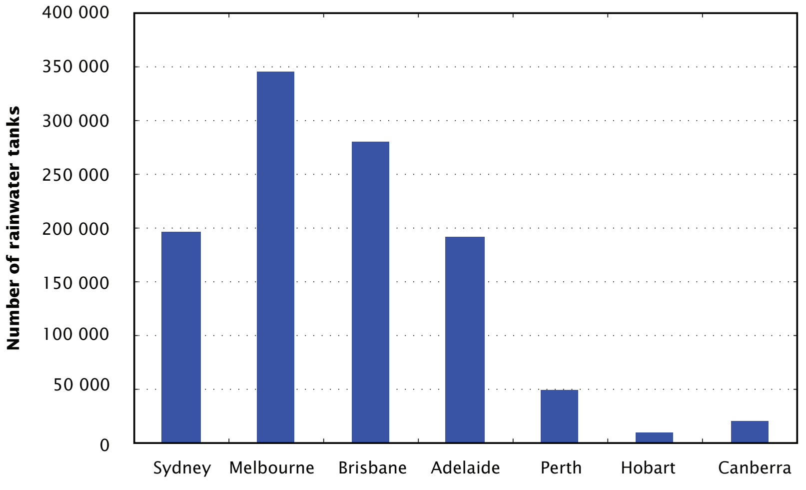
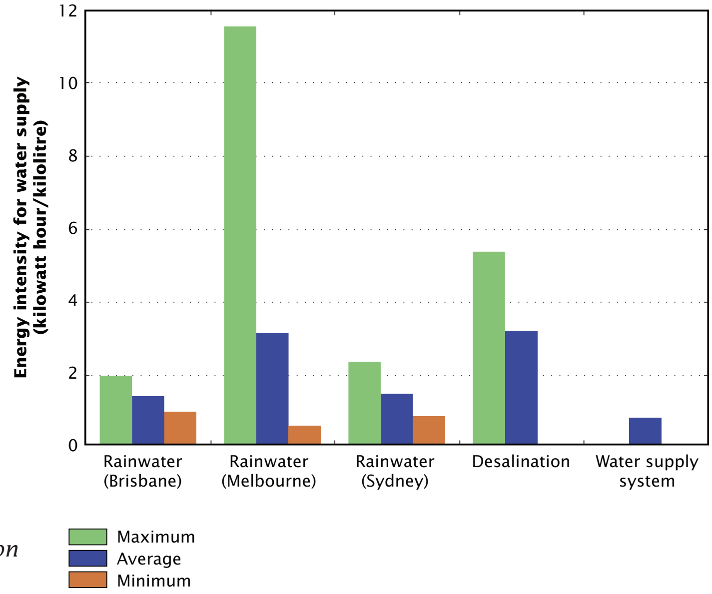


Figure 7.7: *The number of urban rainwater tanks in major Australian cities in 2010.*[18]

The use of tank water usually requires the use of a pump, which, in turn, raises questions about their energy efficiency. Very high variations in energy use are reported (from 0.6 to 11.6 kWh/kL) and the process can exceed the energy used per kilolitre to produce water by desalination (Figure 7.8). The high variation is caused by the use of different types of pumps and accessories, and energy use could be reduced through better design and operation. The potential for improvements in energy and water use makes a case for providing professional services, supported by automated control systems, to improve and maintain the performance of rainwater tanks.



▸ ***Figure 7.8****: The range of energy use of rainwater tanks, compared with desalination and water supply from dams (CSIRO data).*

Recycled water

Water is commonly used once and then discarded, but significant efforts are now being made to recycle wastewater. Recycling and reuse can contribute to sustainability by reducing the economic and environmental costs of wastewater disposal and by providing an alternative water source to substitute for centralised potable supplies. Most efforts have reused water for non-potable purposes, such as for irrigation of crops, pasture, public gardens, and sporting fields. By the mid 1990s, water recycling was supplying water to industry for cooling and industrial processes, and new residential developments in New South Wales and Victoria via third-pipe systems for outdoor use and toilet flushing.

Recent urban water shortages have raised the prospect of indirect potable reuse, where sewage is treated to a level that meets drinking water standards and is stored in an existing reservoir from where it can be extracted for later use. Key international examples of this process in place are Singapore, where about 2.5% of total daily water consumption is reused water,[21] and Orange County in the United States of America.[22] In both these cases, there was considerable emphasis placed on public awareness and education about the scheme, including the development of an education program. The Queensland Government commissioned the Western Corridor Scheme, which is based on a seven-barrier system (Figure 7.9), including storage of treated water in the Wivenhoe Dam. This system can supply up to 66 GL/year of reused water into the South East Queensland water system. Indirect potable reuse has been quietly in place for decades along a few Australian rivers. Canberra's wastewater is treated and disposed of in the Murrumbidgee River, while towns downstream, such as Wagga Wagga, Leeton, Griffith, and Adelaide, extract and treat the river water for potable supplies, as is the common practice for virtually all European river cities.

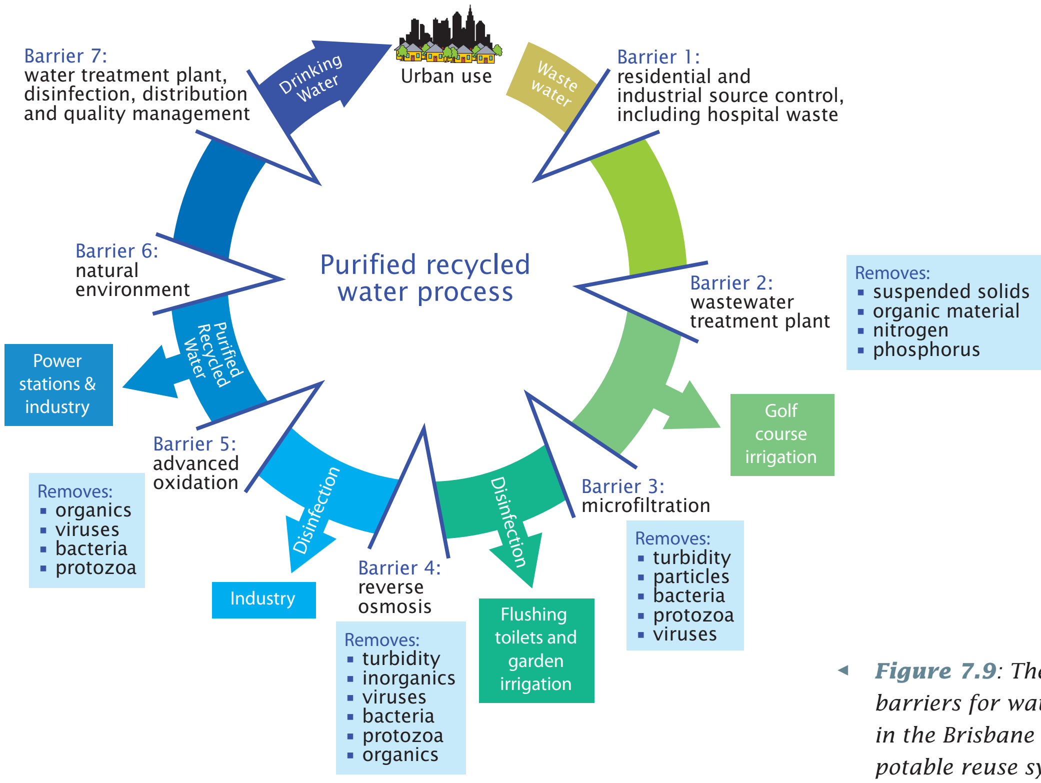


***Figure 7.9**: The seven barriers for water treatment in the Brisbane indirect potable reuse system.*[23]

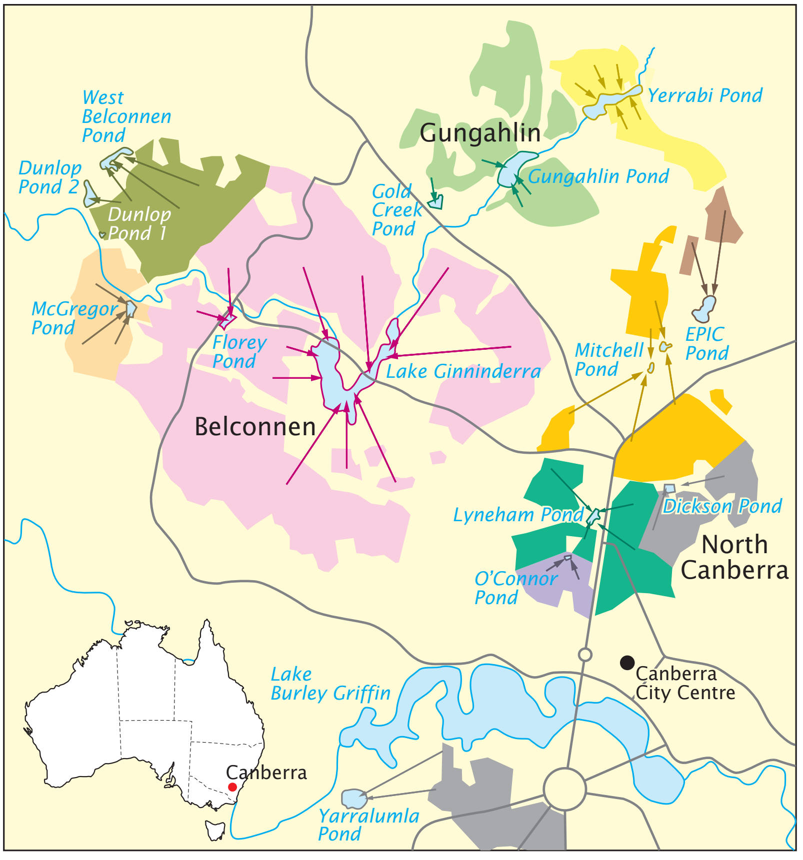
There are substantial community concerns regarding the safety or necessity for use of recycled wastewater, centring on the potential for harmful contaminants that may enter the drinking water system – either because of a failure in the treatment system, how it is operated, or due to some unforseen contaminant. Particular concern has been expressed over control of industrial and hospital contaminants. The Western Corridor Scheme in Brisbane was built at a time of impending water crisis, but now that the Wivenhoe Dam has filled, the water is used only for cooling in a power station and some other industrial uses.

Reuse systems contain advanced water treatment such as dual membrane systems that combine micro- or ultra-filtration with reverse osmosis. In many cases, advanced oxidation using ultraviolet disinfection is used as an additional treatment barrier to ensure almost complete removal of all traces of biological and chemical contaminants. Pathogens have been excluded up to 99.99% and virtually all organic compounds removed.[24, 25,26] Trace chemicals are at concentrations tens to hundreds of times less than the limits set by the Australian Drinking Water Guidelines.[23, 24,27]

Despite the demonstrated effectiveness of advanced water treatment plants, regulators require that potable recycling is done in an indirect manner using some form of natural reservoir between the advanced water treatment and the drinking water treatment plant. For example, the Western Australian Government plans to use aquifers for storage. These natural environments also remove or reduce any pathogens or organic chemicals present and provide an additional control point through dilution and prolonged storage. This allows scheme operators and regulators to intercede if a system malfunction causes pollutants to pass through the treatment plant. In this respect, rapid detection techniques that can almost instantaneously determine if a treatment barrier has failed are needed to ensure the operational effectiveness of treatment plants. It should be recognised, though, that pathogens and chemicals may enter a reservoir or aquifer from catchment land use. Despite all the measures to make potable recycling safe, community resistance remains strong and it may not be swayed, even by strong consultation and education.

Stormwater capture

Stormwater is a large resource that could be collected from urban runoff to substitute for existing supplies and reduce the costs and environmental impacts of disposal.[28] Many municipal councils capture stormwater for non-potable use. For example, new stormwater harvesting projects proposed for Adelaide will increase the total stormwater harvesting capacity from 6 GL/year to about 20 GL/year by 2013 and up to 60 GL/year by 2050.[29] Non-potable water use in Canberra could be supplied from stormwater entering the city's urban lakes and from new ponds (Figure 7.10). These lakes and ponds have the potential to supply 3.3 GL/year, which was 7.6% of Canberra's total consumption in 2007–08.[30] In most capital cities, the limitations for urban



▸ ***Figure 7.10**: Existing and planned lakes and ponds to capture stormwater in the northern suburbs of Canberra. The storages will be used to provide water for surrounding parks and gardens.[30]*

stormwater harvesting are centred on storage sites for the large volumes of water and the high costs of water treatment.

Urban stormwater contains pollutants that are a human health risk and can limit the recreational use of rivers, bays, and beaches. The pollutants of greatest risk to human health include heavy metals, hydrocarbons, organic chemicals, and organisms that can cause disease. The advanced treatment systems used for wastewater are not economically practical for stormwater application because stormwater is dispersed across the urban area rather than being collected centrally in pipes. Alternative treatment processes such as filtering through wetlands or aquifers need to be used to allow cost-effective treatment.

Storage of harvested stormwater is a large barrier to its use. Appropriate places are urban lakes and wetlands, and in brackish aquifers as pioneered in Adelaide and now implemented in most states and territories. Stormwater recycling, using aquifers to store water from which it is later pumped (Figure 7.11), is used increasingly where there are suitable aquifers.

Examples of aquifer storage and recovery projects include the Mawson Lakes scheme in Adelaide, which uses reclaimed wastewater from the Bolivar Wastewater Treatment Plant, blends it with harvested urban stormwater and then injects it into an aquifer. When needed, up to 0.8 GL/year of water is withdrawn from the aquifer and reticulated to 4000 homes for non-potable reuse.

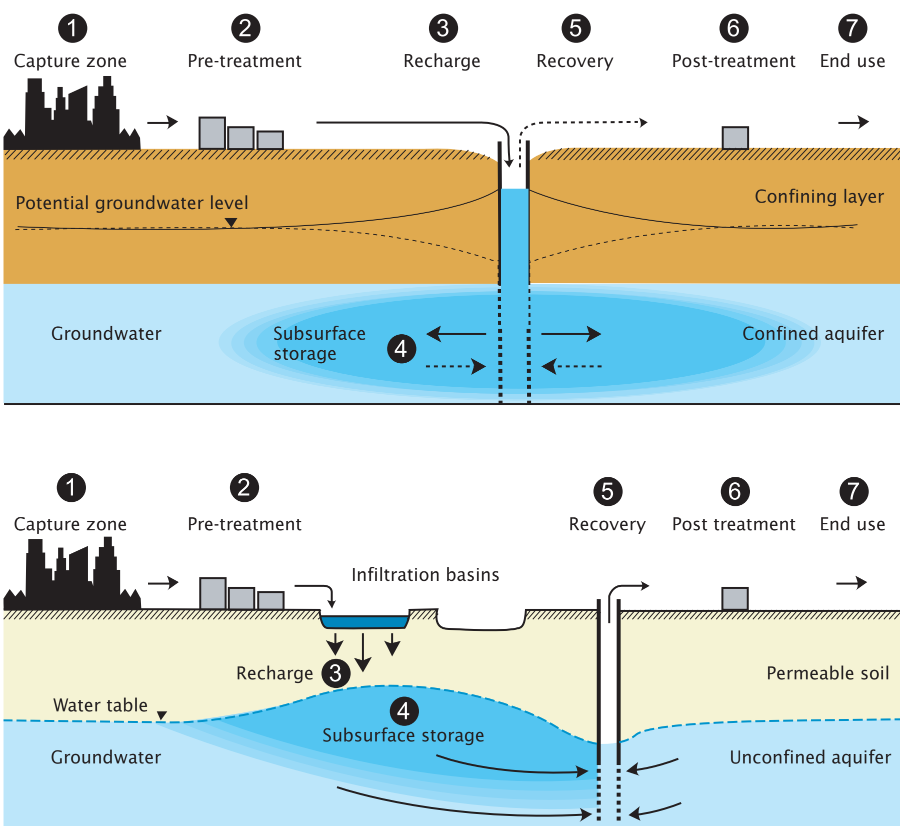


Figure 7.11: *Elements of managed aquifer recharge. At top, aquifer storage, transfer, and recovery in a confined aquifer. At bottom, soil aquifer treatment in an unconfined aquifer.*

Replacing a stormwater pipe. Photo: Tracey Nicholls, CSIRO.

