Chapter 7

Inland Waters

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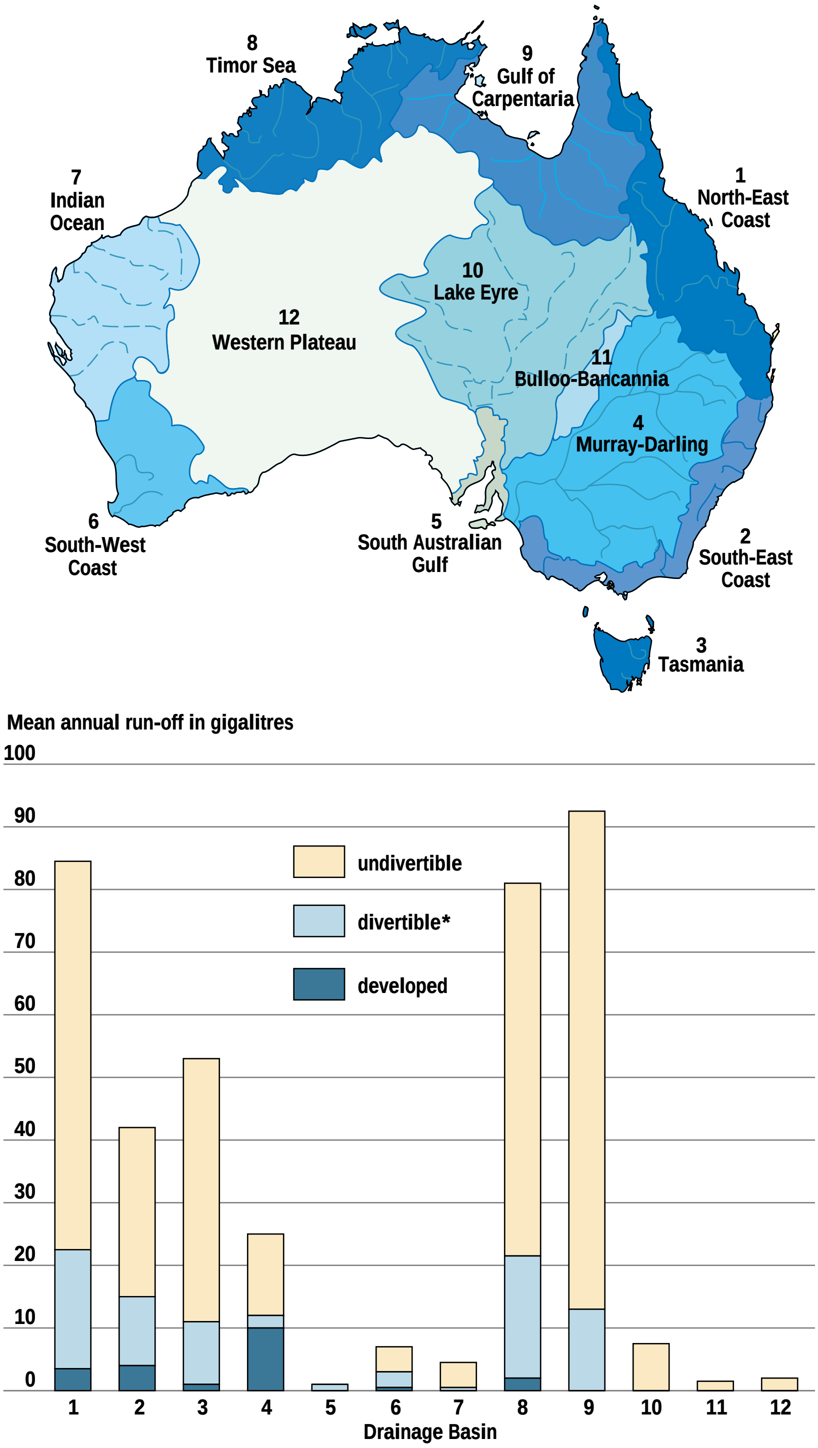
Contents

Figure 7.1 Australia's drainage divisions and surface water resources



*Note: Divertible run-off represents a proportion that could be used without any regard for economic, social or environmental factors. A responsible level of use may well be substantially less than indicated.

Source: AWRC, 1985.

Introduction

Australia is the driest of all the world's inhabited continents. It has the lowest percentage of rainfall as run-off, the lowest amount of run-off, the least amount of water in rivers and the smallest area of permanent wetlands. The Western Plateau drainage division, which covers 32 per cent of the continent (see Fig. 7.1), produces almost no run-off, and a further 17 per cent does not drain to the ocean. Sixty-five per cent of the continent's mean annual run-off occurs in the northern drainage divisions (1, 8 and 9 on the map), and 10 per cent of the divertible fraction (see note under Fig. 7.1) of this tropical water has been developed for human use. Across all the other drainage divisions, 16 per cent of divertible water has been developed, with a regional high of 81 per cent developed in the Murray–Darling Basin. About 15 per cent of all water used in Australia is groundwater (AWRC and DRE, 1983).

Australia has the most variable rainfall and stream flow in the world (see Chapter 2 and Figs 7.3 and 7.4), and our inland streams have high natural turbidity and salinity (McMahon *et al.*, 1992; Williams, 1982). The Murray–Darling river system is Australia's largest, draining about one-seventh of the continent. It ranks with the world's big rivers in terms of length and catchment area, but has much lower annual discharge. The chemistry of our surface inland waters differs from most waters elsewhere, often being dominated by sodium chloride rather than calcium and magnesium bicarbonates (Williams, 1982). Groundwater is often very old; for example, in the Great Artesian Basin water travels across Queensland, to emerge in central Australia in bores one to two million years after it entered the ground (Torgersen *et al.*, 1991).

The generally arid climate and ancient well-weathered landscape mean that mainland Australia has relatively few permanent and freshwater lakes. Lakes on the mainland are often shallow, dry and salty. Only on the Central Plateau of Tasmania do a number of larger permanent fresh-water lakes occur.

Inland waters include all water inland of estuaries, both in surface features like streams, lakes, wetlands and reservoirs, and in the subsurface as groundwater. The biology of Australian inland waters has many special features (Williams, 1982). Although our invertebrate animal groups resemble those of other continents with a similar environment, many species, and some genera and families, are unique to this country. Our aquatic invertebrates lack several groups that are widespread on other continents. Several families here have adapted to a wider range of environments than is the case elsewhere. The fish of Australian inland waters are represented by few species, many of which have evolved from marine forms and are endemic. Fewer bottom-dwelling creatures live in the lakes, and the fauna of our salt lakes are endemic. Half of the large aquatic plants are also unique, as are some terrestrial forms of the distinctive riverbank vegetation.

The distinctive physical, chemical and biological characteristics of Australia's inland waters have to be managed using criteria that are appropriate to Australian systems and conditions. Rivers and lakes in other parts of the world vary less, are generally less turbid and have fauna with different water-quality requirements, and so do not necessarily provide models for our use. The management of inland waters is increasingly being carried out on a catchment basis, to cover land, water and coasts. All types of waters are included in such an approach, which, in principle, can be applied nationwide.

The condition (or state) of our inland waters encompasses both natural characteristics, such as river flow variability, and the effects of human pressures exerted on the environment.

Much of what follows in this chapter is based on catchments, and their surface, subsurface and groundwater components (see Fig. 7.2). Various features of catchments combine to affect both the amount and quality of water that flows across the surface and as groundwater.

Land use affects soil properties and the amount of water infiltrating to groundwater, the rate of run-off and erosion, and hence the amounts of agricultural chemicals, sediment, and phosphorus and other nutrients reaching water bodies.

Topography and climate combine to influence the risk of salinisation after clearing, and the types of water bodies available for aquatic organisms.

Urban centres and industry produce wastes that can pollute waters, sometimes so badly that almost all life disappears.

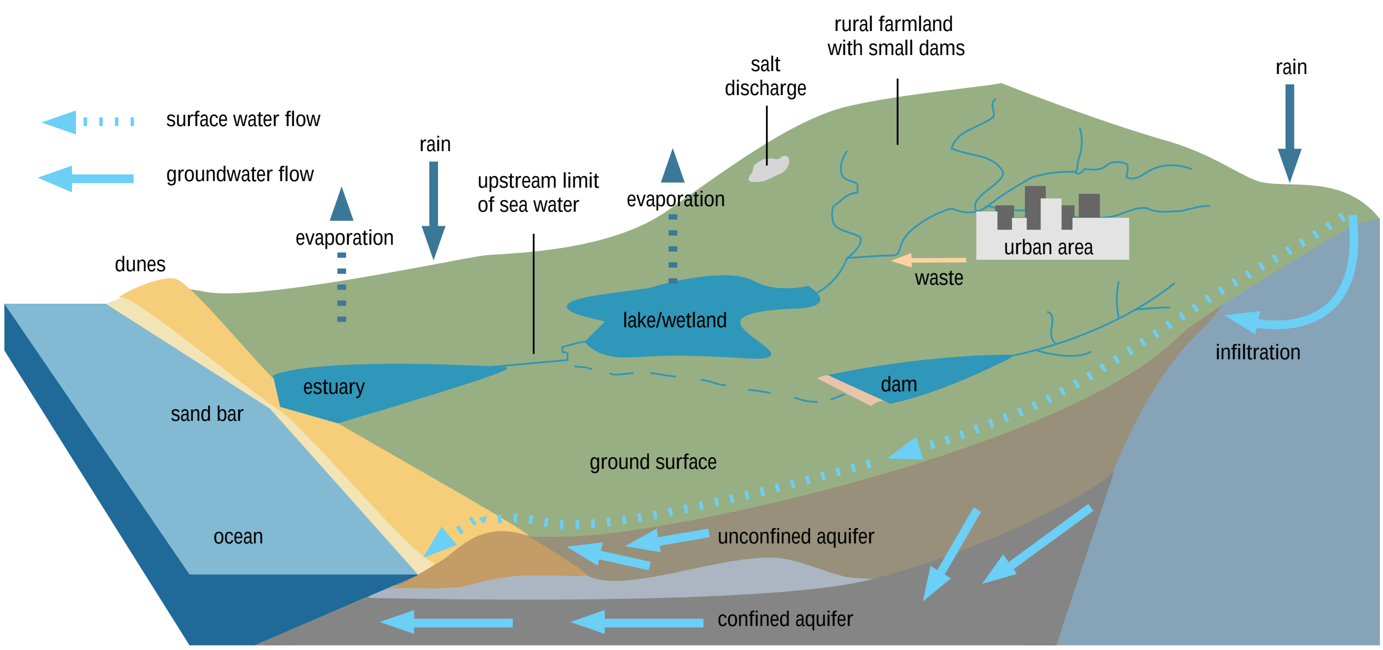
The combined effects of topography, climate and land use can produce major changes to coastal waters, and can cause pollution and sedimentation in estuaries, reducing the productivity of fisheries and the diversity of life (Zann, 1995). Some sources of pollution, like sewage and industrial effluent, can be identified easily and dealt with if sufficient resources are available. Others, such as run-off from farmland, are more diffuse and therefore harder to identify and treat. In some cases land management is not the only answer, and water bodies need to be managed by, for example, altering flows or mixing reservoir waters.

Timely reports on the state of inland waters should help target our efforts to restore damaged environments, and to avoid further problems of the kind reflected increasingly in press headlines. However, such reporting is only likely to be successful nationally if databases are available for future reports. Many of the indicators used in this chapter were chosen for pragmatic reasons, and it is to be hoped that future reports will be able to identify the preferred indicators more systematically.

This chapter is based on four key management issues:

- water resources — the quantity of available water, vital for the human environment with significant impacts on the non-human environment
- catchment pollutant sources — increasingly the focus of management to solve water quality problems
- habitat quality — a focus of conservation strategies and some aspects of water quality control
- water quality — another vital component of the human environment, but with greater impacts on the non-human environment.

Figure 7.2 General relationships between catchments, surface waters, groundwaters and the coast



Pressure

Two main types of pressures affect inland waters. The first are intentional changes from direct human modifications of catchments and attempts to reduce the natural variability of systems. The second are unintentional pressures that have been indirectly caused by human actions, as well as inappropriate human responses to pressures and natural constraints of catchments and climate. Pressures usually occur in groups, producing multiple impacts.

Inland waters originate in catchments. Water moving across the surface of catchments moves soil particles, nutrients and chemicals. Therefore, any problem occurring in one part of the catchment can cause another one downstream. In a similar way, water moving through the soil into groundwater takes chemicals with it. This pollution can emerge elsewhere, causing downstream problems. Therefore, it is impossible to consider inland waters in isolation from land and its use, or from near-shore coastal waters and estuaries. The following discussion on pressures and responses recognises these interdependent links.

Direct pressures and their significance

When Europeans first arrived in Australia, they cleared the land and planted exotic species to provide familiar food, and to make the landscape seem more like home. Their descendents and more recent settlers have followed similar lifestyles and so the effects on water bodies and the land have intensified.

To carry out most land uses in the better-watered temperate parts of Australia, settlers replaced the deep-rooted native vegetation with shallow-rooted pastures and crops. This caused a number of environmental problems that affect inland waters today, including: salinity, waterlogging, sedimentation and turbidity, nutrient enrichment, pesticides, and flooding. In northern Australia, where grazing without clearing is common, the amount of sediment and nutrients transported to waters has increased. Clearing and grazing of areas next to lakes and rivers (the riparian zone) has had particularly severe effects on water bodies and on vegetation.

Rice growing in the Murrumbidgee Irrigation Area: expansion in irrigation has been the major factor contributing to the growth in water use in Australia.

Mining, urbanisation, industrial activity, aquaculture and waste disposal from rural and non-rural industries all pollute waters. The most common pollutants are nutrients, organic matter, metals and pesticides.

Society has tried to accommodate and respond to the variability and seasonality of rainfall by constructing dams to guarantee water supply for themselves, domestic stock and irrigation. But storages affect natural flow, temperature, water chemistry and sediment regimes and replace a flowing water habitat with a still one. The dams themselves stop fish migrating, thus affecting breeding. Flow modification also affects aspects of water quality, like dissolved oxygen levels, and the regeneration and survival of plants.

Other land disturbances, such as urbanisation and agriculture, can greatly increase flow inputs to wetlands, or may result in wetlands being drained. Increasing water use by remote communities — which are now removing more water from inland waters — is also adding to the pressure on the environment.

Lakes, wetlands, rivers and reservoirs are all used for recreational activities, both active (like canoeing and water-skiing) and passive (like bush-walking and picnicking). These activities exert pressures that lead to erosion of river banks, trampling of vegetation and disturbance of habitat and wildlife. Activities in the catchment or the water body may also directly affect water quality in water supply dams.

Indirect pressures

Our use of land and water bodies changes their characteristics and creates indirect or unintentional pressures. These pressures also include inappropriate attempts to correct land- and water-degradation problems.

Removal of native vegetation for agriculture has caused salinisation of land. This process now affects a large area of agriculturally productive land and native bush land in Australia, and will affect more before it stops (see the box on page 7-20). It puts salt into water, with serious impacts on human uses and environmental health. Salinity also occurs in irrigated areas as a result of rising watertables.

Soils are affected by how we use them. In particular, soil structure is destroyed by repeatedly driving large, heavy farm machinery over it, by excessive ploughing and by other land-use practices. This results in compaction and water repellence that reduce both the amount of water penetrating to the root zone of plants and replenishment of groundwater. Repellence can cause or increase sheet erosion, loss of topsoil and gully formation. These processes result in increased amounts of sediment in inland waters.

Soil acidification associated with applying fertilisers to some forms of intensive horticulture and improved pastures can cause acidification of inland waters.

Excess nutrients (especially phosphorus and nitrogen) in water bodies arise from eroded soils, fertiliser, septic tanks, discharges from sewage-treatment plants and animal wastes. In most parts of Australia, phosphorus is bound to soil particles and soil erosion will carry it from paddocks to water bodies. In other catchments, phosphorus can move dissolved in water, especially where soils are poor in clay and iron and cannot bind it.

When phosphorus and nitrogen occur in excess, they can result in algal blooms in rivers and creeks, thereby reducing natural biodiversity and increasing risks to human and animal health from toxins.

Monoculture crops require rigorous pest-management programs that may include more chemical applications than mixed crops. In some cases herbicides and pesticides have been shown to cause more damage to the natural organisms in water bodies (for example, frogs) than to the target organism (WA Department of Environmental Protection, 1995).

Like nutrients, herbicides and pesticides can be moved around the environment attached to sediment particles, in solution, and in the atmosphere; ending up in water bodies.

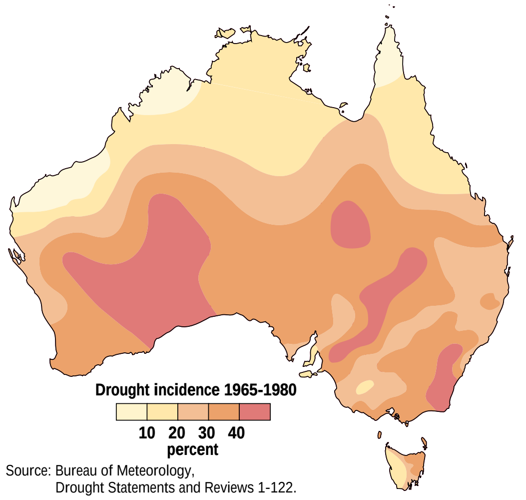
As catchments are cleared, the flood risk increases because water can run off the land more rapidly than when it was covered with vegetation (see the box on page 7-14).

Wetlands are often mined for diatomaceous earth and peat, and rivers for sand and gravel. Other changes include desnagging to remove trees and other obstructions, and river 'improvements' such as straightening.

Our need for water — for ourselves, for stock and for irrigation, particularly during drought (see Fig. 7.3) — drives the demand to manage water supply. Most large water storages do not fill in a single season and so the storage represents several years of stream flow. In river systems it is very easy to get into a situation where too much stored water has been promised (that is, allocated) to users, based on expectations of rainfall and river flows that may not eventuate. Rivers are prevented from flowing at the appropriate times for their biota to thrive, and reproductive cycles can be seriously affected.

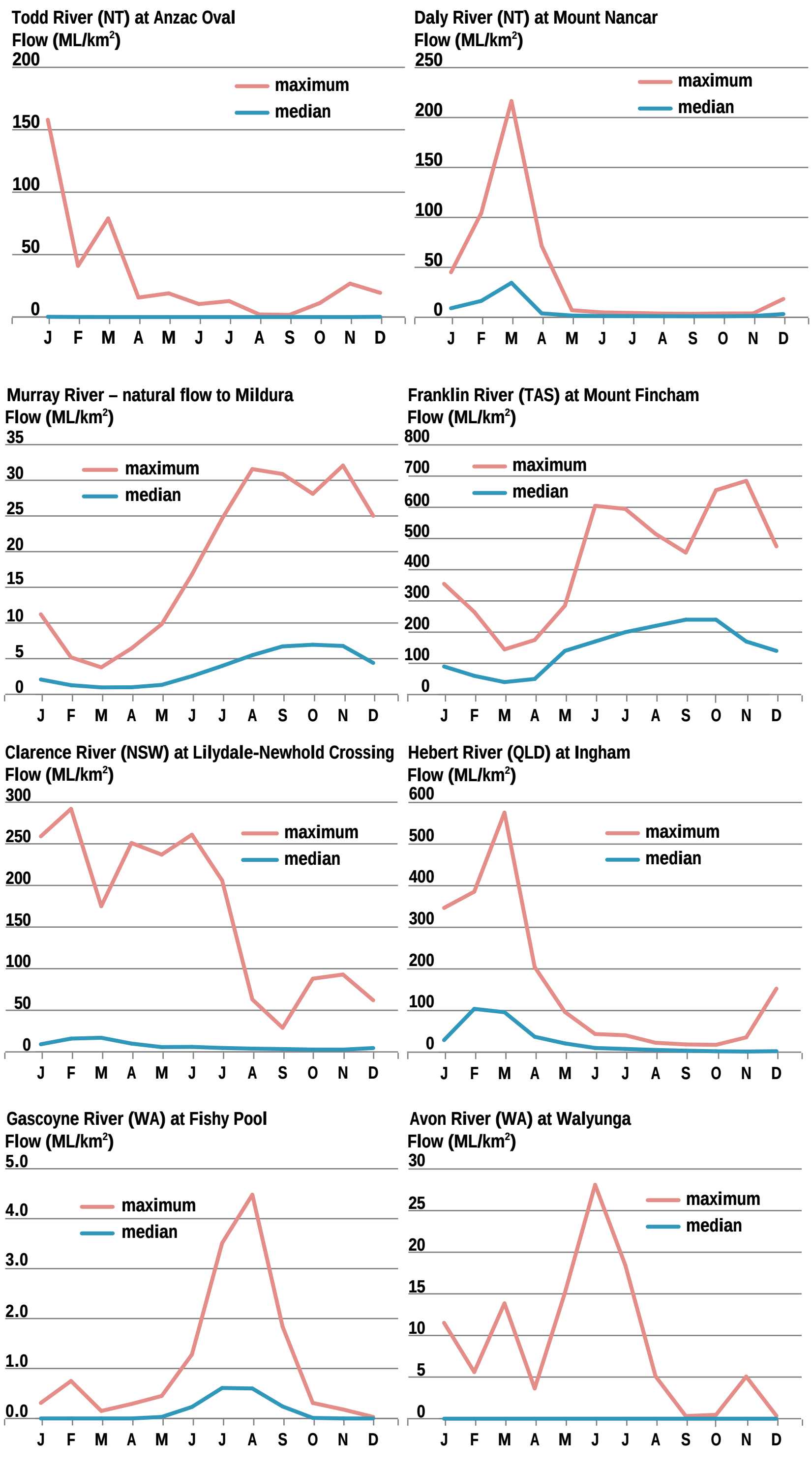
Invasions by introduced animals and plants are causing major problems in Australian waters. Some of the worst include: weed infestation by water hyacinth in lakes, choking of irrigation drains by weeds, spread of woody shrubs across floodplains in tropical Australia and increased turbidity caused by European carp (*Cyprinus carpio*).

Figure 7.3 The incidence of drought 1965–80



Source: Bureau of Meteorology, Drought Statements and Reviews 1-122.

Figure 7.4 Monthly flows for selected rivers illustrating seasonal variability across the continent



Source: MDBC, NT POWA, QDPI, pers. comm.

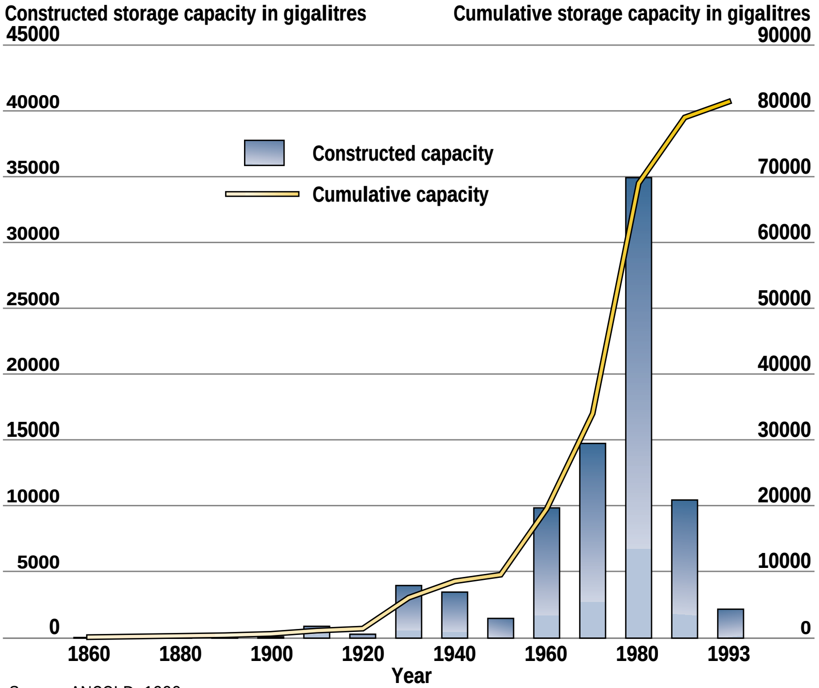
State

Water resources

The nature of surface water varies considerably through time and across the continent (see Fig. 7.4). Australia's environments range from the wet tropics in the north to cool temperate in the south, with the vast proportion of the inland being arid. Surface water resources are distributed extremely unevenly between Australia's 12 drainage divisions (see Fig. 7.1). Only half these divisions produce a significant level of useable run-off. The Murray–Darling Basin is now facing major environmental problems because of overdevelopment of its water resources.

Groundwater occurs almost everywhere, but is highly variable in quality and useful quantities cannot always be obtained. In large tracts of inland Australia, it is often the only practical source of water supply for the economically important pastoral and mining industries and their associated communities. The Great Artesian Basin ranks among the largest groundwater systems in the world and is of critical importance over a large area of eastern Australia. Where good-quality groundwater is readily available, it is also used extensively in coastal communities. In the Perth region, it constitutes about two-thirds of total water use and about 30 per cent of the water supplied by the Western Australian Water Corporation. Districts such as Bundaberg, Mackay and Ayr–Home Hill along the Queensland coast use large quantities of groundwater for both urban and irrigation purposes. It provides domestic water supplies for over one million Australians in about 600 communities (AWRC, 1992). Of the 15 million megalitres (ML) of groundwater estimated to be available annually for extraction in Australia, about 15 per cent is developed for human use.

Figure 7.5 Growth in capacity of major storage reservoirs



Source: ANCOLD, 1990.

Development and state of the resource

After World War II, in an attempt to ensure a reliable water supply for domestic and irrigation purposes, and to drought-proof Australia, a massive nationwide program of dam-building took place (see Fig. 7.5). Australia has the highest per capita water storage of all countries, because we have the world's most variable rainfall. Sydney stores 932 kilolitres (kL) of drinking water for every inhabitant, compared with 250 for New York, 182 for London and 86 for Birmingham. For irrigation water, New South Wales stores 1580 ML per sq km of irrigated land, compared with 760 for the United States, 380 for Egypt and 150 for India (NSW DWR, 1994). Australia's storage capacity in major reservoirs totals some 81 000 gigalitres (GL), or 3.7 times the developed resource. This is equivalent to three Olympic swimming pools for every one of the country's 17.8 million people.

The bulk of our water storage is concentrated in a few very large reservoirs. Australia's 10 largest storages hold about 50 per cent of national capacity. In New South Wales, the 10 largest storages contain 90 per cent of that State's storage volume (NSW SOE, 1993). Most of these large water bodies are concentrated in the south-east of the continent along the Great Dividing Range, and in Tasmania. This reflects availability of run-off, topography suitable for dam construction, and population distribution. The one striking exception is Australia's second-largest storage, Lake Argyle in the north-west of Western Australia. Hundreds of small storages scattered across the rural landscape are also important for water supply and irrigation.

Changes in some farm practices, such as the move to smaller paddocks for better and more efficient management of livestock, have resulted in large increases in the numbers of farm dams (Banens, 1981). For example, in a 10-sq-km catchment in the Yass valley of New South Wales the number of farm dams increased from six in 1959 to 780 in 1985 (Srikanthan and Neil, 1989). Victoria alone is estimated to have some 300 000 small farm dams (VSOE, 1988). With such numbers, although farm dams are individually small, significant reductions

Near Colac, western Victoria. Farm dams reduce stream flow but they can become important microhabitats for flora and fauna.

in stream flow can occur, particularly under dry conditions. In the Lal Lal Reservoir catchment in Victoria, for example, farm dams reduce average annual stream flow by seven per cent, increasing to a 50 per cent reduction in drought years (VSOE, 1988). This has implications for large and local-scale water resource planning and management, as well as for the environment. On the other hand, farm dams frequently represent the only near-permanent water in the landscape and therefore can become important microhabitats for fauna and flora.

