Inland waters

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Introduction

Water is essential for life. Not only is all life on Earth based on carbon and water, but by flowing across, through and under the landscape, water also connects patterns and processes of various kinds and ensures the survival of all species, including people. Inland waters are therefore an essential part of this world. Water has many values—aesthetic, cultural, natural and economic—and, like many ‘common property’ resources, it is managed by a variety of means for a variety of ends. Inland waters are highly valued parts of the natural and cultural landscape. Throughout the world, inland waters are heavily used and, as the human population grows, are under threat from pollution and overuse. Over half of the world’s large rivers are now dammed or controlled in some way (Nilsson et al. 2005). Freshwater biodiversity around the globe is declining rapidly (Millennium Assessment Board 2005).

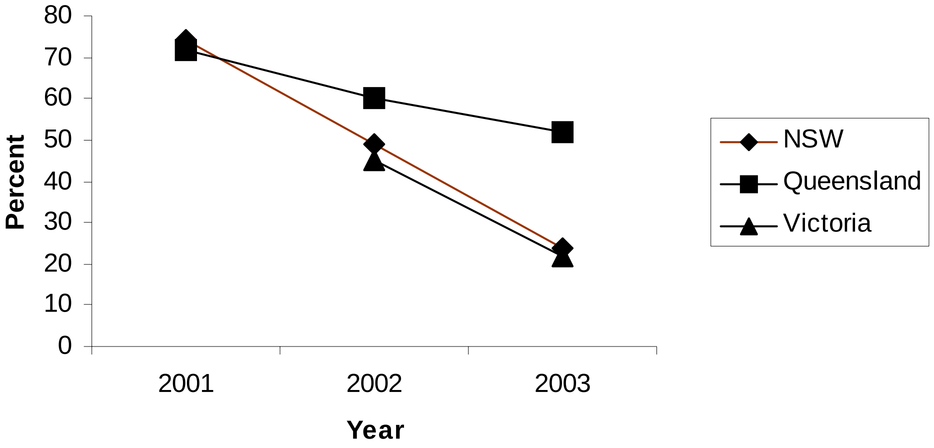
Catchment scale influences

Hydrological condition

Surface water availability and use patterns

Australia is the driest inhabited continent in the world, and more than 80 per cent of the population lives in a narrow coastal strip (see ABS 2004). The bulk of the landmass is arid or semi-arid, with intermittent water flow in many streams. The coastal strip, however, often has a more constant water supply, which is being placed under increasing stress by population increases. While Australia does not appear to be short of water on any of the global maps of per capita water availability—and certainly not as short of water as countries like Kuwait—there is, nonetheless, strong evidence of the stress being placed on Australia's continental water resources. Australia is the third largest per capita user of water in the world (Radcliffe 2004). The delicate balance between water supply and demand is evident in the extensive regulation of river flows through dams and weirs, extraction and pumping of water for urban and rural use, low water levels in water storages (Figure 1), and water restrictions in many of the major cities as a result of long, dry periods and reduced runoff in recent years.

Figure 1: Percent capacities of selected storages in eastern Australia

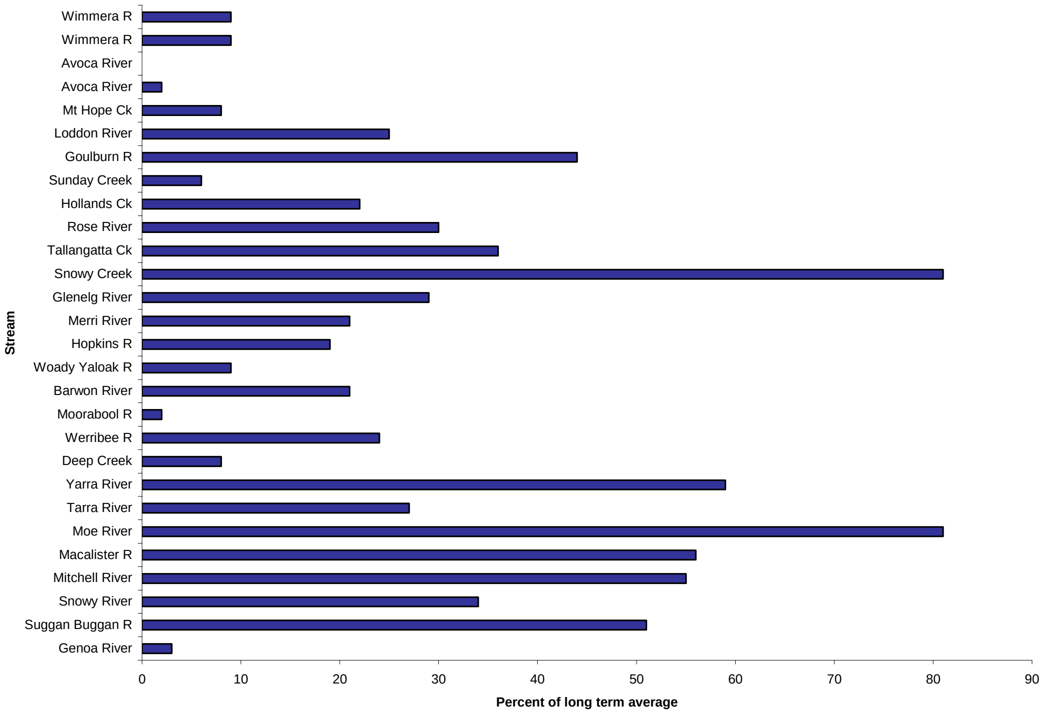


Source: adapted from Hanna (2003, Table 1, p. 398)

One of the reasons for this somewhat paradoxical situation is that most of the water is where the people are not, and vice versa. The majority of the runoff from the continent occurs in tropical and subtropical rivers flowing to the north—particularly in northern Queensland, the Gulf of Carpentaria and northern Western Australia (see the Australian Natural Resources Atlas: http://audit.ea.gov.au/ANRA/water/water_frame.cfm?region_type=AUS&region_code=AUS&info=availability). Over most of the continent (the exceptions being parts of Tasmania and subtropical and tropical high rainfall regions) annual evaporation exceeds rainfall for most, if not all of the year, so that rivers and streams are naturally highly seasonal and would not naturally flow (or be reduced to very low flows) for long periods of the year. In southern Australia, extraction of surface and groundwater is extensive and it supplies agricultural production and the needs of the urban areas. In the Murray-Darling Basin, for example, extractions from the Murray River almost equalled the annual average flow of the river, until a Cap was imposed on further extractions.

One of the facts of life of water supply in Australia is not just the geographical disjunction between supply and demand, it is also the natural climate and runoff variability. This variability and long periods of low flows have made it essential to build large dams. Rivers in southern Australia are extensively dammed and regulated to provide year-round security of supply for urban and domestic use, and irrigation water for use during the summer. Such engineering works are also necessitated by the fact that the natural flow variability in Australian rivers is the highest in the world—this 'wide brown land' is characterised by 'droughts and flooding rains' (Figure 2). In comparison to the need, Australia stores up to seven years' worth of water in the major dams. Coupled with the relatively flat topography of this old and weathered continent, the result is that Australia's major river systems usually possess one or more large, shallow storages. These storages take a long time to empty and a long time to fill after periods of low flow. So Australian water resources have, from the earliest days, been engineered to supply a scarce resource and to provide security of supply in dry periods.

Figure 2: Streamflow in Victoria during the drought period (at 30 Sept 2004) as a percentage of the long-term average (ML/day)



Source: adapted from Department of Primary Industries, Victoria (2004)

Urban areas in Australia cluster around the coast. Coastal development is very rapid as many Australian people become 'sea changers' and seek coastal life styles. As a result, the modification of coastal catchments and river systems is extensive, with flow regulation for water supply and flood prevention.

Almost 70 per cent of the water extracted in Australia is used for agriculture. Consumption has stabilised in some catchments, such as the Murray-Darling Basin. Because of climate variability, irrigated agriculture is extensive and growing in area. The majority of irrigation water is used for pasture; lesser amounts are used for some of the higher value crops and for horticulture. Indeed, there is an inverse relationship between the amount of water used and the value added per megalitre. This situation is changing as water markets and other reforms (discussed later) change water use patterns. Water use efficiencies in the pasture and horticulture sectors in regions such as the Murray-Darling Basin are increasing due to improved irrigation practices and the growth of crops that yield greater returns per megalitre of water used (for example, see rice growing in the MIA <http://www.rga.org.au/environment/water.asp>). There are, therefore, many positive developments.

Urban and industrial use is a relatively small proportion of the total water used (Table 1). Surprisingly, perhaps, urban areas are actually net exporters of water if all sources and sinks are accounted for. Urban areas have large areas of impervious surfaces in their catchments—roads, pavements and roofs—so the hydrology of urban areas is highly modified. On an annual basis, Mitchell et al. (2003) calculated that storm water runoff from urban areas in Canberra exceeds the water imported from storages for domestic and industrial use. The problem here, of course, is variability: storm water runs off rapidly in large volumes and would need to be stored and treated before reuse. Most Australian cities reuse relatively small amounts of water (Table 2), practicing a policy of ‘once through’ from storage to disposal of wastewater (usually to the sea). This situation is changing as recycling and reuse practices are being adopted in response to the recent period of low rainfall and water restrictions. Many Australia cities (for example, Adelaide, Melbourne, Wollongong, Sydney, and Brisbane) either now have water recycling plants in operation, or major developments are planned (Radcliffe 2004).

Table: Water consumption* by selected industries, 1996–97 and 2000–2001

Sector	Water consumption (ML)	
	1996–97	2000–01
Irrigated agriculture	15 502 973	16 660 381
Forestry and fishing	18 815	26 924
Mining	570 217	400 622
Manufacturing	727 737	866 061
Electricity and gas supply	1 307 834	1 687 778
Water supply	1 706 645	1 793 953
Household	1 828 999	2 181 447
Environmental flows		459 393
Other	522 513	832 100

* Water consumption = mains water use + self extracted water use + reuse water use – water supplied to other uses – instream water use; Source: adapted from ABS (2000, 2004b)

As urban populations grow (particularly in coastal regions and in urban centres in and around Sydney and south-eastern Queensland), supply management is becoming an issue. Forecasts of future water demand frequently exceed the sustainable water yield from the present catchment areas, so new sources of supply will be required to meet predicted demand patterns. If the gap between supply and demand is to be closed, then either new dams will need to be built, or new groundwater systems accessed, or significant increases in reuse and recycling will need to be achieved. In the short-term, demand management is also an important part of the policy mix. Many states and regions, especially south-western Western Australia and south-eastern Queensland, are actively involved in water resource planning of this type. In peri-urban regions there is a growing issue of competition for water between urban and agricultural use. An increased number of inter-basin transfers of water is expected as pressure on water resources grows. Historically, these have been for hydro-electricity generation and for irrigation supplies (for example, the Snowy scheme) or to provide water for urban areas (for example, the Shoalhaven in New South Wales and catchments to the south of Perth in Western Australia).

Table 2: Water discharge and reuse from water utility sewage treatment plants in Australia, 1996–99 and 2001–02

State or Territory	1996–99			2001–02		
	Effluent GL/year	Recycled GL/year	%	Effluent GL/year	Recycled GL/year	%
Queensland	328	38	11.6	339	38	11.2
New South Wales	548	40.1	7.3	694	61.5	8.9
ACT	31	0.25	0.8	30	1.7	5.6
Victoria	367	16.9	4.6	448	30.1	6.7
Tasmania	43	1	2.3	65	6.2	9.5
South Australia	91	9	9.9	101	15.2	15.1
Western Australia	109	5.5	6.1	126	12.7	10
Northern Territory	21	1	4.8	21	1.1	5.2
Australia (total)	1538	112.9	7.3	1824	166.5	9.1

Source: Radcliffe (2003, Table 2, p. 7)

Groundwater availability and use patterns

While surface waters are unconditionally renewable—runoff will continue as long as severe climate change is avoided—groundwater, on the other hand, is only conditionally renewable. This is because some of the groundwater used for irrigation and urban water supply is quite old. Most of the groundwater resources of Australia are recharged annually, but some groundwater supplies are tens to hundreds of thousands of years (if not millions of years) old and response times to changes in recharge are also very long (in the order of centuries to thousands of years). This means that rapid use (at a scale of decades) makes the resource practically non-renewable. Also, there is evidence of overuse of groundwater in both urban and rural areas. Groundwater levels and pressures are declining, and this in an environment where restrictions on the use of surface water are causing an increased use of groundwater resources. Unlike surface water, where there are caps on new licences, for groundwater there are limited caps over a relatively small area of Australia. For example, groundwater levels in the Gnangarra mound aquifer under the city of Perth are declining, and there is evidence of overuse in many major aquifers (Radcliffe 2004, NLWRA 2001c) .