Stormwater harvesting in the City of Orange (New South Wales) is the first large-scale, potable stormwater harvesting project in Australia and uses the local aquifer for storage and additional treatment.

An advantage of aquifer storage and recovery is the natural filtering and treatment of water that occurs while it passes slowly through the aquifer, although it should be noted that the effect of stormwater injection on chemical reactions in the aquifer must be fully understood to ensure that good water quality is achieved.

Reducing reservoir evaporation

Reservoirs still remain the main source of water for cities, but they lose large volumes of water through evaporation. In dry periods, reservoir levels decline over a period of several years, and the loss of water to evaporation can be as large as the water supplied to the city. For example, Brisbane's three water supply reservoirs can lose 248 GL/year through evaporation, which is comparable to their supply rate of 240 GL/year. A range of evaporation reduction techniques has been considered for small dams but the only likely technique for large dams is the use of a monolayer on the water surface. Monolayers are artificially synthesised long-chain alcohol films one molecule thick (approximately 2 millionths of a millimetre) that inhibit evaporation when applied to a water surface. Evaporation reductions of between 10% and 30% have been recorded for small trials, but new polymers have the potential to double that. Monolayers have not yet been applied to large reservoirs because of limitations of cost relative to water savings, potential effects on water quality, and break-up by winds. Before monolayers could be applied to potable water reservoirs, the potential impact on water ecology and recreational use would need to be fully quantified, as well as any potential impact of the products of biodegradation of the monolayers on water treatment. Financial analysis of the benefits of monolayers has indicated that they have the potential to supply additional water at a cost of $0.28 to $0.68 per kilolitre.[31]

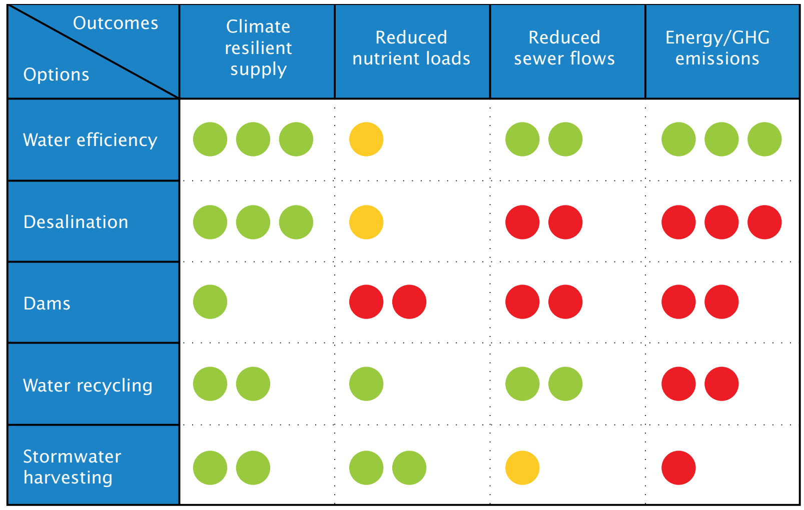
Choosing the best options

This chapter has outlined a range of new options for urban water supplies. Added to these are traditional sources of large dams and groundwater supplies, and continuing improvements in demand management. Suitable options for augmenting water supplies will vary from city to city, with very large differences in the cost, social, and environmental practicality of each option, depending upon the circumstances of each city. Each of the major Australian cities also has a different vulnerability to increased pressures on supplies from population growth, climate variability, and climate change.

Comprehensive planning and risk assessment can be used to determine the optimum portfolio of approaches for each city.[28] This might include decisions on the reliability of supply required into the future, which is often expressed in terms of the acceptable frequency of water restrictions. Given recent unprecedented droughts and the risk from climate change, the risk assessments should be evaluated using a range of possible future conditions and identifying the risks, probabilities, and mitigation strategies associated with each climate scenario. Some of the

A Canberra suburban lake used for stormwater capture and reuse. Photo: Greg Heath, CSIRO.

Figure 7.12: *A simple rating of urban water supply options against considerations other than cost. These might influence both environmental costs and benefits and social acceptance of the options. Green dots represent the strengths of the options; red dots represent the weaknesses; and orange dots indicate no affect.*



options, such as desalination plants, take several years to progress from planning to operation, requiring long lead times, but they also involve very large capital expenditures so there are financial incentives not to build them too soon.

Traditionally, a heavy emphasis has been placed on financial and technical considerations when exploring water supply options. Now, more consideration is given to the social acceptability and environmental cost or benefit of an option and techniques such as multi-criteria analysis can more broadly inform decision making. Figure 7.12 shows, for the purpose of illustration, a simple example of some of the supply options ranked against four considerations other than cost and technical feasibility. Strong differences are shown and different options would be chosen depending upon how important each factor was to the particular city.

Technical feasibility and the cost of the different supply options varies strongly between Australian cities. Figure 7.13 shows the spread of costs for various options across a number of cities. One of the reasons for large differences in costs is the relatively high cost of pumping over

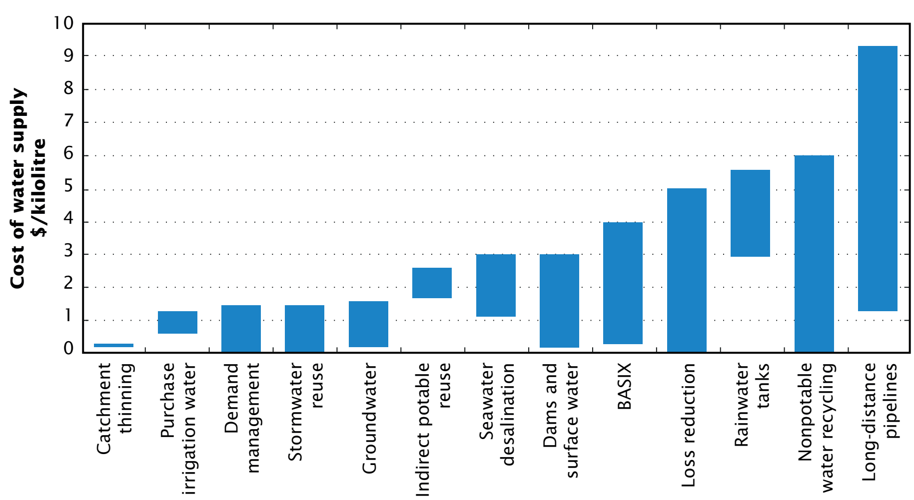


Figure 7.13: *The range of costs to provide additional water to Sydney, Adelaide, Perth, and Newcastle (2006 dollars). 'BASIX' refers to improvements in building sustainability including water saving.*[32] *(Adapted with permission from Marsden Jacob Associates, 2006.)*

long distances or to higher elevations. The distance and elevation to transport recycled water from sewage treatment plants to points of use has a large bearing on its cost. Pumping costs often eliminate inter-basin transfers of water as a good option under normal circumstances, although under drought conditions these may become critical, as has recently occurred in Victoria and Queensland. The cheapest option shown in Figure 7.13 is thinning of forests in water supply catchments to increase runoff, but it is the least proven and most speculative option.

Stormwater capture is probably the most difficult option to assess because it relies heavily upon the availability of storage. For example, the application of managed aquifer recharge across a city is only possible where suitable high-yielding and high-water-quality aquifers exist. Sydney and Melbourne have highly variable aquifers across the urban area, with most of Melbourne's aquifers yielding less than 0.4 ML/day and only the lower tertiary aquifer centred on Werribee in the city's west offering viable yields of between 1 and 5 ML/day. Stormwater capture is most cost-effective in new urban developments where it can be incorporated at the planning stage. Re-engineering existing urban developments is a lot less feasible. Cities are now combining decentralised systems of local stormwater harvesting and rainwater tanks with their existing centralised supply infrastructure. The costs, risk factors, and benefits of different combinations of decentralised and centralised supplies need to be fully evaluated.

In making decisions on the viable options, it must be remembered that major water supply infrastructure is designed to be used for decades, so lifetime costs need to be considered in the decision-making process. New supplies will mostly be more energy intensive and, because it is expected that energy and greenhouse gas emission costs are likely to rise significantly, these factors should be taken into account.

Further reading

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Irrigation

Mac Kirby

Key messages

- Irrigated agriculture is productive and profitable, generating 50% of all agricultural profit from just 0.5% of agricultural land.
- Australia exports 60% of its agricultural produce and demand should grow with increased standards of living and growing global populations.
- Two-thirds of irrigation in Australia occurs in the Murray–Darling Basin where it faces major challenges from climate change, return of water to the environment, and an increasingly open water market.
- New irrigation development is occurring in Tasmania and there are prospects for new developments in northern Australia, and along the east coast.
- Increasing demand for irrigated agriculture and declining water availability will drive increases in the efficiency of irrigated agriculture.
- Efficiency can be improved through more water-efficient crop varieties, improved farm management, precision applications of water, and more efficient irrigation supply canals, and river management.

Introduction

Irrigation is the largest use of water in Australia and the rest of the world, comprising about 70% of total water use. In countries with dry and variable climate, irrigation from rivers or groundwater provides more productive agriculture than is possible from rainfall alone; thus irrigated agriculture in Australia is generally more intensive and profitable than dryland agriculture. It is supported by sophisticated water management arrangements that have undergone substantial reform in recent years to make water a valued and tradeable commodity. With growing global and domestic demand for food and fibre, the future prospects for irrigation in Australia should be strong, yet it faces several challenges.

Irrigation in Australia is concentrated in the Murray–Darling Basin, where, in future, less water could be available for use because of a return of some water to restore environmental values, and because of lower river flows as a result of climate change, bushfires, and changing land use. Irrigated agriculture will need to respond to these challenges by increasing production efficiency (as was evidenced by some industries during the millennium drought), and through opportunities to improve water-use efficiency. Alternatively, there will be calls to expand irrigation elsewhere, such as in northern Australia, but these developments will involve far broader considerations than the availability of water. This chapter describes these large drivers for changes in irrigation in Australia.

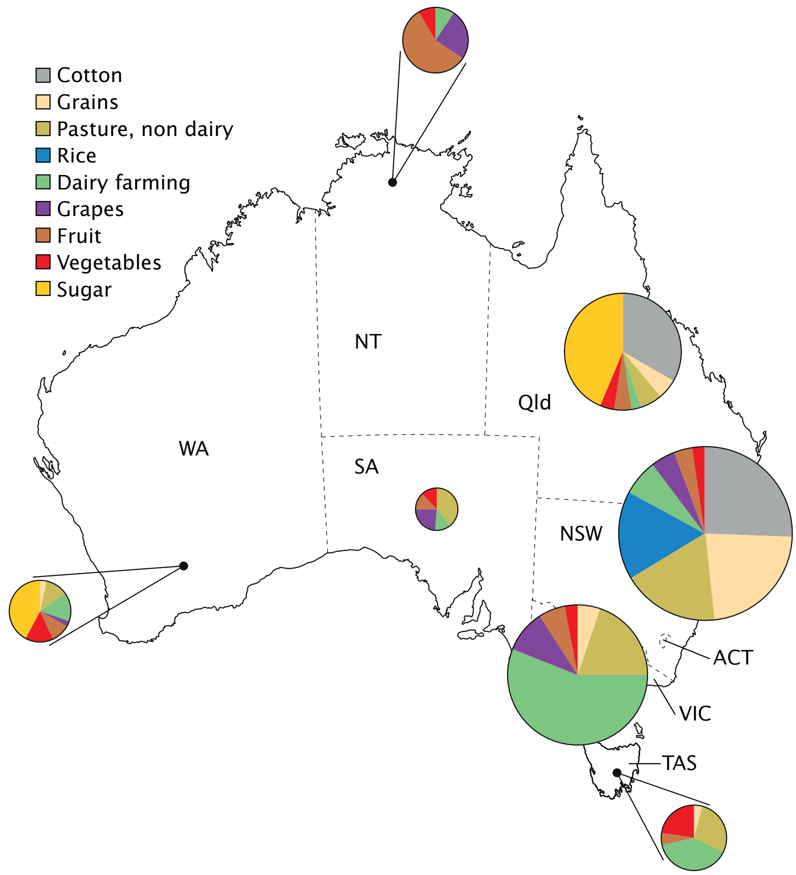
Irrigation today

Irrigation in Australia is dominated by the Murray–Darling Basin where over two-thirds of Australia's irrigation water use occurs,[1] even though the Basin produces only 6% of Australia's runoff. Most of the use occurs in the three large southern valleys of the Murray, Murrumbidgee, and Goulburn-Broken Rivers.[2] This scale of use is made possible by many large dams, including the Snowy Mountains Hydro-electric Scheme, which facilitate regulated releases of water downstream to be diverted into large canals that distribute water across extensive irrigation districts through thousands of kilometres of gravity-fed channels. In some districts, water is piped to farms to provide spray and drip irrigation for horticulture and viticulture. The Ord River scheme in Western Australia and the Burdekin irrigation scheme in Queensland are other examples of large-scale highly engineered irrigation.

Irrigation also occurs in the rivers of the northern Murray–Darling Basin and elsewhere, but not at the same scale. There are fewer large dams and some different types of systems, including pumped groundwater, river water pumped into farm dams, or the capture and storage of floodwaters behind levees. These systems are often self-supplied – where the irrigators are responsible for their own supply. The smaller-scale river systems tend to have less reliable year-to-year supply of water than the major schemes and therefore tend to be used for annual crops rather than horticulture or other permanent plants. Many Australian commodities are grown using irrigation, with dairy, cotton, and sugar being the largest water users (Figure 8.1).

The high production value of irrigated agriculture is shown by its disproportionate contribution to total production. Although just 0.5% of agricultural land was irrigated in 2003–04,[3] it produced 23% of the total gross value of agricultural production[4] and 50% of the profit at full equity.[5] Despite this, irrigation contributes somewhat less than 1% of gross domestic product.[4] It is of course more important to regional economies, making up 9% of the gross regional product in the Murray–Darling Basin in 2005–06,[6] but both national and regional economies are less dependent on agriculture than in the past. Some towns, particularly in annual rice and cotton cropping areas, rely on irrigated agriculture[6] and related processing and service industries. Thus the impacts of any large changes to irrigation due to droughts, climate change, or reduced diversion limits would be minimal at the national level, small at the regional level, but large for those towns and communities that rely upon irrigated agriculture.

There are quite sophisticated water management arrangements, especially in the Murray–Darling Basin, which are used to provide a reliable and equitable supply of water for irrigation



▸ ***Figure 8.1****: Water use (GL) in 2004–05 by state and major irrigation commodity. The size of pie chart represents the volume used in each state. The charts for Western Australia, Tasmania, and the Northern Territory are too small to see at the correct scale, so magnified versions are also plotted, to show the commodity breakdown.*[4]

and other users. Recent reforms have strengthened the legal, market, and price aspects of these arrangements. Irrigators own entitlements to use water (water licences), which have a nominal historical volume of use attached to them. To allow for large year-to-year variability in the amount of water available, annual allocations are made against the entitlements, which in years of drought can be much less than the nominal volume of the entitlement. For example, most entitlement holders in the Murrumbidgee River received annual allocations close to 100% of the entitlement in the 1990s but during the millennium drought annual allocations fell to as low as 10% of the entitlement. There is a plethora of entitlement types, which vary from region to region. High security entitlements provide the most reliable supplies of water, typically at the full volume and are well suited to permanent crops, such as horticulture, and to town water supplies and industry. General security allocations are much more variable from year to year, making them better suited to annual crops, where farmers can decide whether to plant irrigated crops or not, based upon the seasonal allocation. Although the annual allocations vary, farmers build up a long-term expectation from previous allocations and are sensitive to any erosion in the reliability of their entitlements.