In most rural areas and for some rural communities, rainwater tanks are used extensively and often represent the sole source of drinkable water. However, in most cities and many rural towns, regulations and disincentives have prevented their wider use. Adelaide is the only major city where rainwater tanks are used extensively, and in this case the spur has been partly the poor quality of the reticulated supply. Augmentation of community water supplies by rainwater tanks can be both cheaper and more effective than building additional large storages (Gippel and Perrens, in prep.).

The development of groundwater reserves is far from uniform. Many groundwater provinces were not being used at the time of the last summary of the resource in 1983–84, while others were being tapped of their entire divertible resource. 'Mining' of old groundwater is undoubtedly occurring, although we have no reliable up-to-date database for all groundwater basins to show the amount of groundwater abstraction compared with its recharge. The Great Artesian Basin has lost an excessive amount of water as a result of the large number of bores left flowing. Groundwater pressures have declined and some bores have stopped flowing altogether. Bores are now being capped to conserve the resource, but it will take several decades to complete the work.

Irrigated pasture — lower Murray

In 1983, the Department of Resources and Energy listed some of the important groundwater systems under stress (see Table 7.1). Four of these systems are in Queensland which uses a far larger proportion of groundwater for irrigation than the other States. Since then, a surface-water scheme has been built at Bundaberg, thus providing an alternative source, while in the Burdekin delta additional artificial recharge works have reduced the stress on that aquifer.

Aquifers are also affected by increases in recharge from clearing of forests and introduction of irrigated agriculture. These land use changes result in waterlogging and increases in salinity.

Table 7.1 Groundwater systems under stress

System	Aquifer type	Main use	Abstraction (GL/year)	Natural recharge (GL/year)	Induced recharge (GL/year)	Present management	Future strategy
Burdekin Delta, Queensland	surficial	irrigation	263	200	53	extraction limits; recharge to avoid salt water intrusion	further recharge planned and under construction to provide extra 50 GL
Namoi Valley, NSW	surficial and sedimentary basin	irrigation	160	110	0	restricted numbers of bores in part of area	conjunctive use; increased numbers of bores in other areas
Bundaberg, Queensland	surficial	irrigation	100	-	0	replacement of groundwater use by surface water	surface water scheme under construction
Condamine Valley, Queensland	surficial	irrigation	87	13	0	restricted numbers of bores since 1970; metering	surface water scheme planned to partly replace groundwater
Lockyer Valley, Queensland	surficial	irrigation	47	25	1	recharge weirs; control on groundwater use in one area	additional offstream storage (10 million GL) and recharge weirs (5 million GL); restricted numbers of bores

Source: DRE, 1983.

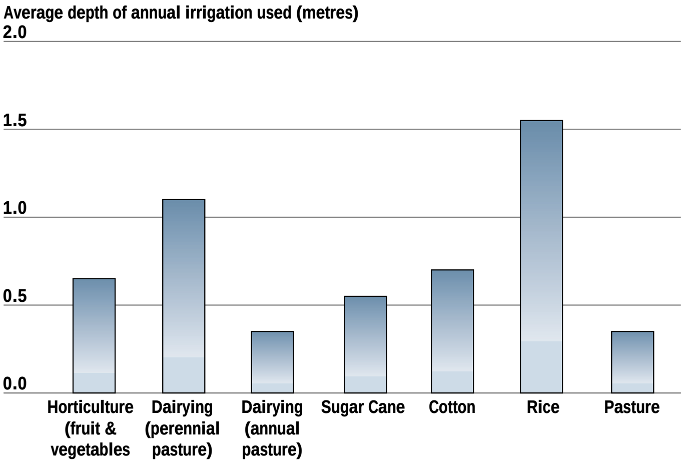
Table 7.2 Area (ha) of irrigated agriculture by major commodity group and State, 1993–94

Commodity	New South Wales	Victoria	Queensland	South Australia	Western Australia	Tasmania	Total Australia
Pastures (incl. dairy)	635 000	555 600	70 000	53 000	14 000	33 000	1 360 000
Cereal crops (non rice)	284 000	23 000	45 000	7 000	1 000	2 000	363 000
Rice	125 000	-	-	-	-	-	125 000
Vegetables	17 000	20 000	27 000	9 000	6 000	17 000	96 000
Fruit	22 000	18 000	25 000	16 000	5 000	3 000	90 000
Grapes	11 000	16 000	– [a]	24 000	2 000	– [a]	53 000
Other crops	176 000	13 000	73 000	4 000	3 000	6 000	275 000
Sugar cane	(<1 000)	-	81 000[b]	-	-	-	81 000
Cotton	189 000[c]	-	48 000	-	-	-	236 000
Total	**1 459 000**	**645 600**	**369 000**	**113 000**	**31 000**	**61 000**	**2 679 000**

Notes: (a) grapes included with fruit; (b) Queensland irrigated sugar cane represents 48% of total cane area; (c) NSW irrigated cotton estimated as 90 percent of total cotton

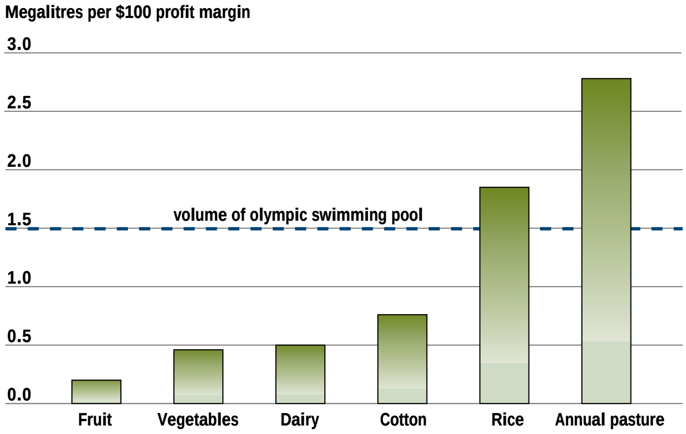
Source: ABS, Australian Irrigation Council, Cotton Growers Association, pers. comm.

Figure 7.6 Relative water use by key irrigation commodities



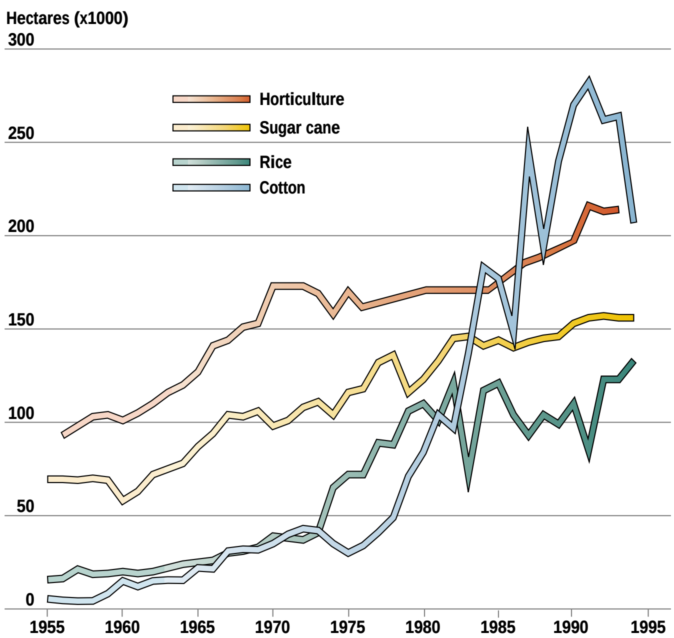
Source: R. Banens, MDBC.

Figure 7.7 Relative profitability of commodities using irrigation



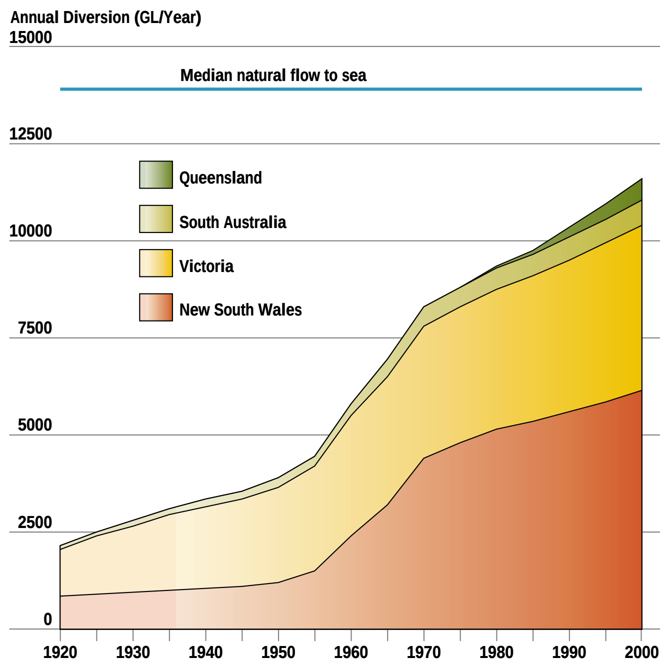
Source: adapted from Hall *et al.*, 1994.

Figure 7.8 Growth in area of irrigated crops in Australia



Source: R. Banens, MDBC.

Figure 7.9 Growth in water use in Murray–Darling Basin



Source: MDBMC, 1995.

The irrigation industry

Of all the developed water in Australia, 70 per cent (15 000 GL) is used in irrigation. This compares with 21 per cent for urban and industrial use, and nine per cent for rural water supply. Expansion in irrigation has been the major factor contributing to the growth in water use in Australia, with consequent pressures on the resource and environment. This growth was particularly evident prior to the early 1970s, with development of the rice and horticulture industries along the Murray and Murrumbidgee rivers, and during the 1980s and 1990s with major expansion of the cotton industry in the Darling River system. About half the irrigated area in Australia is used for pasture (including dairying). This ranges from 14 per cent in Queensland to as high as 85 per cent in Victoria. Two other industries that use a lot of land and water are irrigated cereal crops (including rice) and cotton (see Table 7.2). Water use per hectare and profit margin per ML of water vary significantly between commodities (see Figs 7.6 and 7.7). These factors, coupled with total water use, value of produce and export earnings provide a different perspective on the relative importance of various irrigation commodities (see Table 7.3). Irrigated agriculture makes a large contribution to the Australian economy, with crops such as cotton, rice, wine, sugar and dairy/livestock contributing to a multibillion-dollar export industry.

The area under irrigation is continuing to expand, particularly in New South Wales and Queensland. At the same time, the irrigation industry is undergoing structural reform associated with changes in water marketing and pricing. This has resulted in a shift away from low-value activities such as mixed farming towards high-value crops such as cotton and horticulture (see Fig. 7.8). The development of the cotton industry in the Darling River system has been particularly spectacular, and can be compared with earlier developments in the rice and horticulture industries.

Irrigation in the Murray–Darling Basin is nearly at the limit of the water resource (see Fig. 7.9), indicating that future expansion of irrigated agriculture will be largely through productivity increases and industry restructuring.

Domestic water use

After irrigation, the next highest consumption of water occurs in large urban areas. Although urban use includes industrial and commercial activities, domestic water use is by far the largest component. Domestic consumption has increased significantly over the past 40 years as a consequence of increasing population and rising per capita use. However it varies significantly across the major cities with rainfall, number of rain days, mean temperatures and humidity, availability of water, pricing and education. Annual consumption figures for the

Table 7.3 State of irrigation in Australia

Commodity	Production value ($ million)[a]	Irrigation export value ($ million)[b]	Irrigated area (ha)	Total water use (GL)[c]	Environmental impacts[d]
Horticulture	2600 (Fruit 1490 Vegetables 1110)	496 (wine 247)	214 000	1400 (@ 6.5ML/ha)	slight to moderate impact: localised impact of pesticides, sub-surface saline drainage water
Dairy products	1040	476	280 000	2500 (75% perennial pasture @ 11ML/ha. 25% annual pasture @ 3.5 ML/ha)	moderate impact: regional, localised and downstream impacts of nutrients and organic matter generally as point sources, regional impact on rising water tables and downstream impact of saline drainage
Sugar cane	367	447	183 000	1007 (@ 5.5ML/ha)	moderate impact: localised downstream impact of soil loss and phosphorus, as well as nitrate leaching into estuarine and inshore marine waters, regional impacts of rising water tables and salinisation
Cotton	565	603	264 000	1800 (@ 7ML/ha)	moderate to significant impact: regional and downstream impact of pesticides, large-scale water use in an area of limited water availability and reliability, potential for nitrate leaching to groundwater
Rice	164	228	123 000	1900 (@ 15.5ML/ha)	significant impact: regional impact on rising water tables, salinity, and pesticide and herbicide use, potential for soil acidification in some regions
Irrigated pasture	144 (livestock production)	?	850 000	3000 (@ 3.5ML/ha annual pastures)	significant to severe impact: large scale regional impact on rising water tables and salinisation, and downstream impact of saline drainage

Note: (a) 1992–93 value at farm gate; (b) 1992–93 value free-on-board, source: ABS, pers. comm.; Australian Irrigation Council, pers. comm. (c) Estimated water use rates, source: W. Meyer, pers. comm., for all commodities except sugar cane, source: M. Everson and G. Kingston, pers. comm. for sugar cane; (d) Generally excluding the direct impact of water use.


Australians use a lot of water on traditional gardens but native gardens can use less water.

average household of 2.8 people range from 263 kL for Sydney to 700 kL for Darwin (see Table 7.4). With the exception of the Darwin data, these figures are comparable with an average figure for the United States of 397 kL, and a Californian figure of 556 kL (Sydney Water, pers. comm.).

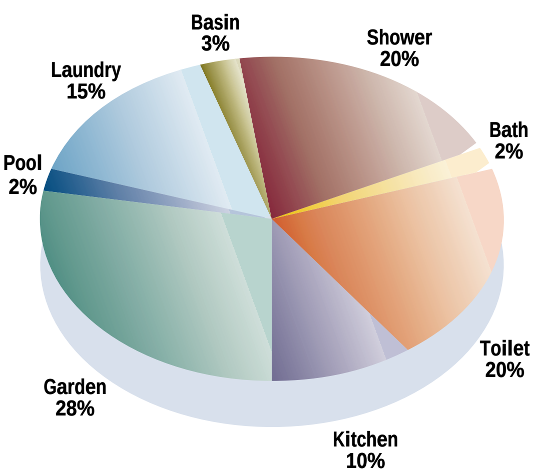
In Australian households, water is mainly used outdoors, with some 30–55 per cent spent mostly watering lawns and gardens. Water use in Darwin is about 700 kL per year for detached houses but 323 kL for flats without gardens (Northern Territory Power and Water Authority, pers. comm.). Not surprisingly, the level of outdoor water use fluctuates markedly with rainfall and temperature, and this often masks other changes in consumption patterns. Topping up swimming pools and associated backwashing of filters is estimated to average about two per cent of total water use across Sydney, with this outdoor component running as

Table 7.4 Average annual household water consumption in Australian capital cities, 1993–94

	Sydney	Perth	Melbourne	Adelaide	Canberra	Brisbane	Darwin	Hobart
Average household consumption (kL/yr)	263	330	270	265	400	430	700	570
Average annual rainfall (mm)	1227	869	656	451	625	1149	1659	626
Average annual rain days	147	119	147	123	107	123	109	159
Percentage outdoor use	30	42	38	56	55	na	est 45	na

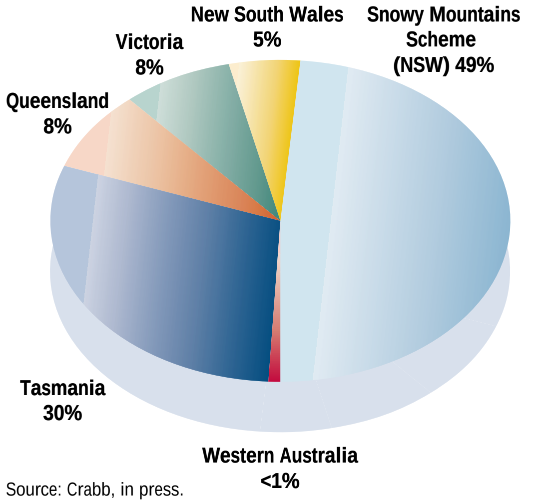
Source: ARMCANZ, 1994.

Figure 7.10 Average residential water use, Sydney, 1993



Source: Sydney Water, pers. comm.

Figure 7.11 Australia's hydroelectric power generating capacity



Source: Crabb, in press.

high as 15 per cent or more of total water use in households with pools (Sydney Water, pers. comm.). Toilets, showers and laundries each account for between 15 and 20 per cent of total domestic water use. The requirement for drinkable water in the kitchen is small — between four and 10 per cent of the total, with the higher figure being more recent and likely to reflect increased adoption of dishwashers (see Fig. 7.10). These figures represent the average for urban households in large cities with secure reticulated water supplies. Country areas with a less secure or no reticulated supply may well have significantly different patterns of domestic water consumption.

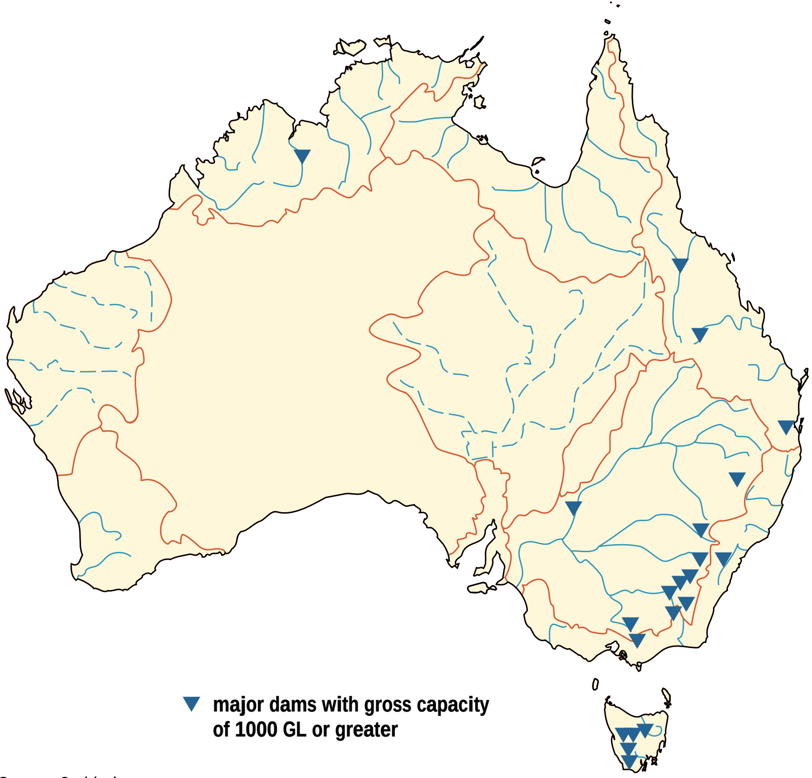
Industry and hydroelectricity

Overall, industry does not consume much water. The largest users are thermal power stations, and the petro-chemical, chemical, smelting, pulp and paper, food processing and mining industries. It is difficult to generalise about water use under this category because of the diverse range of quantity and quality requirements as well as considerable opportunity for recycling. The mining industry, often located in the arid parts of Australia, is already embracing recycling, in response to both scarcity and a desire to reduce aquatic pollution. For example, at the Port Kembla smelter, the production of one tonne of steel requires 217 000 L of fresh water and 74 000 L of salt water, yet only about 4750 L are actually consumed (Crabb, 1986). A number of industries have made the innovative move to using 'grey water' (such as sewage effluent), with both economic and environmental benefits.

In some States, the hydroelectric power-generating industry is also a major user of water. For example, Tasmania, which has about 30 per cent of Australia's hydroelectric capacity (see Fig. 7.11), uses about 13 600 GL annually for power generation. This compares with 480 GL used for all other purposes (Department of Primary Industry and Fisheries, Tasmania, pers. comm.). The Snowy Mountains Hydro-electric Scheme discharges some 2700 GL annually in generating its 5100 gigawatt-hours of electricity (Snowy Mountains Engineering Corporation, pers. comm.). For this relatively efficient Scheme, this means the equivalent of three Olympic swimming pools of water are used to generate the annual power consumption of a typical household consuming 23 kilowatt-hours per day.

Altogether, Australia's dedicated hydroelectricity industry uses about 20 000 GL of water for generation annually, a volume comparable to that used for irrigation. Nevertheless it should be noted that this water is not 'consumed', but is considered an 'in-stream use', since it remains available for other uses after passing through the turbines. For example, the Snowy Mountains Scheme was designed for both hydroelectric and irrigation purposes, and many larger irrigation and domestic water supply storages are now being designed or retro-fitted with small hydro-power stations to improve the efficiency of their operations.

Table 7.12 Major dams in Australia



Source: Crabb, in press.

Water use and the environment

The amount of water in rivers in irrigation areas has been dramatically reduced during the non-irrigation season because of dam construction (see Fig. 7.12) and poorly controlled abstraction of water from rivers. The use of large amounts of water, often for low-value enterprises such as irrigated pasture and mixed farming (see Table 7.3) has increased the amount of shallow groundwater in irrigation areas.

Darling River; large scale abstraction of water has major implications for inland streams.

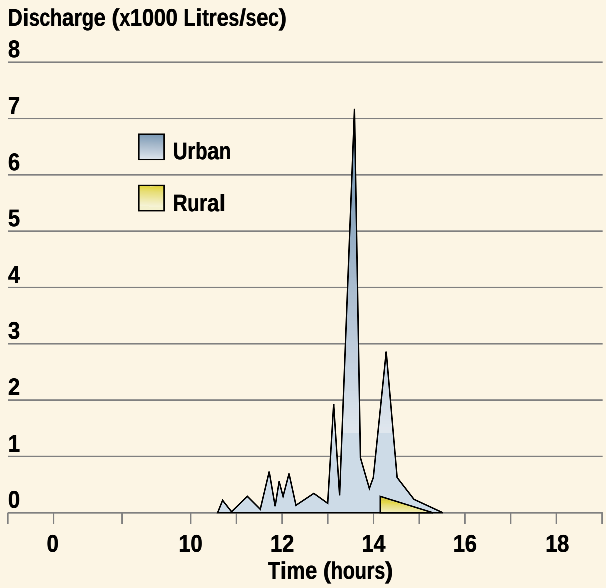
Flooding

Flood waters at St. Lucia, Brisbane, 1974.

Australia is a land of extremes — 'of droughts and flooding rains...'. While both occur throughout the country, droughts last longer than floods, which are irregular, relatively infrequent and variable in magnitude. The cost of flooding, in terms of life and property, can be enormous, averaging $400 million a year across Australia. The Brisbane Valley flood of late January 1974, caused by the intense rainfall of cyclone Wanda and a monsoonal air mass, was the most costly flood in Australia, with a damage bill close to $200 million (1974 value) (NDO, 1992). The waters reached 6.6 m at the Brisbane Post Office, affected some 13 000 buildings in Brisbane and Ipswich, and washed away 56 houses. The April–May flood of 1990 was one of the most extensive and dramatic ever recorded, covering more than one million sq km of inland Queensland, New South Wales and parts of South Australia and Victoria. A number of communities, including Nyngan and Charleville, were completely inundated, and stock losses were estimated at one million head. The total cost of the flood exceeded $250 million (1990 value), with the cost at Nyngan alone estimated at $50 million.

By modifying catchments through land clearing and other development, we have increased the frequency and magnitude of floods, particularly in small catchments, as well as our susceptibility to floods. Changes in land use — particularly clearing of vegetation — and increased imperviousness of the soil associated with urbanisation and soil compaction result in increased total volume and peak discharge. In addition, the time to peak run-off is greatly reduced (see figure below left). For example, in a flash flood in Canberra's Woden Valley caused by severe thunderstorms, the water rose so fast that seven people drowned before any warning could be issued (NSW SES, 1994).

Impact of urbanisation: differences in run-off from similar rural and urban catchment areas during the same storm event.



Source: Aitken & Moodie, 1983.

The changes in flooding frequency caused by dams in many regulated lowland rivers have had a significant environmental effect, with the number of small floods on the floodplains substantially reduced. This also affects the biological health of the rivers, because nutrients and organic matter are no longer being exchanged between the rivers and the floodplain; the community structure of billabongs on the floodplain is partly dependent on flood pulses; and fish movement and recruitment depends upon links between billabongs and rivers (Boon *et al.*, 1990; Hillman and Shiel, 1991; Cadwallader and Lawrence, 1990). For their long-term sustainability and health, rivers and their associated wetlands and floodplains will need to be reconnected to allow a return to more natural flooding regimes.

Before the major development of water resources, it was recognised and accepted that 'floodplains are for flooding'. The harnessing of stream flow through numerous weirs and large dams over the last 45 years has resulted in significant changes to the nature of flooding and people have forgotten what floods are like or have never experienced them. This has given rise to a naive perception that river systems can be 'flood-proofed'. Developers then apply pressure to local governments for approvals for developments on floodplains. Around large urban areas this has often led to incremental creep onto the floodplain — sometimes with disastrous consequences when major floods occur. Levees built to protect communities and property may initially reduce flooding, but in the end can actually exacerbate it by presenting ineffective barriers to major floods. Sometimes such banks fail catastrophically causing even greater damage.

As the enhanced 'Greenhouse Effect' starts to exert its influence over the next 50 years or so, an increase in flooding can be expected in some regions (Bates *et al.*, 1994), adding to the effects of land clearing and urbanisation.

Water for new developments has become scarce, particularly in the Murray–Darling Basin. Some cities are also facing limitations and are now trying to conserve water through strategies such as education, pricing reforms, and recycling, rather than building new dams.

We are starting to realise the environmental consequences of the post-war development of Australia's water resources — among them, disappearing wetlands, and rivers containing too little water at the appropriate times for various fish and bird species to breed. People continue to advance schemes to direct water from coastal or tropical areas to dry areas or those running out of water. The suggestions include piping water from Lake Argyle in the Kimberley to Perth, diverting some northern Queensland and northern New South Wales coastal rivers inland, and towing icebergs from the Antarctic to Adelaide. Restoration is also being considered — the most recent widely publicised example being Lake Pedder in Tasmania. The debate about water supplies in areas of over-allocation and interbasin transfer is now hotting up on environmental grounds. Most governments are not taking the schemes seriously because they are both environmentally and economically unsound and very expensive.

Re-allocating water for environmental purposes, or so-called 'environmental flows', now receives serious consideration. Few resolutions have yet been achieved, but balance between economic and environmental needs is central to the discussion.

The most useful indicator of the impact of water resource use on the non-human environment is the amount of water abstracted each year. Unfortunately, data are not consistent enough to show such an indicator through time.

The message about surface water

- Australia has the highest per capita storage capacity of all countries in the world as a result of dryness and variability of climate.
- Of the developed resources, 70 per cent are consumed for irrigation, followed by domestic, industrial and commercial uses.
- In parts of both the Murray–Darling Basin and eastern seaboard, water is grossly over-allocated and demand continues to increase.
- Over-allocation is placing aquatic environments under severe stress in these regions, but the stress is less severe in the rest of Australia and absent in undeveloped areas such as south-west Tasmania, the wet tropics and parts of the seasonally wet tropics.

The message about groundwater

- Groundwater provides domestic water for more than one million Australians in 600 communities, and 60 per cent of the continent totally relies on it for all uses except drinking water.
- In a number of basins — such as the Great Artesian Basin, Pioneer Valley (Mackay, Qld), Namoi Valley (Tamworth, NSW) and Burnett Basin (Bundaberg, Qld) — groundwater is being used faster than it is being replenished.
- In other areas, rising watertables from clearing and irrigation are waterlogging and salinising streams and large areas of land. Even with remedial action, this problem will continue to increase for some years.