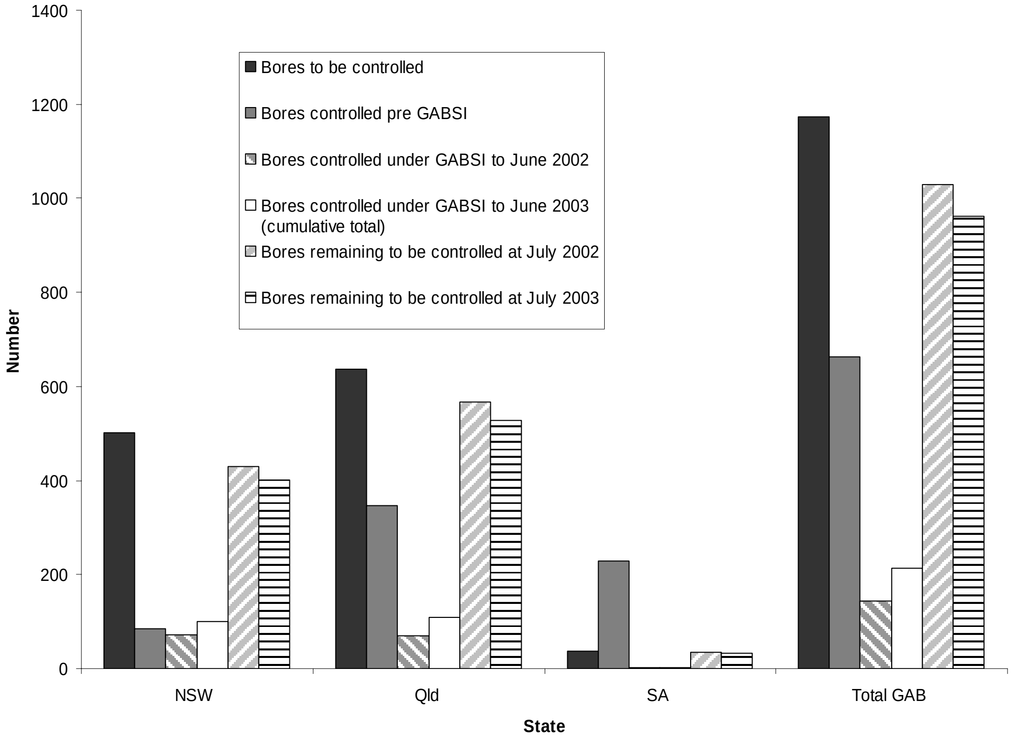
Table 3: Change in mean annual groundwater use between 1983–84 and 1996–97

State or Territory	Total Use (GL) 1983–84	Total Use (GL) 1996–97	Percent Change (‘83–84 to ‘96–97)
New South Wales	318	1 008	217 %
Victoria	206	622	202 %
Queensland	1121	1622	45 %
Western Australia	373	1138	205 %
South Australia	542	419	-22 %
Tasmania	9	20	122 %
Northern Territory	65	128	97 %
ACT	n/a	5	-
Total	2 634	4 962	88 %

Source: NLWRA (2001b, Table 22)

A recent decision to use a new groundwater source to supplement Sydney’s water supply raises questions of sustainability. Over large areas of the Murray-Darling Basin, groundwater levels have declined during the last decade due to the combined effect of the drought and excessive groundwater pumping (MDBC 2004). There are, however, positive signs in some regions. In the Great Artesian Basin, for example, many bores have been capped and drainage canals have been replaced with pipes to reverse declining groundwater pressures and water levels; this has led to the restoration of some spring wetlands. In some areas, this progress has been offset when old casings have failed and started to leak under the increased water pressure, which in turn has allowed higher pressure saline waters to intrude into less saline aquifers.

Figure 3: Status of bore capping under the Great Artesian Basin Sustainability Initiative



Source: adapted from Hassall and Associates Pty Ltd (2003, Table 3.1, p. 10)

Point source pollution of groundwater is generally controlled by Environmental Protection Agencies in the states and territories. Great improvements in groundwater pollution prevention have occurred in the least few decades, but diffuse source pollution (for example, pesticides, fertilisers, and septic tanks) remains poorly controlled in some jurisdictions.

Paradoxically, groundwater levels in shallow aquifers in many irrigation areas have risen to the levels of the mid-1990s because of recharge under irrigated crops. This is undesirable from a number of viewpoints. Over-application of water coupled with low water use efficiency leads to wastage of irrigation water. Significant groundwater mounds have existed under many irrigation regions where river water is used to irrigate crops. During the last decade, some of these mounds have stabilised or even declined due to improved water use management, and as a result of drought. Also, recharge under dryland crops and cleared pastoral lands exceeds the normal rates of recharge under native vegetation, leading to rising groundwater levels in shallow aquifers and dryland salinity.

Across the continent, there are many good examples of market forces bringing about increased water use efficiencies, better irrigation practices, and control of recharge. Similarly, in dryland and pastoral areas, there is an increasing use of perennial crops such as lucerne or agroforestry plantations to control recharge and bring about other sustainability benefits such as increased biodiversity. So the patterns of groundwater levels are mixed—in some places rising under irrigated crops where river water is over used, but either rising or falling in other areas depending on the source of the irrigation water, the demand for groundwater extraction, and the efficiency of use. In the Murray-Darling Basin, the introduction of the surface water Cap in 1995 has caused many irrigators to switch to using groundwater (MDBC 2003).

Available data suggest that, overall, there are now large areas of Australia where groundwater is being used above a sustainable rate; groundwater levels are declining as a consequence of overuse and lower rainfall. There is also evidence of a slow improvement in water use efficiency in agriculture as environmental and other concerns influence management practices. On rice crops in the Murrumbidgee Irrigation Area, for example, water application rates have fallen from just over two megalitres of water for each tonne of rice produced in 1985, to just over one megalitre per tonne in 2001. Much of this improvement in water use efficiency can be attributed to market forces and the rising cost of irrigation water.

Ecological aspects of flow regimes

As noted above, Australian inland rivers were historically, and are naturally, very variable in flow. In rivers like the Darling River, flood peak flows were as much as 1000 times the flow in dry periods. Almost all of these rivers have wide floodplains, where the connection between the channel and the floodplain during high flow events was a critical component of the ecology of those ecosystems. Even coastal Australian rivers (which have shorter, steeper catchments and narrower floodplains) are subject to very large fluctuations in flow, with high flow events and flooding following storms. Extensive damming and regulation of river flows has not only altered (and evened out) the river hydrology, it has also reduced or eliminated flooding. There are very few rivers in southern, eastern and Western Australia that are not regulated in some way, particularly in their lowland reaches. Rivers in tropical, northern Australia are less heavily regulated.

Hydrographs of many regulated Australian rivers now show a flow pattern resembling permanent drought, in which the frequency and magnitude of high flow (flood) events have been reduced and the seasonal flow pattern has also been significantly modified. Before settlement, most rivers ran high and in flood after storms or in the tropical ‘wet’, and then almost (or completely) dried up.

Native Australian species are adapted to the natural frequency and magnitude of flood and flow events, frequently taking their cues for migration and reproduction from seasonal flow changes. Overbank flows provided opportunities for feeding and spawning for native fish in these rivers, and these flows allowed species in billabongs and side channels to reconnect with the main flow. Now that all but major floods have been eliminated in regulated rivers, overbank flows are rarer and most rivers run bankfull in summer to provide irrigation water. This has radically altered the seasonal and inter-annual flow patterns. Thus, flow regulation has altered the ecology and biodiversity of these rivers in many substantial and subtle ways. Flow regulation has similarly altered the ecology of wetlands and lakes within regulated river basins. This is also true for major rivers and reservoirs serving urban areas where connectivity between the main channel and the floodplain has also been severed.

The reduction in flood frequencies and the extensive regulation of flows through the building of weirs and dams has changed the physics of most Australian rivers. In these regulated rivers, where floods once regularly scoured out depositional areas, there are now extensive depositional areas and much larger areas of fine sediments.

Before European settlement, there were frequent (if irregular) occasions when the floodplains and billabongs were flushed with freshwater and sediments were deposited; this now rarely happens. The alteration of flow regimes has also changed the physical habitat of most of Australia's rivers and streams because the scouring action of floods is now much reduced. The changes in land use and the increased erosion of material from the catchments have exacerbated this alteration of the physical regime.

Many people, it seems, forget that it is not just surface waters that have an ecology. There is increasing evidence of a significant stygofauna <http://www.deh.gov.au/soe/2006/emerging/fauna/index.html>.

in underground aquifers, for example in Western Australia (see Humphreys and Watts 2004). This means that alterations to groundwater hydrology are also having effects on the ecology and biodiversity of many poorly-understood species. Over-pumping and salinisation of aquifers will alter ecological communities and eliminate many species. Across Australia, there are also many groundwater dependent ecosystems such as wetlands (including mound springs <http://www.deh.gov.au/soe/2006/wetlands/index.html>.) that are in decline because of pumping of groundwater. This is discussed further in section 'Groundwater dependent ecosystems'.

Because of the widespread alteration of the hydrological regime across the southern part of the continent and the evident river degradation that has occurred, there is now an increasing emphasis on the value of the natural capital represented in the aquatic ecosystems of Australia's riverine and estuarine systems and the need to restore it. The restoration of environmental flows to rivers, wetlands, floodplains and estuaries is a matter of some priority. A number of programmes are now in place to try to achieve this; although, compared with the scale of the problem, progress is slow. It is worth noting, perhaps, that estuaries are as much in need of environmental freshwater flows as rivers and wetlands are. Estuaries are very sensitive to variability and, hence, regulation of freshwater inflows (Webster and Harris 2004). Because of the rapid pace of coastal development and the widespread regulation of coastal rivers and streams, there is an urgent need to restore the hydrological balance of some of our more degraded estuarine systems. Although natural river flows no longer enter many estuaries, estuaries do receive large volumes of urban stormwater runoff of varying quality.

Connectivity—dams and weirs

The regulation of flows, the construction of dams and weirs, the initiation of interbasin transfers and the alterations in the physical habitat of Australia's rivers and streams is changing the connectivity of these systems and the ecological and evolutionary framework of the continent's aquatic ecosystems. The very large number of control structures (dams and weirs to impound water, and levee banks to control overbank flows) on Australian rivers means that the lifecycle of many aquatic species is disrupted, particularly that of the native fish. Connectivity is vital for the survival of riverine species; a vital feature of the lifecycle of many species is floodplain connectivity, active upstream and downstream migration or passive downstream drift. There is growing evidence of widespread endemicity in the aquatic flora and fauna of Australian river basins. Because of the great age of the Australian continent, there has been sufficient time, it seems, for evolution of species to occur in relict invertebrate populations that have been isolated in different catchments.

The present hydrological condition of many Australian surface and groundwater systems, particularly in the southern part of the continent, is highly modified from the natural state. The modifications have been designed to increase the security and productivity of human activities and to ensure constancy of supply. All this has been done in an environment of naturally strong seasonal and inter-annual variability. It is important to remember that, before European settlement, the ecology of the continent was adapted and finely attuned to the natural patterns of variability. The human need for constancy and security since then has resulted in significant changes to the hydrology and ecology of the continent being made (see Table 4 for an example of the impact of weirs). Changes to flood frequencies, connectivity and the seasonality of flows are just as important as changes to the overall annually averaged flow regimes.