In the Murray–Darling Basin, both entitlements and seasonal allocations of water can be traded, giving additional flexibility to adapt to the changing availability of water. In dry years, trade can be strong and the price of water can be quite high. In 2008–09, 1739 GL of allocations were traded in the southern Murray–Darling Basin and 1080 GL of entitlements were traded.[7] High security entitlements traded at around $2000/ML and general security entitlements traded at about $200–$400/ML in Victoria and about $1000 in southern New South Wales. In 2007–08, allocation trades peaked at about $1000/ML.[7] In the southern Murray–Darling Basin, trade has tended to move water use from upstream areas to downstream irrigation areas, shifting use from dairy pastures, rice, and other annual crops to horticulture and grape vines. Water is now a valuable commodity and its trade is changing the nature of irrigated farming across the Basin. While the trade is economically beneficial, there are some concerns over impacts on the local communities and irrigation districts from which water is lost.

These recent developments underscore much of the tension in the current debate over water for irrigation. Irrigators and other users own entitlements to use water that have a commercial value and can be traded. Individual farmers, communities, governments, and others have invested in infrastructure to store, convey and use that water. Plans and policies to change arrangements, entitlements, or the allocation of water to different uses are bound to disadvantage some users, and raise claims for compensation.

Irrigation canal near Hay, New South Wales. Photo: Greg Heath, CSIRO.

Future prospects

There are strong economic prospects for irrigation. Growing global populations and a growing standard of living will increase demand for food and fibre over the coming decades. Demand for the expansion of irrigation is likely to strengthen given the appeal of its high productivity and profitability. Australia produces enough food and fibre to support more than its own population, exporting 60% of its agricultural production.[8] Australia's population is forecast to grow to about

35 million people by 2056[9] and food demanded by this population can be supplied at current production levels.

World prices of major commodities (grains, meat, and dairy) are projected to rise in coming years, with a continued growth in demand[10] and will, all other things being equal, lead to the continued profitability of Australian irrigated farming. Although the growth in demand and increasing prices are generally favourable for irrigated agriculture, the dairy industry expects that price volatility will be a greater challenge than climate change or access to irrigation water.[11] The wine industry has experienced low prices for some years, and a shift from premium to bulk wines. The outlook is for continuing low wine prices.[12] Thus, although sustained water access is important to irrigators, price and other terms of trade are crucial to profitability. The irrigation industry has adapted to these pressures and so remains competitive in the global market.

Future of irrigation in the Murray–Darling Basin

Despite the strong prospects for irrigation produce, there are some risks to future water availability for irrigation in the Murray–Darling Basin. River flows in the Basin are projected to decline by 11% (2500 GL/year)[13] under a mid-range projection of climate change to 2030, with further reductions in later decades or under conditions of more severe climate change. Other risks to future water availability (see Chapter 2) include reductions to river flows from vigorous regrowth of forests following very large bushfires in north-east Victoria and southern NSW, new forest plantations, farm dams, and the increased use of groundwater. These could collectively reduce river flows in the Murray–Darling Basin by a further 1500 GL/year by 2030.[13]

Water access for irrigators will also continue to reduce as a result of increasing return of water to the environment in the Murray–Darling Basin. The Living Murray Initiative aimed to return 500 GL/year (averaged over 5 years) to the environment, although the actual recovery was less and difficult to determine (as at 2009) because of the millennium drought.[14] The Australian Government is buying back water entitlements to recover water for the environment and, up to early 2011, had recovered nearly 1000 GL. It is expected that the Murray–Darling Basin Plan (yet to be released at the time of writing) will require further water to be returned to the environment. While the precise amount is being strongly contested and will be reviewed every 10 years, claims on the amount required to achieve sustainable rivers, lakes, and wetlands generally vary from 2000 to 5000 GL/year.

Rural communities are concerned that the needs of urban water supplies or industrial users may compete against those of irrigation. Located outside of the Murray–Darling Basin, Adelaide and associated areas and towns obtain some 180 GL/year from the Murray River, and Melbourne has recently obtained entitlements for 75 GL per year from the Basin, facilitated by a new pipeline.[15]

Future growth in demand for urban water could be partly met by purchasing entitlements from irrigators, and the higher price of urban water to consumers makes this quite cost-effective. Compared with irrigation, however, the volumes involved in urban water are modest, but they may be locally significant.

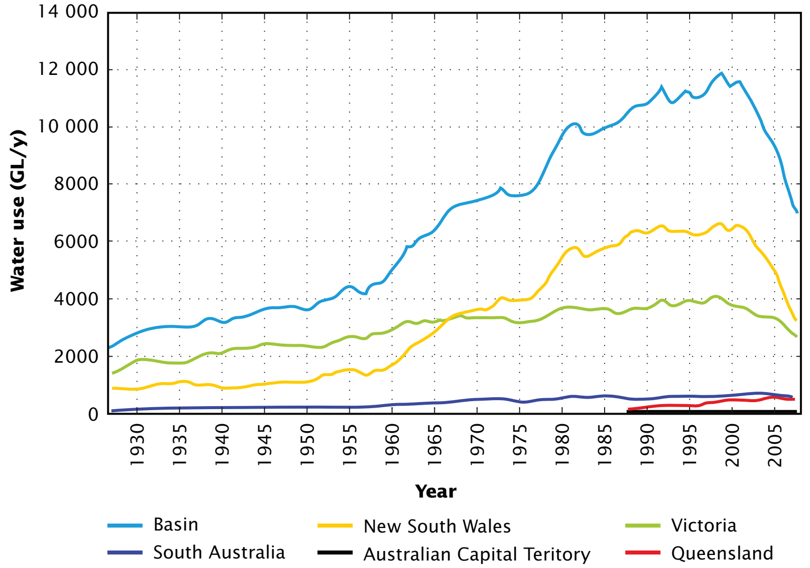
Also of localised concern are the impacts of trade in entitlements, which will move water out of some irrigation districts and into others. Lower overall availability of water for irrigation will increase competition for the resource, and trade improves overall efficiency of water use, but there are concerns about local community impacts and the problem of 'stranded assets' – where a reduced number of water users are scattered across a whole irrigation district and are left paying to run the whole supply infrastructure. With fewer users in a scheme, irrigation would ideally withdraw to the most profitable areas, closing the most distant and least efficient parts of the canal network, which often incur large losses of water. Irrigators are concerned that a 'Swiss cheese' pattern is emerging with a random loss of entitlements in a district requiring the whole irrigation network to be maintained.

Exit fees placed on the sale of entitlements, or regulations to limit trade in entitlements, are used to deal with the problem of sold entitlements. They have the disadvantages of restricting trade and not really tackling the problem of improving efficiency of the system. For example, no more than 4% of a district's water entitlement can be traded-out in a single year in New South Wales and Victoria. At the same time, governments are making large investments to improve irrigation infrastructure and make it more efficient, but without knowing if long-term use in those areas will be maintained. These problems can be solved by charging prices that more completely represent the fixed and variable costs of maintaining irrigation, but they could also be mitigated by improved projections of the future of irrigation in each district and identification of the opportunities to make irrigation districts more efficient (see below).

Irrigation during the millennium drought

The types of changes and adaptations that irrigation may face in the Murray–Darling Basin are well illustrated by the experience of the millennium drought.

Water use in the Basin fell 70% from 2000–01 to 2008–09 (Figure 8.2; Table 8.1), by far the biggest recorded drop in use. Earlier droughts had less impact on irrigation because the level of water use was less and earlier droughts were less severe. Some water plans were suspended in the drought and emergency measures were put in place. Because future droughts of the same intensity can be expected, this means that historical expectations of water users cannot be met in the long term. Lower overall use of water would result in more reliable allocations during intense drought, so there is a trade-off between levels of use and its reliability.



▸ ***Figure 8.2**: The historical growth of water use in the Murray–Darling Basin, more than 90% of which is for irrigation. Water use fell sharply during the millennium drought.*[16]

Despite the 70% drop in water use in the millennium drought, the gross value of irrigated agricultural production fell by only 14% (Table 8.1), leading some to suggest that irrigation productivity is quite adaptable to drought, and thus to other reductions in water supply. However, there are several factors influencing gross value of production and each irrigation commodity experienced and responded to the drought quite differently.[17]

Table 8.1: Irrigation water use and gross value of irrigated agricultural produce (GVIAP) in the Murray–Darling Basin.[1,17]

	2000–01	2005–06	2006–07	2007–08	2008–09
GVIAP ($m)	5085	5522	4922	5079	4349
Water use (GL)	10 516	7370	4458	3142	3492

Some major commodities, particularly dairy and cereals, experienced major price increases in 2008, which offset lower production. The price spikes masked a potentially worse impact of the drought for some commodities and cannot be relied upon in future droughts. By contrast, cotton, experienced a decline of 80% in water use, 80% in production and a 75% decline in gross value from 2005–06 to 2007–08 as prices changed little. Cotton is an annual crop and farmers are used to large variations in production between years, but several years of low production can increase debt, reducing the viability of farms and having consequences for regional communities.

Dairy is a major commodity in the Victorian part of the Basin. It experienced a decline of about 78% in water use from 2000–01 to 2007–08, but raw gross value rose. This was due partly to the price of milk almost doubling, but also because water trade allowed dairy farmers to adapt to lower allocations either by buying the additional water they required or selling water and using the proceeds to buy feed instead of growing it. This enabled dairy production to continue, but at higher cost than before the drought.

The rice industry suffered the most in the drought. Rice production and water use in 2007–08 fell to about 1% of their 2000–01 values, leading to the closure of several rice mills.[18] This points to the impact of the drought on communities and processing industries, not just the farmers. Some rice farmers switched to winter cereals, which maintained production throughout the drought. The water use of high value commodities such as fruit, nuts, and vegetables was maintained by purchasing water allocations, but at a high price.

Water trading gave individual irrigators flexibility and was estimated to increase production by $370 million in the southern Basin at the height of the drought.[19] These benefits transfer into benefits for communities, regions, and the Basin as a whole.

The drought is only a partial analogy for future adaptations, though, because it was treated as a temporary change and farm debt was allowed to increase. Some of the future changes to irrigation will be more permanent and thus require more fundamental economic, as well as social, adaptations.

New irrigation developments

With good prospects for irrigated agriculture but declining water use in the Murray–Darling Basin, there will be strong interest in developing other irrigation areas. Irrigation is increasing in Tasmania, where there are plans to develop an additional 120 GL/year from the current 636 GL/year,[20] which is modest in scale compared with the Murray–Darling Basin. It is often speculated that there could be dramatic increases in irrigation, both in northern Australia and basins of the east coast of Australia, but a comprehensive assessment of opportunities and costs is yet to be undertaken. Possibilities include large schemes to dam coastal rivers and transfer water over the divide into the Murray–Darling Basin or other western-flowing rivers. Such schemes may be technically feasible, but are not economic at present[21] (see Chapter 1).

Any new developments will be driven by several factors other than water availability. Often there are other limits such as the availability of flat land with suitable soils for cultivation that will not be subject to salinity, and to which water can be easily supplied. Agriculture requires associated processing industries, transport infrastructure, and markets, all of which need to be economically viable. In the wet–dry tropics, the extremes of the dry and wet seasons suit few crops and encourage many pests and diseases, which have resulted in pioneering schemes failing in the past. Other water users must be considered and a duty-of-care exercised to minimise environmental impacts. Opportunities for new irrigation will be found but, as noted in Chapter 1, they will not be as easy to realise as the maps of abundant runoff (Figures 1.2 and 1.3) might suggest.

Improving irrigation system efficiency

Much attention is being devoted to increasing water use efficiency: producing more product and greater profits from the use of less water. There are two main areas of focus: efficiency in water management and infrastructure; and on-farm efficiency in irrigated agriculture.

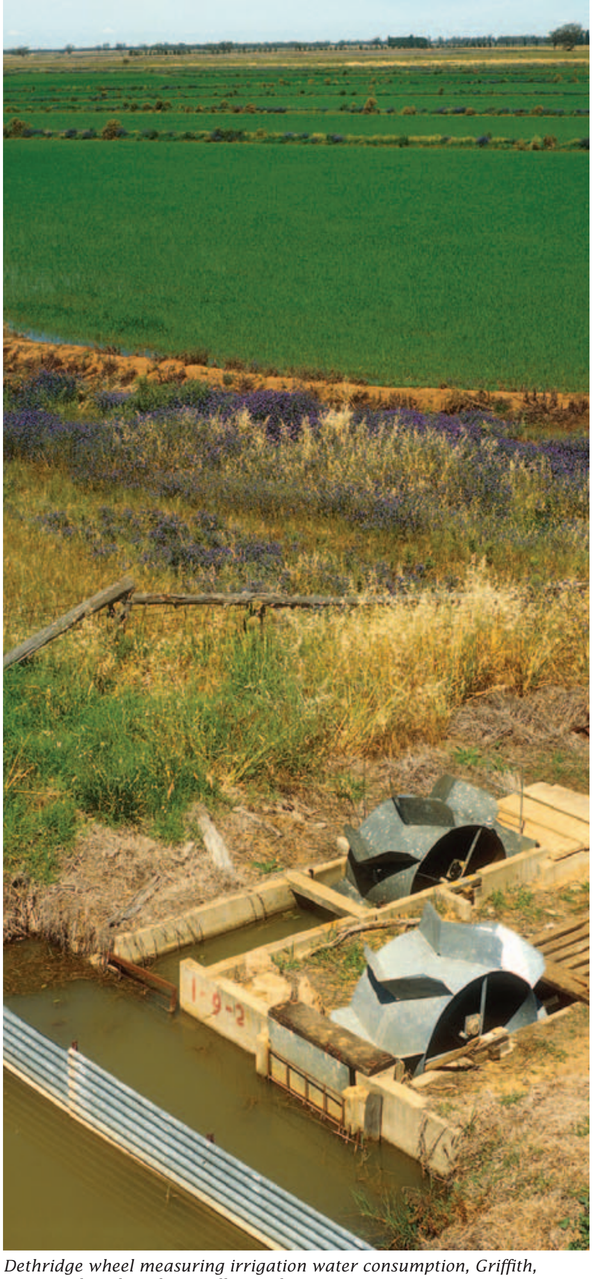
Increasing the efficiency of a water supply can be achieved in part by reducing water losses. Australia's largest irrigation areas have extensive canal systems (Murrumbidgee Irrigation Area about 3500 km,[22] Murray Irrigation area about 3000 km,[23] Goulburn Murray Water area in northern Victoria about 7000 km[24]). Significant volumes of water can be lost from these canals. On-farm and off-farm losses in the Murrumbidgee valley total 300 GL annually.[25] True losses (water that can be captured and better used) need to be distinguished from apparent losses (water, such as groundwater recharge, that is not really lost but is available for use elsewhere). Canal seepage is a true loss if it recharges saline groundwater and becomes unsuitable for use, or is an apparent loss if it recharges a fresh aquifer or drains back to the river and is available for further use. Off-farm losses include leakage, seepage, and evaporation from delivery canals and storages – estimated true losses are 130 GL/year in the Murrumbidgee valley. On-farm losses include evaporation from the soil surface and recharge to saline groundwater – estimated true losses are 100 GL/year. The remaining 70 GL/year of the total 300 GL/year of losses in the Murrumbidgee valley are apparent losses of water draining back to the river and aquifers and are used elsewhere.

Sprinklers irrigating a field of Lucerne near Wagga Wagga, New South Wales. Photo: Bill van Aken, CSIRO.