Catchment pollutant sources

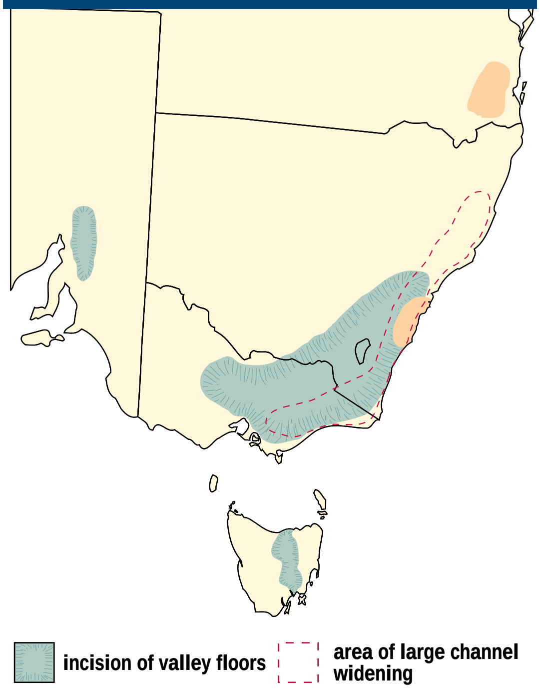
Catchments shed sediment, nutrients (particularly phosphorus and nitrogen), organic matter and agricultural chemicals such as pesticides. Land can also become salinised from extensive clearing or irrigation, and industry and urban areas produce a variety of wastes.

Sediments and river channel change

Rivers provide sources of sediment, places where sediments are deposited, habitats for many creatures, locations for recreation and sources of water for human use. Although their physical state is difficult to report nationally, four categories of channel change can be identified: valley floor incision, dramatic widening, increased meander migration and channel burial. Some channels have not changed (Rutherfurd *et al.*, in press).

Channel incision occurs mostly in uplands in the humid temperate areas, as a result of increased run-off after clearing (see Fig. 7.13). A reconstruction of sediment yield from an incised catchment shows early rapid incision and high sediment yield, then a decline as incision slows (CSIRO, 1992).

Figure 7.13 Areas of major channel changes in south-eastern Australia



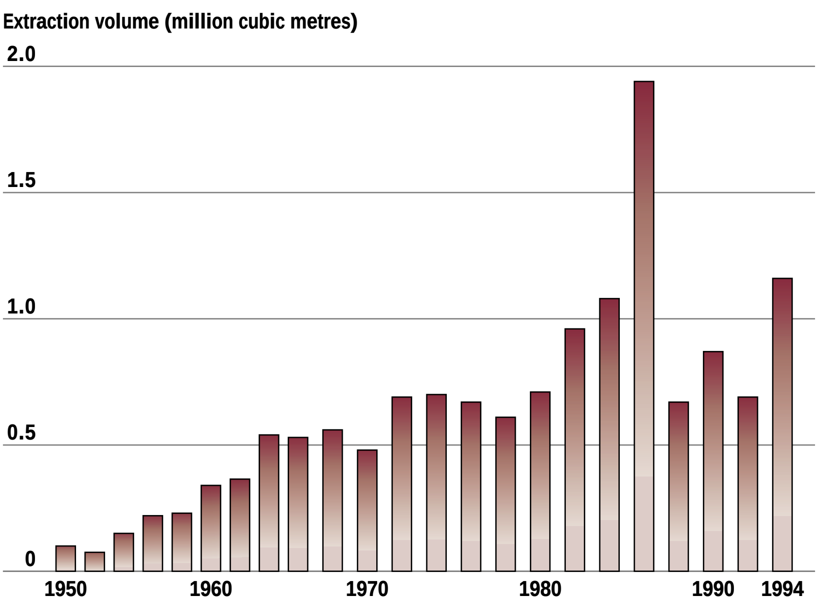
Source: Rutherfurd *et al.*, in press.

Incision of small stream resulting from land use.

This pattern began in the 1830s in the south-eastern uplands, and as late as 40 years ago in the south-west of Western Australia. It is probably still being triggered in areas of modern upland clearing and heavy grazing. Channel incision has also occurred as a result of the straightening of rivers in Western Australia, New South Wales and Victoria (so-called ‘river training’); and as a result of sand and gravel extraction, particularly in Queensland and New South Wales (see Figs 7.14).

During the early stages of incision, some parts of streams are buried by sediment originating in incisions upstream. This is happening in the south-west of Western Australia. Mining also causes channels to be filled or buried. Examples can be seen in the King and Ringarooma Rivers of Tasmania, in the gold-mining districts of central Victoria and New South Wales, and in the uranium province of the Northern Territory.

Figure 7.14 Sand and gravel extraction from rivers in Queensland



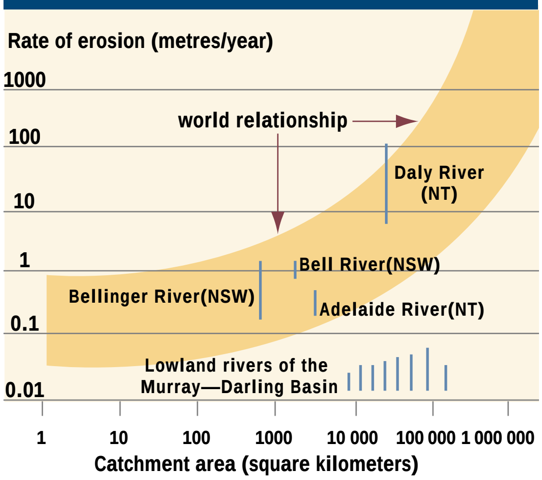
Source: QLD Department of Primary Industry Year Books.

Dramatic channel widening has been documented in coastal Victoria and New South Wales. Widening can be a natural process or the result of land use. Almost all valleys in the Southern Tablelands of New South Wales are incised as a result of increased run-off due to grazing. The Avon River in Victoria has increased its width 25-fold, with little identifiable human cause. By contrast, the Latrobe River with large-scale human intervention — 70 meander cut-offs and five desnagging episodes — has widened by only 50 per cent. Sand and gravel extraction can also cause channel widening (Rutherfurd *et al.*, in press).

The rate of bank erosion of large streams is proportional to the amount of water in the channel, which in turn is proportional to the catchment area. Four estimates of meander migration rate for Australian streams conform to the apparent world pattern established by Hooke (1980) (see Fig. 7.15). There is no quantitative evidence that land use has increased these rates, although eroding, cleared and grazed river banks are obvious. However, other Australian rivers do not conform to the world pattern, including the low-gradient, muddy channels of the Murray–Darling Basin, in which the flow of water is very small relative to catchment area. There is no quantitative evidence that migration rates have increased since settlement, although eroded banks are evident. However, some evidence establishes widening of these channels (both of convex and concave banks) at rates between 0.16 and 0.74 m per year, probably as a result of increased flows for irrigation (Rutherfurd *et al.*, in press). Yet, the banks of these muddy rivers contribute less than five per cent of the total sediment in transport (Olley *et al.*, 1995).

Channel change alters some habitats. Generally, the new habitats are less diverse than the original ones, and so are likely to be biologically of lower quality. Using the criteria of rate of channel change, increase of sediment yield and the number of cases, it appears that gullying has wrought the largest

Figure 7.15 Rate of riverbank erosion in relation to catchment area



Source: Hooke, 1980; Rutherfurd *et al.*, in press.

change, followed by channel incision in valley floors, mining, meander migration, urbanisation and river 'training'.

Dramatic channel changes produce large quantities of sediment, the fine-grained part of which moves quickly downstream or onto floodplains. The coarse fraction often moves as a 'slug', burying the riverbed, increasing local flooding and causing additional channel widening as the channel through which it moves adjusts to accommodate flood flows. Mining also produces slugs of sediment, often of enormous size. The biological effects of these coarse-grained slugs are poorly known, but are likely to be significant because they move slowly and so have a prolonged period of impact. Granite catchments yield more coarse grains than others, and so slugs can be natural features, although land use can increase their size (Rutherfurd *et al.*, in press).

Sand and gravel extraction — already noted as a secondary cause of channel change — can directly cause such change. Almost everywhere in eastern Australia these resources are being extracted at a rate faster than they are renewed (Rutherfurd *et al.*, in press). The rate of extraction in both New South Wales and Queensland is steadily rising, to meet demand for construction (see Fig. 7.14).

Phosphorus

Phosphorus, which is an essential nutrient for life, can lead to nuisance growth of blue-green algae and water plants (see the box on page 7-48). Australian catchments have many sources of phosphorus, some related to land use, some derived from animal and human wastes as well as natural sources from the soil (see Table 7.6 and Fig. 7.16).

Estimates of the production (or generation) rate of phosphorus from a land use or land type, as summarised in Table 7.6, tell only part of the story. The area covered by a particular land use and its position in a catchment influence the amount of nutrient that reaches a water body. It is important to know the proportional contributions to nutrient levels in water bodies from different land uses in order to manage eutrophication.

There are few estimates of the relative amounts of phosphorus from different sources entering our streams. Table 7.7 contains a national and some individual catchment estimates, some of which should be treated with caution. The estimate of diffuse sources reaching the Great Barrier Reef is probably too low, given that large floods were not adequately sampled. Floods were well sampled in the case of Lake Burley Griffin, but the sampling period was short. The estimate for the Murray–Darling Basin point-source contribution is likely to be too high, given that measurement-based estimates from the Lower Murrumbidgee and Murray are lower than the Basin-wide estimate of 44 per cent. The Western Australian cases are generally well measured and highlight large variations in the proportion of total phosphorus derived from point sources, with some noteworthy results. For example, the point sources of a city like Perth produce no larger proportional contribution than the small towns and intensive industries of the Peel–Harvey catchment. The very high point-source contribution to Princess Royal Harbour (Albany) originated from a fertiliser factory. This has now been rectified.

The Murrumbidgee at Wagga Wagga transports about 620 tonnes of phosphorus each year. Of this, sewage contributes about 44 tonnes — an amount

Table 7.6 Nutrient generation rates for different land uses in catchments

Land type and use	Total phosphorus generation rate (kg/ha/yr)	Total nitrogen generation rate (kg/ha/yr)
Rural (Australia wide)		
Grazing		
— improved pasture (includes irrigated pasture for dairying)	0.1 – 3.00	0.6 – 10.8
— unimproved pasture	0.002 – 0.4	2.0 – 15.0
Crops — unirrigated	0.2 – 2.0	2.0 – 6.0
Horticulture	15.0	6.0 – 35.0
Forests	0.01 – 0.2	0.9 – 10.0
Urban and industrial (Australia wide)		
Industrial and suburban land	0.1 – 3.6	1.0 – 22.4
Sewage treatment plants	4[a]	35[b]

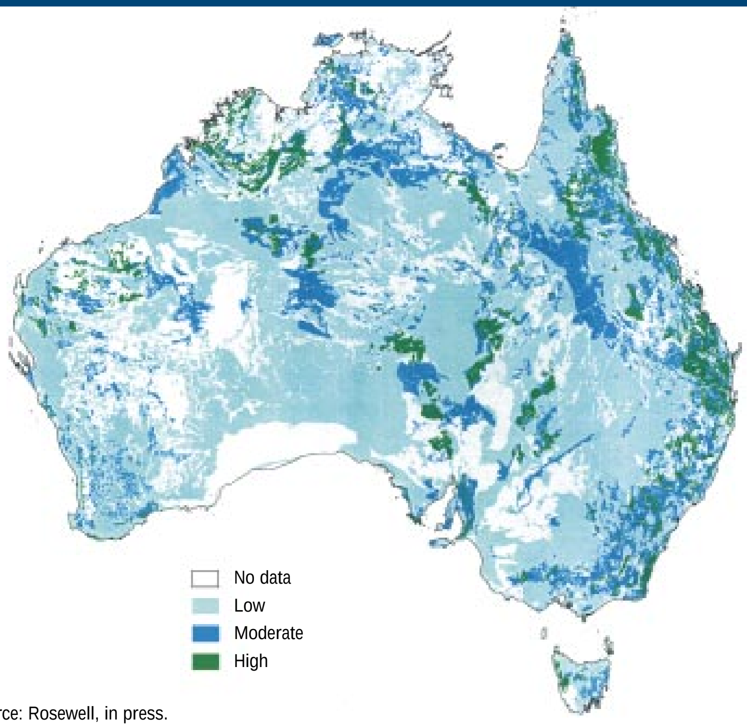
Note: Broadacre land uses on soils that contain clay and iron contribute phosphorus mainly in particulate form by sheet and rill erosion, and in dissolved form where soils are sandy. An emerging view suggests that erosion of channels produces up to 11 times the maximum amount of phosphorus listed in this table. The urban and industrial category includes point sources (industrial and sewage treatment plant discharges) and diffuse sources from urban stormwater run-off (see Chapter 3).

a. Based on 0.2 kg/person/year; b. Based on 1.0 kg/person/year

Source: Sewage treatment plants; Wasson — various sources; Young *et al.*, in press.

Phosphorus transport has been calculated by combining measured concentrations of total phosphorus in the surface horizons of major soil types with the sheet and rill erosion estimate of the box on page 6-28 High mean annual run-off occurs along the eastern seaboard, from the eastern uplands, in parts of NT and WA and in a few locations in central Australia.

Figure 7.16 Estimated phosphorus transport resulting from sheet and rill erosion.



Source: Rosewell, in press.

that has prompted considerable expenditure to dispose of sewage off-river. Of the 580 tonnes from diffuse sources, less than five per cent comes from fertiliser-enriched surface soils. So the two sources of phosphorus assumed by many management agencies to be of greatest significance in this region, namely sewage and fertiliser, actually constitute less than eight per cent of the total load of the nutrient (Olley *et al*., 1995).

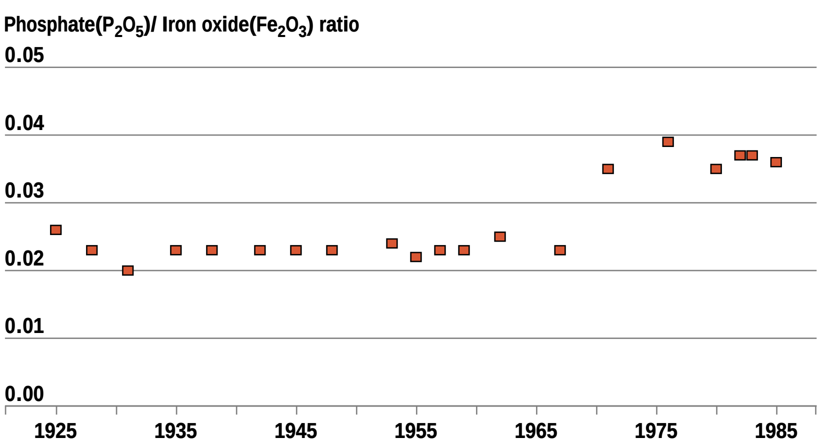
Sewage may be only locally significant as a source of nutrients. In the Hawkesbury–Nepean system sewage phosphorus is deposited in the riverbed within a few kilometres of its discharge point (Jones, 1994). In the Barwon River in northern New South Wales, the same process occurs within a few tens of kilometres (G. Hancock, pers. comm.). However, scientists are still trying to determine how much of this phosphorus is subsequently available for plants and algae.

Table 7.7 Estimated proportionate contributions of different sources to phosphorus loads in waterbodies

Location	Point sources (per cent)	Diffuse sources (per cent)	Reference
Hawkesbury–Nepean	15–18 (sewage)	75–82	Cuddy *et al.*, 1993
Murrumbidgee at Wagga Wagga	8 (sewage)	92 (>95 per cent from gullies and streambanks)	Olley *et al.*, 1995
Murray at Albury–Wodonga	32	68	Walker and Hillman, 1982
Murray–Darling Basin	44	56	GHD, 1992
Lake Burley Griffin	29	68	Cullen and Rosich, 1979
Upper Murrumbidgee	23	77	NCPA, 1994
Drainage to Great Barrier Reef	14	86	Furnas *et al.*, 1994
Peel Inlet	35	65	Bott, pers. comm.
Harvey Estuary	15	85	Bott, pers. comm.
Princess Royal Harbour	75	25	Bott, pers. comm.
Oyster Harbour	10	90	Bott, pers. comm.
Swan Estuary	35	65	Bott, pers. comm.
Australian agricultural districts	22	64 (erosion) 6 (leaching) 8 (fire)	McLaughlin *et al.*, 1992

Note: Different methods have been used to derive the percentage contributions from point and diffuse sources. Some are based on measurements, some on models.

Figure 7.17 Change in phosphorus content relative to iron in the Burrinjuck Reservoir sediment core



Source: Olley *et al.*, 1995.

Very few long-term records exist to allow determination of whether the amount of phosphorus reaching Australian inland waters is changing through time. However, a core of sediments from Burrinjuck Reservoir, on the Murrumbidgee River record increasing amounts of phosphorus (see Fig. 7.17). The increase has occurred since the 1970s, even though phosphorus has been removed at the Lower Molonglo Water Quality Control Centre. This suggests that most phosphorus reaching the lake did not come from Canberra.

As the amounts of sediments and phosphorus entering waterways increase, fine sediments in reservoirs and riverbeds can become significant storages for the nutrient. Under various chemical conditions, some stored phosphorus is released and supports blue-green algae (Donnelly *et al.*, 1992, 1994; Harris, 1994).

Nitrogen

In fresh water, nitrogen is not usually the limiting nutrient for algal growth, but it can control the growth of algae in estuaries and near-shore marine environments (see the box on page 7-48).

Nitrogen can also pollute groundwater. In South Australia industrial wastes have increased the nitrate concentrations of groundwater used by people (Lawrence, 1983). In central Australia, natural processes involving bacteria on soil surfaces and in termite mounds produce nitrate (Barnes *et al.*, 1992), which is then leached, and contaminates groundwater used by remote settlements. At high concentration, nitrate is a human health hazard.

Few studies have been done to document the major sources of nitrogen in Australian catchments (McLaughlin *et al.*, 1992), but Table 7.6 summarises the available data. Horticulture and urban land uses have the potential to produce most nitrogen, along with animal-processing industries. An investigation of nitrogen transport to the Great Barrier Reef lagoon shows that rivers draining rural lands contribute about 60 per cent, rainfall about 20 per cent and sewage three to four per cent (Furnas *et al.*, 1994). The rest comes from ocean upwelling.

Other pollutants

A wide range of other pollutants is produced by industry and urban waste disposal. The most important source industries and activities are listed below.

- waste disposal and treatment industry
- electricity generation

- town gas production
- fire-fighting
- transport industry
- agriculture and aquaculture
- chemical and petroleum industries
- mining and mineral-processing
- manufacturing industry
- domestic and commercial developments

The main contaminants of industrial waste streams are metals and inorganic chemicals, organic chemicals such as phthalates, phenols and cresols, aromatics, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls and related compounds (PCB), halogenated aliphatics, pesticides and metabolites, radionuclides and biological compounds (AWRC, 1990).

While these contaminants probably all occur in Australian catchments, few measurements are available even on a local scale and certainly very few at a national level to assess the scale of the problem (O'Loughlin *et al*., 1992). The accuracy and thoroughness of reporting and recording incidents of point-source pollution varies widely between and within States. It is unlikely that the situation will change for some time. Legal sensitivity makes people reluctant to disclose the nature, extent and location of most actual and potential contamination sites. For more information about waste-generation rates, see Chapter 3.

Pesticides sprayed on crops sometimes end up in rivers as run-off.

Table 7.8 gives one example from each State and the Northern Territory as an indication of contamination incidents.

Of the diffuse sources of pollutants, pesticides are probably the most important. While it should be possible to determine their level of use from sales or import figures, as far as can be determined no one has collated this information nationally, or for most regions. An exception is a pesticide audit conducted by Rayment and Simpson (1993).

Table 7.8 Examples of point source contamination in Australia

Location	Source	Contaminants	Present and future effects
Botany sandbeds, Sydney (NSW)	Manufacturing industry	Petroleum hydrocarbons, organic solvents and heavy metals	Contamination of a major industrial water resource; contamination of wetlands and marine environment
Rum Jungle (NT)	Mine waste	Heavy metals, acid waters, total dissolved solids	Concern for future contamination of surface waters by groundwater discharge; remedial measures in place
Willawong and Kingston hazardous waste sites (Qld)	Industrial waste	Organic solvents, petroleum hydrocarbons	Long-term environmental effects
Mt Gambier region (SA)	Timber treatment	Arsenic, chromium and tin compounds, phenols, cresols and pesticides	Localised contamination of the shallowest aquifer leading to long term resource degradation, environmental effects and some potential public health impacts
Mt Direction and Westbury (Tas.)	Timber industry	Tannins and lignins	Potential future degradation of resource and environmental impact
Western suburbs, Melbourne (Vic.)	Manufacturing industry, landfills	Petroleum hydrocarbons, organic solvents, phenols, heavy metals, nitrate, sulfate, pesticides	Widespread contamination of a vulnerable, brackish water; highly transmissive aquifer with low attenuation, leading to environmental effects Limited potential for public health effects except where highly contaminated groundwater is intersected in excavations
Perth Coastal Plain, Kwinana (WA)	Petroleum, chemical and mineral refining and processing; heavy metals, nutrients, food processing	Petroleum hydrocarbons, organic solvents, pesticides, total dissolved solids	Widespread contamination of surficial sediments and aquifer has led to resource degradation and environmental impact; also poses a substantial threat to public health in the long term

Source: AWRC, 1990.

Dryland salinisation in south-west Western Australia

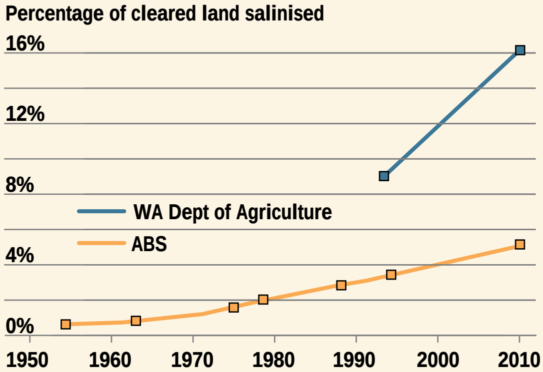
River of salt, south of Kellerberrin, Western Australia; salinisation destroys agricultural land and native vegetation and increases stream salinity.

Before extensive land clearing occurred, native vegetation used most of the water in the soil and unused water leaked into the groundwater. However, the replacement of native plants with shallow-rooted crops and pasture grasses has led to more water leaking into the groundwater, causing watertables to rise. As the watertable nears the ground surface, waterlogging begins and salt stored in the soil is mobilised, creating saline seeps. Water and salt emerge in the floors and sides of valleys, forming salt crusts, killing plants, aiding erosion as plants die, and increasing the salinity of streams.

In south-west Western Australia, about 14.6 million hectares have been cleared for grazing and cropping. This area receives less than 900 mm of rainfall each year and, because it is dry, wind-borne sea-salt has been stored in the soils in large quantities for millennia. Typically, between 20 and 120 kg of salt lie beneath a square metre of ground (Schofield, 1989). This salt is being mobilised as the watertable rises at rates between a few millimetres and two metres each year. Water levels beneath areas of native vegetation in the wheat belt are five to 10 m lower than those in cleared areas nearby. Since clearing, the levels have risen between five and 20 m on hilltops, between five and 10 m in the middle of hill slopes, and about five metres in valley floors (Salama and Bartle, in press).

Estimates of the area of salinised land (see figure below) from the Australian Bureau of Statistics (ABS) show an average increase of 0.07 per cent each year since 1955, which represents an annual increase of nearly 12 000 ha. But these figures underestimate the problem. A recent, more reliable, survey based on aerial photographs and ground surveys (McFarlane, pers. comm.) shows that the area of salinised land in 1994 is nine per cent of the cleared area (equivalent to 393 average wheat farms), not 3.1 per cent as estimated in 1993 by the ABS. The ABS estimates rely on landholders' perceptions — probably reflecting bare land rather than salinised land, which can be either bare or thinly vegetated (WA Select Committee into Land Conservation, 1990).

Estimates and projections of the area of salinised land in south-west Western Australia



Source: McFarland, pers. comm.; ABS.

The best estimate of the area of salinisation of cleared land in 2010 is 16 per cent or 2.9 million hectares. This is 11 per cent higher than the ABS estimate. This figure will increase before the rising watertables reach a new equilibrium, at which point the area affected is expected to be 24 per cent in the western south-coast region and 29 per cent in the eastern south-coast region, about 4.5 per cent and 13.5 per cent more respectively than in 2010. To make matters worse, most of the ground that will be affected between now and 2010 is the better-quality agricultural land in the valleys.

The salinisation of land also increases the salinity of streams, making them unsuitable for human or domestic stock use, and affecting their biota. The salinity of streams in south-west Western Australia has been declining generally in uncleared catchments since 1940, but rising sharply in cleared catchments (Schofield, 1989). Total soluble salts have risen at an average rate of between one and 76 mg/L/year and this rate is increasing.

In 1985, 43 per cent of the run-off in the south-west drainage division was considered divertible for human purposes. Of this, 52 per cent has since been degraded by salt. In those cases where river salinities have increased, they are continuing to do so and are likely to increase fivefold over the next 30 to 40 years (WA Select Committee into Land Conservation, 1990).

Governments and landholders have been slow to respond to salinisation of land and streams in this area. Land clearing has continued well after the causes of salinisation were identified. In some areas, the government has imposed clearing controls, and these appear to have slowed but not halted stream salinity increases. The only practical way of slowing salinisation is by major revegetation, which involves changing land use significantly over wide areas. Where commercial forestry is possible, the salinity trend may be reversed within a decade. In drier areas, the increase in salinisation will continue if current land uses are maintained. The salt in the wetter areas will be flushed out under current land uses in about 10 years, but, in the dry areas, centuries will be needed if current land uses continue (Peck and Williamson, 1987).

Salinisation

In some parts of Australia — most notably the large irrigation areas of the Murray–Darling Basin, which were established at the turn of the century — salinised surface soils, caused by land use, have been present for a long time. The south-west of Western Australia has also suffered from dryland salinity since early this century. In other areas, such as the dryland agricultural areas of central and northern New South Wales, salinity is regarded as a more recent phenomenon. However, it is difficult to assess the scope of the problem, as large areas of the continent lack long-term data. Available data sometimes conflict, indicating that we need standard definitions of relevant parameters. The key indicators of environmental state are rate of rise of groundwater levels, area of land underlain by shallow watertables and rate of change of stream salinity. The best-documented area is in south-west Western Australia (see the box opposite).

Irrigation-induced land degradation

All irrigation practices add water to underlying groundwater. If more water is being added than can move laterally in the aquifer, groundwater levels will rise. Unless the groundwater is highly saline, most irrigation-induced land degradation begins as waterlogging. After time, and depending on evaporation rates and degree of flushing, salt concentrations increase until they affect crop yield. Waterlogging alone also reduces crop yield.

In 1985, the Murray–Darling Basin Commission estimated that 360 000 ha of irrigated land had shallow watertables, and 87 000 ha of land in the Victorian portion of the Basin were visibly salinised (MDBC, 1993a). Victoria's 1991 State of the Environment Report contained an estimate of about 140 000 ha of salinised irrigated land, representing about 30 per cent of the State's irrigation areas. It has been estimated that high watertables lie under some 220 000 ha (41 per cent) of the Shepparton irrigation region. In South Australia, 4600 ha of shallow groundwater exists in irrigation areas (State Dryland Salinity Committee, 1989–90).

The Wakool, Deniliquin and Murrumbidgee irrigation areas of New South Wales were estimated to contain 199 000 ha of land with shallow watertables and 9000 ha of land that is visibly salinised (1985 figures, MDBC, 1993a). By 1991, the area of land overlying high watertables had increased dramatically. For example, the salinised area in Berriquin (part of the larger Deniliquin area) had grown from 22 000 ha in 1985 to 91 300 ha in 1990).