Table 4: Fish species found at the Branch River Crossing, NSW

Common Name	Number of fish	
	Above Weir	Below Weir
Port Jackson Glassfish	0	237
Long-finned Eel	5	11
Silver Bellies/Biddies	0	83
Hypseleotris Gudgeon	7	5
Flat-tailed Mullet	0	28
Australian Bass	13	49
Bully/Sea Mullet	6	10
Freshwater Mullet	2	1
Flat-head Gudgeon	71	148
Dwarf flathead Gudgeon	3	1
Blue eye	0	49

Source: adapted from World Wildlife Foundation Australia (2003, Table 1)

Connectivity—groundwater and surface water

The interconnection between groundwater and surface water is a poorly understood process in Australia. Groundwater and surface water are usually interconnected and interchangeable resources. In many cases it is actually the same water: groundwater becomes surface water, surface water becomes groundwater. Groundwater pumping within a catchment has the effect of reducing baseflow in a gaining stream and, in some cases, it can turn a gaining stream into a losing stream, causing induced recharge. But because this linkage has not been grasped by either government or the general public, Australia's surface water and groundwater have been managed completely separately. As a result, the same resource has often been double accounted and even double allocated—once as surface water, and a second time as groundwater—but it is actually the same parcel of water.

This has not been recognised because of the long time lag between when groundwater is pumped and when streamflow is actually reduced as a result. The effects of the huge increase in groundwater use during the 1960s, 1980s and late 1990s across Australia have, in some catchments, not yet been observed in reduced streamflows. Even though many of Australia's surface water catchments are now fully capped, this is still not the case for groundwater use. For example, in some parts of Australia it is still possible to drill a bore on the banks of a fully capped river and call it groundwater and get it approved.

The possible extent of double accounting of groundwater and surface water in the Murray-Darling Basin is described in MDBC (2003) and a description of the possible extent of double accounting in Australia is provided in Evans (2005). The implication of not recognising surface water – groundwater interaction and the continued development of groundwater in many catchments is the reduction in river baseflow. This may occur over months, or very slowly over decades, or even longer. As the baseflow index may typically be between 10 per cent and 50 per cent in Australia (see, for example, Neal et al. 2004), the reduction in baseflow can have the effect of significantly reducing streamflow, especially during the critical, low-flow dry season. This in turn has the effect of reducing the security of supply to surface water users and it can have significant impacts on the environment generally and, more specifically, on stream ecology, even leading to the complete drying out of streams in some cases.

The water cycle and land and vegetation condition

Vegetation

Native vegetation has an important role to play in the overall water budget of the continent through its control of the water balance and hydrology of large areas of the landscape. There has been considerable change in the vegetation of the Australian continent since European settlement in 1788. The native vegetation of Australia evolved in harmony with the variable climate and it is a very efficient user of water. Land clearing causes major changes to the hydrology of catchments; altering interception processes, evapotranspiration rates, and water flows. Land clearing has been extensive and this continues in some places. The basic change that has occurred in the intensive landuse zone is the replacement of structurally and functionally diverse native ‘bush’ that was dominated by perennials of various kinds, with a pastoral and arable cropping regime that is dominated by annual grasses and other crops. Not only is the undisturbed Australian ‘bush’ species-rich, it is also functionally diverse; this ensures that the vegetation is highly efficient in its water use (Pate 1999). A wide range of perennials and annuals with quite different growth strategies and phenologies ensure that almost all of the water arriving in the root zone is utilised. This process of maximising water use efficiency by native vegetation appears to take hundreds of thousands if not millions of years of evolution and ecological development. Subsurface water recharge under native bush is very low compared with the agricultural regime that has replaced it over the large areas of the continent where arable farming dominates.

The National Land and Water Resources Audit (NLWRA) assessed the state of the continental vegetation in 2001. There is a problem in assessing continental-scale vegetation change since settlement because of differences in the systems of reporting used by states and territories. While these are being addressed there are, nonetheless, difficulties in taxonomy and mapping systems. Notwithstanding these difficulties, the overall pattern is clear. Large areas of the wheat and sheep zone in eastern and south-western Australia have severely degraded vegetation. In parts of these regions, less than five per cent of the original vegetation remains, and introduced exotic weeds of various kinds are a problem (see Morgan 2000). Catchment condition, as measured by a number of indicators, is poor (see NLWRA 2002). Habitat fragmentation leads to species loss and reduced biodiversity and, more importantly from the point of view of water and hydrology, it leads to reduced functionality and water use efficiency. Fragmented and less diverse landscapes tend to be ‘leaky’ in terms of water, sediment and nutrient flows. Estimates of the change in the continental water balance since settlement have shown that, in many regions, a significant amount of water that was originally evaporated by the vegetation is now diverted to recharge (see Gordon et al. 2003). This is the fundamental reason for the outbreaks of dryland salinity that have occurred since settlement.

Estimates of the reduction in tree numbers since settlement show that as many as 12–15 billion trees have been lost from the Murray-Darling Basin since European settlement (Walker et al. 1993). The situation is not all one-way, however, because early photographs show fewer trees in some places than now exist. Also, widespread replanting is underway in agroforestry and other revegetation schemes. Some revegetation is targeted towards recharge and salinity control, other revegetation activities aim to restore biodiversity by increasing the extent of native vegetation and the linkages between fragments. At the scale of individual farms and small catchments, some of these efforts have been very successful. Connectivity is as important for the terrestrial landscape as it is in the aquatic realm. Nevertheless all the information to hand—vegetation cover and condition, agricultural extent, and urban development—indicates that the hydrological balance of the Australian continent has been significantly altered by land use change and clearing in the last 200 years (Gordon et al. 2003).

Widespread reforestation, either through plantation forestry or through smaller-scale agroforestry activities, changes the hydrology of catchments. Rapid growth of deep-rooted perennials, such as trees, uses water—more water, in fact, than mature bush—so that during the early stages of the reforestation cycle, water use increases and runoff decreases. Reduced runoff means less water for irrigation or urban supply. This is an important and topical interaction between vegetation and hydrology (Zhang et al. 1999, Best et al. 2003). As pressure on the resource increases, trade-offs will need to be made between revegetation strategies and the various productive and domestic uses of water in catchments.

Erosion

Large-scale estimates of erosion susceptibility and extent were also made by the NLWRA in 2001 (see also Prosser et al. 2001). Erosion of soil and sediment from hillslopes, erosion through gullying and contributions from riverbanks contribute to greatly increased sediment loads to rivers and estuaries (Table 5). Catchment condition is poor and sediment loads are high across large areas of the wheat and sheep zone of eastern and south-western Australia. Sediment loads to rivers are now estimated to be about ten times higher than they were before European settlement. Immediately after clearing of vegetation, sediment loads were more than one hundred times higher than beforehand. Together with the altered physical regime, this has changed the nature of bed sediments and habitats over long stretches of Australia’s inland and coastal rivers (Wasson et al. 1996). These changes have had a strong influence on biodiversity and river function.

Table 5: Components of sediment supply

Sediment source	Quantity (10^6 t/year)
Gross sheetwash and rill erosion	666*
Delivery to stream from sheetwash and rill erosion	50
Gully erosion	44
Streambank erosion	33
Total sediment supplied to rivers	**127**
Total suspended sediment stored	66
Total bed sediment stored	36
Sediment exported from rivers	25
Total of stores and losses	**127**

* Does not include sheetwash and rill erosion estimates for the Gulf, Western Plateau or Northern Territory as river budget assessments were not undertaken in these areas.
Source: NLWRA (2001a, Table 5.4 in ‘ Water-borne soil erosion’)

In many places across the continent—particularly the upland regions of the east and southeast—gully erosion is the major source of the sediment contributed to rivers and streams (see NLWRA 2001a). The initiation of the gullying process appears to have been rapid once the original land clearing occurred—sometimes more than a century ago. Intense rainfall is characteristic of many warm temperate, subtropical and tropical regions of Australia, so much of the gullying probably began in a single intense storm soon after clearing of the landscape on susceptible slopes. This is a common story in Australian hydrology and geomorphology—all the important things happen during infrequent, intense events; once again reinforcing the story of the importance of climate variability and the frequency and magnitude of individual rainfall and flood events.

Prosser, Olley and others (Wasson et al. 1996, Martin and McCulloch 1999, Prosser et al. 2001) have been able to use geochemical and other techniques to identify the sources of material in river sediments, to trace these to particular events in particular parts of catchments, and to examine trends over time. It appears that across large areas of the landscape, most of the intense periods of erosion are now over and that some kind of new equilibrium is being approached. Much of the eroded material has not yet worked its way through the bigger river systems, with large amounts of sediment stored in river channels in areas of low gradients of rivers (such as in the lower Snowy River), where it causes substantial ecological problems.

Erosion of sediments is much increased after fire. The large-scale fires that burned across the Victorian and NSW high country in 2001 and 2003 caused greatly increased erosion in these areas and led to poor water quality and the deposition of large amounts of soil and other materials in stream beds and lakes downstream of the fires (SAP 2003). Because of the high altitude and low temperatures in those areas, recovery of the vegetation and catchments is expected to take many decades.

All the evidence, therefore, points to close connections between land use, vegetation and its condition, and the hydrology and water quality of inland waters.

Water quality—nutrients and sediments

Increased loads of nutrients and sediments to inland waters increase the fertility of the water (causing eutrophication) and may lead to algal blooms and alteration of aquatic habitats. Just as erosion has increased since settlement so too have the loads of nutrients and other materials. River condition in much of the wheat and sheep zone has been extensively modified and is consequently poor.

The nutrients of most interest are nitrogen and phosphorus because of the important role they play in plant growth and the biological enrichment of receiving waters. In general terms, phosphorus is the key limiting element in freshwater systems and is mostly tightly bound to particulate material; nitrogen is generally the more soluble of the two. Nitrogen is usually the limiting element on coastal and oceanic waters. Nitrogen may be limiting in subtropical and tropical freshwater systems, where microbial process lead to nitrogen being stripped from surface waters. Geochemical tracer work in agricultural catchments seems to indicate that the biggest source of increased phosphorus loads to receiving waters is from gully erosion and streambanks rather than from fertilisers applied to paddocks (Martin and McCulloch 1999, Prosser et al. 2001). Because of generally low population densities across inland Australia there are few major towns discharging sewage effluents into inland rivers (Canberra and Albury-Wodonga being exceptions), so the major contributor to increased phosphorus loads to rivers is land use change and increased erosion. There are, however, nutrient enrichment problems downstream of irrigation areas and intensive dairy regions around the country, where runoff of animal wastes and agricultural chemicals is a regional problem. Estuarine impacts also result from this runoff. This is particularly true in higher rainfall regions.

Australia’s cities mainly discharge major wastewater streams to the oceans, although some coastal communities and suburbs discharge to coastal rivers. Direct discharges, storm runoff, sewer overflows and septic tank infiltration cause local problems with phosphorus enrichment in urban rivers. City water companies have programmes in place to control and improve the quality of these urban flows, through the construction of urban wetlands and other systems to detain and remove nutrients.

Nitrogen sources in landscapes come from fertiliser use and application, animal wastes and sewage discharges (Caraco and Cole 1999). Generally speaking, subtropical and tropical landscapes, such as those that characterise the Australian continent, tend to be poor in nitrogen because of high rates of denitrification. (This is one reason for the prevalence of nitrogen fixing cyanobacteria in water storages—they have a competitive advantage.) So as a result of agricultural development and urbanisation, nitrogen loads to rivers and coastal waters have increased markedly since settlement. Furthermore, the forms of nitrogen have changed from predominantly organic (and less biologically available) forms to inorganic and more biologically available nitrogen forms. This is a particular problem in estuaries, where nitrogen stimulates algal and plant growth, which increases the effect of the changed land use (Webster and Harris 2004).

A number of urban wastewater treatment plants now incorporate both phosphorus and nitrogen removal systems, thereby improving the quality of the water discharged. The initial focus was on phosphorus removal because of the key role played by phosphorus in freshwater systems, but biological nitrogen removal is now also widely used, particularly in waste-streams that reach coastal waters.