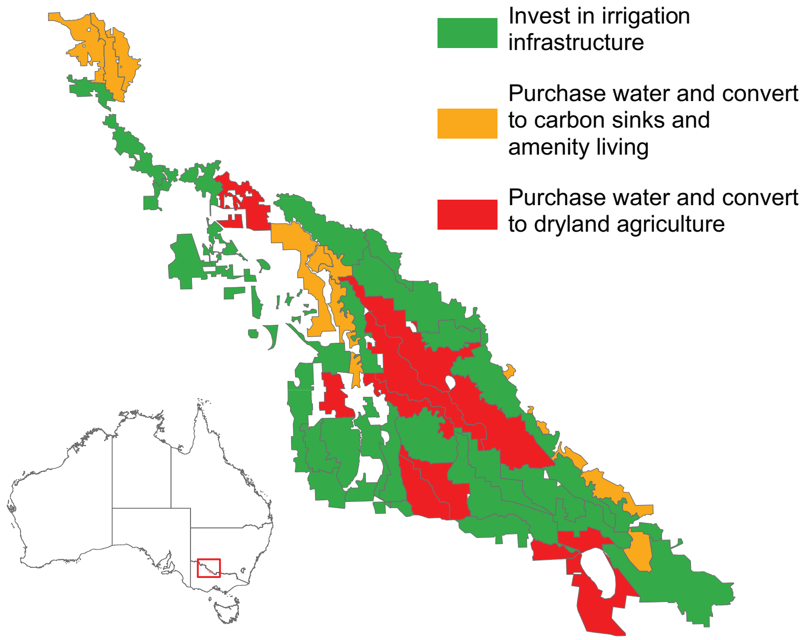
Problems emerge if the gross application of water is accounted for without considering what is normally returned for others to use. For example, installing better irrigation technology to halve the water application rate and double the area of crop may, through the more efficient use of the same volume of water on twice the area, reduce the volume of water that once seeped back to the river or an aquifer. Thus, the returned water, which was once used elsewhere (by the environment or another irrigator) is now no longer available. The same occurs if the gross amount of water applied is traded out of a valley: the removal of the gross amount ignores the return flow. Around 10% of diverted water may return to the river, but this estimate is highly uncertain.[26] The issue of reduced irrigation return flows may become significant as water becomes more tightly managed.

Investment in savings measures require a full cost–benefit analysis. Savings in off-farm losses could be made by piping or lining canals, though piping is unlikely to be economic in many circumstances.[25] Savings of on-farm losses could be made by conversion to pressurised irrigation systems (from furrow or other 'inefficient' systems), treating on-farm channel seepage losses, and reducing evaporation from on-farm channels and storages.

Modernisation of measurement and control structures also improves the efficiency of water infrastructure. Traditionally, Dethridge wheels (simple wheels turned by the flow from a channel) were used to measure water flowing onto farms, but were known to systematically under-measure the amount of water supplied.[26] They are being replaced with more accurate



Dethridge wheel measuring irrigation water consumption, Griffith, New South Wales. Photo: Bill van Aken, CSIRO.



▸ ***Figure 8.3***: *Torrumbarry Irrigation Area showing a classification of zones for investment in the context of declining water used for irrigation. Green locations are a priority to maintain irrigation because they are the most productive land and most efficient for water supply. Amber locations have environmental value, so could be priority areas for ecological restoration. Red areas are priority for conversion to dryland agriculture because they are the least effective for irrigated agriculture and the most expensive for water supply.*

remote-controlled channel management systems. Sophisticated control systems are also being used to better manage flows in the main supply canals and reduce rejection flows caused by the conveyance of more water than is taken by farmers. The excess water, 'rejected' through channel ends, often discharges into wetlands, but at a normally dry time of year.

Restructuring canal layouts can lead to water savings from reduced evaporation. A smaller and more effective canal layout can also keep an irrigation scheme viable under lower allocations or when water is lost in trade. For example, farms in the Torrumbarry Irrigation Area of Victoria were assessed for their relative prospects for irrigation productivity based upon soils and salinity.[27] Water is likely to trade out of Torrumbarry, and it would be beneficial to retire those areas with both low productivity and high cost of water supply to leave the most viable district (Figure 8.3). If the canal infrastructure were to be modernised to the new configuration shown in Figure 8.3, total agricultural production of the area would increase by 9%, even though water use would decline. Water from other areas could be purchased and allocated for environmental flows (62 GL, or 20% of 2004–05 water use). Of the areas identified for retirement, some have value for ecological restoration (amber) and the others could be returned to dryland production (red). Thus, water savings may benefit both irrigation and the environment.

Improving on-farm efficiency

A number of improvements to on-farm efficiency have been beneficial in recent years and could be further developed and adopted to meet future reductions in water availability. They focus on producing more crop from less water, or more profit from the water used, by considering the whole farm enterprise and measures that improve crop quality, not just crop production.

The measures include new crop varieties, the use of deficit irrigation, irrigation flow monitoring, more even watering by laser levelling of fields, better irrigation scheduling, lining of farm channels to reduce seepage losses, and converting irrigation systems from gravity systems to sprinkler or drip irrigation. Savings may be significant, but costly, and are not always profitable.[25,28] Water is typically a small input cost on a farm and some of the measures increase other costs such as energy and capital.

As an example, improvements from new cotton varieties that are more drought tolerant have in some cases doubled water use efficiency from one to two bales of cotton per megalitre. Better soil management, irrigation scheduling, and on-farm design further enable more of the applied water to be used by the crop.

For grapes, the development of new rootstocks, and research around partial root-zone drying and deficit irrigation (applying less water than the crop demands), have lowered water applications by 30–50%. These have reduced yields but improved the quality (colour, tannins, etc.) and raised the price.

For annual crops such as rice, maize and wheat, irrigators can integrate dryland farming techniques into new farming systems to optimise planting and better choose when to irrigate with limited water. Strategies such as retaining crop residues in the Riverina (previously uncommon) and spreading available water further by irrigating winter cereal crops, which require less water than rice, have shown potential to increase whole-of-farm water use efficiency.

The IrriSATSMS system is an example of how new technology and services can improve irrigation water use efficiency. IrriSATSMS combines satellite data on crop development with local weather data and delivers daily information to farmers on crop water requirement via their mobile phones. This approach aims to provide growers with a user-friendly daily irrigation water management service and a benchmarking and auditing mechanism for growers and water providers through the reporting back of the amount of water applied and crop produced.[29]

Climate change may influence crop water use efficiency, as well as threatening water availability in southern Australia. Increases in the atmospheric concentration of CO_2 may promote crop growth and water use efficiency, but this effect is strongly variety dependent. For example, under a projected 2050 climate (higher CO_2, higher temperature and lower rainfall), yield increases of 1–10% could be achieved by changing varieties. Decreases in grain yields of 2.2% were predicted in early maturing varieties. Supplemental irrigation at key times through the growing season may mitigate the impact of climate change, although this requires further investigation.

Monitoring soil moisture in an irrigation district, Griffith, New South Wales. Photo: Greg Heath, CSIRO.

Conclusions

There are thus many prospects for continuing to improve the productivity and profitability of irrigated agriculture, along with prospects for new irrigation developments. These prospects may outweigh some of the threats to irrigation from a drying climate, return of water to the environment, and growing urban water demand, but that will depend on the local circumstances and adaptability of each region. In some areas, irrigated agricultural will grow while it will reduce in others. The challenge is in making those transitions in a way that is cost effective, socially acceptable, and without further negative impacts on the environment. Improved productivity is also needed to meet the increasing demand for food and fibre from growing domestic and global populations.

Further reading

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Water for the environment

Rod Oliver and Ian Webster

Key messages

- Aquatic and water-dependent ecosystems require surface water flows or access to ground water to survive. They include Australia's highly valued rivers, lakes, floodplains, wetlands, and estuaries.
- Regulation of rivers with dams and weirs and the extraction of water from rivers and groundwater threatens the viability of these ecosystems, many of which are now degraded.
- To function properly, these ecosystems and the species in them require not just adequate volumes of water but the right seasonal pattern and variety of conditions.
- Providing water for consumption while providing for ecosystems often involves trade-offs or compromises. A good understanding of the condition of ecosystems under different regimes of water use, can help make these trade-offs transparent and identify ways to reduce them.

Rivers, wetlands, lakes, and estuaries have become degraded from water extraction and the regulation of river flow using dams and weirs. Water-dependent ecosystems have specific water requirements to keep them viable, and Australian governments have committed to deal with the environmentally unsustainable levels of water use – termed over allocation.[1] Water can be provided for the environment by limiting its use and by other regulations built into water plans and the operation of dams and rivers. Alternatively, water entitlements are bought and managed specifically for the purpose of improving environmental outcomes. By reducing levels of extraction, environmental water provision is often in conflict with other uses, most acutely in the heavily used, but highly valued, rivers of the Murray–Darling Basin. Environmental water management is becoming more formalised, with ambitious goals and involving significant trade-offs with other uses, so it is important to understand the water needs of these ecosystems and how they can be met. A key element of this is transparency on the ecological outcomes or targets that will be achieved by returning or keeping specific allocations of water for the environment.

Aquatic and water-dependent ecosystems include rivers, lakes, floodplains, wetlands, and estuaries that depend on surface water flows or ground water to sustain their characteristic biota. As described in Chapter 2, these water ecosystems are of great value to many Australians. They provide important aesthetic, recreational, and cultural benefits that are part of our national identity. Water environments provide valuable services such as good water quality and habitat for plants and wildlife, and they provide direct economic support for tourism and fishing industries. For Indigenous people, water environments have a strong religious value that is intertwined with environmental and livelihood values.

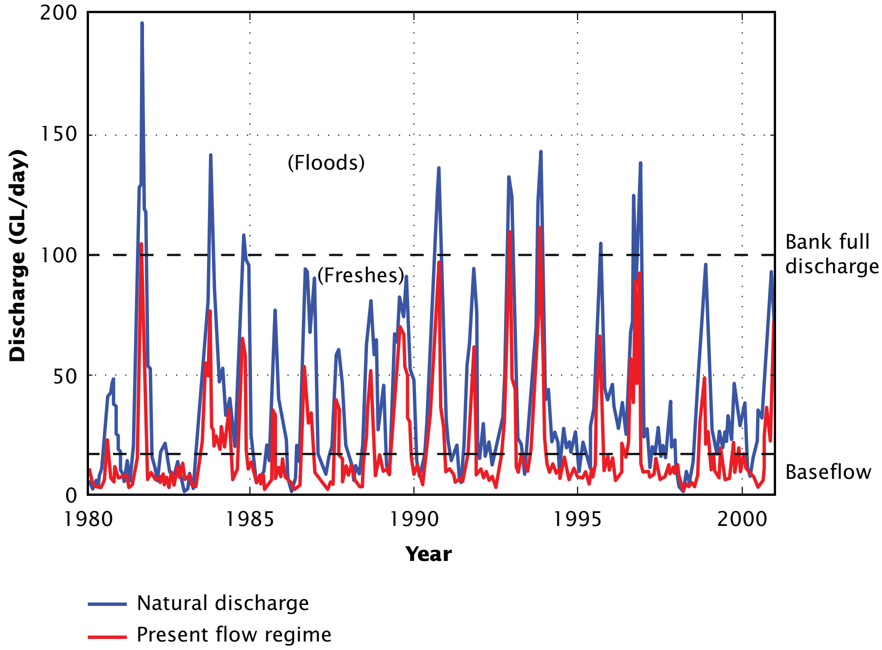
There are several threats to water-dependent ecosystems, including direct habitat destruction to make way for other land uses, decline in water quality, and the proliferation of pest species of water plants and animals (such as carp and cane toads). One of the largest threats is the impact of water use and water resource development on the flow regimes of rivers. Water supply infrastructure – such as dams and weirs – removes water from rivers, and regulates discharge downstream, altering the patterns of floods and seasonal flows that the ecosystems need. Ecosystems naturally survive droughts and floods, but the changes in flow regime resulting from water use and flow regulation artificially extend or intensify the droughts that some ecosystems, such as floodplain ecosystems, experience, putting them under increased stress (Figure 9.1). Even in rivers unregulated by dams, and in groundwater aquifers, high rates of water use can reduce the amount of water available to support ecosystems and threaten the benefits they provide. Levee banks and other structures on floodplains can isolate wetlands and forests from the floodwaters they require.

The challenge in managing water resources for multiple uses is to provide sufficient water to the environment to sustain ecosystems and maintain water quality while ensuring efficient and effective use of extracted water.

The condition of aquatic ecosystems

Despite their high value, water-dependent ecosystems are under threat across the world.[2] Over half of the world's largest river systems are moderately or strongly modified by dam construction, flow regulation, and water use, and half of the world's wetlands have been lost, but unevenly across countries.[3] Freshwater populations of vertebrate species were reduced by half between 1970 and 2005, which is a sharper decline than observed in marine or terrestrial ecosystems.[4]

Australia does not have a comprehensive inventory of the distribution or condition of freshwater ecosystems, despite this deficiency having been previously noted.[5,6] Major loss of habitat has been observed, but the exact loss of ecosystem values and species cannot be determined. It is important for conservation to know the status of the remaining ecosystems. Across the 40% of the continent that is most intensively used, over 85% of the rivers have been



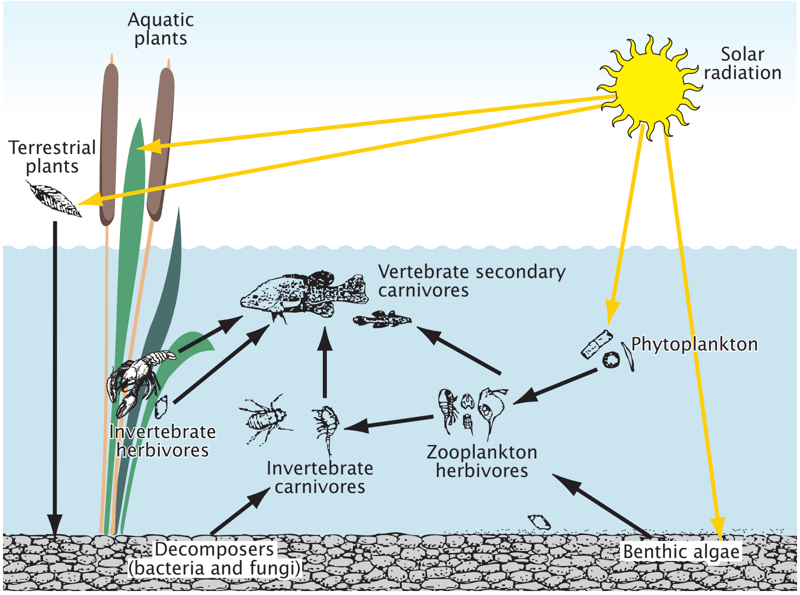
▲ ***Figure 9.1****: Flows in the Murray River at the South Australian border with Victoria illustrating how the present flow regime compares with natural flows. River regulation and extraction of water upstream have reduced the frequency and size of floods that exceed the bank full discharge and spill into wetlands and floodplain forests. For the 21-year period shown, flows would have exceeded bank full discharge and wetted floodplain in eight years under natural conditions but under water regulation the floodplain only received water in three years. Volumes of water spilling to the floodplain were also far less than would have occurred naturally. The longest gap between floodplain watering events in this period would have been six years under natural flows, but it was eleven years under the present regime. The character of base flows has also changed, with the summer season of low flows now being longer and with a lower discharge than under natural conditions because of upstream extractions.*

degraded by human activity to some extent.[7] In the Murray–Darling Basin, 20 of the 23 rivers were rated in 2008 to be in poor or very poor ecological condition.[8] Populations of native fish in the Basin have declined significantly over the past 50 years, with fish communities currently reduced to about 10% of their pre-European levels.[9] Now more than half of the 35 native fish species in the Basin are considered threatened or rare under state, territory, or Commonwealth listings and exotic species make up 56% of the total fish biomass in the lower catchment.[10] Approximately 50% of Australia's wetlands have been lost to other uses, including 90% of floodplain wetlands in the Murray–Darling Basin, 50% of coastal wetlands in New South Wales and 75% of wetlands on the Swan Coastal Plain in the South West of Western Australia[11] and many remaining wetlands are experiencing significant long-term declines in river flows. Associated with the wetland loss is the decline in annual average waterbird numbers across Australia from 1.1 million in 1983 to 0.2 million in 2004.[12] Other important aquatic species, such as many macro-invertebrates and amphibians, have also significantly declined in numbers and distribution.[13]

The flow–ecology link for sustainability

Environmental sustainability requires that populations of plants and animals are self-sustaining. This means providing suitable habitat to ensure that populations can be supported at all stages of their life cycle. Provision of habitat includes food sources for each species, conditions for a species to live, to survive competition with other species, and to breed. Food webs (Figure 9.2) show that species are dependent upon each other through predator and prey relationships. To maintain a viable ecosystems, a relatively stable mix of different types of species is required.