Salinity problems associated with irrigation in other States are much less significant and quite localised at present. However, the prospects of waterlogging and salinisation have caused authorities to reassess the area available for development in the Burdekin River Irrigation Area in north Queensland.

Dryland salinisation

Dryland areas are those that depend solely on rainfall for plant growth. They are susceptible to hydrologic disturbance when deep-rooted native plants are cleared and replaced by introduced shallow-rooted crops that use less water. More water then moves below the root zone, raising groundwater levels to a higher point in the soil profile and remobilising salts in the higher, previously unsaturated zone. Salt usually then appears at the surface after evaporation follows periods of waterlogging.

For Western Australia, the estimated area of salinised land in 1994 was 1.6 million ha or nine per cent of the area of cleared agricultural land in the State (see the box opposite). The Murray–Darling Basin Commission estimated that about 200 000 ha of the Basin suffered from dryland salinity in 1992, although this is now regarded as an underestimate (MDBC, 1993a). In South Australia and Victoria, estimates of areas affected by dryland salinisation stand at about 400 000 and 150 000 ha respectively.

While no one has completely documented the scale of the problem in New South Wales and other States, in 1992 about 20 000 ha were recognised as salinised in New South Wales (MDBC, 1993a). In Queensland, about 10 000 ha were estimated to be affected in 1990, and Tasmania has only recently mapped small-scale scattered pockets of dryland salinisation. In South Australia, 25 000 ha are salinised, and a much larger area has some evidence of salting (State Dryland Salinity Committee, 1990).

Rate of watertable rise

The most comprehensive available information on rates of watertable rise exists for the irrigation areas of the Murray–Darling Basin. Watertables are rising at the greatest rate (about 100 to 500 mm per year) in the developments of the south-eastern parts of the Basin. It is not yet clear whether the rate has slowed as a consequence of improved irrigation efficiency or because of the dry conditions of the last few years. But the rise in salt transport rate in the Murray River at Morgan is slowing (see Fig. 7.29), which may indicate such changes.

Although data on rates of watertable rise in dryland catchments are very limited, long-term observations indicate rises of many tens of metres in some regions since clearing began. Observation indicates that groundwater levels have increased by up to 30 m since the 1880s in parts of south-eastern Australia and by about 20 m in the south-west of Western Australia.

Salt load in streams

In south-west Western Australia, the average rate of rise of stream salinity has ranged between one and 76 mg/L/year over the last few decades (Schofield, 1989). The 1992 State of the Environment Report for Western Australia quotes rates of increase between 11 and 117 mg/L/year for 17 major streams in the south-west of the State for the period 1965–1986. Elsewhere, very few reliable data quantifying the rate of change of stream salt loads exist. In the Murray–Darling Basin estimates of the rate of increase in salinity of the Murray River at

Morgan, made in 1985, suggested a figure of about 1 mg/L/year, compared with an annual fluctuation of about 200 mg/L in river salinity. Preliminary analysis of salt loads in other streams in the Basin shows similar trends.

In South Australia, increasing salinity has made several reservoirs useless for human consumption, and the cost of treatment for Adelaide's water supply is likely to increase as catchments in the Lofty Ranges become salinised. About 21 per cent of the divertible surface water in the State has a salt concentration of about 1500 mg/L, which is above the National Health and Medical Research Council guidelines for human consumption (State Dryland Salinity Committee, 1990).

The message about catchment pollutant sources

- Catchments are the sources of a range of aquatic pollutants, including sediments, nutrients, salt and pesticides.
- The natural character, human disturbance and management of catchments control the nature and amounts of pollutants. Intensive uses produce the most pollutants.
- Sources of sediments and phosphorus include land adjacent to streams, channel beds, banks and gullies. The relative magnitude of these sources varies across the country and through time.
- Fine sediments usually transport other pollutants such as phosphorus, pesticides and pathogens.
- Nutrients also come from point sources like sewage-treatment plants, feedlots and urban and industrial run-off and discharge.
- The relative importance of diffuse and point pollutant sources varies between catchments and with run-off, with point sources being more important in low-flow conditions and in areas of urban development and animal waste disposal.
- The spread of salinised land is increasing salt loads to rivers in many parts of Australia, although the rate of increase of load in the Murray River might have begun to slow.
- Increasing agricultural use of pesticides will result in increasing levels in waters with unknown biological and health consequences.
- Other pollutants such as trace metals and synthetic organic chemicals are important in some localities, although their biological and health consequences are largely unknown.
- The leaching of nitrate to surface and groundwaters from sewage, intensive animal industries, food-processing, fertilisers and natural sources is a potential human health hazard in some areas.

Impacts of forestry

As in all cases where the vegetation cover of a catchment is changed, forestry — both native forests and plantations —inevitably affects soils and water. Although it occurs in lowland regions of Australia, the impacts on water quantity and quality are likely to be most extreme in the uplands where run-off is produced.

Water quantity

Plants draw water from the soil, and transpire some of it to the atmosphere. As well, they catch rain on their leaves, from where it can evaporate. Through these processes (known as evapotranspiration), surfaces covered by vegetation lose more water than those that are bare. When a forest is removed, more water flows into streams, from run-off and soil seepage. Vigorously growing young trees use a lot of water. The amount depends on the number and type of trees, and can be greater than that used by a mature native or plantation forest.

In forested areas the flow of water in streams increases immediately after clearing and logging (Bosch and Hewlett, 1982), and then is reduced as regeneration begins. Fire can produce results similar to clearing and logging.

Some of the differences between initial water-yield increases in different catchments are due to different forestry practices. Among these, the most significant are in the area of logging. Run-off has a tendency to increase as the logged area of a catchment increases.

Native forests in Australia are a mosaic of untouched, logged and regenerating patches, producing a stream-flow response that is difficult to relate to specific forestry operations. Few streams have large entirely forested catchments, and agriculture also influences flow rates in large catchments. The only way of describing the state of water yield as a result of forestry land use is therefore by using small research catchments, of the kind illustrated in the diagrams, where the individual effects can be isolated and measured.

Water quality

Increased run-off and flow through soil after logging can increase the sediment load of streams by increasing slope erosion. It may also increase stream size, and so sediment that moves out of forests can be derived from the streams themselves (Olley *et al.*, 1995). In spite of this, few quantitative data are available to demonstrate relationships clearly. A recent review (Campbell and Doeg, 1989) concludes that timber-harvesting operations have significant effects on stream sediment levels, water quantity, water temperature, nutrients and aquatic biota. The effects appear to be site-specific, with some studies (Grayson *et al.*, 1993; Olive and Rieger, 1987) failing to demonstrate any effect of forestry operations on water quality because of very high natural variability or good forestry practice.

During the establishment phase of plantations, erosion of forest roads, hauling of logs downhill and clear-felling cause increased turbidity and sediment loads (Boughton, 1970; Cornish, 1989). Elevated sediment loads are therefore likely to occur at a number of times during the growth/harvesting cycle of both native and plantation forests. However, few studies in Australia last long enough to detect these changes. Studies in other countries show that the effects are still evident 20–50 years after logging, in the form of elevated stream sediment loads and woody debris (Beschta, 1978). Only one Australian catchment has been studied for more than 30 years, at Coranderrk near Melbourne (Doeg and Koehn, 1990).

Ecological impacts

While changes in flow regime and water quality associated with logging activities have been shown to cause significant impacts on stream ecosystems in other regions of the world, research in this area in Australia is still in its infancy (Campbell and Doeg, 1989). Recent studies of streams in Western Australia, Tasmania and New South Wales have shown that logging and associated road building cause significant changes. For example, spread of tree disease, changes in characteristics of bed sediments, amount of wood debris, water temperature and shading that are associated with declines in the abundance and diversity of macroinvertebrates and fish (Richardson, 1985; Growns and Davis, 1991; 1994; Davies and Nelson, 1993; 1994).

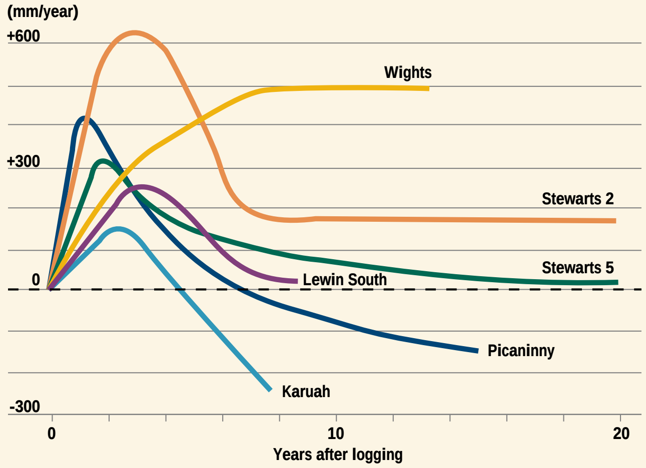
Chemicals are widely used in forests to control competing plants and pest insects. Commonly used chemicals include the atrazine and glyphosate herbicides, and a variety of pyrethroid and other insecticides. These chemicals have been shown to cause disturbance and mortality of stream fish and invertebrates (Barton and Davies, 1993; Davies *et al.*, 1994). In some areas public concern is high over the contamination of untreated rural domestic water with chemicals used in forestry. Concentrations of 1–100 µg/L of atrazine were regularly recorded in some Tasmanian plantation forests (Davies *et al.*, 1994).

Responses

Although people have long recognised the threat that forestry operations pose to water resources, they have rarely considered the value of water or the role of forests in ecological processes, in calculating the value of forests. Responses in some States, particularly Western Australia and Victoria, have been to carry out research into water quantity and quality in relation to forestry operations. Victoria, Western Australia, New South Wales and Tasmania now have codes of forest practice and practical guides for field operations to protect water quality. Education and enforcement of these codes is essential. Where water supply either is at risk (for example, in the mountain ash forests near Melbourne) or could be enhanced by thinning (for example, part of the Perth supply), careful research has played a key role in identifying options. The closed-catchment policy for Melbourne's supply has been maintained because of the risk posed by logging and human recreation (O'Shaughnessy and Jayasuriya, 1987). A similar policy exists for Sydney and Perth.

In general, forest activities and their impacts have not been explained to the public and research has been either non-existent or patchy, with research results often neither analysed nor published. Under such circumstances, it is difficult to be confident that policies and practices are appropriate. Continuing public protest over logging is partly a response to a lack of information, among other concerns.

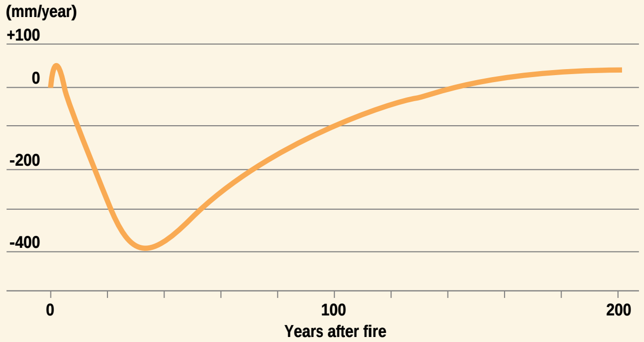
Changes in run-off following logging



Generalised water run-off curves from small research catchments show responses to logging. Stewarts 5 (Vic.), Picaninny (Vic.), and Karuah (NSW) all show flow increases after logging, then a decrease to values lower than the pre-logging flows in the last two cases. That is, streams have less water in them as a result of forest regeneration. Lewin South (WA) shows an increase and then decrease, but groundwater played a more significant role than in the Victorian and NSW cases. Wights (WA) and Stewarts 2 (Vic.) were converted from forest to pasture, but show different responses. Groundwater in the Western Australian case played a major role in maintaining flow at a higher level than would be expected once pasture had established, a factor that is less important in drier areas. Curves are smoothed from the original data.

Sources: Karuah, NSW (Cornish, 1993); Picaninny, Stewarts 2 and 5, Vic, (Nandakumar and Mein, 1993); Lewin South and Wights, WA (Ruprecht and Stoneman, 1993.)

Changes in run-off following wildfire



Long-term water yield following wildfire in mountain ash (*Eucalyptus regnans*) forests of Victoria. After the 1939 fire, an initial rather small increase occurred in stream flow (run-off) in catchments in the Melbourne water supply region, then a period of decreased flow for 20–30 years as regrowth used water that previously replenished streams. Gradually flow increases, and should reach the pre-fire values after about 130 years — assuming that no other disturbances to the forest arise.

Sources: Kuczera (1987), Jayasuriya *et al.*, (1993).

Groundwater: a vital but often neglected resource

People living in about 60 per cent of the Australian continent are totally dependent on groundwater, and those in another 20 per cent use more groundwater than surface water. The volume of groundwater in the upper one kilometre of the earth's crust is 10 times larger than the combined volume of all rivers and lakes on earth. Groundwater allows streams to flow through prolonged dry periods and yet, for many people, it has a certain mystical quality, perhaps because it cannot be seen until it is pumped or flows to the surface. This mystique is reflected in the widely accepted but scientifically baseless practice of water-divining.

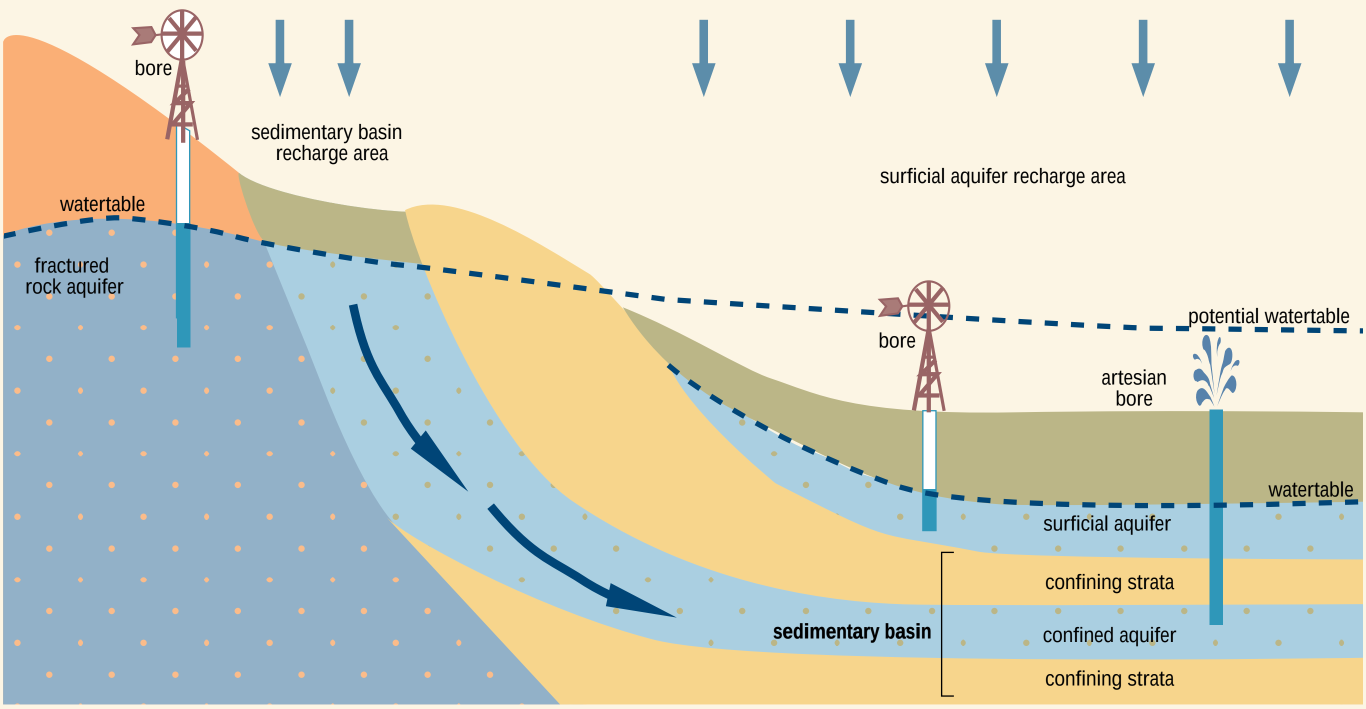
Despite its vital role in supporting communities and industries, people often abuse groundwater. They often regard it as free and unlimited in quantity and generally do not appreciate that groundwater can be over-used and become polluted. Not long ago the tendency in waste disposal was to deposit waste underground and to ignore any consideration of leakages from surface facilities, presumably on the premise 'out of sight, out of mind'. The huge groundwater clean-up costs that many countries are now facing provide ample evidence of the folly of these practices.

Groundwater is an integral component of the hydrologic cycle and constitutes the largest terrestrial water store in that cycle. At its source, it is inextricably linked to the surface environment. It sustains many wetlands and supports vegetation. In turn, disturbances to the surface environment affect aquifers. Management of land and water resources must therefore be approached in an integrated way that takes full account of both groundwater and surface water.

At the broadest level, the way in which groundwater occurs in aquifers is not difficult to understand. Aquifers may be unconfined or confined, and may be further classified as 'surficial', 'sedimentary basins' and 'fractured' (see diagram below). They are all susceptible to pollution where they intersect the surface, but surficial ones are at greatest risk in the short term because they are hydraulically connected to the surface over much larger areas proportionally, and through shorter flow paths.

A key factor in groundwater management is the very much longer time period for aquifers to respond compared with surface waters. For example, it takes a matter of weeks for water to travel in surface streams from inland of the Great Dividing Range in Queensland to central Australia after flooding rains. In the Great Artesian Basin it takes a million years for water to travel a similar distance. While surficial aquifers react significantly more rapidly, the slow response time still needs to be recognised in managing them. In particular, cleaning up polluted aquifers is a prolonged and costly process.

It is not hard to find examples of groundwater contamination in other countries. In Bangkok, the large resource underlying the city is subjected to major pollution from human and industrial waste products deposited in the recharge areas above it as well as from salt-water intrusion from the sea because of overpumping for water supply. In Europe, both industrial and agricultural contamination are widespread. In many places, the nitrate level in groundwater has soared above the 50 mg/L permissible drinking water limit and continues to increase. Given the large number of possible contaminants, and the fact that several hundred new organic molecules are fabricated and released into the environment each year, this obviously presents a control problem that can only be tackled at the national or international level.



Running bores in Great Artesian Basin

Internationally, the quality of surface water in some locations has improved substantially in the last 30 years — thanks to the construction of waste-water treatment systems and the recognition of the need to protect and rejuvenate catchments, streams and their ecosystems — but the same cannot be said about groundwater. Over the same period groundwater quality has decreased markedly. Its usage has increased in the last 30 to 40 years — doubling in the United States since 1950. In Australia and worldwide, aquifer systems are suffering from dual pressures; the level of exploitation of the resource is increasing at the same time as they are sustaining increased levels of pollution. In Australia there is still time to reverse these trends if action is taken soon.

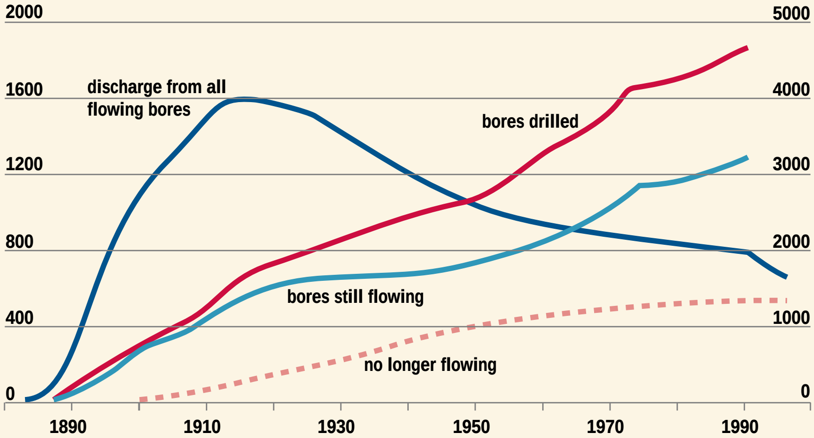
The Great Artesian Basin — the lifeblood of much of eastern inland Australia — is recharged mainly along the western slopes of the Great Dividing Range running parallel to the New South Wales and Queensland coastlines. It lies under one-fifth of the continent, but at considerable depth (1000–2000 m) in the areas where its water is used. Uncontrolled flow from bores in the Basin has caused major and unnecessary depletion of water resources (see figure below). A program of bore capping is under way, which will gradually stem the water, although at considerable cost.

If pollution were to occur in the Great Artesian Basin, the time scales already mentioned make it obvious that a clean-up would be almost impossible to achieve. It is therefore a matter of concern that in 1990 the Australian Water Resources Council listed the New South Wales recharge area as a possible site of major groundwater contamination. It listed dissolved solids, metals, pesticides, and nitrate as contaminants, and agriculture and mining as sources (AWRC, 1990).

The Burdekin River delta in Queensland is the site of a major surficial aquifer formed as the river changed its course over the centuries and deposited water in alluvial materials near its mouth. The aquifer was first used to irrigate sugarcane in the late 1800s. The area under sugarcane expanded spasmodically in the first half of the 20th century and after several dry years, such as occurred in the 1930s (see Fig. 7.8), the aquifer showed signs of stress. After substantial expansion of the cropped area and corresponding increases in water withdrawals in the early 1960s, it was clearly under threat, with sea-water intrusion on a large scale a potential consequence. This led to a detailed assessment of the water balance and trials of artificial recharge as a means of supplementing natural recharge. The Burdekin is now the site of the largest artificial recharge operation in Australia, which has sustained agricultural output for more than 25 years.

On the Swan Coastal Plain in Western Australia, groundwater from mainly unconfined aquifers provides about 60 per cent of Perth's water requirements as well as playing a vital environmental role. Rainfall is the main source of recharge while extraction by bores is the largest withdrawal component. About 80 000 private bores are unlicensed and unregulated, and rough estimates of their use for gardens suggest about one megalitre of water per garden per year. Aquifer management attempts to maintain water supply and to safeguard environmental requirements but management to date cannot take account of the unlicensed bore extraction. Authorities have identified and investigated several sources of pollutants, including nutrients from septic tanks and organics from petroleum product storage leaks (Barber *et al*., 1993).

Artesian bores in the Great Artesian Basin

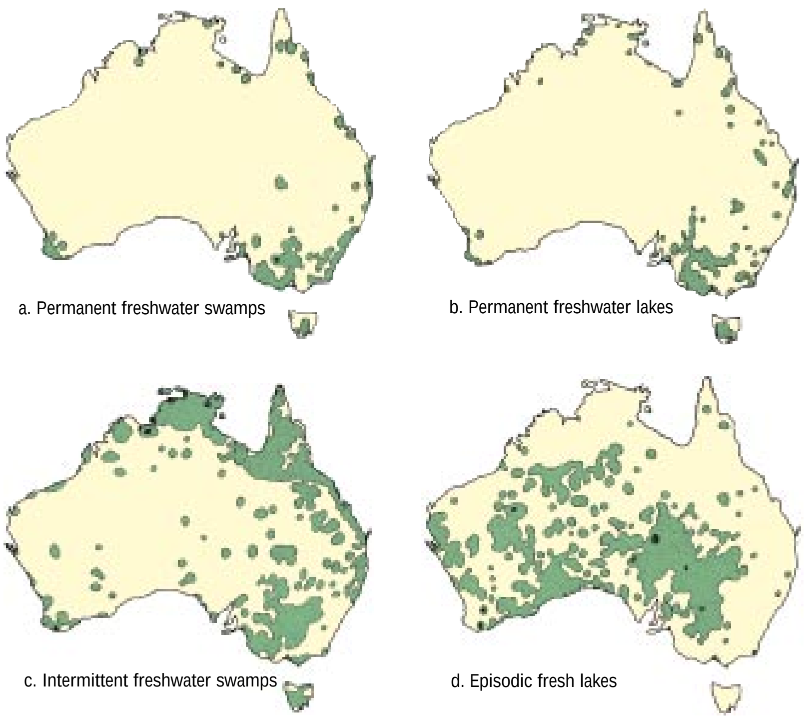


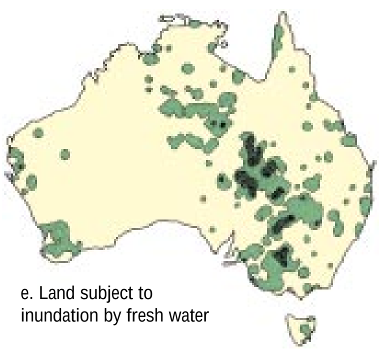
Note: bores still flowing include capped bores.

Source: Queensland Department of Primary Industries, pers. comm.

Kakadu National Park (above); a healthy wetland and Lake Wyangan, near Griffith, NSW; a degraded wetland

Figure 7.18 The distribution of wetlands in Australia





a. Wet, vegetated with persistent emergent species, water greater than 1m deep

b. Areas of open water generally greater than 1m deep, little permanent vegetation

c. Alternately wet and dry, with emergent vegetation when wet, less than 1m deep

d. Mostly dry lakes

e. Water present for short periods after rain; typical wetland vegetation not present

Source: after Paijmans *et al.*, 1985.

Habitat quality and biota

Wetlands

Wetlands are areas of land that are flooded naturally or are inundated or waterlogged on a permanent, seasonal or intermittent basis. They include marshes, ponds, lakes, billabongs, meadows and swamps. Australia has a wide variety of wetlands, many of which have unique features and are of high ecological value. Numerous species of birds, fish, amphibians and other aquatic life depend on them as habitats for survival (McComb and Lake, 1990). National inventories of wetlands were developed in 1985 (Paijmans *et al.*, 1985; ANCA, 1993), listing the various types and their locations (see Fig. 7.18). The Ramsar Convention lists 567 wetlands of international significance, 40 of them in Australia (Phillips, 1993). Although significant wetland areas are protected by various levels of reservation within national parks and World Heritage Areas, on a national scale wetlands are not well-protected from human impacts.

The extent and condition of Australia's wetlands have deteriorated greatly since European settlement by draining, changes to water regimes and increased sediment and nutrient inputs (Usback and James, 1993).

In Victoria, one-third of natural wetlands have been destroyed, including half of the area of non-permanent fresh-water wetlands. A survey of New South Wales coastal wetlands estimated a 70 per cent reduction of some types (Goodrick, 1970). In a 1992 survey, 38 per cent of New South Wales lakes were found to be degraded by nutrient enrichment and only 18 per cent were considered to be in 'good' ecological condition (Timms, 1992). Some 70 per cent of wetlands on the Swan Coastal Plain, Western Australia, have been lost since European settlement and a survey of those north and south of Perth has shown that most lakes and seasonally wet areas have been substantially or completely altered (Halse, 1989–94). In South Australia, drainage has reduced wetlands in the south-east to 11 per cent of their former area. A 1981 inventory of Tasmanian wetlands found that 63 per cent of the lowland wetlands recorded were slightly to severely disturbed (Kirkpatrick and Harwood, 1981), while the majority of larger Tasmanian water bodies are now artificial and subject to regulation.

Rivers

Australia has a wide diversity of rivers, ranging from upland perennial streams and lowland floodplain rivers to the ephemeral rivers of the arid interior. Most rivers in the lowlands and in agricultural catchments are degraded, with moderate to severe disturbance of riparian and channel habitats as well as increases in salinity, decreases in flow, changes in flow regime and increased nutrient loads. For example, in Victoria, the water quality and aquatic animal and plant life of most rivers and streams are seriously degraded (VSOE, 1988). This is worst in the central, north-west and south-west of the State, where high levels of turbidity, nutrient contamination and salinity occur, and where erosion and riparian vegetation losses are severe. A survey of the state of 27 Victorian river basins revealed that only 44 per cent (12) had more than half of their stream length in an excellent or good environmental category (Mitchell, 1990). A recent survey of the Maroochy River catchment, Queensland, found that only 14 per cent of stream length was rated environmentally as very good and the largest category (26 per cent) was classified as poor (Anderson, 1993). Such results are typical of many Australian rivers on the developed coasts.