Influence of climate variability and change

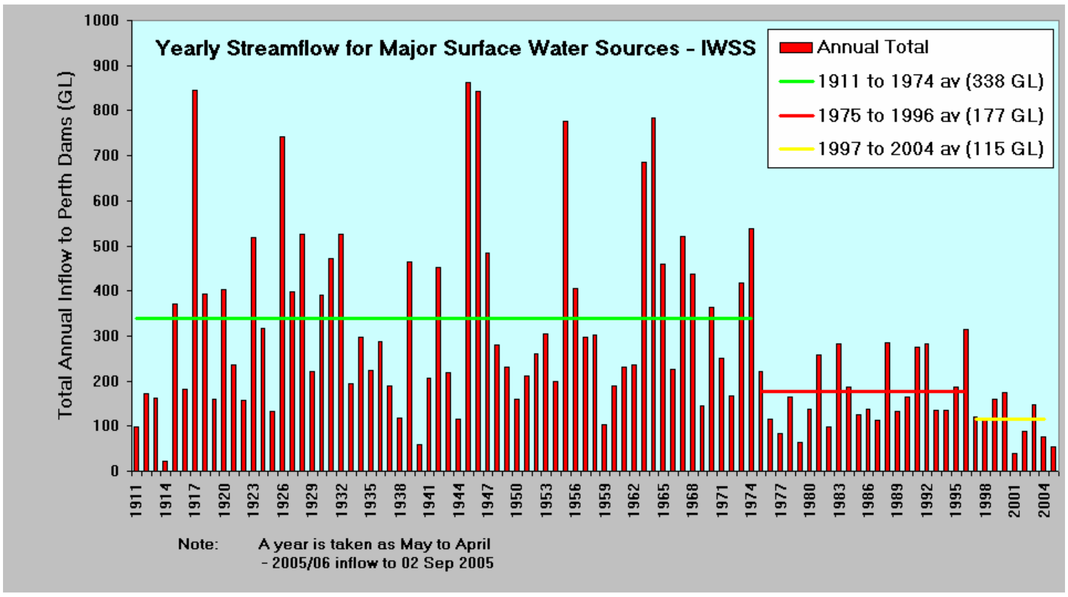
The debate over climate change is still not settled. While some deny the reality of anthropogenic climate change, others are now convinced that the severe lack of rainfall across large areas of the continent in since 2001 is evidence of a warming and drying trend. Whatever the position, there is strong evidence that, particularly across southern Australia, we are now seeing altered climate patterns and changes in seasonal flow patterns that are quite consistent with the predictions of the climate change models. These models predict reduced rainfall and runoff across southern Australia. Both models and observations agree; there has been a marked warming and drying trend across southern parts of Australia in the last three or four decades, which is apparently due to a southward migration of the subtropical high pressure ridge and a concomitant weakening of the zonal westerlies. In those regions of the continent that are dependent on winter rainfall, there has been a significant reduction in rainfall since the mid 1970s. This extends from Western Australia, through Victoria to eastern Tasmania.

A number of lines of evidence now show that the recent events are part of a longer term warming and drying trend during the last two hundred years (Thresher et al. 2004). The associated warming in southern Australia means that, in many regions, the balance of rainfall and evaporation has changed in favour of much drier conditions. This has been exacerbated by the recent one in one-hundred-year dry period in many regions. Observations have shown that, when compared to the 1982 low rainfall period (which had similarly low rainfall totals), the 2002–05 (and continuing) dry period was much more severe because it was, on average, as much as one degree warmer. The evaporation rate was consequently higher in 2002–04. The low flow conditions in the Murray-Darling Basin have been particularly severe, with storage levels at unprecedentedly low levels and widespread and severe stress being registered. Large areas of mature River Red Gum (*Eucalyptus camaldulensis*) along the River Murray corridor (about 250 000 hectares) have been killed by the combination of salt ingress to the floodplains, low flows, and the lack of flushing overbank floods. Recent surveys show that the situation is getting rapidly worse; it has been exacerbated by low river levels during this very dry period.

All major southern Australian cities have been on water restrictions in recent years and some are now permanent. The situation in Goulburn is particularly severe, with the city’s reservoirs going below 10 per cent of full storage levels (in late 2005). All major city water companies are studying future supply options, including desalination, new dams, reuse and recycling schemes and demand reduction options.

The situation in Western Australia is particularly severe, with a sharp and sudden drop in runoff in Perth catchments of 50 per cent during the mid-1970s (see Figure 4, and IOCI 2002). If the altered hydrological regime in Australia is a sign of climate change, then Australians shall have to live with a new set of realities. Certainly, water-supply planning benchmarks that used long-term runoff averages have been suddenly changed and planners are dealing with new levels of uncertainty. The reduced rainfall and greater evapotranspiration has also had the effect of significantly reducing recharge, thereby causing groundwater levels to decline.

Figure 4: Yearly streamflow for Perth dams



Note: A year is taken as May to April
- 2005/06 inflow to 02 Sep 2005

Source: Water Corporation (2003)

Habitat scale influences

The larger-scale changes to land use, water allocation and flow regulation, which occur across the continent, have led to smaller-scale changes in habitat in inland waters. Within wetlands and in rivers reaches, habitats are modified by reduced flows, increased sedimentation of fine materials and removal of riparian vegetation. Thus the larger scale modification of the landscape has local effects that strongly influence biodiversity and ecosystem function.

Surface water quality

Sediment and turbidity

Although many Australian rivers and storages are naturally turbid, soil erosion has significantly increased sediment loads to rivers and estuaries. Because of the altered disturbance regimes, it is presumed that suspended sediment concentrations are higher now than they would have been before European settlement of Australia. The highly-erodable clay soils, combined with the dilute and largely sodium-dominated nature of surface waters in Australia, means that clay and other particles stay in suspension in the water column and settle only very slowly. Inland waters flowing from catchments with large areas of intact native vegetation tend to be clearer than those originating in agricultural and urban catchments—there is a close link between soil type, topography, climate, land use and levels of suspended material in inland waters. The NLWRA showed that high levels of sediment and turbidity were widespread in inland Australia in 2000, particularly in areas of the wheat and sheep zone, where land clearing has been extensive. Increased sedimentation smothers species that require clean water and rocky substrates and interferes with gill function in invertebrates and fish. Fine sediments can become devoid of oxygen, which kills susceptible species. Turbidity can limit light penetration and growth of native aquatic plant communities.

Nutrients

In the assessments done for the NLWRA in 2000, nutrient levels in excess of the water quality guidelines were found in approximately two-thirds of catchments assessed. (The NLWRA focused its effort in the intensive land use zone.) The trends over time were mixed, with increases of nitrogen and phosphorus being approximately equal to decreases. The Australian landscape is naturally stripped of nitrogen through denitrification and low levels of nitrogen deposition, whereas phosphorus levels in inland waters tend to be high because of the large amounts of eroded and suspended materials in the water. Ecological processes in rivers, therefore, adapt to the scarcity of nitrogen relative to phosphorus.

Land use change in Australia has increased the export of nitrogen and phosphorus from catchments, and made these two nutrients more available for plant growth in rivers and storages; agricultural and urban catchments show higher levels of dissolved inorganic nitrogen and phosphorus in the water than pristine forested catchments, where organic forms predominate (Harris 2001). High concentrations of nitrogen and phosphorus in inland waters can lead to algal blooms under certain circumstances, oxygen depletion and, possibly, fish kills.

Freshwater wetland and lake systems can exist in two states—one with clear water, populated by a diverse assemblage of water plants; the other turbid and dominated by planktonic algae and cyanobacterial blooms. Once flipped from clear to turbid, it is often very difficult to reverse the process. It does seem that as a result of land use change, urban development, flow regulation and increased sediment and nutrient loads from the catchments, many (if not most) standing and slowly flowing Australian surface waters have been flipped into the turbid state; examples include lakes Mokoan and Wellington in Victoria. Both lakes are now highly turbid and they are frequently subject to major algal blooms, often of toxic cyanobacteria. Populations of water plants in most Australian rivers are also much reduced—through increased sediments, nutrients and rapid changes in water levels—so that what we now see are turbid rivers flowing through bare channels with few water plants.

Salinity

The NLWRA data for 2000 show that salinity is a problem in about one-third of catchments assessed, particularly in south-western Australia, and in the southern Murray-Darling Basin (see Table 6). These are all areas with a long history of clearing and intensive agricultural use. Reductions in the area of perennial native vegetation in these catchments have altered the surface and groundwater hydrology, increased groundwater recharge, and increased salt ingress to rivers and streams. The salinity trends in all regions were mixed, partly because of the short (8–10 year) data records analysed, but also because of climate and flow variability in these rivers. Instream and groundwater salt concentrations decrease during wet periods when dilution is greater, although falling groundwater tables (near the surface) may reduce salt ingress, so a clear distinction must be made between salinity exceedances (concentrations, which vary with flow) and loads (the amount of salt moving through a catchment system). It is dangerous to make definitive statements about salinity trends based on concentration data alone because of climate and flow variability, complex interactions between hydrology and salt stores, long groundwater residence times, and changing river management practices. The Murray-Darling Basin Commission salinity audit of 1999 (MDBC 1999) predicted rising salinity loads throughout the rivers of the southern Murray-Darling Basin for the following 100 years as groundwater salinity moves through these systems. These predictions have not transpired up to 2005 because the severe drought during the early 2000s caused regional lowering in groundwater levels and hence reduced salt discharge. This does not imply that a return to more normal rainfall patterns would not cause an increase in salt discharge.

Table 6: Exceedance of water quality guidelines for Australia (number of river basins)

Water quality measure	Number of major exceedances	Number of significant exceedances	Number of basins assessed
Nutrient: total nitrogen	19	19	50
Nutrient: total phosphorus	40	20	75
Salinity: electrical conductivity	24	18	74
Turbidity	41	10	67
pH	7	6	43

NLWRA 2000

Herbicides, pesticides and other agricultural chemicals

Many regulatory and licensing programs have focused on the elimination of industrial, agricultural and other chemicals from the aquatic environment. While action is still required in some cases, it can be said that, overall, such programmes have been reasonably successful in the last decade and that instances of toxic concentrations of such chemicals are not frequent. For example, in all the recent major studies of the effects of urban development on the ecology of coastal waters and lagoons (Perth, Adelaide, Melbourne, Brisbane), toxic substances have been found to be a secondary issue behind biodiversity loss and nutrient loadings. Exceptions include streams downstream of some irrigation areas, some industrial and mining sites, disused sheep dip sites and old waste dumps, which continue to pollute groundwater. Innovative remediation techniques are now being developed and applied to many of these sites (for example, at the Kwinana oil refinery in Western Australia) including the development and use of specific microbes that have been selected to metabolise and eliminate industrial and other chemicals efficiently.

While cases of catchment-scale pollution from agricultural and industrial chemicals are rare, there are still recent examples of downstream impacts on ecosystems and on coastal fisheries (especially oysters). Because of the complexity of hydrological processes arising from altered flow regimes and of connectivity between events on land and in streams there is, as yet, considerable uncertainty around the evidence for the precise pathways and mechanisms of direct downstream effects (Harris and Heathwaite 2005). Nonetheless, there is enough evidence to be concerned that this is an area requiring more investigation (Table 7).