Changes to water flow can change the populations of water plants and algae (primary producers) resulting in complex population changes in higher level organisms that consume them. Higher level predators also exercise top-down control on the unsustainable explosion of populations of lower level organisms, so flows need to be sufficient to cater for all types of organisms in an ecosystem. Natural disturbances, including floods and droughts, help sustain a resilient and diverse community of species where none completely dominate.



◂ ***Figure 9.2****: Example of some of the food sources in an aquatic food web. Benthic algae, phytoplankton, aquatic plants, and terrestrial plants are primary producers that grow using nutrients and sunlight. They are consumed by herbivorous zooplankton and invertebrates, which in turn are consumed by invertebrate carnivores and fish.*

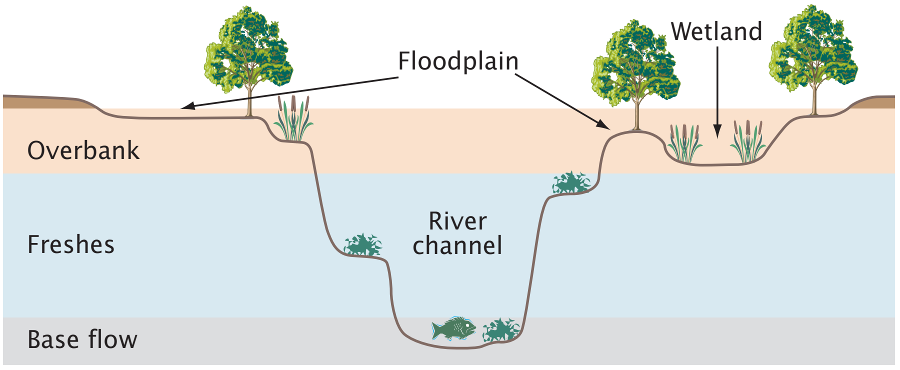
Populations of each plant and animal also need to be large enough and sufficiently dispersed and inter-connected to ensure that localised extinction does not put the whole population at risk. Where populations are isolated, or environmental assets cover a small area, their viability as ecosystems is reduced. The Australian lungfish, part of an ancient group of fish, is only found in the Burnett and Mary Rivers of South East Queensland, for example, and is vulnerable to exposure of breeding habitat as a result of river regulation.

To provide sufficient water for environments, it helps to know how ecosystems of rivers, floodplains, wetlands, and estuaries depend on variations in river flows or discharge of groundwater. The amount of water is important, but so are the patterns of flow, which change with river regulation. Often it is the seasonality of flows, the size of floods, or their duration that triggers organisms to respond or that determines the suitability of habitats. Many Australian waterbirds do not have a seasonal breeding cycle, but are opportunistic, reflecting Australia's unreliable river flows, and only breed when wetlands are inundated for several months.

Water requirements of rivers

Rivers have distinctive flow patterns that create and define a variety of habitats: 'base flows' are slow and steady; 'freshes' are rises of water level with faster currents, but flows are contained within the channel; while flood peaks spread beyond the river banks to recharge floodplains and wetlands and connect them with the river (Figure 9.3). Each flow level supports a diversity of organisms.

▸ ***Figure 9.3****: Different river features are inundated at different levels of flow. Overbank flows inundate floodplains and wetlands, and freshes fill much of the river channel with fast flowing water.*



It is important to maintain base flows in rivers, which could dry out or stagnate from upstream extractions. Some flow is required to keep habitats inundated, to supply nutrients and dissolved oxygen, and to prevent smothering from deposition of fine sediment and algae. Flow is also important to maintain adequate water quality. Freshwater flow from upstream is often required in Australian rivers to dilute salt discharges from groundwater. As explained in Chapter 5, although toxic algal blooms are associated with eutrophication, it is the maintenance of flow in a river that can be used to prevent their occurrence.[14] The construction of weirs to increase the depth of water for pumping reduces the velocity of base flows and removes their benefits. It is the interplay of flow, turbulence, and light penetration that is often critical to river food webs as microalgae are a major source of food.[15]


Burtundy Fishway, Darling River, New South Wales. Photo: Kris Kleeman, © MDBA.

Freshes and floods provide signals for some fish to commence breeding. The connection of habitats along a river is also important because it ensures access to different habitats at each stage of the life cycle and allows cross breeding between populations. One of the main impacts of weirs, dams, and other structures has been to prevent fish passage. Fish ladders can overcome this by bypassing these structures, illustrating that flow management should be complemented with other measures. However, many of Australia's smaller fish are unable to pass through fish ladders.

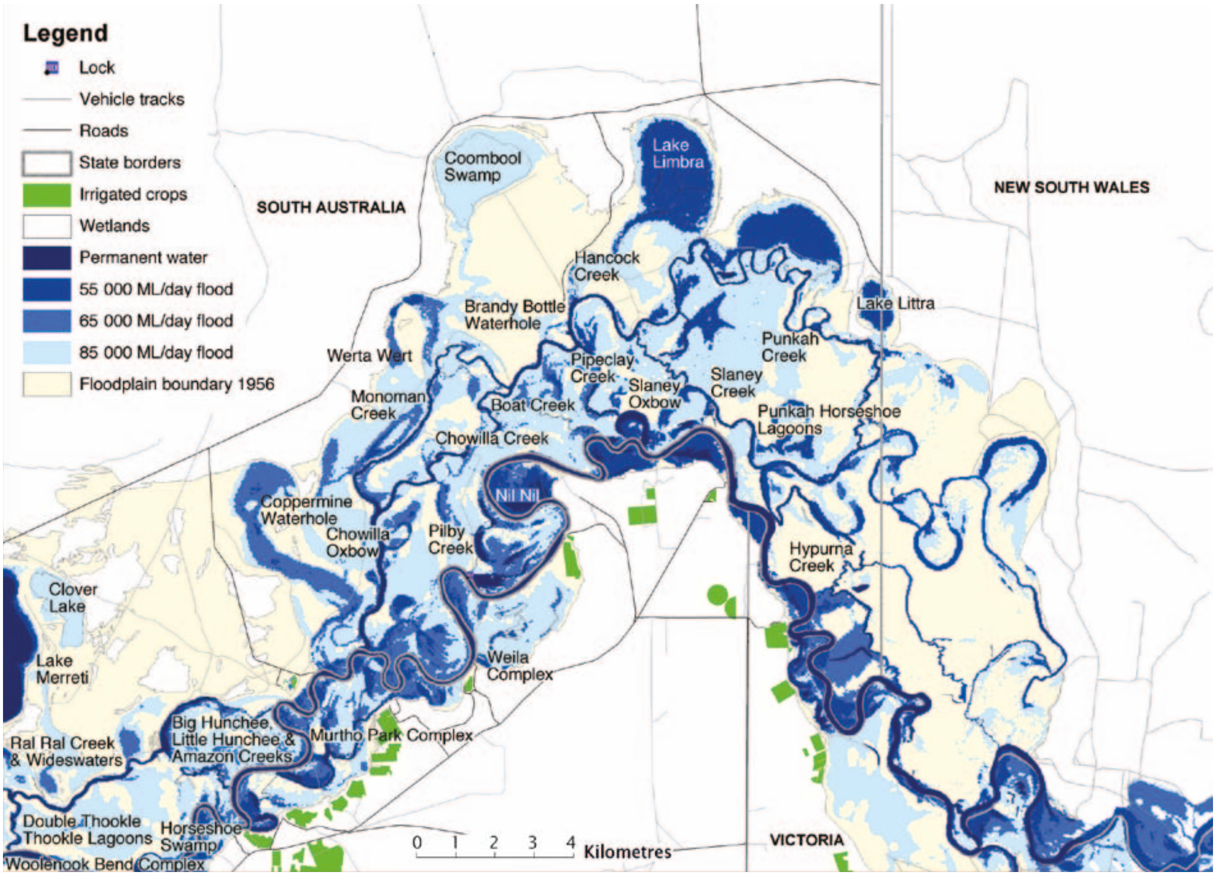
The natural destruction created by floods can renew a river and maintain a diverse range of habitats. High flows are important to shape and clear a river of accumulated sediment, plant matter, and debris. For example, the dam on Lake Jindabyne has been modified in recent years to allow flow to be released down the Snowy River in an effort to reduce the amount of sand that had accumulated over several decades of impounding floods. Floods in the Daly River (Northern Territory) scour out sand from the pools that provide deep, slow-flow habitat for animals and plants that live there during the dry season.

Water requirements of floodplains and wetlands

Floods that overtop river banks inundate floodplains and wetlands, replenishing soils and recharging shallow groundwater aquifers. They provide important connections between the river and floodplain, enabling exchange of sediments, nutrients, algae, fish, and other organisms.

Although floodplains appear flat, subtle variations in topography create habitats of varying frequency and depth of inundation that suit different plants and animals. Only the largest floods inundate the whole floodplain, perhaps once every few decades. At lower elevations, and closer to the river, the floodplain may be inundated perhaps once every year (Figure 9.4). Different species are adapted to different flooding frequencies and depths. In the Murray–Darling Basin, river red gum forests are found where floods occur typically every 1 to 5 years, while other species such as black box tends to occur higher on the floodplain where flooding is less frequent. Trees rely on groundwater between floods but evaporation accumulates salt in the floodplain soils. Periodic flooding is required to both recharge the groundwater supplies and flush salt from the soils. A floodplain ecosystem can be reduced greatly in extent when flow regulation reduces the frequency and area of inundation.

In places, the floodplain can cover tens of thousands of hectares and support vast wetlands, such as the Kakadu wetlands adjacent to the South Alligator River in the Northern Territory. Some wetlands have groundwater connections and remain full with water while these connections persist. Others dry out as floodwaters evaporate. Wetlands often have a channel or 'flood runner' connecting them to the river and to each other so they flood as soon as the river height is sufficient to fill the channel, rather than relying on flooding across the whole floodplain. Wetlands are scattered across floodplains, forming mosaics that inundate consecutively at increasing flow heights and have varying frequency, timing, and duration of connections (e.g. in January 2011,



▲ ***Figure 9.4***: *Extent of flooding on the Chowilla floodplain for different discharges of the Murray River, as determined from remote sensing and river gauging. A 55 000 ML/day flood inundates small areas of wetland near the river while an 85 000 ML/day flood inundates extensive areas of floodplain forest as well.*


Black winged stilt, Werribee, Victoria. Photo: John Manger, CSIRO.

Lake Albacutya at the very downstream end of the Wimmera River filled for the first time since 1974). Wetlands are critical habitats for aquatic plants and insects, waterbirds, frogs, turtles, and fish because they retain water for extended periods. Defining the conditions needed by these species locally, regionally, and nationally is complex but continuing research is increasing our understanding of the ecology of floodplain ecosystems.

Connections between river and floodplain in lowland rivers can last for several weeks and stimulate growth of large populations of algae. Some animals such as zooplankton have dormant stages – they reside in floodplain soils and emerge on re-wetting to take advantage of the food resources. Some of this soup of aquatic organisms mixed with terrestrial plant and animal detritus is carried by return-water back into the river, thereby providing food for organisms in the river. These types of rivers are known as 'flood-pulse' rivers because their ecosystems depend more on periodic flooding than on the supply of material from upstream catchments. The connection between river and floodplain in regulated rivers is frequently reduced, depriving them of food. Measurements in the Murray River during the millennium drought suggest the floodplain provided little food to the river and the food webs relied instead on in-stream production by microalgae, leading to an overall depletion of food resources.[15]

Many waterbirds rely on floods to fill large expanses of wetland making them suitable for breeding with appropriate nesting sites and abundant food resources. Some of the most important breeding areas are large shallow expanses that occur towards the ends of inland rivers (e.g. the Macquarie Marshes on the Macquarie River, the Lowbidgee Floodplain on the Murrumbidgee River, and the Coongie Lakes on Cooper Creek). Such extensive wetlands are sometimes drained or protected from inundation by levee banks to convert them to agricultural land; for example, three quarters of the Lowbidgee wetlands have been lost to agriculture.

Water requirements of estuaries

Estuaries are a transitional habitat between rivers and the sea, where variations in salinity are critical to maintaining diverse habitat. Typically, salinity increases from near zero where a river enters an estuary to that of the sea towards the mouth. Under flood conditions, an estuary might be flushed with freshwater all the way to the mouth, but in periods of no river flow the whole estuary may become saline.

Rivers transport sediment, nutrients, and other materials into estuaries stimulating growth of algae and aquatic plants (primary production) and making estuaries highly productive. Because they can support both freshwater and marine species, they also tend to be zones of high biodiversity, and coastal fish use estuaries as nurseries, especially during high river flows. For example, barramundi and banana prawn recruitment in the Fitzroy River (Queensland) estuary is stimulated by high river flows,[16] probably as a result of increased access to refuges and food on an inundated floodplain and increased availability of organic detritus that is used as food for juveniles.

Reductions in river flows, due to upstream water use, can have detrimental effects on estuaries by changing the salinity and mixing conditions. Most of the fish, invertebrates, and plants living in estuaries have optimal salinity ranges and varying salinity imposes a physiological stress on them. Without river flows to mix the waters in an estuary, they can become stratified leading to depleted oxygen concentrations in bottom waters, killing crustaceans, and fish. Such events have occurred in the Swan Estuary, Perth and the Gippsland Lakes in recent years, associated with reduced river inflows. Significant river flows are also required to periodically scour an estuary mouth, keeping it open to the sea and enabling fish and crustaceans to migrate in, as well as flushing salt and nutrients out. Occasional flushing by floods reinvigorates and renews estuaries, ensuring they continue to support a diversity of species.

Managing environmental water

There is a logical sequence of considerations to ensure that adequate water is provided for the environment through water plans and river operations. The details of how environmental water decisions are made vary from jurisdiction to jurisdiction[17,18] but good, transparent plans involve the following steps:

- Identify the sites or environmental assets that are to be protected or restored.
- Describe the desired range, size, and connection of habitats needed to support the ecosystems and set target conditions for them and the biota that they support.
- Assess the volume of water and the patterns of water delivery that are required to support the different habitats and the diversity of dependent biota.
- Ensure the required water is provided for in water plans and operations under foreseeable conditions of climate, water storage levels, and patterns of water use.
- Balance and optimise provision of water for the environment against other uses and values, modifying target conditions and assets protected accordingly.
- Complement environmental water management with other measures such as structural works, catchment management, and control of invasive species.
- Monitor and evaluate the provision of water to the environment and assess the ecosystem response against the targets from the species level up to the integrated ecosystem to adapt management to unforeseen or uncertain outcomes.

Because of the need to maintain regulation and water use, not all features of the flow can be reproduced at their natural frequency, so it is important to know how ecosystems will respond to each flow characteristic. At times there will be inevitable competing demands between water for human use and that for ecosystems so there will be a trade-off, or compromise, of ecological condition to allow use of water while protecting or restoring some ecosystems or some ecosystem values. Many ecosystems are not in a pristine state as a result of loss of habitat from land use, or species numbers have been reduced by other threats such as water quality and pests, so the outcomes of flow will differ strongly from just requiring a natural flow regime to reproduce the natural state of ecosystems. This makes it important to know the likely ecosystem condition for a range of flow regimes so that the trade-offs between environmental condition and levels of use are shown transparently. One of the criticisms of many water plans is that, although they provide water for the environment, the ecosystem assets or values that are to be protected are not clear, so there is little accountability of whether the environmental flows actually meet ecological needs.[17,18]

To undertake these planning processes requires good ecological understanding of the water needs of ecosystems, but it also requires that understanding to be integrated and applied to the practical considerations of water plans, and there are a range of formal techniques to do that. Better use of those techniques can overcome the problems of lack of transparency in the ecological outcomes of water plans.