By contrast, the northern Kimberley, Central Desert and Nullarbor Plain regions of Western Australia have suffered little disturbance or land clearing and rivers in these areas retain many of their natural values. However, rivers of the south and east of the State are frequently highly modified with multiple problems of high nutrients, sediment inputs and salinity (WASOE, 1992).

Creation and destruction of inland water habitats

Water storages and associated channels in Australia create a substantial amount of artificial wetland habitat, which is often of low ecological value and has an unnatural water regime. It usually also represents lost natural river or wetland habitat. Australia has more than 400 major dams greater than 10 m high (Crabb, in press). In Victoria in 1992, 83 400 ha were flooded for 2430 impoundments. In Western Australia, more than 80 000 hectares have been flooded (WASOE, 1992). In the nation's largest river system, 73 per cent of the length of the River Murray below the confluence with the Darling has been converted into a series of 10 weir pools (Thoms and Walker, 1992).

While irrigation and drainage channels also create aquatic habitat, it is frequently of poor ecological quality. In 1988, the Wimmera–Mallee area of Victoria had 16 000 km of open channels in domestic and stock water systems.

In 1980, the national estimate of farm dams was more than 400 000 (Timms, 1980). The number is increasing, with figures from the late 1980s putting the number of small farm dams in the south-west agricultural area of Western Australia and Victoria alone at more than 400 000 (Lane and McComb, 1988; VSOE, 1988). There are also many unrecorded and unlicensed farm dams.

Changes in wetland and river hydrology

Regulation has drastically altered the flow regime of many Australian rivers. The construction of dams and weirs causes changes in hydrology, and small farm dams and the operation of pumps in the main river channels and their tributaries also often affect flow. Only a few Australian rivers have not been altered hydrologically by human activities. For example, all 22 coastal drainages between Fraser Island (Queensland) and Lakes Entrance (Victoria) are impounded (Harris, 1985). Most unregulated rivers are in sparsely populated areas — that is, northern and central Australia.

Lake Corangamite

The condition of Lake Corangamite, a saline lake in western Victoria, has significantly declined since its major inflow stream, Woady Yaloak Creek, was diverted in 1980 (Williams, 1992). The diversity of aquatic biota and waterbirds subsequently declined by 1992. The salinity of the lake had increased by 40 per cent, water levels had fallen by about 2 m and many islands, which were previously used as nesting and refuge sites, had become peninsulas or disappeared. The biological community became typical of a high-salinity lake. Some elements of the biota — including species of shrimp, snail, fish and widgeon grass — virtually disappeared, decreasing the lake's value to bird life, and so both the diversity and abundance of birds also declined. Pelicans, ibis, spoonbills and cormorants no longer nested at the lake.

The allocation of river flows for environmental purposes is now a major issue in Australian water management. The hydrological cycle links changes in the catchment, changes in river flow, and in riparian and channel habitats. Most Australian rivers have been degraded by a combination of these factors (Cullen *et al.*, in press).

Changes in Australian river flows may take the form of all or one of the following:

- decreases in the volume of discharge or occasionally, increases (for example, with inter-basin transfers)
- changes in and reversal of seasonal flow patterns (for example, higher summer instead of winter flows)
- reduction or enhancement of the natural variability of flows on scales from hours (in hydro-electric dams) to months and years (for large irrigation or urban supply storages)
- changes in the frequency, typically suppression, of small to medium floods
- changes in the form of floods, especially the rate of rise and fall

These changes affect the channel form, sediment transport, water quality, habitats and biota of Australian streams — from small creeks to large lowland rivers. Consequently, regulation of the rivers has had major impacts on their ecological health: changing biological communities; eliminating species and reducing water quality through erosion; reducing habitat diversity; disrupting biological processes linked to floods; and flooding or de-watering key habitats. For example, the reduced frequency of flooding on the floodplain of the River Murray has severely affected red-gum forests, with reduced growth, greater mortality and minimal regeneration (Cullen *et al.*, in press). With fewer

Downstream of Gogeldrie Weir on the Murrumbidgee River; eroded, degraded riverbank.

flows, forest litter accumulates and floodwaters lose oxygen and can become toxic to fish. Since European settlement, reproduction and recruitment of fish in floodplain habitats of the Murray has been reduced and is now limited to small species such as gudgeons (Cullen *et al*., in press).

Changes caused by humans in the water regimes of Australian wetlands include changes in water-level fluctuations (size, frequency and seasonality) and changes in water balance (input, output and seasonality), all of which affect their ecological health. Such changes have occurred to the majority of wetlands along the River Murray, the western Victorian lakes and those on the Swan coastal plain (Pressey 1986, Williams 1992, Froend *et al*,. 1993).

Significant environmental degradation commonly occurs when major water inputs are reduced in flow or diverted (see the box on page 7-27). However, prolonging wetland flooding well beyond the natural pattern may also have significant impacts. The wetlands of the River Murray have a total area of about 2200 sq km, including the Coorong and Lower Lakes (Pressey, 1990). Some 35 per cent of the area that used to be flooded intermittently now never dries out, and 11 per cent receives irrigation water and now may be virtually permanently wet.

Changes to the structure of inland water habitats

Wetland and river habitats rely for their ecological health on their physical environment being maintained. In Australia, physical destruction or degradation of inland water habitats is widespread due to the removal of riparian (bank-side) vegetation, increased bank erosion, river engineering — including realignment, straightening and desnagging — and construction of barriers to fish migration. While the impacts of these practices are well demonstrated in the River Murray, their effects are common to most Australian rivers.

Riparian zones influence habitat composition, stability and energy inputs, and act as 'filters' for the exchange of water, nutrients, sediments and pollutants between terrestrial and aquatic systems (Bunn *et al*., 1993). The vast majority of Australian riparian areas have been degraded since European settlement. Clearing of native bank-side vegetation for agricultural and urban development has been extensive in lowland sections of most of our rivers.

A recent survey of the Murray and its side-channels found that riparian vegetation was in generally poor condition due to clearing, weed infestation, soil salinisation, grazing and regulation of flow (Margules *et al.*, 1990). At least 30 per cent of the study area was cleared, and introduced weeds constituted 18–63 per cent of plant species. Regeneration of red gum and black box was also affected.

Bank erosion is widespread in Australian rivers, causing increases in sedimentation and changes in channel form, both of which have negative impacts on river health. The Murray suffers conspicuous bank erosion, where slumping of banks follows rapid drops in water level. An estimated 1.8 million tonnes of material fell into the lower Murray over a 153-km section in 1988–89 alone (Walker, 1992) and channel-widening has averaged 16 cm per year since 1977 in the Lake Hume–Lake Mulwala reach (Tilleard *et al.*, 1994).

Storages trap sediment, increasing river erosion immediately downstream. Impoundments trap up to 73 per cent of sediment in the Murray (Thoms and Walker, 1992), and at least 50 km of river could be deepened substantially from its sediment supply being trapped in the Hume Reservoir (Tilleard *et al*., 1994). The 180-km Hume–Lake Mulwala reach conveys all the regulated flow destined for downstream use. Here, channel changes include lateral migration of bends, channel deepening and widening, and side-channel development. Regulation has also slowed development of key side-channels. The river bed between Hume Reservoir and Albury has deepened by up to 24 per cent since 1977. Natural changes in channel form are also occurring in the Murray — for example, near Mildura.

River engineering works, designed to provide improvements for human use, have often caused river ecosystems to deteriorate. Along the Goulburn and Upper Murray rivers some 870 and 400 stream-management works respectively, have been recorded (Vic. DWR, 1989), resulting in serious environmental degradation. Levee-bank construction separates rivers from their floodplains, as it has done for the Murray downstream of Mannum, and in many other areas of the country.

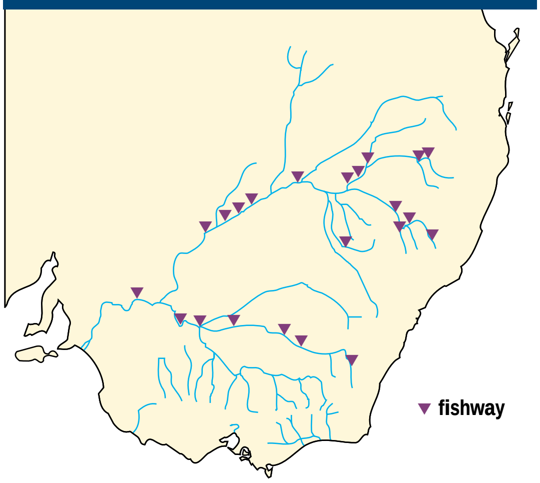
Desnagging — the removal of logs and wood debris from river channels, usually to facilitate the passage of water or boats — results in loss of biological habitat and increased stream erosion. Extensive desnagging was carried out in lowland reaches of the Murray–Darling until road and rail transport replaced paddle steamers (Pressey and Harris, 1988). Desnagging and willow removal in the Barmah Choke section of the Murray have reduced overbank flows at the Edward River and Gulpa Creek off-takes for a distance of about 20 km, affecting the health, growth and reproduction of trees in the Millewa Forest (Murphy, 1990).

Many species of inland-water fish migrate over long or short distances to complete their life cycles. Blocking of fish migration by dams, weirs and fords has resulted in population declines in many coastal catchments (Harris, 1984). Some structures have fishways, but many of these are not properly designed or maintained. Of 54 fishways in New South Wales rivers, only 10 have been assessed as effective. Twenty are recorded in the Murray–Darling Basin (see Fig. 7.19), but none is on high-level (10 m or more) dams and only two have been assessed as being effective as fish passages (Cullen *et al.*, in press). Golden perch and silver perch were once common as far upstream in the Murray as Lake Hume, but have now disappeared above Yarrawonga Weir. Dams also have the potential to cause genetic isolation of fish populations, with accompanying loss of genetic diversity.

Changes in water quality

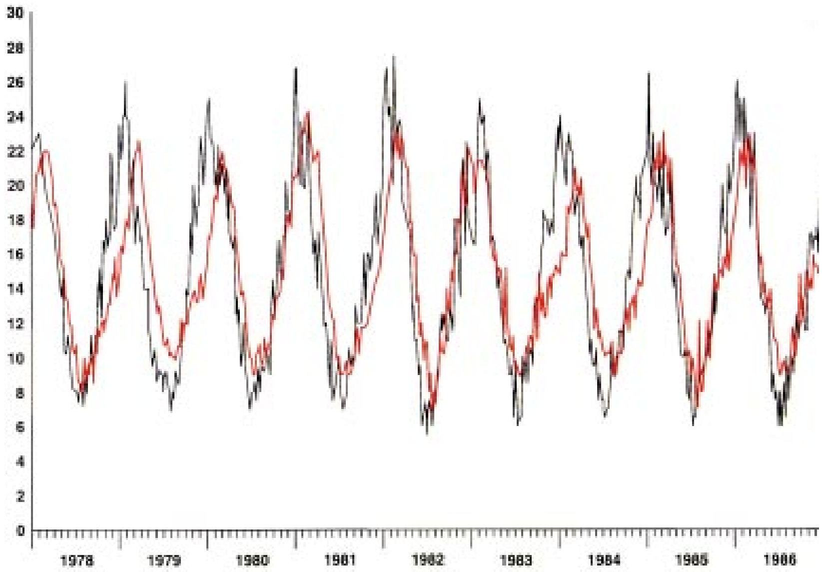
While the main aspects of the state of inland water quality are discussed elsewhere in this chapter, several other related issues affect wetland and river health. Metal poisoning of wildlife from sources such as lead shot and mercury in sediments is a problem in several inland waters. Hunters put large amounts of lead shot into wetlands — for example, Bool Lagoon in South Australia receives four to six tonnes of it per year (Lund *et al.*, 1991) and Howard Springs in the Northern Territory receives 330 000 shot per ha (Whitehead and Tschirner, 1991). Lead poisoning from shot at Bool Lagoon killed magpie geese, swans and black ducks. Mercury, a leftover from gold mining, has been recorded from the sediments and biota of the Gippsland Lakes and tributaries, with some fish above safe limits for human consumption. In Lake Eildon, 70 per cent of large trout sampled had mercury levels above those safe for human consumption. Other sites at Walhalla, Wandiligong, Chewton and Maryborough also showed mercury levels in sediments high enough to predict high levels in fish (VSOE, 1988).

Figure 7.19 Location of fishways in the Murray–Darling Basin



Source: Modified after Mallen-Cooper, 1989.

Figure 7.20 The effects of the Hume Dam on water temperature in the River Murray



Source: MacKay and Shafron, 1989.

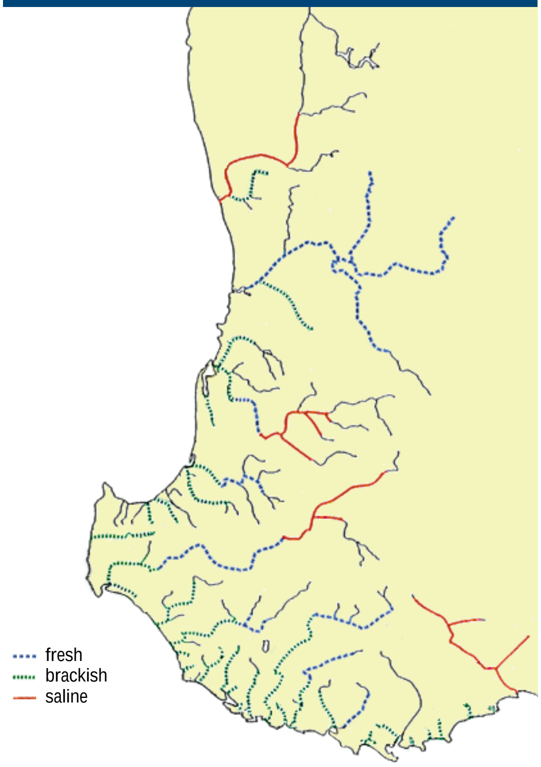
The modified temperature regime in the Murray downstream of Hume Dam (red line) does not vary as much as the natural one (black line).

Other cases of ecological impacts from metals include acid discharges from several Tasmanian mines (most notably Mt Lyell), zinc pollution from the Captains Flat mine in New South Wales, and acid drainage from the Rum Jungle mine in the Northern Territory polluting the Finniss River (Jackson, in press). While its impact is not significant on a national scale, mine discharge has had major local environmental effects on several rivers.

Changes in river temperatures and oxygen levels downstream of storages also affect the health of Australian rivers (see Fig. 7.20). The modified temperature regime in the Murray downstream of Hume Dam does not vary as much as the natural one, and seasonal changes are offset by about one month (Walker, 1985). Such effects are evident for between 40 and 100 km below several dams in the Murray–Darling Basin (Mackay and Shafron, 1989). Summer oxygen levels reflect the discharge of oxygen-poor bottom water. Such changes have caused major disturbances to the biology of several Australian rivers. Examples include the loss of native fish and invertebrate species and their replacement with exotic species such as carp, trout (*Salmo* and *Oncorhynchus* sp.) or redfin perch (*Perca fluviatilis*) (Cullen *et al.*, in press).

Many Australian rivers and wetlands are saltier than they were before European settlement and some are fresher, causing changes in their fauna and flora (Hart *et al.*, 1990, 1991). Salt-affected streams occur throughout half of Victoria and predominantly on the lower-lying plains to the north and west of Melbourne (VSOE, 1988). Salinity levels in the Yass River, New South Wales, are increasing by seven per cent per year (NSW SOE, 1993), while salinity in the River Murray increases downstream (see Fig. 7.28). In Western Australia, many rivers are more saline inland (for example, the Kalgan), and fifty per cent of south-west rivers (those that rise in agricultural areas) have increased salinity (see Fig. 7.21).

Figure 7.21 Severity of salinity stress in Western Australian rivers



Source: WA Select Committee, 1990

Inland water biota

The complex and multiple changes to the quality and extent of Australian inland water habitats have caused fundamental shifts in the structure and function of ecosystems and the composition of biological communities. There is certainly scientific evidence for major changes in Australian inland-water-ecosystem structure and function as a result of changes in habitat. But, as yet no published information is available on the extent to which such changes have occurred at a national or even regional level, other than for wetland and riparian vegetation. Indicators of change in the biota of inland waters include changes in the distribution and abundance of native fauna and flora and measures of the impacts of introduced and displaced biota, including aquatic weeds and faunal pests. While many specific examples exist of declines in the biological values of Australian inland waters associated with forestry, pesticide use, sewage effluent, mining, dam construction, increased salinity and river regulation, much effort is still required at a national and State level before the state of wetland and river ecological health can be reported in a systematic and consistent manner.

Although scientists routinely carry out widespread monitoring of water storages for plankton, there is little information on the composition of algae in other inland waters that can be used to assess the impacts of human activity. However, it is likely that the incidence of algal blooms, particularly of nuisance blue-green algae, has increased, suggesting widespread reduction in the diversity and stability of ecosystems in agricultural and urbanised catchments (see the box on page 7-48).

The composition and abundance of planktonic algal communities varies widely over different places and times, making it difficult to measure trends.

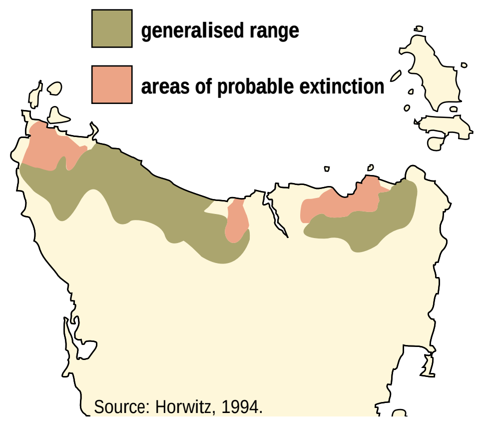
Habitat degradation has reduced the range and diversity of many aquatic plant species, especially in eastern Australia. Of our many different aquatic plants, five species are currently considered endangered (ANZECC, 1993).

Macroinvertebrates, which include aquatic insects, are both diverse and abundant in inland waters. They are surveyed to assess human impacts on aquatic ecosystems. Their communities are often affected by changes in water and habitat quality in Australian wetlands and rivers. For example, a study of Gowrie Creek, south-east Queensland, showed that the macroinvertebrate diversity declined by 90 per cent, with only two or three families present below a sewage outfall (Cosser, 1988). Such systems recover downstream, usually with marked changes in the types of species present. Studies of forestry impacts on Tasmanian and Western Australian streams show large changes in the abundance and diversity of macroinvertebrates, mainly associated with sediment inputs from logging and riverbank disturbance (Growns and Davis, 1994, Davies and Nelson, 1994) .

Scientists have also recorded changes in the distribution of many invertebrates. The River Murray crayfish (*Euastacus armatus*) has declined in range and abundance since the 1940s (Walker, 1985) and 13 out of 14 native snails have disappeared from the banks of the River Murray due to artificial changes in water level (Walker, 1994). The Tasmanian giant crayfish, *Astacopsis gouldi*, is also declining in range (see Fig. 7.22).

Native fish species have suffered declines in abundance and diversity in most regions of Australia since European settlement. Surveys in Victoria indicate that only two out of 17 segments of river basins still have high-quality native river fish populations (VSOE, 1988). Similar evidence exists for most of the country. Most species of the lowland river fish, including the murray cod (*Maccullochella peeli*), trout cod (*Maccullochella macquariensis*), Macquarie perch (*Macquaria*

Figure 7.22 Range of the giant Tasmanian crayfish



Source: Horwitz, 1994.

australasica) and barramundi (*Lates calcarifer*), have declined in range and abundance (Jackson, in press). Some 33 per cent of inland-water native fish species have undergone major reductions in range (Wager and Jackson, 1993).

In Australia, frogs are declining in number and abundance, a trend also occurring in many other areas of the world (Barinaga, 1990; Tyler, 1991; 1994). Thirty-two species have been recorded as being in decline, with only limited data available for many others. Primary causes are decline in wetland and riverine habitat and water quality. Several species of aquatic tortoise and lizards are currently listed as endangered or vulnerable (Cogger *et al.*, 1993).

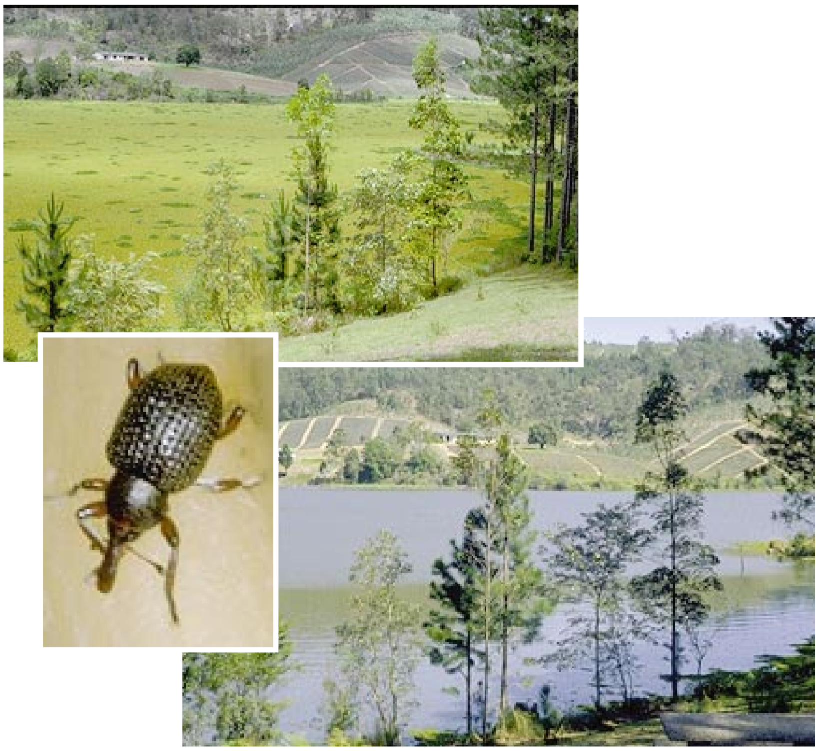
The abundance of water birds varies greatly, mainly in response to patterns of rainfall (Norman and Nicholls, 1991). Large variations in population estimates make it impossible to assess trends from current data. Populations are frequently large; Western Australian waterbird numbers were estimated at around 1.5 million in both 1989 and 1991 (Halse, 1989–94).

Three aquatic mammal species are found in Australia: the platypus (*Ornithorynchus anatinus*), water rat (*Hydromys chrysogaster*) and false water rat (*Xeromys myoides*). Of these, only the platypus is restricted to fresh water. Decline in platypus abundance or range indicates severe changes in environmental conditions. Platypuses are still known throughout their original range, but frequently have locally reduced populations — for example, in the lower Murray and Murrumbidgee rivers (Jackson, in press).

Exotic/displaced fauna and flora in inland waters

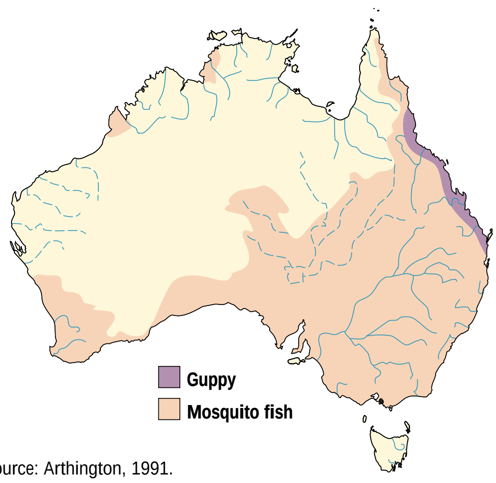
The introduction of exotic aquatic fauna into Australia, and the movement by people of native species or stocks to areas outside their natural range, have a profound effect on inland water ecosystems (Arthington and McKenzie, in press). Fauna have been introduced mainly for recreational fishing and the aquarium and aquaculture industries. Twenty exotic fish species have established or are likely to establish self-sustaining feral populations. Many of them were introduced in the 1800s and early 1900s and their spread has often been helped by active translocation (McKay, 1984). The aquarium industry imports increasing numbers of exotic aquatic species each year — worth some $2.7 million in 1994 alone. Nine species of these aquarium fish have now established feral populations. Some, like the guppy, *Poecilia* sp., have wide distributions (see Fig. 7.23). Accidental or intentional releases of exotic aquarium species are seen as a principal cause of new introductions into Australian inland waters.

Populations of exotic fish have become established in all States and Territories, ranging from New South Wales with 18 species to the Northern Territory with only one (Arthington and McKenzie, in press). The most widespread are the brown trout (*Salmo trutta*), mosquito fish (*Gambusia holbrooki*) and several species of cyprinids — the goldfish (*Carassius auratus*), European carp, redfin perch and tench (*Tinca tinca*). All of these species have aggressively expanded their ranges since first introduction, most with human assistance. Trout and salmon have been stocked intensively since the late 1800s, although climate has largely limited the expansion of their range. European carp has rapidly extended its range and continues to do so (Shearer and Mulley, 1988; Arthington and McKenzie, in press). The Boolara carp strain expanded rapidly into the Murray–Darling Basin during the 1970s and 80s and is now well established throughout Victoria (see Fig. 7.24). In the early 1990s, carp established self-sustaining populations in Tasmania. Goldfish are the most widespread of the exotic fish in Australia, being found in every drainage from the Fitzroy River in Queensland to the south-west of Western Australia and in Tasmania (Brumley, 1991).



Wappa Dam, Queensland, before and after the weevil *Cyrtobagus salvinaea* was introduced to control a *Salvinia* sp. infestation.

Figure 7.23 Distribution of guppy and mosquito fish in Australian waters



Source: Arthington, 1991.

The Lake Pedder *Galaxias*, an endangered native freshwater fish.

Direct evidence from Australia and elsewhere indicates that certain exotic fish species are hardy, opportunistic, readily dispersed, and have an impact on native biota and ecosystems. The conservation status of native fauna and the general state of inland waters partially reflect the establishment of exotic and translocated fish. However, many human pressures also affect aquatic systems. The impacts of exotic fish range from direct competition with and predation of native fauna, through habitat alteration and destruction, to acting as vectors for disease (Arthington and McKenzie, in press). Exotic fish have been implicated in the decline of nine endangered, eight vulnerable and five rare or common native fish species (Wager and Jackson, 1993). Trout are assumed wholly or partly responsible for declines in the abundance and range of nine species, as well as for changes in species composition and abundance of stream invertebrates. The negative impact of European carp on Australian inland waters includes the loss of aquatic plant species and communities in both rivers and wetlands (Roberts, 1993). This has been linked to loss of other fauna, changes in nutrient status, and algal blooms.

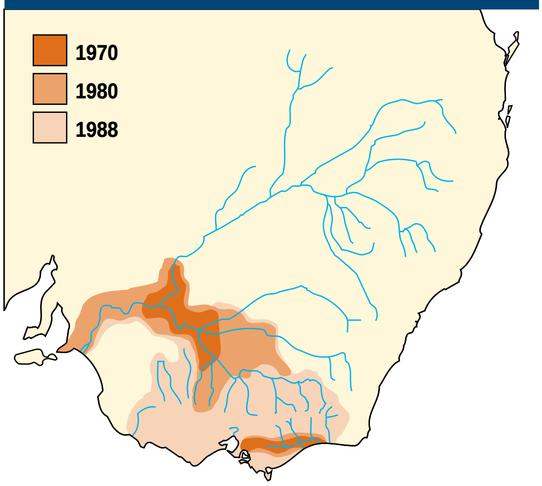
Exotic fauna pose a significant disease risk in Australian waters. Eight diseases or pathogens are known to be associated with established exotic fish species, while a further 10 have either been found in Australian aquaria or detected in quarantined aquarium fish, or are known to occur overseas in fish brought into Australia for the aquarium industry (Langdon, 1988).