Table 7: Reported emissions to inland waters from National Pollutant Inventory facilities (kg)

Substance	2001			2004		
	From facilities 10–50 km from coast	From facilities >50 km from coast	Total for facilities > 10 km from coast	From facilities 10–50 km from coast	From facilities >50 km from coast	Total for facilities > 10 km from coast
Total nitrogen	36 462 128	1 950 869	38 412 997	2 493 071	1 643 984	4 137 056
Sulfuric acid	39 440	2 100	41 540	1 333 771	1 920	1 335 691
Ammonia (total)	15 450 626	125 044	15 575 670	915 136	318 054	1 233 189
Manganese and compounds	38 922	5 995	44 917	1 091 630	57 028	1 148 659
Total phosphorus	8 735 614	267 325	9 002 939	655 709	178 811	834 521
Total volatile organic compounds	2 111	167 213	169 324	295 065	746	295 811
Ethanol	57 224	2 000	59 224	290 313	118	290 431
Zinc and compounds	66 334	86 052	152 386	265 019	20 975	285 994
Chlorine	381 304	14 909	396 212	209 688	1 876	211 563
Copper and compounds	23 814	5 433	29 248	87 518	56 836	144 355
Fluoride compounds	1 276 162	22 656	1 298 818	90 183	22 165	112 349
Hydrogen sulfide	16 700	168	16 868	59 665	4 650	64 315
Cobalt and compounds	606	31 770	32 376	29 339	16 280	45 619
Nickel and compounds	5 835	754	6 590	13 173	19 161	32 334
Lead and compounds	23 067	21 288	44 355	16 015	6 120	22 134

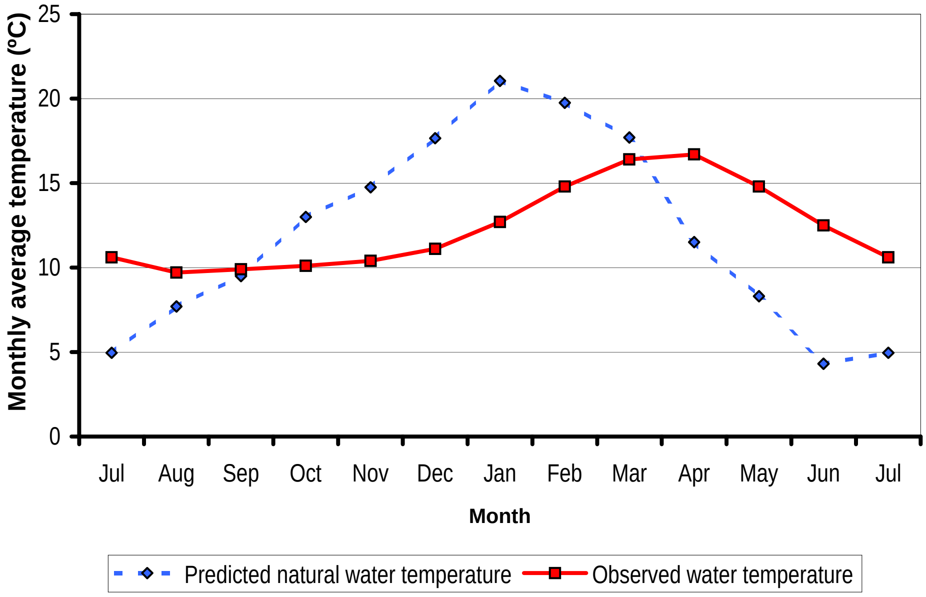
Toluene (methylbenzene)	334	2 622	2 956	7 619	64	7 683
Xylenes (individual or mixed isomers)	330	1 529	1 860	5 666	34	5 700

Source: National Pollutant Inventory database

Thermal pollution

Dams and large weirs placed across Australian rivers cause stratification of the water behind the dam walls, with water being warmer at the top and colder at the bottom. Because the water tends to be discharged at the base of the dam wall, these weirs and storages discharge colder water than would be ‘normal’ for the river. This impacts on the reproductive and migratory behaviour of downstream species. Because of the stratification cycle in the pool behind the wall, downstream discharges show quite different seasonal temperature patterns to those normally encountered in the river (Figure 5). Spring and summer temperature rises (which are often the spawning and migration cue for native animals) are delayed or eliminated. Data indicate that major dams can influence river water temperatures for hundreds of kilometres downstream from the wall and that temperatures may be reduced by as much as 10–12 ^{o}C. The precise pattern of behaviour will depend on the size and shape of each dam or weir, the pattern of seasonal discharge, and climate variability from year to year. Nonetheless, effects are evidently far-reaching and ecologically important. In some large dams, off-takes are now being constructed higher up the dam wall to reduce thermal pollution effects.

Figure 5: Effect of cold water releases from Blowering Dam on the Tumut River



Source: NSW Fisheries data 2002, cited in Department of Environment and Conservation, NSW (2003, Figure 5.3)

Instream habitat

Instream habitats have been influenced by land use change in the catchments and gullying and other forms of erosion. Prosser et al. (in NLWRA 2001) were able to model the process of erosion, transport and deposition as a function of climate, slope, stream power, land cover and soil types; accounting for most of the observed patterns of erosion and deposition. As noted above, much of the eroded material has not reached the oceans, so large sections of the lower reaches of many Australian rivers now store these sediments and have slugs of sand that have smothered instream habitats of various kinds. This material is influencing ecological and biogeochemical connectivity within the channels and, particularly at low flows, has very much modified the habitat.

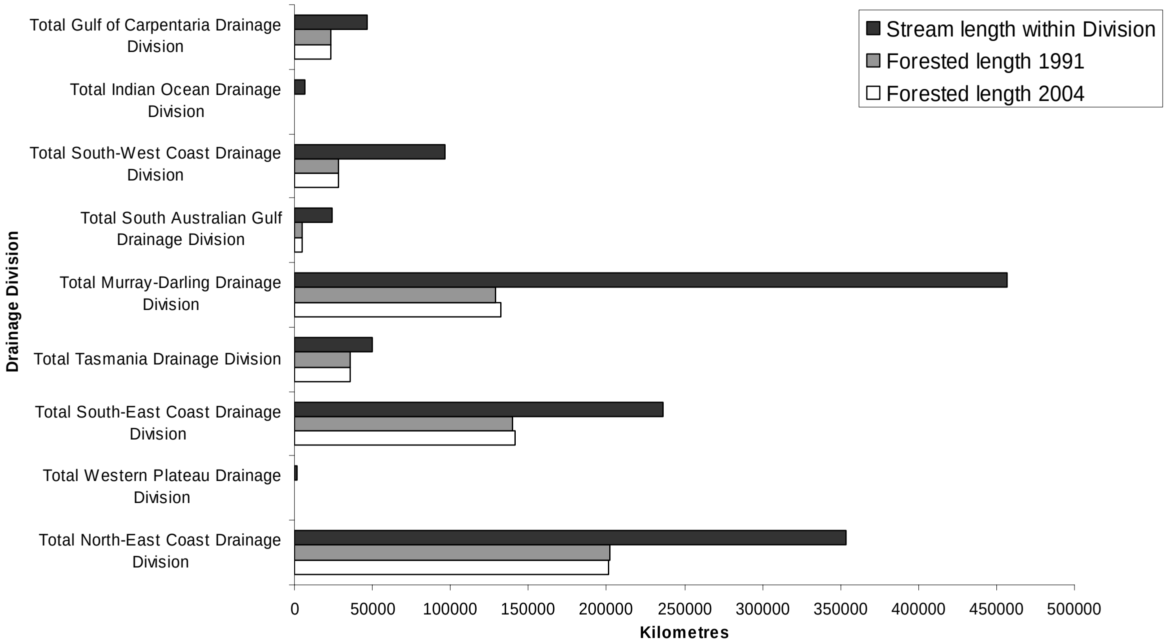
Instream habitat has been further modified by extensive ‘de-snagging’ of lowland rivers and by the decline of native vegetation and water plants. Very small scale aspects of instream habitat (such as sediment grain size and the existence of biofilms on snags and plant stems) are vitally important for the survival of the diverse flora and fauna of Australian rivers—especially invertebrates and juvenile fish. Therefore, the alteration of the physical habitat, through the replacement of a diverse set of structural habitats over a range of physical scales (cobbles, riffles, snags and a diverse range of aquatic plants) by a much more uniform habitat structure (sandy or muddy depositional environments with few snags or plants) has led to reduced biodiversity. Re-snagging programmes—to replace ‘snags’ in lowland rivers—are an important way to replace habitat for fish, birds and other aquatic organisms, but the scale and scope of these programmes is small compared to the scale of the problem.

Riparian vegetation

Riparian vegetation serves a number of critical ecological and biological functions. Riparian vegetation is a major habitat for many terrestrial plant and animal species, acts as a buffer for material moving off adjacent land, contributes detritus and other material to the instream ecosystem, acts as a nutrient filter, removes nutrients from the water, and shades the channel itself. Rivers with native riparian vegetation in better condition tend to have better water and instream habitat quality than those with vegetation in worse condition. Because of the key role of sites adjacent to the river channel in contributing material to the channel, measures of the intactness of riparian vegetation are, therefore, important components of measures of river health.

The proportion of river reaches with healthy riparian vegetation varies greatly between and within regions (Figure 6). As a general rule, the data seem to show a rough proportionality between habitat fragmentation, land clearance and the remaining riparian vegetation, so that there is less riparian vegetation in heavily cleared parts of the intensive land use zone (for example, Western Australia, the southern and central Murray-Darling Basin, and western and central Victoria) than in parts of northern Queensland, Tasmania and eastern Victoria. There appears to have been little change in the length of vegetated riparian zones in the major catchments between 1991 and 2004. Only minor increases in the condition of riparian zones have been recorded during that period.

Figure 6: Forested streamlength in the drainage divisions of the intensive landuse zone



Source: Environmental Resource Information Network (2004, unpublished data)

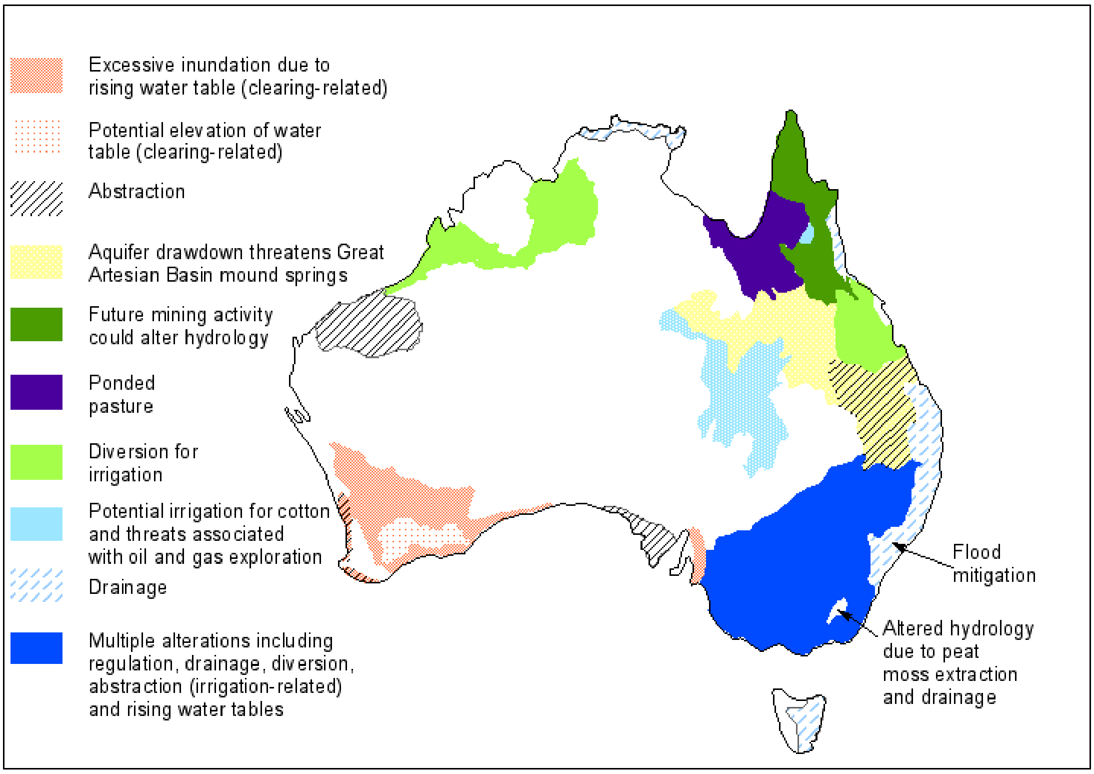
Wetlands

Wetlands are an important part of the aquatic waterscape because of high biodiversity and productivity, their potential role in improving water quality, and their key role in providing habitat for birds, amphibians and threatened species. Wetlands are structurally diverse and support a large range of biofilms and other important microbial populations. Unfortunately, wetlands have frequently been regarded as useless swamps to be drained, farmed or otherwise ‘reclaimed’ for agricultural and other uses. Wetlands also suffer when river flows are regulated because of either permanent inundation through their use as off-river storages or almost permanent desiccation because of the elimination of overbank flows. Most wetlands in south-eastern Australia consist of remnant fragments of their former extent.