First, there are a range of techniques to characterise the important features of flow in undeveloped rivers and to identify the missing features in rivers where water is extracted or regulated so that these can be reproduced.[19] For floodplains and wetlands, the flow levels in the river need to be converted to the extent and duration of inundation of flooding. This can be done using aerial photography or satellite remote sensing[20] (Figure 9.4 is an example). Accurate elevation data from laser altimetry and satellite remote sensing is critical to detect the subtle topographic differences that lead to different communities of plants and animals.

Knowing how flow creates habitats is a critical first step, but those habitat conditions then produce a response in the ecosystem, which is the ultimate aim. Understanding the response should consider not just that of individual species (especially indicator or target species), but also the overall ecosystem through food webs and competition between species as determined from experiments and monitoring of ecosystems.[21] Ecological research is producing increasingly good information about the response of species and ecosystems. Although it has been known for a while that waterbirds require wetlands to be inundated for months for successful breeding, there is now evidence that breeding by some species in the northern Murray–Darling Basin can be triggered by 25–30 days of high flow, shorter than the 50 day threshold used elsewhere. The quicker response could be because food is generated more quickly in the northern Basin.[22]

Individual results need to be extrapolated to the broader situations that occur in nature, through a conceptual understanding of how ecosystems function as a whole (such as the flood-pulse behaviour of lowland floodplains described above). Conceptual models are used to group


The Coorong and mouth of the Murray River. Photo: Michael Bell, © MDBA.

similar classes of organisms and describe the various ecosystem functions that can be related to physical features of flow and water quality to provide a basis for extrapolation.

Numerical models of ecosystems can be built if better information is available. They describe the physical environment of ecosystems and ecosystem responses to a changed environment to reveal their condition under different management scenarios. An early example was the Murray Flows Assessment Tool used to underpin the return of water for the Living Murray Program.[23] The study of the Coorong at the mouth of the Murray River, outlined below, is a recent example. Model predictions can be checked over time against observed changes to an ecosystem. They provide a testable hypothesis on how an ecosystem will respond to environmental flow management. When the actual ecosystem response differs to that hypothesised, experiments can be undertaken to refine the concepts behind the model, lead to better ecosystem understanding, and improve targeting of environmental flows. This is the essence of adaptive management and increasingly ecology is being applied through ecosystem models.

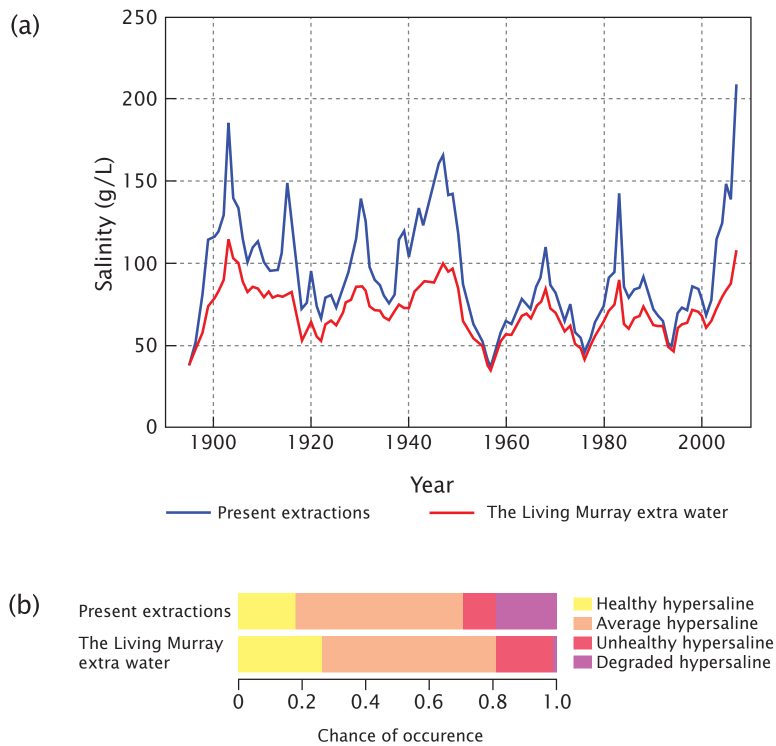
Engineering measures and broader catchment management can be used to enhance the outcomes of environmental water. Regulators, weirs, and embankments are used to direct water to priority ecosystems, reduce losses, and protect ecosystems from water at undesirable times. The Barmah Millewa forest on the Murray River, for example, has a network of regulators to control flow to different parts of the forest. Water can also be pumped and piped to provide critical supplies to a wetland. In 2009, 122 ML/day were pumped into the Hattah Lakes wetlands for a

Figure 9.5: Map of the Coorong and surrounding region.[25] *During moderate to high river flows, water discharges through the barrages near the Murray Mouth and into the Coorong, diluting its salinity. The salinity naturally increases towards the south-east as freshwater gradually evaporates leaving saline water behind. Extended periods of low flow increase salinity throughout the Coorong.*

period of 50 days. This was an emergency measure to provide relief to highly stressed wetlands while long-term solutions were sought. The water supported the regeneration of river red gums and breeding of waterbirds such as Australasian shovelers, hardhead ducks and great egrets, but it did not create the nutrient exchange processes of natural flooding.

The Coorong – applying ecological understanding

The Coorong, at the mouth of the Murray River (Figure 9.5), provides an example of how ecological understanding can be used to design efficient planning of environmental water. The Coorong is valued particularly for the numbers and varieties of waterbirds that nest and feed there. Most of the freshwater input to the Coorong occurs nears it mouth, through the Murray River barrages, so, contrary to most estuaries, salinity increases away from its sea connection, driven by evaporation from the lagoon. Four broad habitat conditions were identified in each of the North and South Lagoons, related to particular water levels and salinity conditions. Each supports distinctive groups of bird, fish, invertebrate and plant species.[24] During the millennium drought there



▸ ***Figure 9.6****: Figure 9.6: (a) Simulated yearly averaged salinity in the South Lagoon of the Coorong for inflows from the Murray River under the present water extraction regime in the Murray-Darling Basin and under enhanced environmental flows provided by the Living Murray initiative. (b) The frequency of occurrence of the four ecosystem states for each simulation, showing that environmental flows are able to almost completely avoid the degraded hypersaline state that would otherwise be experienced 20% of the time.[27]*

was virtually no flow through the barrages, which increased salinity in the South Lagoon of the Coorong to over four times that of sea water and caused the ‘unhealthy’ and ‘degraded hypersaline’ states to dominate there. These are states of reduced diversity of species. In the ‘degraded hypersaline’ state, only one fish and one bird species are common.

A hydrodynamic model of the Coorong was developed to predict salinity and water levels in the lagoon in response to freshwater flows through the barrages.[26] The model assesses the relationship between flow releases in the Murray River and the occurrence of the four ecosystem states in each lagoon. Under present extraction levels in the Murray–Darling Basin and the historical climate, the degraded hypersaline state occurs for 20% of the time in the South Lagoon (Figure 9.6). Providing a minimum flow of 1500 ML/day through the Murray mouth, as the Living Murray scenario portends, reduces the peaks in salinity and avoids the degraded hypersaline state for 99% of the time. It would only take 4% higher discharge on average than the current regime to achieve the 1500 ML/day minimum flow target. This suggests that significant improvement in ecological condition of the Coorong could be achieved with a relatively modest increase in flow, but that flow is needed at the critical times of greatest salt stress.

Environmental water operations

Water for the environment used to be provided by regulating water use through water sharing plans. Operating rules for dams (in regulated rivers) ensured water was released downstream to maintain a base flow, transmit floods of desired timing, duration and peak, or to minimise damage from continuous supply of water downstream for extraction.

These measures are now being complemented by water being provided to the environment through water access entitlements in the same way that irrigation and urban water users have entitlements to use water. An allocation of water is made against these entitlements each year and environmental water managers (like other users) can use those allocations at their discretion to achieve the best outcome – in this case to meet environmental targets. An early example of environmental entitlements was the return of up to 500 GL/year of extracted water to the Living Murray Initiative to provide water to six ecologically significant sites along the Murray River. State governments hold similar entitlements to provide environmental water and the *Water Act 2007* (Commonwealth) established the Commonwealth Environmental Water Holder to manage water to protect and restore the environmental assets of the Murray–Darling Basin. The Australian

Pig nosed turtle, Northern Territory. Photo: John Cann.

Government is purchasing water entitlements from irrigators in the Murray–Darling Basin to be managed by the Commonwealth Environmental Water Holder.

The benefits of actively managing environmental water through entitlements are potentially high, but they pose additional challenges to obtain the best ecological outcomes. Environmental managers will hold well in excess of 1000 GL of entitlement in the Murray–Darling Basin. Although this is a large volume of water, it still falls short of the several thousand gigalitres of water involved in large floods, so environmental allocations will not produce floods purely from dam releases. They are more suited to supplementing or 'piggybacking' on natural floods in rivers to extend the duration or area inundated by the flood in ways that increases their environmental benefit. Alternatively, the water may be used to maintain river flows, or supply to wetlands, in dry periods to provide habitat and prevent poor water quality. Ecological knowledge can be used to match the use of water against the greatest needs at the time.

Annual allocations against the environmental entitlements could be traded to increase the environmental outcomes or to minimise the conflict between consumptive and environmental uses. Demand for consumptive water use is highest in dry years, while some ecological outcomes can best be achieved in wet years, so trading allocations between the two classes of users in wet and dry years may benefit both. These are just a couple of examples of how managing water entitlements for the environment will become quite sophisticated. It is a complex problem of optimising outcomes from a limited resource, where precise ecosystem understanding is fundamental to achieving the best outcomes.

Conclusions

The policies and legislation that provide water for the environment have strengthened in recent years, but implementing those principles in water plans has been slow.[18] In many water plans, there is limited description of ecological conditions, the desired environmental outcomes are often inadequately specified, and they lack detailed monitoring, evaluation, and reporting linked to the environmental outcomes. To develop robust plans for environmental water requires good ecological knowledge, much of which can be applied now, with excellent prospects to link aquatic ecology with environmental management to find better ways to work with nature to restore and protect key environmental assets.

As competition for water use becomes more intense, environmental water management will come under the same pressure as other uses to increase efficiency and maximise outcomes from the water used. The ecological outcomes achieved and their value to society will need to be demonstrated, requiring strong application of ecological knowledge.

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Water in mining and industry

Ian Prosser, Leif Wolf, and Anna Littleboy

Key messages

- Mining, manufacturing, and other industries use about 20% of all water consumed in Australia. They use water in cities and in some fully or over-allocated rural systems, placing them under the same pressures as other users to use water more efficiently.
- Water efficiency improvements have been made by adopting new technologies, more efficient processes, incorporating reuse, and recycling and finding alternative sources of water.
- Mining is a large industrial water use that is growing fast, and uses water in remote areas where it often ‘self-supplies’. It discharges large quantities of water to the environment, requiring risks to water quality to be managed.
- Coal seam gas is an industry set to expand on a massive scale in Queensland and northern New South Wales. It poses several water management challenges, including potential impacts on surrounding aquifers and their water users, and the safe treatment, disposal, or use of the saline water that is extracted.

General industrial water use

Before considering mining water use in detail, it is worth outlining some of the general features of industrial water use, of which mining is part. Manufacturing, mining, food processing, electricity, and gas supply and other industries consumed 2840 GL of water in 2008–09: about 20% of total Australian water consumption for that year.[1] Water is typically a very small fraction of total input costs for industry, and considerable value is created, so industrial uses tend to have very high gross value added per gigalitre consumed compared with agricultural uses. The gross value added from mining is comparable with that from manufacturing industries. Where competition for water is resolved through an open water market, industrial uses should be competitive given that water is a low proportion of input costs and high gross value is produced. The marginal cost of securing additional water for a marginal increase in productivity should be low for industrial users. The critical question, though, is the effectiveness of the water market and whether industrial uses face other impediments to water access, particularly as they require reliable supplies of water (i.e. high-security entitlements).

In some rural areas, industries are located in fully utilised systems (e.g. the Hunter Valley or the Murray–Darling Basin) where there are no new water licences available for industry to expand or where the total licensed extraction is actually being reduced. Industrial water use is often not favoured in these situations and can come under community pressure.[2] Growing industry water needs could be met by purchasing entitlements from the water market but the high-security entitlements that industry requires are a very small proportion of total entitlements and are infrequently traded, limiting the ability of the water market to meet the need. Alternative solutions might be to purchase sufficient lower security entitlements to meet industry needs or to allow industry to transfer lower security entitlements to high-security entitlements at suitable exchange rates.

Many industries use urban water supplies on which restrictions for household use have been placed in recent years, raising expectations that industrial users should also curb consumption. The commercial and industrial sectors use 20 to 30% of total urban water supplies and have become more water efficient in several ways.[3] They have adopted new technologies that use less water, reduced pressure, and flow rates (e.g. lower flow rate washing processes), and they use alternative supplies of non-potable water such as rainwater, groundwater, and stormwater. Some users have developed fully integrated water management by reusing and recycling water as much as possible between uses within the site and minimising any discharge of wastewater to the environment.

The Foster's brewery at Yatala, between Brisbane and the Gold Coast, is an example of an industrial water user that has increased its efficiency through a range of measures.[3] The brewery

Cockburn Sound, Western Australia. Photo: CSIRO.

had been using the measures to reduce water use, supplied by Gold Coast Water, with usage falling from 1010 ML in 2005–06 to 840 ML in 2007–08. It then doubled its brewery capacity with only a 15% increase in water consumption. Water efficiency measures included treating wastewater from the brewery to recover pure water and use it for cleaning, steam, and cooling. The water treatment also reduces salt discharge to the environment by using reverse osmosis as part of the process. Sludge is dewatered to recover further water, and water consumption was reduced by implementing more efficient industrial washing processes.

Increases in water efficiency allow businesses to demonstrate their social responsibility and establish reputations as good corporate citizens. With water prices set to double in some urban areas and industry's requirements for highly reliable supplies, improved water efficiency can be driven by direct financial incentives.

Water in mining

Use of water in the mining industry shares many of the characteristics of other industrial uses but it has some distinctive features that make it worth considering in further detail. The mining sector is a large industrial user that is growing rapidly. Mining includes mineral extraction (including coal), petroleum, gas, and quarrying. Most water is used in arid or semi-arid regions where water is scarce and there are few competing users such as agriculture and towns. The sector can be the largest water user and even a key water supplier. The industry mostly supplies itself with water that is often regulated separately from the water entitlement system or water supply utilities that provide for other users. Much of the water is extracted to dewater mines or is a by-product of extraction and can be acidic and contain toxic amounts of metals or other pollutants. It is often discharged to the environment, with controls placed on its quality, but in arid regions the discharges may be sufficient to detrimentally alter the natural flow regime. Alternatively, extracted water is disposed of in evaporation ponds.

As the world's population grows, migrates towards cities, and improves in standard of living, the demand for Australian minerals and metals will increase. There has been exponential growth in the production of most Australian metals and coal products since the 1950s. By far the highest production level in the sector is for coal, which since 1994 has almost doubled production from 456 Mt/year[4] to approximately 815 Mt/year in 2008.[5] Iron ore also has a very high production rate, having grown from 129 Mt/year in 1944 to approximately 340 Mt/year in 2008.[5] Increasing production has used up most of the higher-grade ores so that the industry is increasingly accessing ores of lower quality, which require greater volumes of water to be used per tonne of metal produced. Both the increasing production and declining ore quality make continuing access to water a critical business imperative for the industry.