Native crustaceans have been moved on a large scale, mainly in association with aquaculture or farm dams. At least eight species of crayfish of the genus *Cherax* are actively cultured in Australia, and several of these, most notably the yabby, the redclaw and the marron, have been shifted to large areas outside their natural range (Kailola *et al.*, 1993). The yabby (*C. destructor*) is the most widespread. Risks to inland waters associated with these moves include disease, physical damage to habitats through burrowing, competition with native crayfish and the transmission of symbiotic or parasitic organisms.

Other introduced fauna have also had significant impacts on inland waters. These include several waterbirds, the cane toad, fresh-water snails and other invertebrates (Arthington and McKenzie, in press). The cane toad (*Bufo marinus*) continues to expand its range in eastern and northern Australia and is now known to extend from the eastern end of the Gulf of Carpentaria to New South Wales. The New Zealand snail *Potamopyrgus niger*, first introduced into south-eastern Australia in the 1800s, has replaced native hydrobiid riverine snails in disturbed catchments.

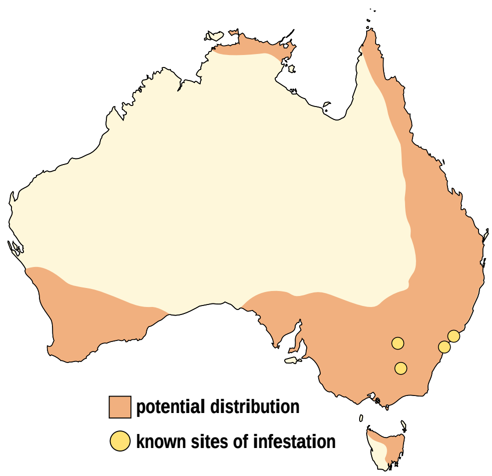
Australian inland waters contain 65 species of aquatic plants regarded as weeds, about 15 of which are significant pests and 13 of which could become so (Arthington and Mitchell, 1986; Humphries *et al.*, 1991) A further five exotic species that are not yet present in Australian inland waters could pose a serious threat if introduced. The established species have been introduced and spread by several routes: intentional plantings for aesthetic, economic or

Figure 7.24 Range expansion of the Boolara strain of European carp up to 1988



Source: Shearer and Mulley, 1988.

Figure 7.25 Known and potential distribution of alligator weed



Source: after Julien, 1995.

management reasons; accidental or intentional releases or plantings associated with agriculture or the aquarium industry; or accidental translocations from other sources.

Exotic aquatic plants are becoming more abundant in all States and Territories. Such increases may be due to recent local introductions or may be a response to deterioration in the quality of wetlands or rivers. Extensive cover of floating or tall shrubby aquatic weeds decreases the amount of light penetrating the water, causing declines in the diversity and abundance of native submerged plants, as well as reducing dissolved oxygen levels and temperatures, which have a negative impact on aquatic fauna (Jacobs, in press). Intense infestations of aquatic weeds also reduce flow rates in wetlands or rivers, decreasing mixing and enhancing sediment build-up, and thermal layering of the water body.

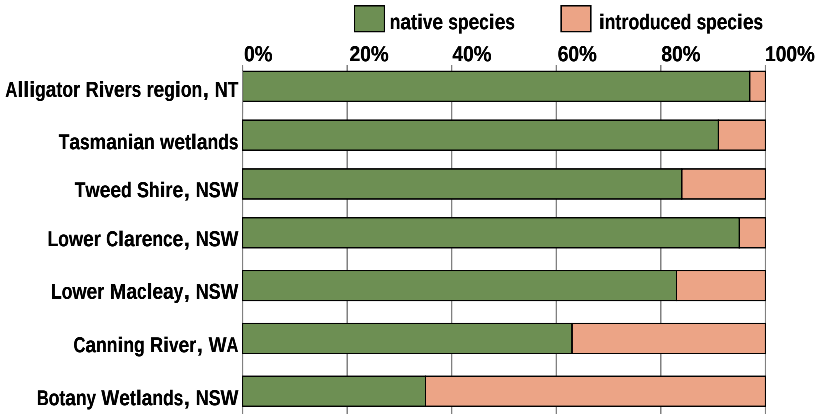
Some of the introduced aquatic plants posing significant environmental risks for Australian inland waters are the giant sensitive plant (*Mimosa pigra*) and the alligator weed (*Alternanthera philoxeroides*). *M. pigra* is causing a major and expanding infestation of Northern Territory wetlands and their riparian zones (Harley, 1992; Lonsdale, 1992). Alligator weed, introduced around 1947 in central coastal New South Wales has been found in locations from southern Queensland to the Australian Capital Territory. The most recent and extensive outbreak occurred at Barren Box Swamp in central New South Wales. A recent study of the potential spread of this species suggests that it is likely to become a more extensive problem over the next decade (see Fig. 7.25), although biological control has been instigated (Humphries *et al.*, 1991; Julien *et al.*, 1992).

There is little information on the impacts and spread of many aquatic weeds in Australia. The proportion of exotic, aquatic plant species in Australian wetlands varies from zero in remote areas to almost complete local dominance in some less-isolated and smaller wetlands (see Fig. 7.26). Where infestations occur, the area covered by exotic species is highly variable (Jacobs, in press), ranging from around two per cent for the lower Macleay and Clarence River wetlands up to 60 per cent for the Botany wetlands (all in New South Wales). The density of some of these weeds ranges up to 15 kg per sq m, and *M. pigra* annually produces about 0.8 kg dry weight per sq m.

Exotic plants also invade the riparian zone and floodplains, the most notable species being the rubber vine (*Cryptostegia grandiflora*) in northern Queensland, hymenachne (*H. amplexicaulis*), *M. pigra* and willows (Bunn *et al.*, 1993) (see page 4-19).

As with animal pests, the impacts of exotic weeds often cannot be separated from other impacts, to which the weed invasion may often be a response. Changes to wetland habitats through altered water regimes or water quality and through physical disturbance to aquatic habitats and riparian zones can all favour the spread of introduced or translocated aquatic or riparian plants. Their quick growth responses to pulses of nutrients, high dispersal ability and ability to survive stress periods are also important.

Figure 7.26 The proportion of native and introduced plant species in the various wetlands

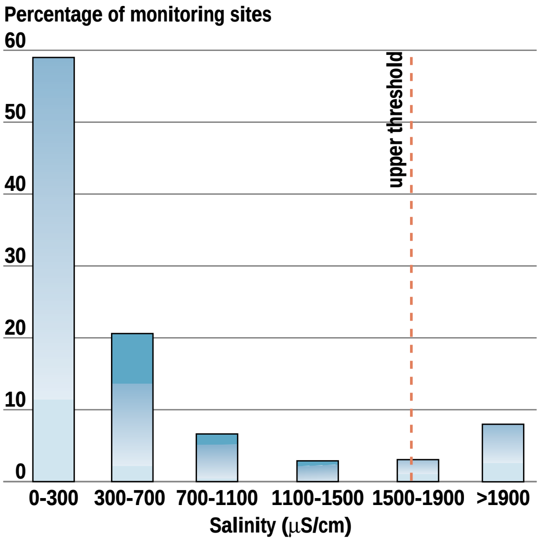


Source: Jacobs, in press.

The message about habitat quality and biota

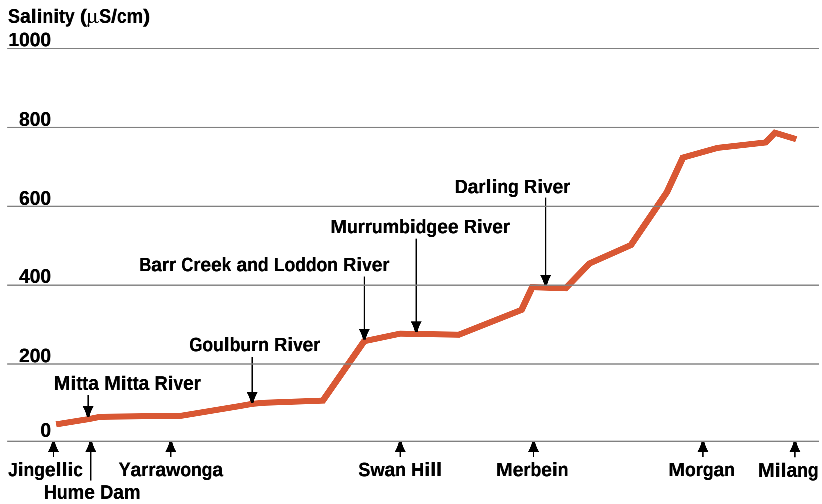
- Aquatic habitat quality has deteriorated markedly in areas of agriculture, urban land use and substantial water regulation.
- In many parts of Australia (such as the wet tropics and mountainous areas) where such changes have not occurred, aquatic habitat is still of high quality.
- The area of natural wetlands has been significantly reduced since European settlement.
- Large areas of artificial wetlands (farm dams, sewage treatment ponds, reservoirs, and irrigation channels) have been created, but these are often of low ecological value.
- Regulation, physical barriers, erosion, desnagging, channel modification, introduced species, pollution and algal blooms have all substantially altered and degraded river habitat quality.
- The range and abundance of many species of native aquatic biota have declined significantly, to the point where many are threatened and endangered.
- The introduction, spread and establishment of a large number of exotic biota (such as carp, trout and *Mimosa pigra*) have exerted significant impacts on the biological communities and habitats of inland waters.
- No national or even regional system exists for reporting on the ecological health of Australian inland waters. Systems presently being developed are limited in coverage and developing slowly.

Figure 7.27 Conductivity in Australian rivers



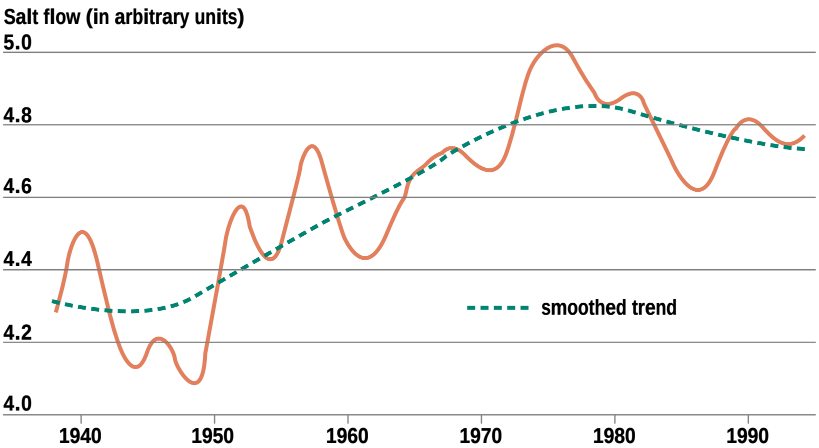
Source: Liston and Maher, in press.

Figure 7.28 Downstream salinity profile of the River Murray



Source: Mackay and Eastburn, 1990.

Figure 7.29 Generalised salinity trends in the River Murray at Morgan



Salinity increased from 1945 to 1977. Since then it has levelled out, coinciding with the completion of a number of salinity-mitigation schemes. It is not clear how much of the change is due to these schemes.

Source: Morton, 1995.

Water quality

The key environmental water-quality problems are: salinisation, nutrient enrichment, sediments, pesticides, trace metals and organic susbstances.

Indicators of environmental water quality

Indicators of the quality of water needed to maintain aquatic ecosystems have been chosen to reflect potential adverse impacts on water bodies of the problems identified above, and to be scientifically credible and easy to understand (Liston and Maher, in press) (see Table 7.9).

The Australian Water Quality Guidelines for Fresh and Marine Waters (AWQG), produced by the Australian and New Zealand Environment and Conservation Council (ANZECC) and other state of the environment reports provide thresholds for physical and chemical constituents that, if exceeded, are likely to produce an impact on the ecosystem (Liston and Maher, in press; ANZECC, 1992). The Guidelines provide a single guideline value for some indicators, such as conductivity. However, for most of the indicators used in this report the AWQG recommend a range of values, to reflect the marked differences that occur in natural water quality across Australia and the different conditions to which various aquatic ecosystems are adapted. In this section, water bodies are grouped into two categories based on their altitude — namely, upland and lowland ecosystems. For most indicators, upland aquatic ecosystems require water quality of a higher standard than lowland ones.

Australian waters — broad-scale issues

Artificially high salt levels are a major issue for many rivers in Australia. Aquatic ecosystems are adapted to particular salinity regimes and any changes can result in adverse impacts on the biota.

The data presented in Figure 7.27 confirm that salinity (as measured by conductivity) is a cause for concern in some rivers. Most of the sites where conductivity exceeds 1500 microSiemens per cm were on west-flowing New South Wales and Victorian rivers, and on Western Australian rivers. East-flowing coastal rivers in general do not show salinisation. Salinity of water storages has not been identified as a major national issue so no data on it are provided here.

Table 7.9 Indicators of environmental quality

Broad scale issues	**Indicators**
Salinity	Conductivity
Eutrophication	Total phosphorus,
Eutrophication	Chlorophyll a
Suspended sediment	Turbidity
Local issues	**Indicators**
Toxicity	Pesticides, Trace metals
Eutrophication	Biochemical Oxygen Demand (BOD)

All of these indicators can be related to potential or actual ecosystem impact.

Source: Liston and Maher, in press.

A more detailed examination of salinity in Australian rivers reveals that great differences can occur between rivers, in different parts of the same river (see Figure 7.28) and at different times at the same place (see Fig. 7.29). This variability is partly natural and partly caused by human activities. It indicates that care must be taken when using average levels of salinity or when trying to identify long-term trends.

As more nutrients enter rivers and storages, marked changes in aquatic ecosystems can occur, such as the more frequent occurrence of algal blooms — an indication of ecosystem degradation (see the box on page 7-48).

The key plant nutrients are phosphorus and nitrogen. In nutrient limited waters, small additions of these nutrients can lead to rapid plant growth. Phosphorus is usually the more significant nutrient and is commonly used as an indicator of potential algal problems (see Figs 7.30 and 7.31). Other factors influencing algal growth include light regime, salinity, temperature, the ways the waters mix and levels of nutrients, including trace elements such as molybdenum. A more common way to measure the amount of suspended algae in a waterbody is to measure the concentration of pigment (chlorophyll) in algae. In 75 per cent of lakes and storages, chlorophyll levels exceed those indicative of a healthy ecosystem. The link between the concentration of phosphorus in a lake and the amount of chlorophyll (or algae) is moderately strong. A number of storages have strong average relationships (see the box on page 7-48).

In this section turbidity is used as an indicator of suspended sediment. Increased suspended sediment may smother bottom-dwelling animals and plants, and may reduce light penetration, thereby favouring algal species such as blue-green algae.

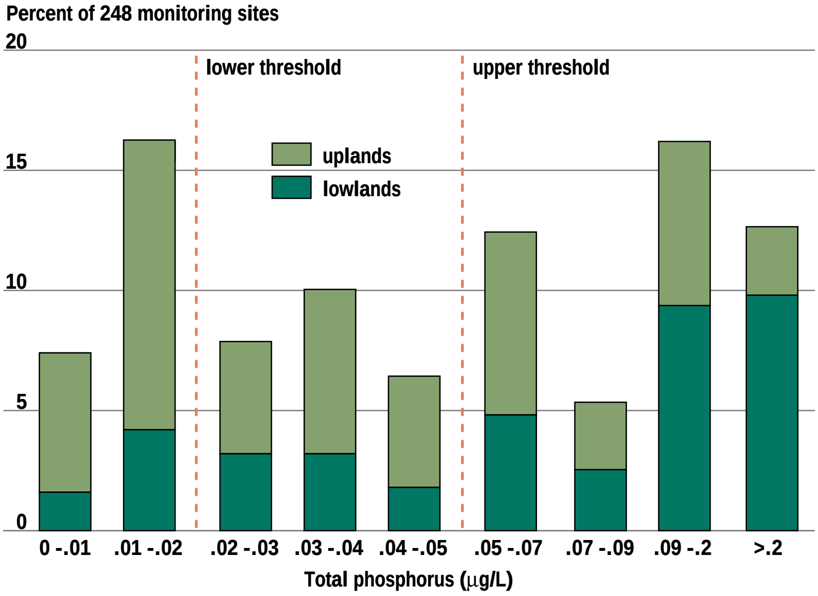
Turbidity in Australian waters shows a significant natural variability, much of which can be related to changes in flow. Generally, the higher the flow the more turbid the water and hence the greater the sediment load in transport.

Australian waters — local issues

Although they are thought to affect only a limited number of aquatic ecosystems in Australia, local impacts are likely to be important. Water-quality problems are often linked to particular local activities (Liston and Maher, in press). The most important of these impacts on aquatic ecosystems are due to trace metals derived from mining, urban

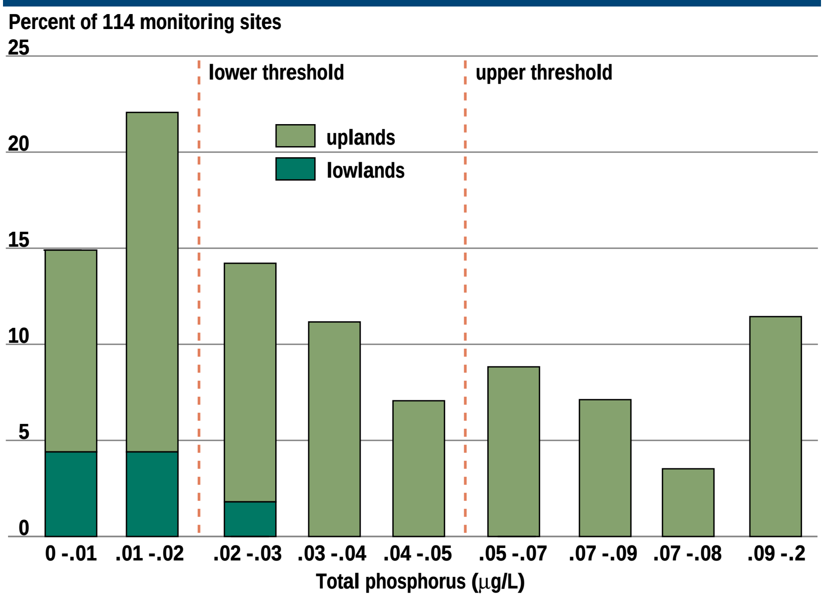
Acid mine drainage in the Mt Lyell area of western Tasmania.

Figure 7.30 Total phosphorus level in selected Australian rivers



Source: Liston and Maher, in press.

Figure 7.31 Total phosphorus level in selected Australian reservoirs and lakes



Source: Liston and Maher, in press.

Natural differences occur in the concentrations of phosphorus in Australian waters. In general, upland waters should have the lowest natural levels and so should be below the lower threshold. Lowland waters can have higher natural levels of phosphorus and should fall below the upper threshold. For both eco-regions, a large proportion of sites have phosphorus concentrations above their relevant threshold. Of the sites that exceeded the threshold by a factor of two or more, most were lowland ones. Many of these water bodies are in regions used for grazing, intensive agriculture or urban development — activities that increase phosphorus loading to ecosystems. Most storages have phosphorus concentrations below the upper threshold, with some high concentrations, particularly within some upland storages.

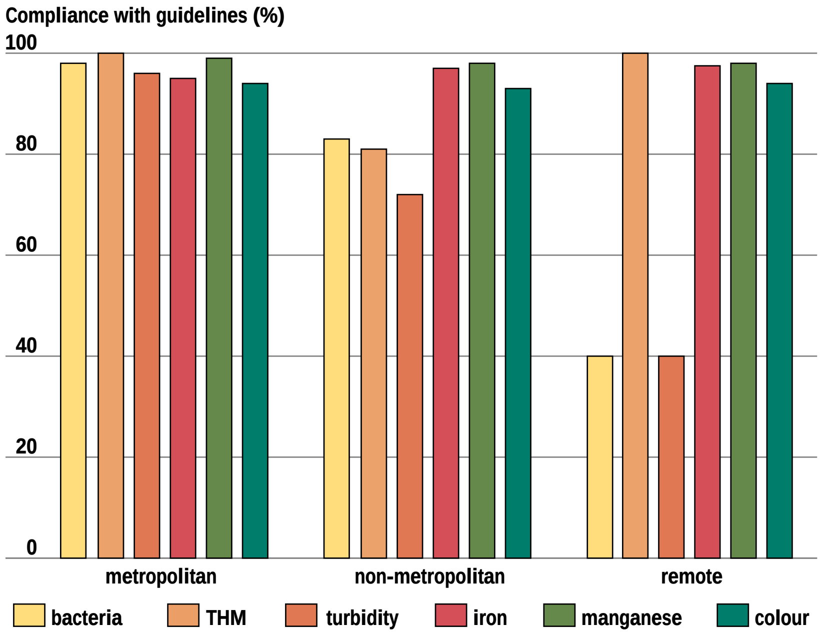
Table 7.10 Indicators and guidelines for drinking water quality

Indicator	Guideline level	Reason for concern
Microbiological indicators		
Total coliforms	0 CFU/100 mL	Indicator of faecal pollution
E. coli or thermo-tolerant coliforms	0 CFU/100 mL	
Chemical indicators		
Aluminium	0.2 mg/L	Aluminium flocs. Affects appearance and should preferably be reduced to 0.1 mg/L (potential health problems for dialysis patients)
Chlorination by-products (trihalomethanes)	0.25 mg/L	By-products induce tumours in rats and mice
Nitrate (as NO_3)	100 mg/L (50 mg/L in infants)	Can cause methaemaglobinaemia (blue-baby syndrome) especially in infants
Aesthetic indicators		
Turbidity	5 NTU	High levels affect palatability and appearance
Colour	15 HU	as above
Taste (as salt)	500 mg/L	affects palatability
Supply amenity		
Calcium and magnesium (as carbonate)	200 mg/L	Requires increased use of soaps; causes pipe corrosion or deposits
Iron	0.3 mg/L	Can cause staining of clothing and affects taste
Manganese	0.05 mg/L	as above

Notes:
CFU — colony forming units
NTU — nephelometric turbidity units
HU — hazen units

Source: NHMRC–ARMCANZ, 1995.

Figure 7.32 Bacteria, trihalomethanes (THM), turbidity, iron, manganese and colour in Australian water supplies



Source: Maher *et al.*, in press.

run-off or industrial activity, and to organic chemicals derived from industrial or agricultural activity. Examples of the former include trace metal pollution of the South Esk River in Tasmania and the Finniss River in the Northern Territory. Examples of pollution by organic substances include pesticides in the Namoi and Gwydir rivers in New South Wales, sugar-mill effluent in Queensland, milk, dairy wastes and paper pulping effluent. A commonly used measure of organic pollution is biological oxygen demand (BOD).

Stormwater from urban areas contributes a range of potential pollutants (trace metals, hydrocarbons, suspended sediment, bacteria and organics). Because watercourses are often physically modified (dredged, straightened etc.), the precise causes of degraded aquatic systems are difficult to determine.

Tap-water

Water for drinking should be free of disease-causing micro-organisms, harmful chemicals, objectionable taste and odour, and excessive levels of colour and suspended material (WHO, 1993).

Many factors control whether we have a consistently safe supply of drinking water. These include catchment protection and management, coverage of storage tanks, water treatment and maintenance of a reticulation system that prevents the entry, growth and transmission of pathogens. Storing water in reservoirs allows time for particles to settle out and pathogens to die.

Indicators that can be used to measure the effectiveness of these practices focus on microbiological and chemical health and safety, and on the aesthetic acceptability of drinking water.

Drinking water guidelines and indicators

The guidelines for drinking water are based on concentrations of constituents, that is, indicators, below which no harm or offence should occur to individuals. They provide the following benchmarks.

- Health criteria: water used for drinking, beverage preparation and cooking purposes should be free of harmful levels of toxic substances and pathogens.
- Aesthetic criteria: water to be consumed should be free of objectionable taste and odour, and excessive levels of colour and suspended solids.
- Amenity criteria: water used for washing, bathing and other domestic purposes should be free of gross microbial contaminants and should not contain excessive levels of staining, corrosive or scale-forming agents.

While it is possible to ascertain levels of performance against the benchmarks, it is generally recognised that the guidelines are conservative, with high built-in safety margins.

A comprehensive assessment of the 350 substances listed in the guidelines is too costly for many organisations. It is also unnecessary because most of these substances do not occur in Australian drinking water supplies.

The most commonly used indicators and guidelines are shown in Table 7.10. Obviously, this represents only a small fraction of the 350 substances mentioned above.

Assessment of Australian tap-water quality

In the analysis of drinking water quality it is useful to classify settlements into metropolitan, non-metropolitan, and remote settlements. Smaller communities reliant on surface water have inadequate resources to provide and operate water-treatment facilities, and few barriers are in place to ensure the removal of pathogens, turbidity and colour. For Aboriginal and other remote communities it is worth noting that supply of water has been identified as being at least as important as its quality (Federal Race Discrimination Commissioner, 1994).

Data for bacteria, turbidity and trihalomethanes show that, in general, metropolitan areas with protected water supply catchments and full treatment of water (coagulation, filtration and chlorination) perform well against the drinking water guidelines (see Fig. 7.32). The quality of water in rural areas, which rely on rivers and dams and lakes, is lower and more variable, reflecting the catchment land uses and standard of treatment. Settlements classified as remote, such as Aboriginal settlements, and isolated rural communities, show the greatest and/or most frequent non-compliance with guidelines, reflecting poor water treatment and poor source-water quality and availability. However, remote settlements have few excesses for trihalomethanes, a by-product of chlorination because their water supplies are rarely disinfected. For iron, manganese and colour (see Fig. 7.32), all Australian drinking water supplies for which data were made available show levels of compliance greater than 90 per cent.

Closed versus open catchments

In the latter part of the 19th and the early 20th centuries, several water supply authorities adopted a closed-catchment policy to protect water quality, with good effect.

With growth in populations and increased demand for timber resources and recreational opportunities, the policy has come under intense pressure in recent years, and restrictions over activities in some catchments have been relaxed. In some cases this is being compensated for by increased disinfection and monitoring of supplies from these catchments, as an added safeguard.

Adequacy of water treatment

Where a source water varies in quality over time and it exceeds the guidelines, it needs to be stored, managed and treated to ensure a reliable and safe quality of supply. The level and type of treatment are determined in relation to the potential health (see Table 7.12) or aesthetic concerns, and to the level of suspended solids (see Table 7.11).

Water treatment may consist of simple disinfection, or a sequence of flocculation, coagulation, sedimentation, filtration, and disinfection

Table 7.11 Water supply concerns and treatments

Health/aesthetic concern	Cause	Treatment
transmission of disease	bacteria, viruses or protozoa	storage, coagulation/filtration, disinfection
chlorination by-products (carcinogenic compounds)	chlorination and organics	activated carbon filtration, chloramination, ozonation
colour, taste, odour and algal toxins	organics, iron, bacteria and algae	oxygenation, dissolved air filtration, activated carbon filtration
turbidity	suspended solids	coagulation, filtration, storage
salinity	high mineral content	water de-ionisation
hardness	high calcium and magnesium	water softening

Source: Maher *et al.*, in press.

processes. Poor water clarity and high colour affect the general acceptability of drinking water and often result in customer complaints. High turbidity reduces the effectiveness of disinfection, necessitating higher doses of chlorine. Turbidity also increases the likelihood of pathogen survival. For this reason, performance against the guideline for turbidity is being more closely scrutinised.

Because development has intensified in many catchment areas, and controls on the movement of nutrients are inadequate, the incidence of algal blooms has increased within a number of water supply reservoirs in recent years.

Well-designed offtake structures can be used to limit the amount of algal material entering supply systems.

Treatment plants incorporating full flocculation/sedimentation, activated carbon filtration and chloramine-based disinfection can substantially reduce the nuisance by-products of algal breakdown and trihalomethane formation.