It is now realised that the proper management of the remaining shallow floodplain lakes and wetlands along Australia’s major rivers requires the reinstatement of more natural flooding and drying regimes—something that is quite difficult to engineer in heavily regulated river systems. Irregular wetting and drying stabilises sediments, improves water quality, reduces introduced fish populations, and leads to a diverse population of waterplants and birds.

Ninety per cent of floodplain wetlands in the Murray-Darling Basin, 50 per cent of coastal wetlands in New South Wales and 75 per cent of wetlands on the Swan Coastal Plain in south-west Western Australia have been lost due to drainage and altered flow regimes. Weed invasion, conversion to agricultural use, and increased fire frequencies are ongoing and significant management issues for wetlands (Figure 7).

Figure 7: Distribution of Ramsar-listed wetlands with threatened or potentially threatened water regimes



Source: Davis, et al. (2001, Figure 1)

Fish passages

The construction of dams, weirs, road crossings and other barriers to the migration of fish species has been extensive. Connectivity between upstream and downstream populations has been reduced or eliminated in many river drainages of the southern and eastern parts of Australia. Of the 53 native freshwater species in NSW, 28 undertake large-scale migrations, 16 migrate on local scales, and the status of the remaining nine species is unknown. At present in NSW, there are more than 4300 physical barriers but only 28 fishways that are effective for native fish [link to IW28]. Construction of fishways is increasing, although inadequate, as the effects of migration barriers are becoming understood; but there appears to be a need to consider more carefully the biology and migratory behaviour of Australian native fish because not all native species appear to be able to pass through some of the devices that have been constructed.

Groundwater dependent ecosystems

The role that groundwater plays in controlling the health of ecosystems in Australia is often overlooked. Groundwater dependent ecosystems depend at least partially on groundwater to maintain their health. These ecosystems represent a diverse, yet distinct component of Australia's biological diversity. Clifton and Evans (2001) identified six major types:

- terrestrial vegetation
- river baseflow systems
- aquifer and cave ecosystems
- wetlands
- terrestrial fauna
- estuarine and near shore marine ecosystems.

In practice, there is a continuum of ecosystem types with, for example, wetlands sharing many common features with riparian vegetation. Groundwater level, flux, pressure and quality (including temperature) can all control ecosystem health and location. There is also a continuum of groundwater dependence, ranging from those ecosystems that are entirely dependent on groundwater (for example, the mound springs of the Great Artesian Basin <http://www.deh.gov.au/soe/2006/wetlands/index.html> and most stygofauna <http://www.deh.gov.au/soe/2006/emerging/fauna/index.html>) through to those that make limited or opportunistic use of groundwater (for example, many wetlands throughout Australia).

The first national assessment of groundwater dependent ecosystems was undertaken by Hatton and Evans (1998). Since then, many researchers have published on specific types of groundwater dependent ecosystems, with Hancock et al. (2005) providing an up-to-date assessment of baseflow and aquifer groundwater dependent ecosystems. At the national scale, relatively little is known about these ecosystems, but knowledge is rapidly improving with research. This especially applies to vegetation, wetland and river baseflow systems. The key challenge in this research is to relate the change in ecosystem health to the change in the groundwater regime. This 'response function' is slowly beginning to be understood for specific groundwater dependent ecosystems at individual sites.

The awareness in the scientific community of groundwater dependent ecosystems has increased greatly in recent years; however, the understanding of groundwater dependent ecosystems in the wider community remains poor. Nonetheless, the increased awareness of environmental flows for streams has caused surface water managers to start to consider baseflow for groundwater dependent ecosystems. As the baseflow component of many streams in Australia commonly represents about 50 per cent of the total streamflow, the need to manage groundwater and hence maintain streamflow, especially during the low flow dry season, has become obvious.

Response of animals and plants to catchment disturbance and the alteration of flow regimes

Data from the recent Millennium Ecosystem Assessments clearly shows that freshwater aquatic biodiversity is declining rapidly around the world. This is a result of land use change, flow regulation, water extraction, draining of wetlands, and habitat modification. Australia is no exception to this global picture. The situation is further complicated by the general lack of awareness and knowledge about the biodiversity and importance of aquatic organisms. Compared with terrestrial species, there are few threatened species listed from inland waters, few nominations for the threatened species list, and the general taxonomic knowledge is also poorer. Other than for a few groups of ‘iconic’ species—for example, fish, frogs and waterbirds—there is little knowledge or appreciation of the urgency of the situation.

Bacteria and algae

Cyanobacteria (or blue-green algae) are natural components of Australian inland waters, occurring frequently during low flow periods and in billabongs. There is evidence that cyanobacteria have become more widespread as river modification and the construction of storages has proceeded. Bloom frequencies fluctuate from year to year as both climate variability and flow regulation alters flow regimes in Australia’s inland waters. Cyanobacterial blooms currently account for about 10 per cent of the total cost of environmental protection in Australia. These blooms are frequently highly toxic to people, stock and pets, so they interfere with many beneficial uses of water. During an algal bloom, people and stock must be kept away from the water, fisheries are closed, and water treatment costs rise markedly. Warm temperatures, long water residence times and stratified water columns, high levels of light, and high phosphorus concentrations favour cyanobacterial blooms. Furthermore, many cyanobacteria species control their buoyancy, so they are able to float to the surface and out-compete other species in turbid waters. Some key toxic species are also able to fix nitrogen from the atmosphere. So an ability to both float and fix nitrogen gives them an advantage under conditions of turbid waters with low nitrogen and high phosphorus—conditions that are found in billabongs, storages, and weir pools during low flow periods. Cyanobacterial blooms, therefore, tend to be more common in dry years and less common during normal flow events. (Indeed control measures employing flushing flows have proved to be successful in many cases.)

Macro-invertebrates

Macro-invertebrate populations are routinely used as indicators of river health. Our understanding of the habitat requirements of macro-invertebrates leads us to believe that there is a causal link between river modification, physical habitat features and river health as measured by this technique. As might be expected from the generally poor state of Australian catchments and rivers, invertebrate data showed that one-third of river length is impaired to some degree, having lost between 20 per cent and 100 per cent of the various kinds of aquatic invertebrates that should live there (Table 8). New South Wales has the poorest aquatic biota condition; approximately 50 per cent of river length has impaired aquatic biota. These data may be under-estimates of the actual condition of our rivers, particularly in the Murray-Darling Basin, because the assessments depend on the identification and sampling of unmodified reference sites. These may be difficult to find in some of the more modified regions. There is inconclusive evidence of change in macro-invertebrate populations in recent years.

Table 8: Sites assessed using AusRivAS, all states and territories, 1990–2004

Period of assessment	Number of sites at each level of diversity compared with reference sites					
	More diverse	Similar to reference condition	Significantly impaired	Substantially impaired	Severely impaired	Total number of test sites
1990–2004	195	2465	1 556	433	56	4 705
1994–1999 (in ASEC 2001)	154	1 702	963	254	39	3 112

Source: Australian River Assessment System (AusRivAS): National River Health Database, with input from: Natural Heritage Trust; state and territory lead agencies for river health assessment; Australian Government Department of the Environment and Heritage; CRC for Freshwater Ecology; Land and Water Australia; and Freshwater Systems Pty Ltd.

Invertebrate communities depend on small-scale habitat preservation (both instream and in the riparian zone), catchment condition, flow patterns and connectivity for their life cycles and reproduction. As might be expected, macro-invertebrate communities show greatest evidence of impairment in inland and coastal regulated rivers, where land use change has been extensive and habitat modification has been extensive. Also, invertebrate communities show evidence of considerable alteration in urban catchments, where nutrient and sediment loads are increased, sewer overflows occur during storm events, runoff patterns are changed and stream channels are frequently physically modified to control flooding.

Fish

All the evidence points to reduced numbers and biodiversity of Australian native fish. In New South Wales, 22 per cent of the fish species that were expected to occur were not found in recent surveys, fish communities were frequently found to be in poor condition, and many species have reduced abundance or restricted distributions. Despite restocking programmes, 11 native fish species are listed as threatened in New South Wales. Many introduced fish species are now abundant and, indeed, recent evidence seems to show that regulation of Australian rivers favours introduced over native species. Recent work has shown that introduced fish abundance and biodiversity can be used as a measure of river health. Thirteen alien species were recorded from New South Wales freshwaters, with Carp (*Cyprinus carpio*), Goldfish (*Genus species Carassius auratus*), Redfin Perch (*Perca fluviatilis*), Gambusia (*Gambusia holbrooki*), Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) the most common. The greatest numbers of introduced species were recorded from rivers in the Murray region. Introduced fish alter habitats, and they compete with and prey on native fish, thus exacerbating the effects of flow regulation and land use change.

Recent trends in New South Wales fisheries statistics show a continued increase in introduced species, a decline of native species, and the continued spread of Carp, Gambusia and Oriental Weatherloach (*Misgurnus anguillicaudatus*). Recruitment of native fish is enhanced in wet years—which have been few since 2001—and the reintroduction of environmental flows and overbank flows is required to further enhance the success of native species.

Frogs

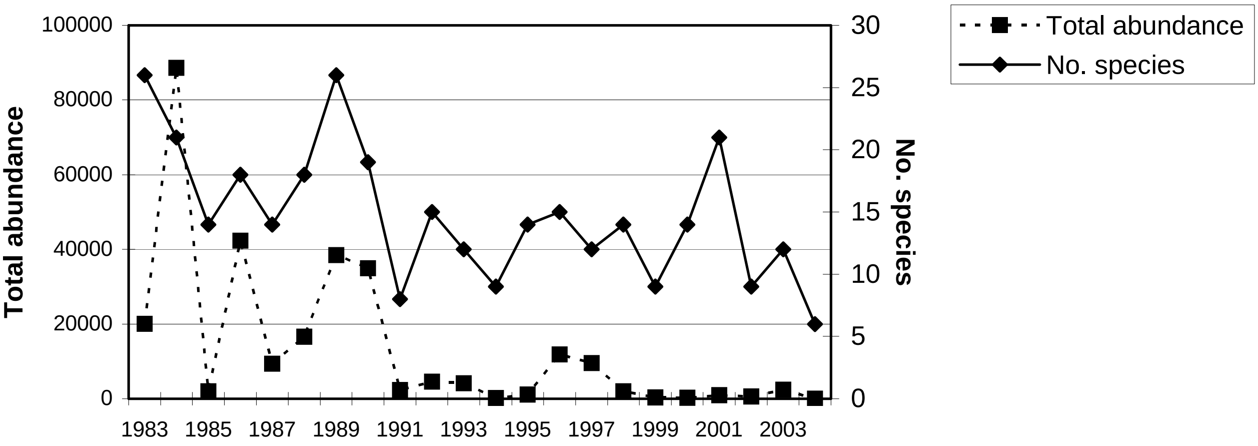
Frogs are very sensitive indicators of declining aquatic ecosystem health and extent, and many species have ‘gone missing’ around the world in recent years. Australia is no exception, ranking thirteenth in the world in terms of overall frog biodiversity and twelfth in terms of the number of threatened species. There is an increasing number of sites in Australia in which frogs are no longer found. Four species are listed as extinct under the *Environment Protection and Biodiversity Conservation Act 1999*, 15 are endangered and another 12 are listed as vulnerable; overall about 14 per cent of species are threatened. Frog populations have decreased markedly in the last decade or so, with several species thought extinct. This is thought to be due to the Chytrid fungus, which is a worldwide phenomenon. The extent to which this has been associated with anthropogenic impacts is unknown but it is suspected to be at least partly responsible for the decline. The change in species composition and abundance continues to be rapid <http://www.deh.gov.au/soe/2006/emerging/frogs/index.html>. The situation is urgent.

Waterbirds

Australian waterbirds fall into two broad categories—migratory species that come to Australia from the northern hemisphere during the northern winter, and native species that breed in Australian wetlands and other aquatic habitats (these may also migrate between regions). Many migratory species are endangered or threatened by habitat loss either in their native habitats or along the migratory routes. Severe reductions in wetland extent in Australia have reduced the available habitat as well as the numbers and breeding success of Australian native waterbirds.