Water use by the mining industry has been relatively steady, as reported by the Australian Bureau of Statistics (ABS) water accounts, consuming 592 GL in 1993–1994 and 508 GL in 2008–2009. The ABS figures and some case studies suggest that water use efficiency in mining has improved greatly since 1994,[6] although to account for the exponential growth in production, efficiency would need to have improved dramatically to maintain steady use. It is believed that there is under-reporting of use, because some enterprises do not report all uses, such as water used in tailing dams.[5]

There are strong prospects for further growth in iron ore extraction in coming decades and exponential growth of the burgeoning coal seam gas industry, which is also a major water user. Demand for water by the mining sector is therefore likely to increase, with projections ranging from 810 GL/year to 940 GL/year use by 2020[7] for Western Australia alone.[8]

Water is used by the minerals industry for operational activities that include:[9]

- transport of ore and waste in slurries and suspension
- separation of minerals through chemical processes
- physical separation of material such as in centrifugal separation
- cooling systems around power generation
- suppression of dust, both during mineral processing and around conveyors and roads
- washing equipment
- dewatering of mines.

Drinking-quality water is required to support towns that have developed in remote areas to house mining staff.

Water is favoured in mineral processing because it is a low cost and low energy way of transporting materials between processes – including disposing of, or storing, waste materials. It is a very efficient medium for supplying chemicals and mixing materials and it is an essential ingredient for some chemical processes. It is also the most convenient medium for gravitational and centrifugal separation of minerals from host rocks.

Mines that go beneath the water table are dewatered by pumping, which draws-down the water table in the surrounding landscape. This can reduce the water available to other users and reduce the discharge to streams and other groundwater-dependent ecosystems. The water from dewatering must be discharged safely to rivers, lakes, or storages and may need to be treated to remove acidity or high metal concentrations (see Chapter 5). In 2008–09, the mining sector had a regulated discharge to the environment of 37 GL; over 90% came from the coal industry – mainly from large open cut mines that extend below the water table.[1] Coal is by far the largest user in the mining sector because of the huge mass of product mined.

Water is critical for low production, but high value, products such as gold where water is needed to transport and process very low grade ore. Over 250 ML of water is required to produce a tonne of gold, but the price of gold is so high that it still represents a value added of $80 000 per ML of water used.[10] At the other extreme, petroleum companies use relatively low volumes of water over short periods for drilling and they produce water as a by-product of extraction that needs to be disposed of safely.

Black Flag Lake near Kalgoorlie, Western Australia.
Photo: Bill van Aken, CSIRO.

Mines in arid regions rely heavily on groundwater of variable quality. Possible conflicts in use in these areas are with Indigenous access to water (see Chapter 2) and water-dependent ecosystems. The mining industry provides its own infrastructure to supply water in remote areas, so water provisions tend to be part of the development approval for the mine itself, rather than being a licensed extraction under a water sharing plan. Elsewhere mining occurs in fully utilised systems such as the Hunter Valley, Murray–Darling Basin or parts of the South West of Western Australia where water use can also be part of the development approval outside of water sharing plans, even though there are other water users and water supply utilities. It is not clear whether it is justified to keep mining water use separate from other water use entitlements, but in fully allocated regions this separation may hinder mining companies from participating in water trade.[2]

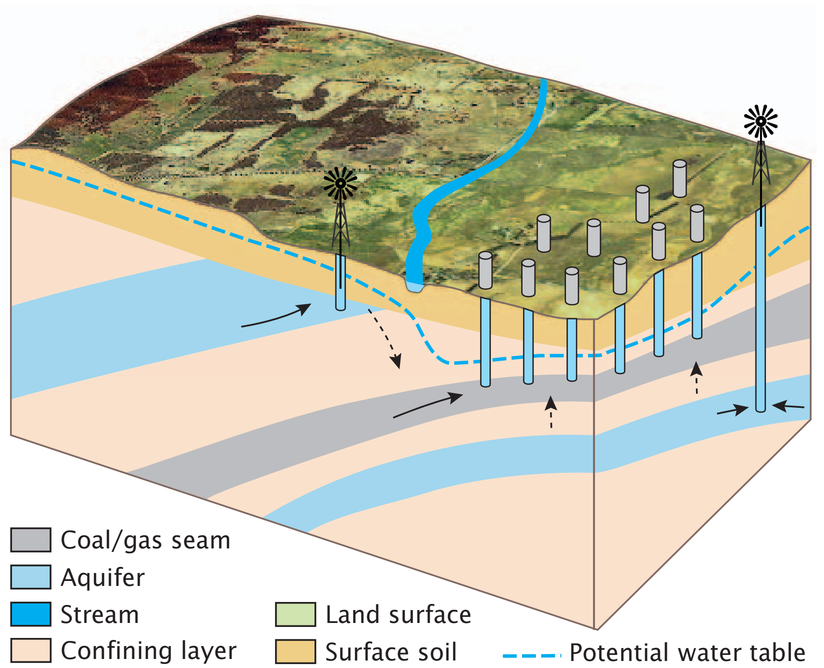
The pressures on water supply for mining foster the same adaptive strategies that industries in general have used to manage water scarcity, including incentives to improve water use efficiency through using more efficient processes and new technologies. Dry or near-dry processing technologies have been applied to several products such as gypsum, phosphate, and uranium. However, they introduce new challenges (e.g. dust generation and dispersal) and are an active area of research.[10,11] The level of reuse and recycling of water is growing, both among processes within a single site, and with other water users (e.g. Newcrest Mining in the Cadia Valley now uses treated town wastewater[12]). The mining industry is often able to use lower quality, alternative sources of water, and some separation processes are more effective using highly saline water.

Mining industry water use was less susceptible to the millennium drought across southern Australia, largely due to the majority being in northern Australia, its greater reliance on groundwater, and the relatively small fraction of the resource that it uses. Dry conditions can actually reduce the amount of mine dewatering, thus reducing costs. Individual mines were affected by the drought and some, such as the Newcrest mine mentioned above, turned to alternative sources. The impacts of climate change are likely to be similar to those of the drought. Mines in southern Australia are likely to experience lower water availability, more severe droughts, and full allocation of water to users. There is less chance of reduced water supply to mining in northern Australia under climate change.

Water and coal seam gas development

New coal seam gas developments in Queensland and New South Wales present major challenges concerning the large volumes of brackish groundwater that will be abstracted from the coal seams as part of the process. These are part of broader public concerns regarding the conflict of mining development with agricultural land use and lifestyle values of the affected regions. Worldwide, a new technology to extract methane from deep lying coal beds has led to unprecedented development in areas previously not viable for economic exploitation. Queensland holds exceptionally large reserves of coal seam gas. The extracted gas will be cooled and compressed

Dump truck and bulldozer moving waste rock at the Ranger Uranium Mine, NT. Photo: Paul Peter.

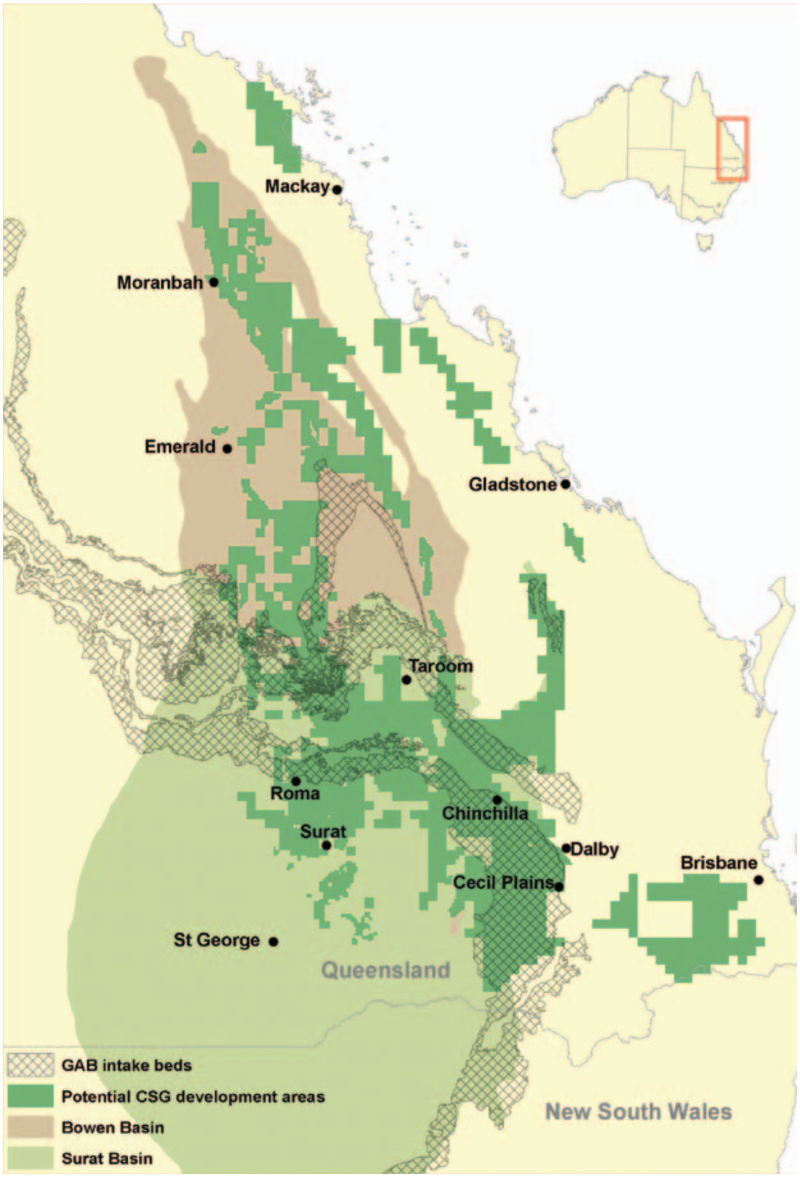


▸ ***Figure 10.1***: *Schematic block diagram of coal seam gas production. Many wells are drilled into the coal beds that hold the gas, extracting water and gas to the surface. Interactions with the hydrology of adjacent and overlying aquifers that are used by others are of potential concern. A network of pipes is used to transport the gas and water to a treatment plant from where gas is piped to the coast, liquefied, and exported.*

to produce liquefied natural gas, which has about 1/600th of the natural gas volume and is well suited for export to China and elsewhere.[13] Seven new liquefied natural gas (LNG) projects have been announced in Queensland. Together, they could provide over 50 Mt/year of LNG for export and production is expected to rapidly expand to 15 times its current size.[14] Proven and probable reserves have grown from 3600 petajoules (PJ) to over 28 000 PJ in the last 5 years, compared with an annual gas consumption of 213 PJ/year in Queensland for 2010.[15] Coal seam gas has been produced from the Bowen Basin since 1997 and production started growing in the Surat Basin in 2005. Exploration is also occurring in other Queensland basins, northern New South Wales, and Western Australia where there are known coal deposits.

The gas is bound to the coal by the pressure of the surrounding water. It is released from the coal by extracting large volumes of water to lower the water pressure. This poses two water management challenges. Firstly, the depressurisation could affect users of water in surrounding aquifers (Figure 10.1) and, secondly, the released water needs to be disposed of safely.

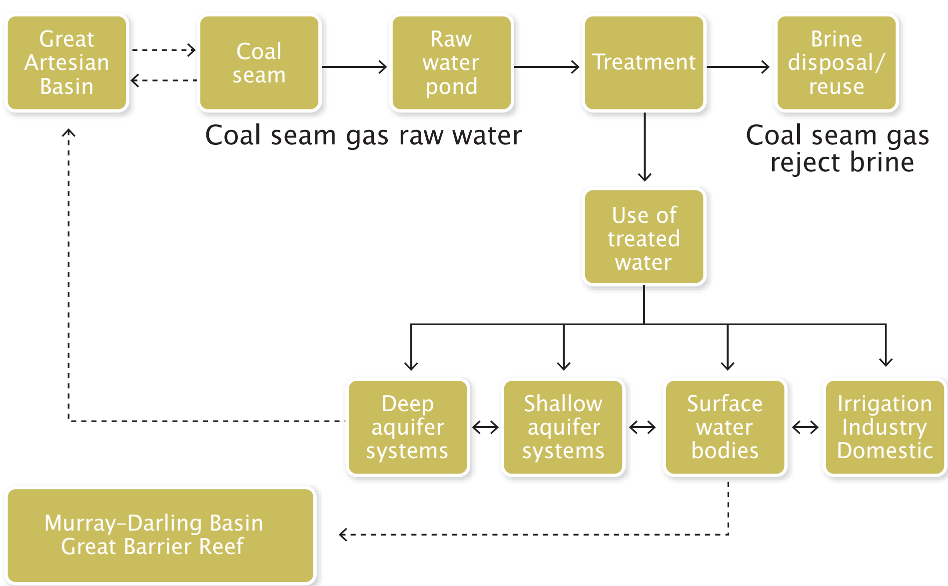
The water in the coal seam aquifers is not used because it is of poor quality, containing salts and some hydrocarbons associated with the coal and gas, but depressurisation could affect the surrounding aquifers that are used (Figure 10.1). In the Queensland developments, there are concerns over possible interactions with usable aquifers in the Great Artesian, Bowen, and Surat Basins (Figure 10.2). Usable aquifers can occur above or below the coal seams and are used for irrigated agriculture, and stock and domestic water. Removing water from the coal seams could induce leakage from the surrounding aquifers. The extent of that leakage will depend upon the amount of water removed, the distance between the aquifers and whether there are intervening



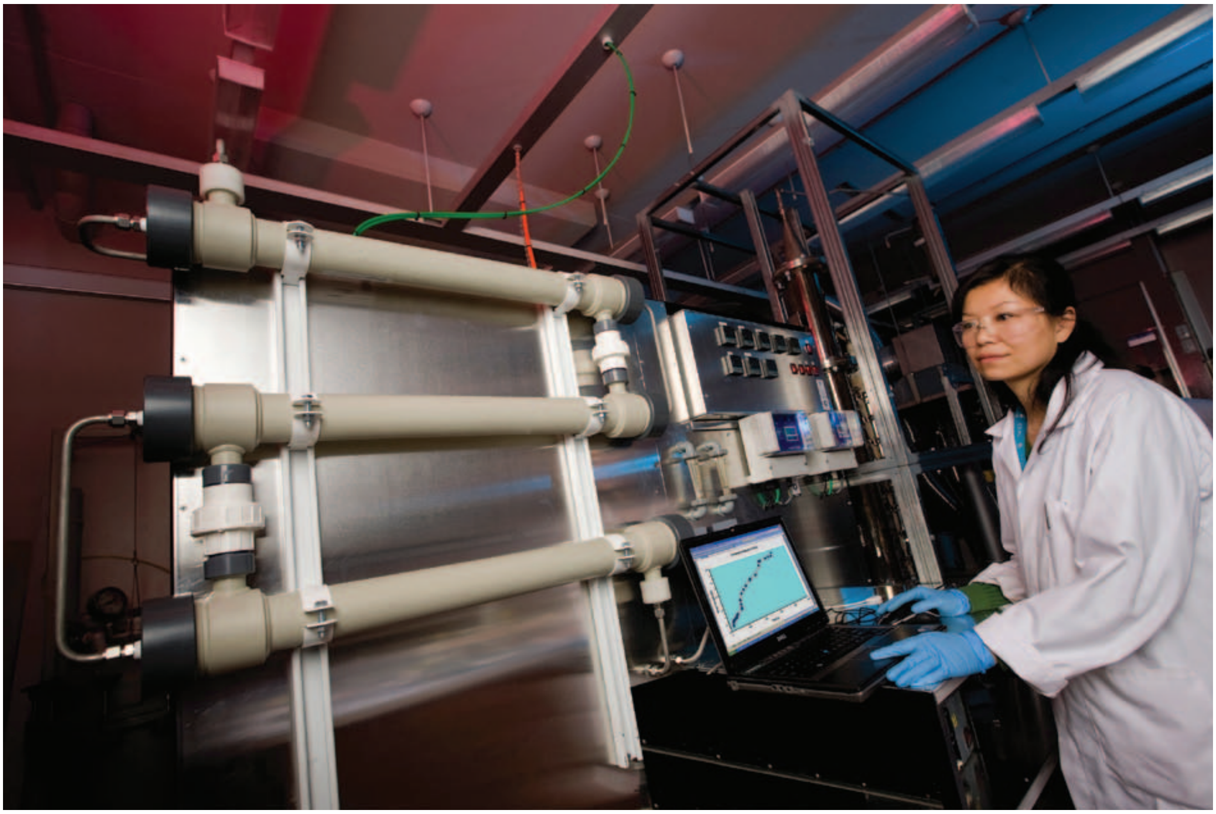
◂ ***Figure 10.2***: *Potential coal seam gas production areas*[16] *in relation to the Surat and Bowen basins and the intake beds of the Great Artesian Basin.*

impermeable layers that prevent leakage. Estimates of water extraction were initially predicted to peak at 261 GL/year for a 40 Mt/year industry (with a range of 227 to 419 GL/year), but have now been reduced to a peak of 160 GL/year and may be reduced further as the process proves to be more efficient than expected.[16] This extraction rate compares with an estimated bore discharge of 500 GL/year in 2001 for the entire Great Artesian Basin – a rate that is leading to reductions in artesian pressure. Extraction of gas and water occurs across many wells in each gas field (Figure 10.1), with prospects for 30 000 to 40 000 wells to depths of up to 1000 m below the ground in the Queensland developments. Wells are often laid out on a grid within a few hundred metres of each other.