These problems highlight the value of having effective planning controls over catchment land uses, and total-catchment management plans as a way of maintaining high water quality.

The message about water quality

- Australia experiences water quality problems caused by salt, pathogens, nutrients, algae and suspended sediments.
- Regional and local water quality problems are associated with nutrient and organic enrichment, pesticides, trace metals and industrial pollutants.
- In particular, high levels of phosphorus, in conjunction with reduced flows in streams, have resulted in extensive and frequent blooms of toxic blue-green algae. These blooms may be increasing in frequency and intensity and can have major consequences.
- Increasing salinity and turbidity in some aquatic environments have contributed to the elimination of sensitive species, resulting in altered ecological communities.

Table 7.12 Main groups of water-borne micro-organisms of concern for human health in Australia

Disease-causing group	Typical pathogens	Health risk
Faecal bacteria	Salmonella excluding *S. typhae*; *Shigella*, *Vibrio cholerae*, enteropathogenic *E. coli*	Mainly gastroenteritis; risks variable; risks from organisms such as cholera now very low
Faecal protozoans	*Cryptosporidium* and *Giardia*	Gastroenteritis; risks uncertain, but possibly quite significant
Viruses	Enteroviruses, Norwalk virus	Risks, if any, extremely low
Parasites (tapeworms)	Zoonoses such as *Echinococcus* (hydatids)	Respiratory and skin infections; risks low
Environmental bacteria	*Legionella*, *Aeromonas*, *Pseudomonas*, *Mycobacterium*	Encephalitis; risks very low but usually fatal
Environmental protozoa	*Naegleria*	Generally low, but always fatal

Source: Maher *et al.*, in press.

Table 7.13 Responses to minimise health risks

Potential type of water contact	Management options	Treatment options
Water supply	Protect catchments, storages and reticulation systems	Clarification and disinfection
Spas and pools	Treatment	Filtration and disinfection
Cooling towers	Hydraulic design and drift prevention	Continuous disinfection
Sewage	Avoid cross connections, discharge of untreated sewage and direct contact with raw sewage	Treatment and disinfection prior to discharge or reuse
Stormwater	Avoid recreational contact	Extended detention where feasible
Recreational use	Avoid contact with sewage-contaminated water	Reliance on natural die-off, sedimentation and predation Avoid recreational contact after heavy rain

Source: Maher *et al.*, in press.

- Domestic water supplies for large cities generally have excellent health and aesthetic qualities.
- Although limited information is available, domestic supplies for rural and remote communities are found to be highly variable, ranging from excellent to poor, with respect to health and aesthetic qualities.
- Where problems in domestic supplies exist they are generally a combination of micro-organisms, chlorination by-products, taste, odour and algal toxins, iron, manganese, turbidity, salts and hardness.
- Increasing development pressures on catchments are resulting in deteriorating water quality and need for treatment.
- Australia's drinking water supplies are generally free of industrial pollutants.

Response

Responses have been of many types, including Federal, State and local government policies, legislation, administrative structures, community education, direct management, changes in community behaviour, setting resource-use targets and so on, as well as initiatives taken directly by communities themselves. They may take the form of broad, strategic solutions (macro-level) or occur at a more local level (for example, a single paddock).

Responses directed towards improving the condition of Australia's inland waters are concentrated in five main areas:

- macro level responses, such as the National Strategy for Ecologically Sustainable Development, State of the Environment reporting, the Murray–Darling Basin Initiative, water market reform, best practice, long-term monitoring and water quality guidelines
- catchment management
- water conservation and management
- biological conservation and management
- water quality control and management

Many other obvious target areas for response are not yet being adequately addressed. These are presented at the end of this section, along with an assessment that indicates the extent of implementation and effectiveness of each response strategy (see Table 7.14).

Macro-level responses

Various State and national legislative instruments and policies can influence the quality of inland waters. Relevant Acts include legislation relating to agriculture, forestry, health, environment, export of various commodities requiring Foreign Investment Review Board approval or Commonwealth government licensing, water supply, irrigation, waste disposal, catchment management, land management, rivers and waterways, industry licensing and approvals, planning and development, local government and industry agreements. All of these tools can be combined to form appropriate responses.

Government and opposition policy statements also provide a basis for the development of responses. However, it is quite common for policy statements to be inconsistent or to conflict across sectors, which can make them less useful unless the boundary issues are resolved satisfactorily. The COAG 1995 Water Reform Agreement provides a national framework to overcome some of these difficulties.

Murray–Darling Basin Initiative

This program promotes and coordinates effective planning and management, for the equitable, efficient and sustainable use of the land, water and other environmental resources of the region. It relies on the Commonwealth and the four State governments concerned — New South Wales, Victoria, South Australia and Queensland —

Pathogens, public health and water pollution

Water polluted by animal and human wastes can seriously affect human health. Pollution barriers, such as closed catchments and water treatment, are intended to protect major Australian water supplies, and increasingly stringent standards are being applied to sewage discharges. However, these approaches can and do fail. Waterborne diseases still far out-rank potential risks from chemicals in water. Even with sophisticated water treatment, in Australia there is still a risk of becoming ill from drinking water, and from water-based recreation (see Table 7.12).

Pressures

Risks arise from many types of water contact, including consumption of drinking water, use of spas and swimming pools, inhalation of cooling-tower drift and swimming in open waters.

Rapid urbanisation and increasing intensity of rural land use are reducing the integrity of many water supply sources, especially where supplies are inadequately treated. Greater volumes of waste water and lack of treatment of stormwater discharged to lakes and streams are issues of increasing concern, as many rural areas use water from these sources without treatment.

State of supplies

Some waterbodies may be improving in quality because of point-source discharge controls for abattoirs, feedlots and sewage. Overall however, general quality is probably decreasing because of increasing land use pressures and lack of management of stormwater.

Recent disease incidents include an apparent viral outbreak affecting some thousands of individuals just outside Melbourne (presumed to be from sewage-contaminated supply). Outbreaks of gastroenteritis in country towns are often attributed to unprotected and untreated supplies but this has not been well documented. The intermittent nature of outbreaks, different types of water contact and the fact that food poisoning and direct person-to-person transmission of disease are also routes for infection makes tracing of waterborne disease outbreaks difficult.

Fully treated water supplies are buffered against any changes in source water quality ensuring consistently high quality at the tap. Recent improvements in the understanding of health effects of microorganisms and disinfection practice have almost eliminated the risk presented by *Naegleria*, but the significance of finding organisms such as *Cryptosporidium* in water supplies, a result of improved detection methods, is not yet clear.

Even though source water quality may be declining, water supplied at the tap is satisfactory microbiologically because of good water management and treatment in cities.There is some evidence of improved drinking water quality in rural New South Wales and Victoria. The number of supplies treated in Australia has increased.

Societal responses

Demands to increase water treatment have arisen because of increased community expectations and also because of contaminated sewage.

Historically, a closed-catchment policy and disinfection of water supplies are the major responses to the risk to public health (see Table 7.13). Chlorination results in the formation of potentially carcinogenic by-products such as THM. However, the risks from disinfection by-products such as trihalomethanes are many times lower than those presented by disease-causing organisms that the treatment destroys.

Catchment protection, especially where supplies are derived from largely unoccupied catchments, should remain a priority. Little opportunity exists for closing catchments already developed. Authorities should resist pressure to open up protected catchments and to urbanise groundwater catchments.

working together with the people of the Murray–Darling Basin community to implement and achieve its goals (MDBC, 1990; 1993b; 1995b). The Initiative is one of the largest integrated catchment management programs in the world, encompassing more than one million sq km.

The key to the Initiative is the Natural Resources Management Strategy,(released in 1988) which provides philosophical and organisational structure for governments and communities to coordinate their work.

The Strategy aims to:

- maintain or improve water quality through ongoing research into the problems affecting catchment areas and the run-off entering rivers
- control and, where appropriate, reverse land degradation
- protect, and in some cases rehabilitate, the natural environment
- conserve the cultural heritage

Two funding programs support the Strategy: the first covers investigations and education, and the second integrated catchment management. The former finances the research needed to study the resource management problems facing the Basin and to develop solutions and management tools to treat them. The outcomes are then translated and implemented into practical on-the-ground solutions under the second program, which is based on integrated regional land and water management plans. To ensure commitment from the community, integrated catchment management activities require a significant financial contribution of at least one-third from the local community.

The Murray–Darling Basin Commission is responsible for coordinating the efforts of the governments and communities involved in the management of the Basin. The Commission receives its direction from decisions of the Murray–Darling Basin Ministerial Council, which consists of Natural Resources Ministers representing the various government agencies in the Basin.

The Waterwatch project encourages community participation in long-term monitoring activities.

The Murray–Darling Basin faces grave and worsening degradation of its land and water. The development of an appropriate structure for its management has been a long and painful process. The Initiative brings this process to maturity — as perhaps best demonstrated by the Council's recent landmark decision to place an interim limit on further water diversion from the Basin's rivers (MDBMC, 1995). A final cap on water diversion will be made by 30 June 1997.

Water market reform and irrigation industry restructuring

As well as undergoing recent expansion in some sectors, the irrigation industry is being extensively restructured. This is because of changes in water pricing to seek full cost recovery, the ability to trade in water, the emergence of major environmental problems — such as rising watertables and salinisation — and continuing reductions in farmers' terms of trade. Restructuring will not be easy, will involve difficult decisions by irrigators and agency managers, and may involve considerable pain for individuals and communities. However, restructuring is necessary to ensure a profitable and sustainable future for the industry, based on the realistic cost of water.

In areas of mixed farming, such as the western edge of the riverine plains between Kerang in Victoria and Wakool in New South Wales, broad-scale flood irrigation is now only marginally profitable. As a result of proposed economic reforms and environmental constraints imposed by salinisation, many irrigators may decide to sell their water allocation and retire their properties from irrigation. Regions not suited to sustainable irrigation will decline in prosperity, although alternative dryland agricultural industries may develop. By contrast, irrigators in more suitable regions may purchase water from the market, invest in upgraded delivery systems and increase more-profitable activities such as cotton-growing, horticulture or dairying. Expansion of irrigation in areas such as the Sunraysia and Riverland regions of the southern Murray–Darling Basin is likely to increase prosperity there. Additional changes are also occurring, including aggregation of farms into larger units to achieve economies of scale, adoption of improved production technology, particularly in relation to inputs of water and nutrients, and training of irrigators in management and marketing.

The large-scale restructuring of the industry should lead to greater water-use efficiency, as well as sustainability and improved profitability.

Best practice

Adoption of best practice methods for all land uses, including urban, industrial and rural, has the potential to bring about substantial improvements in the quality of inland waters. Such methods are being devised through world-wide benchmarking as well as through experimental jointly funded programs like Landcare.

Long-term monitoring

Monitoring provides data that can be used to indicate broad and specific changes to background environmental conditions as a result of both natural and man-made pressures.

Long-term monitoring is critical for providing data that highlight trends in a system — whether it is improving or degrading further. At times, data may need to be collected over long time periods for the significance of change to be fully apparent. Although people who collect and interpret data know this only too well, government agencies and governments themselves often need to be convinced of the role of monitoring and the importance of long time-series data. In a period when many government agencies are undergoing severe financial restrictions and perpetual restructuring, and adopting shorter planning perspectives, agencies are reducing monitoring or even ceasing it in some areas. This is particularly significant for basic hydrographic monitoring — formerly managed by State water authorities. Many have cut back only to areas of immediate interest for possible water resource development. However, the data agencies used to collect are often critical for many other areas of research and monitoring, such as flora and fauna and nutrient loads. Governments at all levels remain to be convinced of the importance of long-term monitoring, which needs to be reflected in guaranteed funding over reasonably long time-frames, not subjected to the annual budget cycle. They also need to understand the differences between monitoring and research and the relative roles of each.

In Australia, long-term monitoring of critical sites provides the only way of telling whether changes are occurring to the environmental state, and of estimating the rate of change and its significance.

Water agencies in all States carry out measurements of stream flows and height on rivers in which they are interested (usually those that are or could be used for water supply). These gauging measurements (gauging) are also carried out in some other areas. Modern digital loggers and automatic samplers, and also remote telemetry, enable more monitoring to be carried out and at less cost. Very little water quality monitoring is conducted often enough and long-term programs are relatively uncommon. Long-term monitoring of the biota of inland waters is rare in Australia. The National River Health Program and Waterwatch are major initiatives in this area.

Community water-monitoring initiatives can be tied in to the critical gauging stations of water agencies and cross-checked to ensure results are comparable.

Water quality guidelines

Guidelines have been produced at a range of levels from local through to international.

The Organisation for Economic Cooperation and Development (OECD) and the World Health Organisation (WHO) have guidelines for various water uses — in particular, human drinking water standards. As well as referring to OECD or WHO levels, Australian States have also used their own guidelines which are generally set by health or water agencies.

At a national level, the National Heath and Medical Research Council (NH&MRC–ARMCANZ) has produced drinking water guidelines (see Table 7.10). ANZECC (1992) has produced environmental water quality guidelines.

These guidelines are useful to various groups (such as the OECD, health managers and industry) providing some consistency between water quality requirements in different States and countries. They simplify planning and management for industries and regulators and save costs, as well as making uniform reporting and internal and external comparisons easier. Until recently, guidelines were variable between States or absent.

Catchment management

Catchment management responses are strategic level responses and include:

- integrated catchment management initiatives
- the National Landcare Program
- research
- educational and monitoring programs such as the Western Australian Ribbons of Blue and the national Waterwatch
- rural adjustment schemes (State and national)
- catchment revegetation programs
- protection/restoration of riparian vegetation
- agricultural extension and advice

Total and integrated catchment management schemes incorporate all of the other responses above to develop general large-scale catchment improvements. Catchment management ultimately only works if researchers accurately assess the environmental resources of the catchment area and authorities set appropriate management goals. These need to be conservative enough to ensure that whole-catchment improvements — such as reduction of land degradation, salinity and improvements in water quality — can occur.

The total or integrated catchment management approach provides a mechanism to bring together the various parties and interests in a catchment and to focus disparate groups on common goals. Catchment goals are likely to be different from those of individual land-users and there will inevitably be winners and losers if long-term sustainable development is to result. This approach provides a way of identifying the winners and losers, of arranging outcomes that benefit as many interests as possible while ensuring sustainability, and of arranging mechanisms to support change. In some cases it will be necessary to remove some areas from production, at least in the short term. Rural adjustment provides a way of doing so.

The National Landcare Program provides important focus and financial resources to support local community landcare initiatives and field-scale trials (see Chapter 6). These activities often need to be supported by research that must be translated into useful information and guidelines.

Programs such as Waterwatch and Ribbons of Blue are important in helping communities to understand the role and importance of monitoring water quality, as is the National River Health Program for developing protocols and standard biological indicators of water quality and catchment change. Many school-children and adults involved in these programs have discovered that monitoring, although it can be done at low cost, is time-consuming. Similar programs overseas have shown that, despite the greatly reduced cost, the information they collect is often as useful as that collected by water management agencies.

The aim of catchment management is to repair catchments and to prevent undesirable changes in land use. If the aim of Landcare is for the community to become involved, then social indicators such as number of groups and degree of community participation may be valid indicators of success.

In some instances Landcare is an inappropriate response, as its scale is too small to address whole-catchment or off-farm problems such as salinity and excess nutrients. Also, the non-participation of farmers in critical parts of catchments (for example, recharge zones) can undermine the good work of others.

Much relevant research has already been done but is not widely available to the community because it is not in a form that is easily accessible to the community. Considerable scope still exists to turn research results into useful products and guidelines that are easily accessible and are directly relevant to landholders.

Catchment management is now an important community activity.

Total Catchment Management is a New South Wales initiative that is underpinned in legislation. Queensland and Western Australia have State-level integrated catchment management policies. South Australia and Victoria are using the same principles to coordinate various programs and agencies to bring about whole-catchment management.

Whole-catchment management is quite a challenge, even when a river system occurs wholly within one State. Bringing about environmental improvements often involves considerable amounts of money as well as goodwill from landholders. In the case of the Peel–Harvey estuary system, Western Australia, the strategy involved catchment management in the coastal area and the construction of a new channel to the ocean costing more than $50 million (see page 7-46).

The challenge is even greater where a river system crosses State boundaries. The approach taken by the Murray–Darling Basin Natural Resources Management Strategy (NRMS) provides an outstanding example of integrated catchment management. The NRMS provides a mechanism for coordinating management goals between the Commonwealth and State governments and for funding investigations and implementation. However, the Australian constitution gives the States primary responsibility for land management, and hence strong political will and persistence is necessary to cooperate on a common approach and avoid lowest common denominator decisions.

Water conservation and management

Many people will remember the 1000-km algal bloom that occurred in the Darling River in late 1991 and focused world attention on Australia. Such incidents are caused by a number of factors, including: modification and reduction of river flow by reservoirs and direct take-offs; point-source pollution from sources such as town sewage treatment works and industry; non-point-source pollution from farming and horticultural practices; and lower-than-expected rainfall and run-off.

The responses to conservation and management of water include water conservation and demand management, water pricing, water rights or transferable water entitlements, education, recycling, monitoring, research, agricultural advice, reservoir management, reservoir redesign, flood control, water-sensitive urban design and regulation.

Water conservation encourages the community to use less water and to become more conscious of levels of use. Several States have imposed water restrictions because of drought. The restrictions commonly include time restrictions on watering gardens or bans on fixed hoses.

The WA Water Corporation has recently proposed a 10 per cent reduction in community water use, with restrictions imposed. So far, consumers have reduced consumption by up to 9.4 per cent and other restrictions are being considered.

As well as restrictions, most agencies are now moving rapidly to a full ‘user pays’ system, charging for water at close to its true supply cost (taking account of costs such as treatment, pumping, pipelines and reservoirs). The ‘free’ allowance previously built into the normal water rate is being phased out and all water consumed must be paid for. Pricing is also being altered to progressively remove subsidies, whereby some sectors of the community pay less per kilolitre than others.

The trend towards ‘user pays’ makes people more aware of the true cost of water and provides real incentives for them to use less and save money. In the long run, the community also saves money by delaying the need for construction of expensive new water resources such as dams and bore fields.

The next logical step is to move to water rights (also known as Transferable Water Entitlements) that can be traded like any other commodity. If water can be sold there is an incentive to improve the efficiency of its use, so there is some left over to sell to someone else. This measure can result in significant improvements in efficiency in large water-users such as industry and irrigators.

In a system of transferable entitlements, water rights can also be bought or reserved to protect the environment. Nowadays, people are starting to think of ‘sustainable yield’ as the amount of water that can be sold after an adequate amount has first been allocated to the environment. Such allocations need to take account of years of very low flow, when the amount of water available may be severely reduced. Ideally, any water allocation should indicate a range available, not guarantee an absolute entitlement. The actual amount available should range from a minimum (to take account of very-low-flow years), which in some cases might be nil, through to a more generous amount in high-flow years.

Good agricultural advice and practices go together with water rights, demand management and water pricing. Crop selection appropriate to particular types of land, proper selection of best-practice irrigation equipment and sound management of tail-water disposal all have an important influence on water conservation and management, and on downstream environment and other water-users. Tail-waters, if they flow back directly into the main river system, can provide high levels of pollutants, particularly salt, nutrients and pesticides.

Education and consultation are vital components of water management, which help the community contribute to and understand pricing and conservation strategies. Water managers also need to be educated about community preferences and should contribute to community education by exposing the environmental trade-offs involved in various community preferences. A well educated community can ensure that water management agencies carry out thorough investigations, and can decide how to maximise their returns from water that will increasingly cost them more.

Other societal responses include reservoir management — for example, the type and timing of releases of water to the environment — and redesign such as roofing small reservoirs to reduce both evaporation and contamination, with consequent reduced chlorination costs.

Biological conservation and management

Once native species are lost from an area, it can be extremely costly or impossible to reintroduce them. In many cases, the changes in biodiversity are absolute with many species and assemblages being lost permanently. The range of approaches to achieve biological conservation and management includes: promulgation of reserves, policing of protected areas, allocation of water to ensure continuation of environmental flows, education, monitoring, research, restoration of wetland systems, pest control, conservation extension advice and management of threatened commercial, recreational and introduced species.

Monitoring has become more important as an educational tool — with the development of programs such as Ribbons of Blue, Waterwatch and Frogwatch — and as a management tool in the National River Health Program. Managers need to be educated so they understand the usefulness and limitations of data; and changing the management culture towards a more-holistic ecosystem approach is vital.

Pest control is an important response, as removal of feral animals and weeds increases the opportunity for native animals and plants to recolonise areas. Many water bodies have a faunal content that is unique to a particular habitat (Bunn, pers. comm.), suggesting that aquatic biodiversity is even greater than had been thought previously. This is a complicating factor in habitat restoration.

Pesticides in aquatic systems can have severe detrimental effects on native invertebrates that form the predominant food supply for many other animals. Some chemicals, including pesticides, can have long-term effects on breeding of aquatic organisms.

Management of commercial, recreational and introduced species is necessary to protect native flora and fauna. Unfortunately, many native species have already declined or disappeared as a result of inadequate protection and management. In some cases, due to lack of knowledge about breeding habits.

Where dams and weirs provide barriers that fish cannot cross, several States have made active efforts to install and improve the design of fish-passage structures (‘fish ladders’), with mixed success.

A number of inland fisheries now use licences, regulations and strict guidelines to protect dwindling stocks of fish (such as barramundi and Murray cod) and crustaceans (such as the Murray crayfish and marron).

Introduced species, unless managed properly, can displace all the native species from an area. Various control and containment programs have been instigated for these pest populations, including attempts to eliminate them, through the release of sterile fish stocks.

Increasingly, water is regarded as a multiple-use resource and catchments and reservoirs are receiving increasing pressure from the community for a range of active and passive uses. Reserve declaration usually nominates a purpose for which the reserve has been created. Reserves require active management unless the community is to be excluded, and in many instances the management resources for generating, implementing and enforcing management plans are not available.

Water quality control and management

Responses aimed at quality control and management include: setting water quality guidelines, standards and objectives for drinking water, recreational water use, stock watering, irrigation, environmental (including aesthetic) uses and various types of waste water; licensing; education; monitoring; research; recycling and re-use, including stormwater management and water-sensitive urban design; water treatment; and best-practice, best available and best-bet technology.

The responses are linked to water supply and treatment costs. Having water of a continually improving standard and responses such as recycling and re-use incur a cost penalty. Although the community wants to consider recycling and re-use as management options, water managers are often reluctant to change established practices. They often cite additional costs and health risks as the reasons, but it may be more an aversion to change that is the problem.

The World Health Organisation has established health standards for human water consumption. In Australia, the National Health and Medical Research Council and the National Water Quality Management Strategy have set guidelines and standards for water for various consumption and environmental purposes (NH&MRC–ARMCANZ, 1995; ANZECC, 1992).

Table 7.14 Summary				
Element of the environment/issue	**State**	**Adequate Info.**	**Response**	**Effectiveness of response**
Water resources Storage and abstraction for human use	Secure supplies but substantial overuse in some regions	✓✓✓✓	Conservation policies; public education in most States; consideration being given to reallocation of water to environment	Good; poor understanding of ecological processes; reallocation could be ineffective
Forest harvesting	An initial increase in water yield is followed by a reduction as regeneration occurs, sometimes dramatically	✓✓✓	Logging restrictions; small-scale and patch logging; fire management	Appropriate, but water issues often not considered in forestry planning
Groundwater	Overuse — use greater than recharge in some areas	✓✓✓	Bore metering and licensing; regulation; capping of bores; water pricing; education; some artificial recharge	Appropriate but limited effect
Farm dams	Proliferation has reduced streamflow particularly during dry conditions	✓✓	No action	Inappropriate — farm dams not considered in water resources planning
Irrigation	Irrigation is the major user of stored water and a large portion is used inefficiently for marginal economic benefit	✓✓✓✓	Water pricing; reform and restructuring of industry; improved irrigation technology	Appropriate but not applied nationally; minimal effect yet
Domestic and urban uses	Supplies adequate but increased demand is leading to more dams	✓✓✓✓	Water pricing; demand management; education; some recycling	Good regional effect; stabilisation of per capita demand where res-ponses have been implemented; minimal national effect
Catchment pollutant sources Agriculture and land clearing	Most waterbodies in areas of agriculture affected by fine and coarse sediment, elevated nutrient loads, and, in some cases, salt; increased volume and rate of run-off; major stream channel changes	✓✓	Strategic revegetation and farm forestry; clearing bans; drainage; broadacre soil conservation and fertiliser management; tree planting to reduce salinity; streambank stabilisation; catchment management and Landcare	Poor — not targeted at water quality; effectiveness of tree planting unknown; streambank stabilisation costly and only partially successful; Landcare working in some areas
Mining	Localised pollution by metals and acid run-off; many sites of disturbance in past areas of coal, alluvial tin and gold mining, sulfide mining and sand and gravel extraction	✓✓✓	Stricter management of all new mines; recycling of water; stabilisation and rehabilitation of some old mine sites	Good in relation to new mines; poor in relation to old mines
Intensive animal industries	Localised but significant pollution by nutrients, organic matter and bacteria	✓✓✓	Guidelines and regulations for effluent discharges, operation, and management; education; implementation of regulations	Inadequate because responses not widely adopted; some local effectiveness
Irrigated agriculture	Localised but significant pollution by sediments, nutrients, pesticides, salt and waterlogging producing serious environmental and social problems	✓✓✓	Guidelines and regulations for effluent discharge and drainage in some areas; improved irrigation techniques; soil conservation; education; industry restructuring; water industry reform	Locally effective but often problem transferred further downstream; guidelines often based on poor biological knowledge; too early to judge effectiveness of restructuring; insufficient land and water management
Urban and industrial development	Localised but significant pollution by sediment, nutrients, oils, organic chemicals and metals	✓✓✓	Guidelines and regulations for effluent management; monitoring; education	Good for trade wastes; poor for general urban runoff; monitoring adequate for some surface runoff; inadequate for groundwater
Forestry	Localised pollution by sediments, nutrients and pesticides	✓	Guidelines and field practice manuals; buffer strips; patch and selective logging; strategic forest and plantation planning	Inadequate because of poor integrated land and water management
Habitat quality and biota (Aspects not already listed above) Drainage	Destruction of wetlands with effects on waterbirds and other biota	✓✓	Almost no response	Inadequate

Table 7.14 Summary (continued)

Element of the environment/issue	State	Adequate Info.	Response	Effectiveness of response
Changed flow regimes	Reduced flows, increased flows, reversal of seasonal flows, reduced medium floods all change habitat quality; reduction and/or extinction of some native species; decline in ecological health	✓✓	Debate, limited trials, and research	In the right direction
Reservoirs and farm dams	1. New habitat and drought refuges 2. Reduced mobility of biota, especially fish 3. Downstream effects, especially erosion, temperature change and changed flow regimes	✓✓ ✓✓✓ ✓✓	1. No active management 2. Fish ladders 3. Little response	1. n.a. 2. inadequate 3. inadequate
Riparian vegetation changes	1. Riparian habitats widely degraded or destroyed 2. Exotic species produce organic inputs to streams different from native species	✓✓	1. Little response; some local fencing and provision of alternative water points; some research and demonstration underway, eg Landcare, Save the Bush 2. Limited control of exotic species	Needs much greater action to protect and repair riparian zones; research and action needs to be in a whole-catchment context
Water quality changes	Changes in water quality affect habitat quality biodiversity and ecological processes, sometimes dramatically; some extinctions in native species; algal bloom enhancement and encouragement of exotic species	✓✓	Catchment management; flow management and point source control	Point source control adequate and effective with increased emphasis on rural and urban catchment management; urban and rural diffuse source control not widely developed
Exotic species	1. Displaced native species 2. Some waterbodies dominated by exotic plants and animals	✓✓	1. Attempts to control import, translocation and spread of potentially damaging exotic species of plants and animals 2. Biological control; management of new outbreaks	Inadequate and ineffective particularly with regard to the control of aquatic plants and fish imports. Education programs required 2. Significant potential effectiveness in some cases
Water Quality (Aspects not already listed above) Chlorination	Produces byproducts that are potentially damaging to human health	✓✓✓✓ (cities) ✓✓(rural)	Shift to chloramination, filtration prior to chlorination, use of dissolved air flotation, and activated carbon to reduce byproducts	Appropriate and appears to be successful; little knowledge of rural communities
Recreation	Localized but relatively minor increases of bacterial, nutrient and algal concentrations in heavily used waterbodies; some water quality unsafe for some recreation	✓✓	Recreation banned in most drinking water supply reservoirs; provision of toilets; bans and warning notices on water bodies	Appropriate and successful
Sewage disposal	Increased nutrient and pathogen concentrations locally; sewage flow often maintains river flow in dry times	✓✓✓✓	Treatment and land disposal; integrated land and water management and research; community efforts to reduce inputs to sewage plants; discharge licences	Inadequate — level of treatment needs to be reviewed; land disposal in some areas is successful but elsewhere may be unnecessary and unsustainable
Management Short-term thinking	Most governments and organisations focus on the short term	✓✓✓✓	Ecologically sustainable development; national and regional strategies	Appropriate but not widely implemented; too early to judge success
Policy development	Policy development and decision making does not take adequate account of science and does not cope well with scientific uncertainty; reduced skills due to restructuring of major water authorities	✓✓	Appointment of scientific advisory panels; more targeted and integrated science — eg CRCs; economics often used in place of science rather than complementary to science; no response to reduction of skills in water authorities	Inadequate; maybe improving in some areas but not in privatised or corporatised organisations; use of economics often inappropriate
Data and monitoring	Inadequate data sets; fragmentary in space and time; short term; often of limited value; often not interpreted or archived	✓✓✓✓	Very little; National River Health Program; key site monitoring; EPA review	Too early to tell; agency restructuring and privatisation hinders effectiveness
Big picture management, integrated decision making	Lack of integrated decision making	✓✓✓✓	Catchment management and flow management	Many single issue policies developed without consideration of whole policies

Peel–Harvey Estuary System, Western Australia

Prior to European settlement, the catchment of the Peel Inlet and Harvey Estuary (collectively called the Peel–Harvey System) south of Perth was covered in deep-rooted native vegetation. The rivers in the catchment flowed directly across the coastal plain, often via swamps, before entering the estuary. The Murray and Serpentine Rivers entered Peel Inlet and the Harvey River entered the southern end of Harvey Estuary through a birds-foot delta. The single exit to the ocean naturally blocked by formation of a sandbar from time to time (see diagram A opposite). Water entering via the rivers took about 53 days to move through the whole system and out to sea through the exit channel (now called the Mandurah Channel).