The distribution and abundance of waterbirds are closely connected to the occurrence of floods and wetland inundation during wet years. Many waterbirds are long lived and adapted to massive, but infrequent breeding events. Reduced flooding and strict river regulation—particularly during the recent dry period—has led to reduced breeding success in the southern and eastern parts of Australia. Over the last 50 years, the frequency of flooding flows in areas like the Barmah-Millewa Forest, Gwydir wetlands, Narran lakes and the Lowbidgee has declined because of river regulation and water extraction; waterbird breeding has also declined. Waterbird populations have declined by more than 80 per cent in the Lowbidgee wetlands in the last twenty years (Kingsford 2004). In the central-west of New South Wales, waterbird surveys show that out of 46 species studied, 29 species are declining and only five are increasing, while 12 showed no overall trend during the study (Reid et al. 2004). Environmental flow allocations for bird breeding, such as carried out in the Macquarie Marshes and the Barmah-Millewa wetlands, do improve breeding success and have been used in localised experimental allocations. Climate change—with its associated increase in the frequency of long dry periods—has the potential to impact strongly and negatively on all species.

Figure 8: Estimates of numbers of waterbirds and numbers of species of up to 50 different taxa counted during aerial surveys in October each year 1983–2004 at Macquarie Marshes



Source Kingsford and Porter (2005)

Wetland and floodplain communities

Wetland and floodplain communities have been degraded across large areas of the intensive land use zone through overgrazing, salinisation, lack of flooding, clearing and draining, and the introduction of weeds and introduced wild animals. Recent surveys of the floodplains of the lower Murray River have found that about 80 per cent of River Red Gums are stressed to some degree, with about 20–30 per cent of them severely stressed to the point of death. The Black Box woodlands of the terraces along the river are also severely stressed, and have experienced extensive historical contraction in range. Salinisation of floodplain soils and the lack of natural flooding events have seriously stressed the trees. If the riverine forests of the lower Murray River are seriously degraded, many other species will be adversely affected and river health will be degraded.

Exotic species

As noted above, it appears that changes in the flow regimes and ecology of Australian inland waters are favouring the spread of many introduced species. Furthermore, introduced species, like Carp, can change habitats and influence the ecology of other species. The continued introduction of more natural flow regimes is essential for the reestablishment of a more balanced fauna in our rivers.

Stream metabolism: the processing and cycling of nutrients and other materials in inland waters

Although the data are sparse, there is evidence that habitat modification and land use change have altered the stream metabolism of inland waters. Increases in aquatic nutrient levels and productivity, as well as a change in the structures and metabolism of biofilms, have changed the sources and availability of carbon and other major nutrients in rivers. More of the carbon supplying stream metabolism now comes from more readily available sources from instream production, and less comes from relatively refractory catchment and riparian sources. These changes are consistent with the change of state from clear to more turbid conditions. All the changes seem to favour increased algal blooms, greater sediment respiration and oxygen demand, and more frequent periods of anoxia in the bottom waters of pools, weirs and dams. Loss of riparian vegetation also favours this same sequence of interactions, particularly in upland streams.

The construction of large numbers of dams and weirs has led to the impoundment of large volumes of water. Through the resulting increasing water residence times, particularly in major river basins, the more easily decomposed sources of carbon are removed and oxygen is stripped from the water. This has led to increased nitrogen stripping through denitrification and a lowering of the nitrogen:phosphorus ratio; further favouring the growth of cyanobacterial blooms. Nitrogen cycling in rivers has been further modified by the construction of impoundments because the cold water that is discharged downstream from the bottom waters of dams and weirs is low in oxygen and rich in ammonia from decomposition of organic matter in those waters. Large dams act as sources of ammonia for downstream ecosystems.

Human response—policy and management

New policy and management initiatives

While it is too early to judge the success of the National Water Initiative (NWI), some statements can be made about the success of the Natural Heritage Trust (NHT) and the National Action Plan for Salinity and Water Quality (NAP). Overall, as in many other countries, there is a trend towards subsidiarity (the devolution of decision making to local communities), outsourcing, and the use of market instruments for the management of natural resources, especially water. Clearly, past water and land management practices have left numerous ‘externalities’—degraded rivers, poor water quality, and reduced biodiversity; particularly in Australia’s icon river basins. The NWI represents the shared commitment of the Australian, state and territory governments to water reform. The NWI goes some way to addressing the needs for institutions to manage rivers as riverine ecosystems as well as managing for all the other uses and values of the water. Robust water reform is underway through the Council of Australian Governments and, more recently, the NWI through the development and use of water markets and changes to titles and legal rights. It remains to be seen to what extent these reforms will be sufficient to restore the rivers and improve the evident loss of biodiversity. See Table 9 for water recovery targets set under the NWI (in the Intergovernmental Agreement on Addressing Water Overallocation and Achieving Environmental Objectives in the Murray-Darling Basin).

Assessment of past NAP and NHT investments and numerous catchment-based environmental flow allocation agreements show that they have been insufficiently strategic in nature and, while addressing local and regional needs, do not address the larger strategic needs for improved practices and sustainable solutions. To this end, there is a need for a fundamental rethink of many present practices because analysis shows that what are presently assumed to be ‘best management practices’ do not, in combination, achieve sustainability or the desired catchment management targets. This is partly a product of the small scale and fragmented nature of investments in managing inland waters, riparian zones and catchments. Innovation is therefore required, new solutions must be found and applied in the form of new land and water use patterns that are sustainable, financially viable and acceptable to the community, whose attitude to water is changing (that is, that water ‘left in the rivers’ and flowing past their ‘back door’ is not ‘wasted’ water). The scale of the problem requires larger-scale, integrated programmes with clear strategic objectives and an environmental outcome focus.

The water reform process in Australia has clearly led to improved efficiencies in allocation mechanisms, improvements in water use efficiencies and, progressively, more efficient use of water for environmental purposes. More effort needs to be made to ensure that profitable or cost-effective solutions are found for some of the problems outlined above, including land and water use patterns that sustain and improve the natural environment. Increased profitability is necessary so that sustainable investments can be made in financial, social and environmental capitals. It is widely accepted that the strategic needs are for sustainable rural and regional communities and for capacity building as natural resource management moves to more complex jurisdictional and governance policies. Rural and regional communities need assistance to operate in a new, and much more complex, regulatory and market environment. Local communities also require more (scientifically defensible) data and analysis upon which to make more robust rational and sustainable decisions about their environment and its future.

Table 9: Indicative water recovery targets for the Murray-Darling Basin within each jurisdiction under the Intergovernmental Agreement

Jurisdiction	New South Wales	Victoria	South Australia	Australian Capital Territory	Australian Government
Indicative Volumetric Target	249 GL	214 GL	35 GL	2 GL	–

Source: Murray-Darling Basin Ministerial Council (2004, Table 3, p. 7)

Management of surface water and groundwater

Largely through the efforts of the Council of Australian Governments, Australia has seen much water reform in the last decades as state, territory and Commonwealth natural resource management agencies have been restructured in an environment of subsidiarity and the introduction of water and other markets. While surface waters are better managed than they were, there is evidently still more to be done [. Surface water and groundwater are still over-allocated in many places; and sustainable, conjunctive water use is still a matter to be addressed. The large-scale decline in groundwater levels in many of the nation’s major aquifers often continues unnoticed. A focus on profitability over other capitals and values (environmental, social, aesthetic) has led to an imbalance, and landscape and waterscape degradation has resulted. A new balance between often-incommensurate values is required, which will be defined in a new sense of ‘place’ and new management practices. This will be realised through new, more efficient and profitable crops and cropping regimes, new land use mosaics that incorporate a variety of annual and perennial crops, and new approaches to conservation areas and biodiversity preservation. Up until now, the Australian landscape has been remade in a European image—reflecting the historical roots of the culture and an overriding European sense of ‘place’. This is nowhere more noticeable than in the design of Lake Burley Griffin in Canberra, with a lake surrounded by parks and spreading shade from deciduous trees—a northern hemisphere urban design in the southern uplands. In all probability, sustainable landscapes and waterscapes in the Australian context of poor, shallow soils and climate variability will look and work differently.

Groundwater management continues to be a ‘poor second cousin’ to surface water management, as the intimate linkage between the two is generally not understood. In many catchments, the introduction of caps on surface water resources has occurred, while groundwater development is often controlled to a limited extent, if at all. The reduction in streamflows has been blamed on the 2002–03 drought, while the impact of groundwater pumping in catchments is generally not understood.

Policy and institutional reform is underway, but all the data on the state of the inland waters environment indicate that there is still much work to be done. There is a slow adoption of policies and practices that encourage increased water use efficiencies, water reuse and recycling, and reduced demand. Australia does not yet have in place policies and practices to ensure that saved water is effectively returned to the environment to produce environmental benefits. Price and regulatory signals are not yet ensuring rapid adoption of new water reuse and demand management policies. Advances are being made in public health and other requirements, but a major shift in public attitudes will be required before extensive water reuse is countenanced.

As in other parts of the world, changes in corporatisation, privatisation and outsourcing policies have led to quite marked shifts in the risk profiles of everything from individual farm enterprises to major water corporations. New intermediaries are appearing and risks are being shared and defined in new ways through partnerships, leasing arrangements, and insurance and risk management protocols. In the urban water industry, for example, many new entities have appeared to operate or lease infrastructure, manage supply and demand, and manage risks. What was once the sovereign risk of governments is now managed by privatised and corporatised entities through insurance and other financial structures. Outsourcing does not always cover all the risks, particularly those arising from extreme events or complex interactions between financial, social and environmental systems. Allocation policies and practices must be robust in the face of climate change and other unpredictable future events. Water pricing policies must take environmental flow requirements and other system level, environmental needs into account.

Above all, what is required is a process to define an accepted community-wide vision and set of objectives for environmental outcomes from water management in this country.

Environmental flow allocations and management

There is a growing interest in environmental flow allocations and managing them for maximum environmental benefit; the NWI is a major step in this direction. Unfortunately, the tools are restricted to a set of assumptions about linkages between catchment condition, flow management, physical habitat changes, and changes in aquatic biodiversity. Precise knowledge of the flow requirements of many key species and communities is lacking. It is known that ecosystems respond to the frequency and magnitude of extreme events more than to annually averaged flows, and that connectivity is essential. It is a major challenge to ensure a more natural regime of environmental flows in river systems that have been specifically engineered to retain high flows for later (slower) release. It may simply not be possible to return flow regimes to their required variability given the huge ‘sunk costs’ of Australia’s physical infrastructure, financial investments, and the requirement for water security. What is possible for what investments, and how Australia should balance the various values and capitals (human, social, physical, financial and natural) in new ways, remains to be determined and agreed.

For Australia’s major river systems, hydrological and ecological modelling is largely inadequate and incomplete (particularly in catchments where there is little hydrological data), leaving managers dependent on the use of expert judgements and other forms of anecdotal information. Uncertainties are large. The state-of-the-art of catchment and ecological science and modelling is such that it is not yet possible to provide many of the answers to urgent and significant questions. There is greater scientific understanding of the hydrology than there is of the ecology, but policy development is operating in an environment of a considerable lack of knowledge about key processes and linkages. This is not a recipe for doing nothing, but it is a situation in which some sophisticated adaptive and risk management is going to be required. Adaptive management will require greater flexibility on the part of many jurisdictions and institutions and also an ability to cope with time lags in environmental responses. Surprises, like the loss of the River Red Gums on the River Murray, will continue to occur. In many cases, nobody knows how to ‘put the rabbit back in the hat’ once it has jumped out, although the Living Murray initiative and the NWI are attempting to restore floods and overbank flows to selected ‘iconic’ sites on the Murray River floodplain. It is important to recognise the limited nature of the water allocations under the ‘First Step’ of the Living Murray programme and that only small benefits are likely. Political will must be sustained to address the ‘Second Step’ before too long an interval has passed. Trial and error, and an ability to rapidly learn from mistakes, will also be necessary.

There is now a legislative requirement to consider the health of groundwater dependent ecosystems in most states and to include groundwater dependent ecosystems in the water allocation planning process. This significant improvement has occurred only since 2001. With the general lack of scientific understanding of groundwater dependent ecosystems, this requirement is often difficult to achieve with any reasonable level of scientific confidence.