For some wells part of the extraction process is to hydraulically fracture the coal beds to increase gas output (a process known as fraccing). Fraccing involves pumping large volumes of fluid into the well under high pressure. This opens fractures in the surrounding coal seam, increases hydraulic conductivity, and in turn leads to higher gas production from the well. Fraccing fluid consists of water, sand, and a small amount (<2%) of additives, used to make the fluid gel-like to better suspend the sand. The sand keeps the fractures open after the injection pressure is removed. Additives used in fraccing can include acids, breakers, cross-linkers, gelling agents, iron control, surfactants, pH control, solvents, and stabilisers.[17] Some of the additives are toxic and the fracturing can extend beyond the coal seam if not executed properly, leading to public concerns over pollution of usable aquifers. Fraccing has been applied in more than one million wells in the United States of America since the 1940s.[18] The United States Environment Protection Authority (EPA) reviewed complaints of drinking water bore contamination believed to be associated with fraccing, but were unable to confirm that fraccing contaminated drinking water bores.[19] A recent study found an increase of methane concentrations in drinking water wells near gas wells, which is of concern, but found no contamination with fraccing fluids.[20] The environmental risk posed by fraccing is reduced by recovery of the fraccing fluid. If the coal seams



▲ ***Figure 10.3***: *Schematic diagram of water flow in coal seam gas production in Queensland. Water is extracted, treated, and used or disposed of in various ways.*



A membrane testing facility for purification of industrial water. Photo: David McClenaghan, CSIRO.

are separated from high water quality aquifers by aquitards this can lower the environmental risk – thus, a comprehensive knowledge of the subsurface hydraulic properties is essential to assess the risks from fraccing.

To resolve the issues of water extraction and fraccing across several development proposals and thousands of wells requires a good characterisation of basin geology and how it controls groundwater pressures, flows, connections, and quality. This will help answer the critical question of how much leakage will occur between the coal seam beds and usable aquifers. The Queensland Government will complete a groundwater model to asses the cumulative impact of coal seam gas on the Surat Basin in 2011. Groundwater models typically use the hydrogeology (drill logs and groundwater levels), hydraulic properties determined from well tests, and other information such as isotope studies of aquifer interactions and ages of water. Industry also uses groundwater models to predict and minimise environmental impacts. However, the modelling of a regional groundwater system the size of the Surat, Bowen, or even the Great Artesian Basin is a major challenge, especially because of the scarcity of groundwater data in this sparsely populated region. The difficulty in the Great Artesian Basin is that groundwater flow velocities are slow, waters are old and any unforeseen consequences of extraction will take decades or centuries to work through the aquifers. The overriding issue is the uncertainty of the potential cumulative, regional impacts of multiple developments.[21]

The extracted water is considered a waste stream of the production process, and is treated, used or disposed of as a regulated waste under the Environmental Protection (Waste Management) Regulation of Queensland (2000) (see Figure 10.3). As with other extractive industries, treatment must be sufficient to ensure that use or disposal has no environmental impacts. The salinity of the water varies from 200 to more than 10 000 mg/L, and it may also contain some hydrocarbons and metals.[22] Using saline water for irrigation can change soil structure or cause salt to accumulate in the soil. Disposal into rivers may lead to increased river salinities or concentration of metals in organisms.

The majority of the extracted water within the last 10 years was directed to evaporation ponds, but this is not expected to continue because of concerns over leakage of saline waters into soils, aquifers, and rivers.[16] A number of reverse osmosis water treatment plants were built subsequently to remove salt and contaminants from the coal seam water. This effectively provides large volumes of high quality water and a waste stream (about 10% of volume) of highly concentrated salt brine. The treated water is suitable for domestic, industrial, or agricultural purposes. Potential uses include coal washing and dust suppression in the mining industry. Treated water could also be reinjected into groundwater aquifers, but always in consideration of the impacts to those aquifers. Large injection trials and modelling exercises are currently underway to prove the feasibility of this option and the high quality of the reverse osmosis treated water would suggest comparatively low risk. Disposal into rivers, however, is not a preferred use because desalinated water could cause 'clean water pollution' – river water has natural concentrations of salts, ions and nutrients required to support life. Rivers in this environment are ephemeral and the ecology adapted to seasonally dry conditions that would be altered by continual discharge of treated water.

The waste stream of concentrated salts (brine waste) following water treatment needs to be disposed of. Typically evaporation dams are used to store brine and further concentrate the salt. The brine stream may receive further treatment to extract the remaining water and produce commercially usable salts, but the process is currently not economically viable.

Overall, the environmentally sound management of coal seam gas water is a major concern for the industry, governments, and affected communities and may delay the development of the resource.[23] Regulations are actively being developed and governments, industry and communities would all benefit from a good knowledge of the risks involved regarding water extraction and disposal, and agreement in advance of appropriate mitigation measures in case the risks eventuate. This requires a good understanding of the behaviour and characteristics of the groundwater systems and how they will change with coal seam gas operations.

Further reading

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Conclusions

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Key messages

- There is a high level of expectation of benefits from water resources across a wide spectrum of economic, social, and environmental values.
- Australia has sufficient water resources to meet its needs, but the locus of use around the major cities and in the Murray–Darling Basin creates problems of regional over-use and the need to find alternative water supplies.
- Demands on water resources are growing – from increased urban populations, increased prospects for irrigated agriculture, and the booming minerals and gas sectors – while, at the same time, society recognises the need to provide water for the environment.
- Climate change poses an additional pressure on water resources but Australia's adaptability to droughts and floods will help the management of further adaptation to climate change for a few decades at least.
- Australia is in a strong position to face its water challenges: having safe and reliable supplies of water, having achieved significant water reforms, and having solid institutions and many opportunities for innovation.

Australia's valued water resources

Australians treasure their water for a range of economic, environmental, social, and cultural values. Water resources are an input into the production of most goods, especially food and fibres. Australians also highly appreciate their rivers, lakes, estuaries, and wetlands because they are associated with a strong sense of place, and they have a desire to protect water resources and environments, both for future generations and for their intrinsic biological value.

Over time, demands on water have grown, not just as the population and economy has grown, but as the broader values of water have been appreciated. As water use has increased, and as water environments became polluted by other uses, water ecosystems started to degrade and there has been a growing awareness of the need to protect water quality and retain sufficient water for the environment. It has also been recognised that some community values for water, such as Indigenous values, have been poorly appreciated or understood.


Adelaide Hills, South Australia. Photo: CSIRO.

Much of the water debate today is about resolving conflicts in values and finding ways to use water more effectively to meet a broader set of aspirations. Science has helped inform this debate: revealing the degradation of ecosystems and consequences of pollution; documenting community values; better evaluating the multiple benefits obtained from water; and providing solutions for more effective uses of water.

Status of Australia's water resources

Australians have always had a strong sense of living in a parched continent, even though that is only partly true. Overall, Australia has sufficient water resources to support its current uses, consuming 6% of renewable water each year – a lower percentage of use than other regions of the world, because, although Australia may be a dry continent, it is also sparsely populated.

Challenges emerge from the very uneven distribution and use of water resources across Australia. River flows are notoriously unreliable from year to year and high rates of potential evaporation create high demand for water for irrigation and gardens, as well leading to large losses of water from dams and rivers.

The population is highly concentrated in coastal cities, which make heavy use of water from surrounding catchments, and irrigation is concentrated in a few valleys of the Murray–Darling Basin where levels of use are considered to be environmentally unsustainable. The unprecedented intensity of the millennium drought showed that these catchments cannot always be relied upon to meet society's needs, at least at current levels of use.

Water resources in other parts of the country are relatively undeveloped, but some of these places are also highly valued for their aquatic ecosystems, or there are other factors, such as land or crop suitability that limit water use. The challenge is to find ways of using these resources in a profitable way without causing expensive and unacceptable environmental damage, and by learning lessons from past over-use of water resources.

The vast, slowly changing stores of groundwater may offer more reliable supplies, but there are the same concerns over sustainable extraction limits – recognising that many wetlands, rivers, and lakes depend on groundwater, especially during the dry season. Over-use can also result in increased salinity that may not be detected for several decades.

The extent of groundwater resources and how much of it can be safely used is poorly understood, as are other parts of the water balance, such as the amount of water going to floodplains and wetlands, and that seeping from irrigation canals. As water resources become more heavily used, it will become important to better understand all parts of the water balance. There are excellent opportunities to do this by combining traditional on-ground measurements with satellite remote sensing, geochemical techniques, and hydrological models.

Future challenges

There will be strong future demands on Australia's water resources, from population growth, growing global and domestic demand for food, and the rapidly growing minerals and gas sectors. Australia's eight largest cities are forecast to require an extra 1150 GL/year by 2050, the equivalent to supplying two new cities the size of Sydney. There are more sustainable ways of providing those supplies than bringing ever more water into cities from ever more distant catchments, only to dispose of much of that water, plus stormwater, into rivers, estuaries, and the sea. The main solutions to date have been to reduce demand and build desalination plants, but there are other potential solutions, including recycling, and capturing and reusing stormwater. These solutions have higher energy requirements than traditional supplies, but there are a good prospects for improving the efficiency and cost of these technologies. Community concerns over recycled water for potable use will also need to be overcome, especially in the context of possible contamination from products such as pharmaceuticals, personal care products, and endocrine disrupting chemicals.

Achieving environmental sustainability of water use is becoming an overarching challenge. Australia's aquatic ecosystems, as well as being of high intrinsic value, support economic uses such as fisheries and tourism and provide ecosystem services such as flood mitigation, water quality, and habitat. These ecosystems require surface water flows or access to groundwater to survive, but it is not just adequate volumes of water they need, it is also the right seasonal pattern, water quality, and variety of conditions. Providing water for consumption while providing for ecosystems often involves trade-offs or compromises. A good understanding of the response of ecosystems to different regimes of water use can help to make these trade-offs clear to all communities and help to identify ways to reduce them.

A major focus at present is rehabilitation of aquatic ecosystems in the Murray–Darling Basin. Research has revealed how changes to flow have impacted these ecosystems and is continuing to reveal the ecosystems' responses that might be expected if flows are returned to the environment. Although the extent of degradation is clear, there is inevitably some uncertainty over how best to achieve the planned outcomes, so, in a way, restoration can be viewed as a major landscape experiment. It requires careful monitoring, evaluation, and adaptive management as plans are implemented and as knowledge improves.

Global population growth and increasing standards of living will increase the demand for food. Irrigation is a profitable and productive form of agriculture, so demand for water for irrigation will grow, but in the Murray–Darling Basin it faces the prospect of reduced water availability as a result of climate change and the increased return of water to the environment. This drives research and innovation to improve the efficiency of irrigated agriculture through more water-efficient crops, improved farm management, precision applications of water, more efficient irrigation supply canals, and river management. Planning how irrigation can adapt to future conditions, informed by a good understanding of how irrigation and ecosystems use and influence water resources, will improve how sustainable use is achieved and reduce the conflict between the aspirations of different communities.

Lake Victoria, New South Wales. Photo: Michael Bell, © MDBA.

The mining industry is a major user of water and it is forecast to grow strongly in arid areas, where water supplies are limited and where there is potential for conflict with Indigenous water values and largely pristine water ecosystems. Coal seam gas, for example, is an emerging industry that can create potential impacts on surrounding aquifers, and requires the safe treatment and disposal of the saline water that is extracted. To be met with confidence, these challenges require a better understanding of deep groundwater aquifers and how they interact with each other. For this industry, water management intersects with other concerns such as threats to rural lifestyles.

Across southern Australia, climate change will intensify the future challenges, with the prospect that it will reduce river flows and recharge, intensify the impacts of droughts, and increase the demand for water. Temperature rises are happening now and there is some evidence that global warming is reducing runoff, but being so variable from year to year, trends in runoff are hard to detect. Runoff into Perth's reservoirs has clearly declined – by 55% since the 1970s – and the millennium drought across south-east Australia was historically unprecedented. By 2030, climate change is likely to reduce river flows by 10– 25% in some regions, with even larger changes by 2050 and 2070 if climate change is not mitigated. Australia's adaptations to highly variable water supplies – through means such as water trade, variable seasonal allocations, augmentation of supplies and water conservation – should be effective for mild reductions in water availability, because these are likely to be felt as more intense droughts. Ever improving skill to forecast water availability for the coming weeks and season is helping with those adaptations. Deeper reductions to water availability, such as those projected for 2070, would require more fundamental change, as the conditions experienced in the millennium drought could become the new average conditions, severely impairing urban water supplies and irrigated agriculture.

It is difficult to translate aspects of the global climate into the local rainfall and runoff patterns that dictate the floods and droughts typical of Australia's hydrology, but the ability to predict the consequences of climate change for water resources is improving all the time. This knowledge can be used in water plans to explore future scenarios, and help take full account of community and environmental costs and benefits of different ways of using water.

Water management is increasingly being integrated with broader societal challenges. Urban water planning is being integrated with overall city planning to improve the liveability and sustainability of cities. Processes to recover energy and nutrients by better wastewater treatment are being developed to reduce greenhouse gas emissions, protect downstream waterways, and provide a source of phosphorus and nitrogen fertilisers. In rural environments, the future of irrigation is intimately related to concerns over global food security, and water management may intersect with the mitigation of greenhouse gas emissions if forest plantations are used to offset carbon emissions. Plantations can reduce runoff and groundwater recharge, but the impacts can be minimised by avoiding the high water-yielding landscapes that supply major reservoirs, or avoiding situations where forests directly access groundwater aquifers that are already in use.


Wastewater treatment and recycling. Photo: CSIRO.

Prospects

Overall, Australia is in a strong position to face its water challenges. Almost all Australians have a reliable supply of very high quality water and safe and reliable treatment of wastewater. By contrast, the United Nations estimates that, globally, 900 million people still lack access to clean water and 2.6 billion people lack adequate sanitation. Although Australia faces significant challenges, it does so from a history of innovation in water management, resulting in part from continued maturing of the institutional arrangements for managing water. Some water resources remain largely unexploited, so Australia has an opportunity to protect its environments during future development, rather than embarking on the more difficult and costly task of restoration. Although some of Australia's aquatic ecosystems are degraded, remnants remain from which rehabilitation can occur.

Although Australia faces major challenges to provide water to meet all its economic, environmental, health, and social needs, it faces those from a position of strength. The challenges are being tackled with a clearer understanding of our water resources, and the strong potential for science and technology to support further innovation and efficiencies. Research successfully solved problems in the past, such as the causes of salinity, or pollution of water by heavy metals, and is answering many of the emerging questions – such as how ecosystems will respond to environmental flows and emerging contaminants, or how water resources will respond to changing climate and increased use of groundwater, or how to recover energy and nutrients from urban water supplies. With innovative water management, there should be little reason to feel that we cannot meet the multiple expectations placed on water resources, while still appreciating that we live in a 'dry country'.

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Index