The soils in the coastal part of the catchment, beneath the Darling Scarp, were mainly light, sandy soils. The native vegetation was adapted to the naturally low nutrient levels in the soils, and to the relatively dry, Mediterranean climate. European settlement brought about many changes:

- The Serpentine and Harvey Rivers were dammed for water supply and much of the remaining flow of the Harvey River was diverted directly out to sea through the Harvey Main Drain.
- Extensive clearing took place, particularly in the 1960s, to make way for agriculture. The replacement of deep-rooted, native plants with shallow-rooted pastures resulted in a rise in groundwater level, which caused seasonal waterlogging of soils and salinity problems. Extensive artificial drainage had to be installed for agriculture to continue.
- Increased run-off resulting from the extensive clearing more than compensated for the amount being removed by dams upstream. More water reached the estuary in total.
- In order to thrive, the introduced dryland and irrigated crops and pasture required applications of fertiliser — especially phosphorus, potassium and the trace metals: zinc, copper and molybdenum. In some cases they also required irrigation.
- Both the drainage and application of fertilisers resulted in more water, carrying higher levels of nutrients, reaching the estuary faster. This sparked off the estuary nutrient-enrichment problems and subsequent excessive growths of nuisance green algae.
- Urban development and rural living contributed nutrients to the system both from sewage and applications of fertiliser to gardens.
- Intensive horticultural and animal industries became significant contributors of nutrients.
- The algal problems reached a point where management was necessary. Algae were causing severe problems and costing the community money.
- The ocean channel entrance and an area into Peel Inlet were dredged to make a navigable entrance.

Over time it became obvious that management needed to occur in two ways — first, to ensure less nutrient entered the Estuary System; and second, to hasten the removal of nutrients from the System. This provided the foundation for the combined management program, consisting of a catchment management program and the construction of a new channel to the ocean (the Dawesville Channel). Catchment management reduced the inputs of nutrients to the System. The new channel works to reduce the algal nuisance in three ways: by massively increasing the flushing (turnover) rate of water entering the System so more estuarine water is removed; it makes the estuaries more saline for a greater part of the year, thus preventing the germination of one of the algae, which requires lower salinity; and by injecting well-oxygenated marine water into the System. Less phosphorus is released from the sediments as the necessary low oxygen conditions occur seldom if at all. These combined measures have achieved real change (see diagrams A, B and C opposite).

The management approach focused on the nutrient phosphorus, rather than nitrogen, because growth of the blue-green algae was shown to be limited by phosphorus. The improved flushing of the Peel–Harvey System will also remove nitrogen, and people were aware that this would be likely to cause slight increases in nitrogen enrichment of near-shore marine waters. However, a judgement was made that this would have less impact environmentally than the problems that would be fixed by the management strategy (Humphries and Robinson, 1993).

The diagrams opposite illustrate the changes that have occurred to the system in terms of:

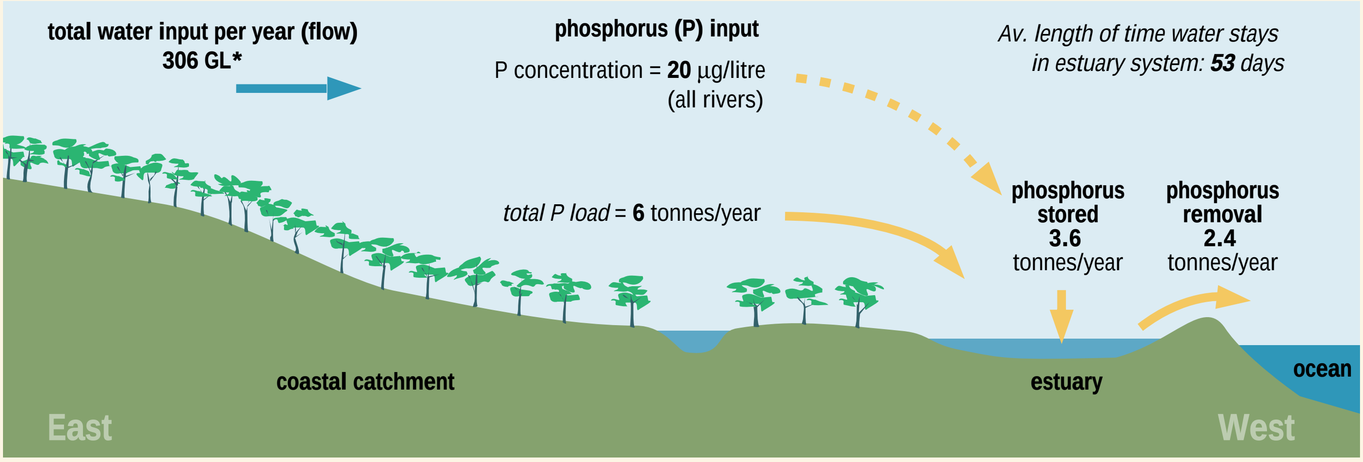
- changes in the amount of water entering the system
- changes in phosphorus concentrations over time in the rivers entering the system
- changes in the total amount (load) of phosphorus entering and leaving the system per year
- the length of time that water remains in the system and changes brought about by dredging the Mandurah Channel and by constructing a new channel to the ocean

All numbers used on the diagrams are for an average year for the pre-European settlement, post-European settlement, pre-management, and post management states of the system as assessed by Humphries, Bott and Robinson (in prep.).

Since European settlement, river flows to the estuary have approximately doubled, even with the dams being built on the Serpentine and Harvey Rivers. During the same time, prior to management, phosphorus loads to the system have increased about 20 times, from six to over 140 tonnes per year.

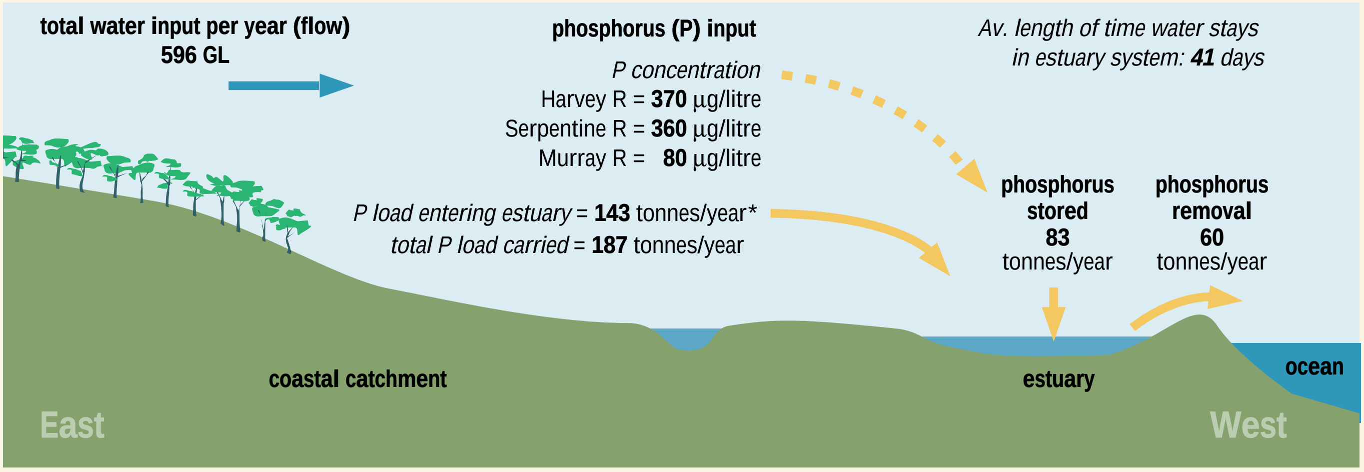
The Peel–Harvey management strategy is one of the largest and the most successful attempts in the world to bring about real improvements to a whole system (Humphries and Robinson, 1995; Humphries and Ryan, 1993).

1. Pre-European settlement: Deep-rooted vegetation in flood plain and headwaters of catchment. No application of fertilisers. No dams on Darling Scarp. No diversions of major rivers (Serpentine, Murray and Harvey Rivers). No artificial drainage in coastal part of catchment. Vegetation adapted to very low phosphorus levels. No problems with nutrient enrichment in estuary.



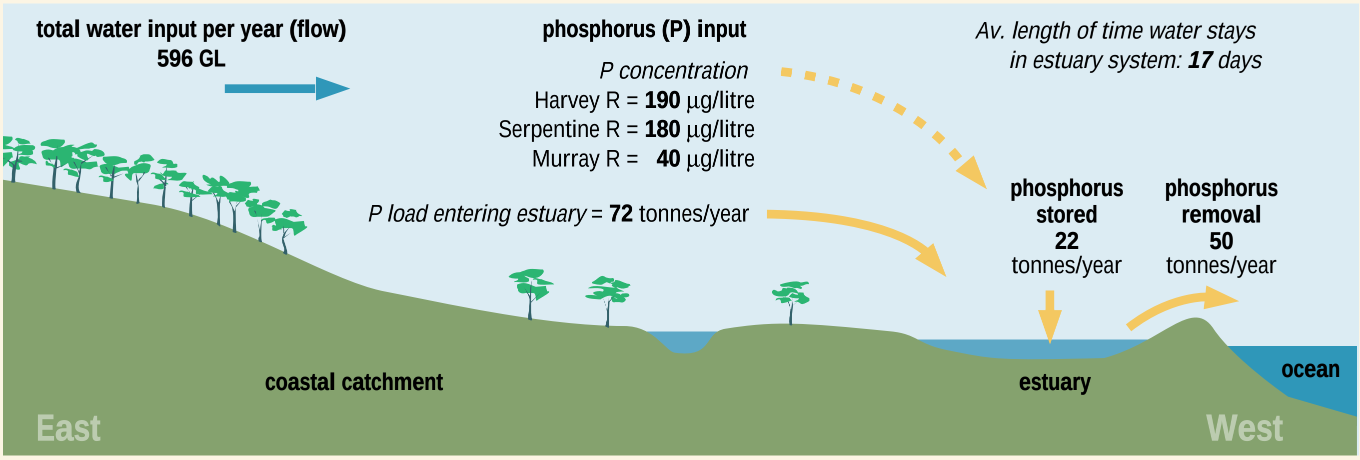
Note: For comparison, an Olympic swimming pool contains approximately 0.015 GL of water.

2. Post European settlement (pre-management): Clearing of deep-rooted vegetation produces water-logging and need for extensive artificial drainage to enable cropping of land. Clearing results in large increases in annual water flows. Increased flow from clearing exceeds water removed by dams on Serpentine and Harvey Rivers. Extensive fertiliser application.



Note: Partial diversion of Harvey River to ocean diverts 44 tonnes of phosphorus a year away from the estuaries and reduces the total amount entering from the catchment to 143 tonnes a year.

3. Post management: Catchment management implemented in urban and rural activities. Less fertiliser applied. Timing of application changed to lessen phosphorus losses. Tree planting on catchment, Drainage into estuary reduced. Activities requiring large inputs of fertiliser not permitted. Design of rural living changed. Additional channel to the ocean constructed to speed up phosphorus removal.



Notes: (1) With the Dawesville Channel, the rate of phosphorus loss to the sea is greatly increased from approximately 40% to approximately 70%.
(2) The phosphorus concentrations and loads are targets required to fix the estuary. These have not yet been achieved but progress has been good. There has been an 80% achievement in the Harvey River and 100% in the Murray River to date. Over the same period, the Serpentine River has barely changed (and may be getting worse) because of inadequate phosphorus controls on intensive animal and horticultural activities in its catchment.

Source: after Humphries, Bott and Robinson, in prep.

Eutrophication of inland and coastal waters

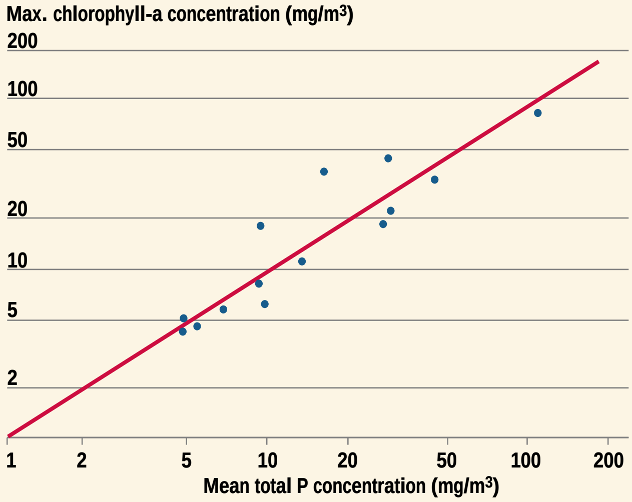
Anabaena circinalis — a common blue-green alga in inland waters

Eutrophication, the process of nutrient enrichment of water bodies by phosphorus and nitrogen, is one of the major water quality problems facing Australia. Human activities accelerate this natural process, resulting in greatly increased amounts of algae, including noxious and sometimes toxic blue-green algae. A number of side effects are associated with the excessive eutrophication of inland, estuarine and coastal waters, including decreased clarity of water, decreased diversity of aquatic plant and animal life and deoxygenation of bottom waters. In terms of water supply, algal blooms are most noticed for their effect on the taste and odour of water, while toxic blooms lead to periodic livestock deaths when animals drink heavily contaminated water.

In fresh water, phosphorus typically limits the growth of algae, whereas in marine waters nitrogen is generally the limiting factor. In estuaries, either of the two elements may restrict algal growth. Increased levels of the limiting nutrient are generally associated with larger amounts of algae (see the diagram below). Relative levels of major nutrients are nevertheless important in influencing the composition of algal blooms. For example, high levels of phosphorus relative to nitrogen in fresh waters encourage the growth of blue-green algae, while high levels of silica and phosphorus are required for the growth of the diatom group.

Other factors are also important. Low flow, abundant light, clear water and warmth all encourage algal growth, while the opposite situation — as well as abundant zooplankton and other micro-organisms — discourages the development of algal blooms. In rivers and estuaries, flow is particularly important in regulating algal blooms. The still waters of reservoirs, lakes and slow-flowing regulated rivers are particularly susceptible to algal growth.

The relationship between maximum chlorophyll-a concentration (a measure of algal levels) and average phosphorus concentration in some south-eastern Australian reservoirs



Source: Banens, 1978.

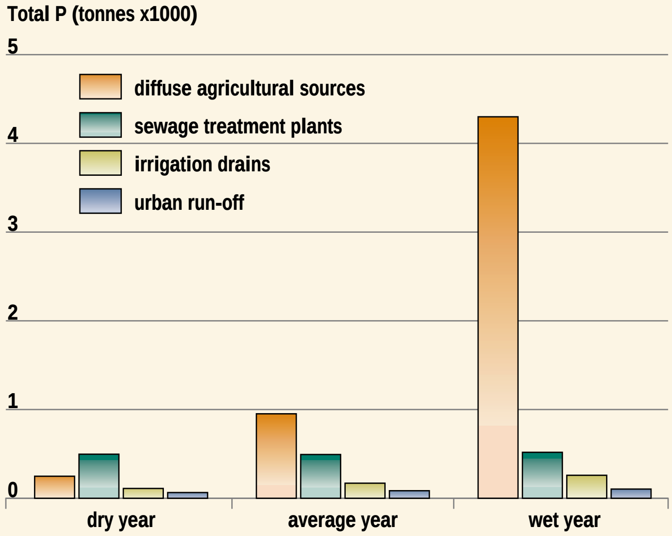
Pressure

Virtually all human activity has accelerated the process of eutrophication both directly, through increased nutrient inputs to waterways, and indirectly through modifications to make water available for human use. Nutrient inputs originate from both point and diffuse sources (see Table 7.7). Point sources include sewage effluents, irrigation drains, stormwater run-off and drains from intensive livestock industries. Diffuse sources originate from leaching or soil loss from farmland and stream banks. In some aquatic systems such as reservoirs, stagnant inland rivers or estuaries, nutrients may also be derived from bottom sediments and decaying organic matter.

One of the reasons why eutrophication problems are so widespread, particularly in rural areas where diffuse sources dominate, is the large difference in nutrient concentration between nearby land and water systems. Soils typically have a nutrient status of between 200 and 500 ppm phosphorus, whereas the minimum threshold concentration for algal bloom development in water is between 0.02 and 0.05 ppm — that is, one-ten-thousandth the concentration of phosphorus in the soil. This means that even a small, barely noticeable leakage of phosphorus from well-managed agricultural land may be more than sufficient to stimulate excessive algal growth in a water body.

Studies in Australia and overseas have shown that, in general, the more intensive the land use, the higher the loss of nutrients from the land into the surface waters (see Table 7.6). Typically, phosphorus generation rates increase from 0.1 kg/ha in forests to 1.0 kg/ha in cropped and urban areas, and much higher values under intensive agricultural use.

Where the phosphorus in the waters of the Murray-Darling Basin comes from



Source: GHD, 1992.

The extensive use of superphosphate fertiliser in Australia is often singled out as the major source of phosphorus in inland waters and therefore, by implication, the principal cause of algal blooms. However, research has shown that applied superphosphate rapidly becomes attached to clay particles in the soil, and is not easily mobilised into streams and rivers except through the physical erosion of the soil. Only in sandy soils, such as those of the coastal plain near Perth, is phosphorus leached relatively easily through the soil into streams. Superphosphate is only one of a number of diffuse sources that contribute to the nutrient load of Australia's inland waters.

While diffuse nutrient sources are particularly significant in rural areas, their relative importance in relation to point sources varies according to location and run-off. A nutrient study for the Murray–Darling Basin (GHD, 1992) showed that diffuse agricultural sources greatly dominated the input of phosphorus to the Darling River system during wet years, whereas in dry years sewage treatment plants contributed just over half the total (see the diagram above).

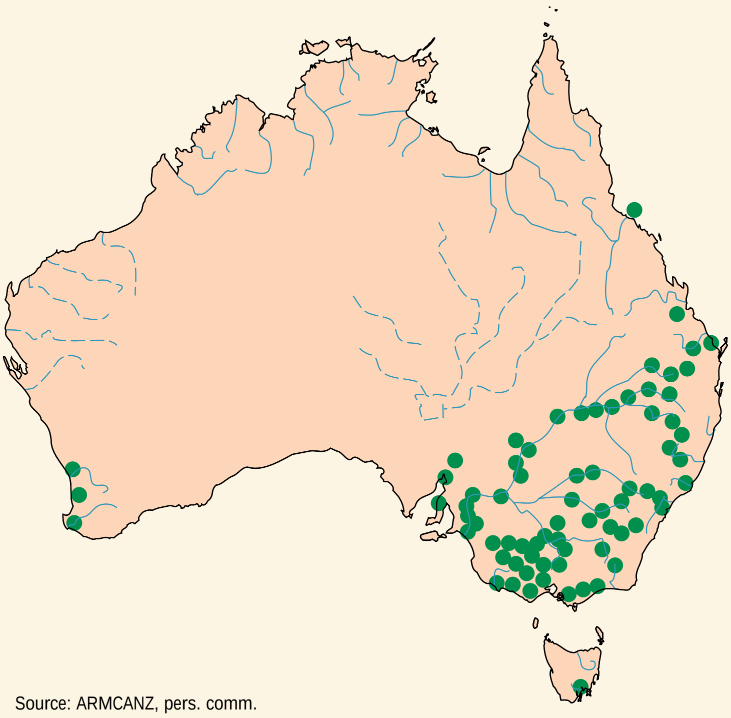
The recent increase in the reported incidence of algal blooms and related water quality problems in Australia may be due to an increased awareness of the eutrophication problem. But it is likely that increased pressure from population growth and human activities has caused a real increase. Ongoing and increasing disposal of sewage effluent, increasing run-off from expanding urban areas and the expansion and intensification of agricultural activities are probably increasing the nutrient loads being delivered to inland and coastal waters. In conjunction with a continuing diversion of flow from our major rivers, the increased nutrient load is believed to be increasing eutrophication. In most cases data do not exist to demonstrate this conclusion.

State

The explorer Charles Sturt noted the vegetable green colour of the largely non-flowing waters of the Murray, which indicated that algal blooms were present in Australia before the impact of European settlers. This suggests that Australia's slow-flowing inland rivers are naturally susceptible to algal blooms. Similarly, both Captain Cook and Charles Darwin noted red-coloured blooms of the blue-green alga *Trichodesmium* on their voyages of discovery, indicating that such blooms also occurred naturally in the marine environment. The first description of a toxic algal bloom (the blue-green alga *Nodularia*) anywhere in the world, and of its impact on livestock, was reported in Lake Alexandrina as far back as 1878 by the South Australian government health inspector (Francis, 1878). While the extent and frequency of algal blooms in Australia have not been documented until relatively recently, numerous rural communities have for many years experienced the taste and odour problems associated with annual summer outbreaks in their water supplies. A national survey of the incidence of major blooms in inland waters in 1992–93 shows the extent of the problem, particularly in the south-east corner of the continent (see the map below). However. it still underestimates the eutrophication problem, as it does not include unmonitored reservoirs, small rural water supply storages, farm dams, natural water bodies, estuaries and inshore marine areas.

Only over the last 25 years have some scientists and water managers become aware of the health and other problems associated with eutrophication. The world's largest toxic blue-green algal bloom along a 1000-km stretch of the Darling River in the summer of 1991, attracted extensive coverage in the media both nationally and overseas. The Darling bloom and the closure of water supplies caused significant disruptions

Location of algal blooms 1992–93



Source: ARMCANZ, pers. comm.

to local communities, as these usually had only a single source of water, and limited and expensive alternative supply options.

Not all major eutrophication problems occur in fresh water. The Peel–Harvey Estuary of Western Australia experienced massive blooms of various species of filamentous algae during the 1970s and ’80s. The size and extent of these blooms was such that the commercial fishery was affected, and the hundreds of tonnes of rotting algae accumulated on the shoreline reduced both the recreational value of the estuary and its value for future urban and tourist development. In this particular case the progressive and severe deterioration of water quality in the estuary and the resultant problems were directly attributable to excessive application of phosphorus fertiliser to the estuary’s catchment (see the box on page 7-46).

Excessive phosphorus-rich industrial discharges into Albany’s Princess Royal and Oyster harbours have resulted in a major dieback of their seagrass beds due to the smothering effect of significantly increased levels of epiphytic algae growing on the seagrasses. Similarly, in a number of areas of the inner Great Barrier Reef, coral degradation and decline has been attributed to increased levels of phytoplankton (floating microscopic algae) associated with elevated nutrient inputs derived from some agricultural activities in the catchments of some coastal rivers.

Societal responses and actions

The world’s largest toxic algal bloom occurring in the Darling River with all its associated water supply problems, was the single most important factor in generating or accelerating government and community action. Responses included: algal and nutrient management strategies focusing on both operational and longer-term actions to manage the problem; a Senate enquiry into toxic blue-green algae; major research funding initiatives; and community education programs.

Research into the primary causes of eutrophication, namely nutrient inputs to aquatic systems, resulted in a series of best-bet management activities targeting the reduction of both diffuse and point sources of phosphorus. For example, better farming practices to ameliorate nutrient loss to streams were identified and guidelines for the use of buffer strips and other techniques for sediment and nutrient interception are being developed. Other research explored and developed options for improved sewage treatment, including phosphorus precipitation, off-river disposal and effluent re-use.

Community-based nutrient management strategies are being developed and implemented through catchment management plans. Such plans include the upgrading of sewage-treatment plants and treatment to reduce point sources, and a review of stream-flow management options to reduce the impact and likelihood of algal bloom development. Community education is an important part of any strategy to deal with the eutrophication problem. This is because long-term management of diffuse nutrient sources requires individual landholders to adopt best-practice methods, while urban dwellers need to change their behaviour in relation to nutrient polluting activities.

One obvious target for nutrient reduction has been the high phosphorus levels in detergents, which form a major phosphorus component of sewage effluent in many cases. As a result of pressure from governments and the scientific community, the detergent industry agreed to a voluntary maximum phosphorus level of five per cent, in conjunction with a labelling program that indicates whether detergents contain phosphorus. This action was followed up by a number of trial community-awareness programs focusing on point source phosphorus reduction from urban areas. Targeting both school and adult groups, these programs educate the community about the benefit of widespread use of low-phosphorus detergents, as well as other individual activities to reduce nutrient input into rivers. Initially trialled in Albury, New South Wales, and since adopted in nearby Wagga Wagga and other places, the phosphorus-reduction campaign has been particularly successful in modifying community behaviour and reducing the phosphorus level in sewage effluent discharged to these rivers.

Research has also been undertaken into the management of algal blooms in inland waters. This has mainly focused on the use of flow and destratification to reduce the likelihood of blooms developing, as well as water-treatment processes to cope with the associated toxins and odours. Contingency plans to cope with the outbreaks of toxic blue-green algal blooms have also been developed. These include emergency water treatment and the identification and development of alternative sources of water. Few management options are available for management of algal blooms in estuarine and marine environments, and prevention remains the best approach.

A ‘red tide’ at Lake Macquarie, NSW caused by the dinoflagellate, *Noctiluca*, an expression of eutrophication.

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