Habitat management (including wetland management)

Habitat management programmes are underway in all states and territories. Much progress is being made with programmes such as the recovery and restoration of riparian vegetation, re-snagging programs and weed control and removal (for example, willows). There have been advances in knowledge about the wetting and drying cycles that are necessary for the management and restoration of wetlands (including some examples of the recovery of the clear and aquatic plant dominated state with a consequent recovery in waterbird populations, such as Lake Merretti in South Australia). Wetland preservation under the Ramsar convention is monitored, although there are examples of Ramsar wetlands that continue to suffer highly salinised and dry conditions after the recent extended period of low rainfall and lack of overbank flows. Management plans are in place but some are difficult to fully enact because of a lack of water. Climate variability and change influence the ability to manage these important assets.

Most habitat management programmes are quite tactical, small scale and specific to particular threats. Integrated catchment management and integrated water resource management plans are rife and widely promulgated. Implementation is, as yet, mostly patchy because of lack of capacity and a lack of integrated policy implementation. The Victorian catchment management authority structure is an exception that should be highlighted. Integrated policy implementation will require the balancing of various forms of social, economic and natural capital to find a more sustainable pattern of water use and management than is presently practised. Under NAP, the NHT regional and catchment committees have set investment priorities and they are addressing habitat and biodiversity management requirements. Regional NHT plans should be more strategic and integrated to tackle the landscape-scale threatening processes discussed above.

The most significant threatening processes are clearly those that that operate at landscape and waterscape scales—land use change, water extraction, irrigation, flow regulation, draining of wetlands, and exotic species management; therefore there is a need to tackle these threatening processes at these larger scales. The NWI is a move in this direction. The real challenge is, therefore, to find a more sustainable mix of public and private investment on public and private land. This must be backed by the necessary institutional, regulatory, governance and market mechanisms that operate at scales that move the entire economic, social and environmental system towards higher sustainability and profitability, increased water use efficiency, improved environmental flows, and river restoration. Piecemeal habitat restoration programmes will not be effective if the landscape-scale threats are not addressed and the landscape-scale science is lacking. Similarly, unprofitable rural enterprises are not able to make sustainable investments in new practices and habitat restoration measures. There is, therefore, a need to tackle a number of system-level policy and management interventions in ways that deliver more sustainable and equitable environmental, social and economic outcomes. The trend is definitely in this direction but the rate of change is slow.

The sustainable future of Australia and its water resources lies in finding ways to balance numerous competing demands for water—the balance of the legitimate demands of people in nature. As Australians begin to understand the peculiarities and complexities of their unique continent, they are moving slowly towards better solutions. The challenge is to make these solutions act with sufficient speed and scale to allow an effective and proactive engagement with new emerging issues such as climate change.

Management of aquatic biota and biodiversity

While there are many recreational fisheries and fishers, particularly on stocked populations of introduced species such as trout, many inland fisheries for native species have been stopped because of the low catch returns and the endangered nature of key species. As noted previously, the population status of many species of aquatic animals and plants is not well known and there are few listings under the *Environment Protection and Biodiversity Conservation Act 1999* or under state and territory legislation. Endemicity in Australia's ancient river basins may be much higher than is presently assumed. Because of the strong link between habitat management and biodiversity management, the same comments apply here as were made earlier—there is an urgent need to address the landscape-scale threats to habitats and biodiversity. Restocking programs may maintain native species of fish and frogs, for example, but true population recovery requires larger-scale and longer-term policy and management initiatives.

There are indications that the need for larger-scale land and waterscape management is recognised and that policy and legislation will begin to address these larger-scale issues through ecosystem-based and regional-scale management of fisheries and other resources. Committees such as the Commonwealth Threatened Species Scientific Committee have, because of the piecemeal nature of threatened species nominations and the need to manage threatening processes at larger scales, begun to draft policy papers addressing ‘multiple species, multiple community’ management needs.

Conclusions

Overall, the state of the inland waters environment in the southern and eastern part of Australia is not very healthy. Significant areas of major inland and coastal catchments are degraded (including vegetation, aquatic habitats and water quality), the pressure on water resources continues to be high, and many indicators show that aquatic ecosystems and biodiversity are degraded across large areas of the continent. Water use and infrastructure development continues to grow and there is little indication that key indicators have improved in the last decade. The indicators that do exist are bedevilled by climate variability and periods of low rainfall, population growth, and changing land use patterns. There is much ignorance and uncertainty over the condition of aquatic biota and we lack key data from many areas, particularly data on trends over time for major groups. In some cases, such as frogs, there are data that clearly indicate that species are declining. Other cases, as for aquatic plants, the situation is less clear. While there are many excellent examples emerging of small-scale habitat and species restoration, many of these are under threat from possible climate change and human-induced, large-scale land and water use patterns.

Introduced species continue to flourish and ecological changes ensue. Species such as Carp not only compete with native species but also alter habitats in undesirable ways. Introduced species appear to be favoured by the large-scale, landscape and waterscape management practices found across large areas of the continent. Exotic species such as Carp and Gambusia continue to expand their range, with little evidence of effective control.

Evidence does point to important changes in climate over southern parts of Australia in the last 30 years (the declining runoff into Perth’s dams is but one example) and this shorter-term trend seems to be a part of a much longer trend that has been going on since the early days of European settlement (Thresher et al. 2004). Rainfall and runoff have declined significantly in many areas of the south and east, and hydrological benchmarks and planning frameworks are being constantly revised. Although there are reasonable models that relate climate to hydrology and runoff, knowledge about potential climate change and its impacts is very uncertain. The situation is urgent and we lack key predictive tools. Attempts are made to manage and set water and environmental policy with far less data and resourcing than would be deemed prudent in the case of economic policy. The trend in subsidiarity to engage communities in natural resource management has not been accompanied by sufficient technical and scientific capacity building at the local, regional or state level.

The reduced availability of surface water has resulted in much greater groundwater use in recent years over much of Australia. This has resulted in declining groundwater levels in many areas. As in most of Australia, groundwater discharge to streams maintains the dry season baseflow; the switch to groundwater use will simply have the effect of reducing river flow in the long term wherever connected groundwater and surface water systems occur. The reduced availability of surface water both reduces the security of supply to surface water users and degrades the river ecosystems.

Australian water resources are characterised by great variability in space and time. Climate variability is a fact of life and climate change has the potential to fundamentally alter the patterns of variability that Australians have grown used to. Through a requirement for security, people have greatly altered the natural patterns of variability and connectivity; this has had a significant impact on habitats and biodiversity. There is evidence from recent climate changes in south-western Australia, which occurred abruptly and without warning, that the past may not be the best guide to the future. Certainly, planning timeframes have shortened greatly in the last 30 years and, as long as predictions of future climates are for warmer and drier conditions, it would be prudent to put in place policies and practices that reduce the human demand for water (for example, the permanent Level 1 water restrictions now in place in some jurisdictions). To do so would relieve the dependence on rainfall and runoff and reduce the potential risks, as well as make more water available for vital environmental values.

Australia’s appreciation of groundwater dependent ecosystems has increased from almost zero only 10 years ago. Nonetheless, understanding is still at a rudimentary level and significant scientific research is required. The translation of the science into practical management presents an even greater challenge to water resource managers.

Water use efficiency and reuse are slowly increasing (Radcliffe 2004). The recent southern dry period has caused an increased focus on supply and demand management and a revision of water management plans in major cities. Water restrictions continue. The Council of Australian Governments’ water reform process that started in 1994 was given momentum by the severe lack of rainfall; more protection of the environment and restoration of environmental flows should ensue. Other Commonwealth, state and territory programmes continue to address many of the issues, but in a piecemeal manner, although there are some signs that this is changing. The Basin Salinity Management Strategy, for instance, provides a framework for communities and governments to control salinity and protect natural resources within the Murray-Darling Basin. It establishes end-of-valley salinity targets for each tributary catchment and a basin target at Morgan in South Australia. Implementation is a shared responsibility between valley communities and governments and there is a commitment to the principles of the Integrated Catchment Management Policy Statement. Subsidiarity and the establishment of regional natural resource management committees is to be applauded, but the policy raises key questions about capacity and the ability of regional communities to understand and manage in a much more complex environment. We must be careful, for example, to ensure that the drought does not deflect us from the important task of returning environmental flows to rivers and streams. Subsidiarity in governance must be supported by institutional reform and the strategic provision of key knowledge needs.

Significant progress on environmental restoration will require policy and management initiatives that tackle the large-scale land and water use issues. New mosaics of land and water use that are profitable, equitable, socially acceptable and environmentally sustainable must be found.

The overall themes of this report are the ways in which variability and connectivity—which are both crucial for the ecology and health of Australia’s inland surface water and groundwater systems—have been changed by human actions over the last two hundred years. The demand for security of supply has led to a large change in the ways Australia’s inland surface waters and groundwaters are managed; it has also changed their health. Overall the indicators show that demand for water use is increasing, although use is capped in some regions and, in recent years, supply has decreased in many regions. There is now good evidence that, as demand increases in the coming years, there will be a growing gap between supply and demand. New technologies, such as desalination, aquifer storage and recovery and other approaches—such as demand reductions, and increased reuse and recycling—will be required to close the gap. Water quality and health-related issues will become a greater issue, as water ‘fit for purpose’ will be required for many agricultural, industrial and domestic purposes, especially with increased pressure to recycle and reuse water. While water of poorer quality may be used for many industrial purposes (for example, cooling water), higher quality water is needed for other uses such as environmental flows and drinking water. Salinity can have a significant impact on water quality. Dissolved salt concentrations vary and determine the suitability of water use; for example, a salinity level above 1500 milligrams per litre is not suitable for irrigation.

Water quality remains poor across large areas of the continent and biodiversity is degraded and declining. Land and water are intimately connected; large, catchment-scale landscape and waterscape management initiatives will be required to restore the health of Australia’s inland waters. The trend towards this scale of intervention is now being contemplated and new policy initiatives are being put in place. Nevertheless, the scale and scope of the interventions required are challenging. Climate variability, a fact of life on the Australian continent, makes the task more difficult because it drives change at scales of decades, and this is superimposed on top of human-induced changes, both positive and negative.

By international standards, Australia is not short of water; but regional variation in intensity of water use is great. In many regions, the aquatic environment is showing the strains of present and past policies and management practices. Australians must make more and better use of what they have. Integrated management of surface water and groundwater is urgently needed in many catchments. If the trend towards warmer and drier times continues, then determined efforts will have to be made to use less water, to make more efficient and effective use of scarce resources, to reuse and recycle more water of varying qualities, and to do significantly more to preserve and protect important natural, cultural and aesthetic values. These are complex and difficult issues, which will require effective partnerships between all members of the Australian community.

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Glossary

Baseflow: the component of the total stream flow due predominantly to groundwater discharge into a stream. It typically is the low flow in a stream over the dry season in Australia.

Anoxia: the condition of being devoid of oxygen. Usually found in the bottom waters of lakes, estuaries and slowly flowing rivers in situations where large amount of organic matter settle and decompose, using up the oxygen in the water

Biofilms: slimy films of bacteria, other microbes and organic materials that cover underwater surfaces, particularly the surfaces of ‘snags’ (fallen trees). Biofilms are ‘hot spots’ of microbial activity and have a major role in ecosystem function underwater.

De-snagging: removal of the ‘snags’ – fallen trees – lying in the river channel of lowland rivers. ‘Snags’ were common in Australian rivers but they interfere with recreational uses like water skiing and look unsightly so are often removed. They were also removed in the mistaken belief that they had a major effect on reducing the flood carrying capacity of our rivers.

Fishways: engineered structures to facilitate the movement of fish up- and down-stream in rivers with many dams and weirs, which control levels and regulate flows and prevent the migration of fish.

Intensive Land Use Zone: the highly settled regions of the continent – largely the coastal regions of the South-west and the east, including the coastal strip, the inland of south-western WA, the northern and eastern parts of Tasmania, and the western slopes and plains of Victoria, New South Wales and Queensland.

Peri-urban: areas surrounding major cities developed for low-density horse and hobby farms or low-density semi-rural housing

Recharge: the flow of rain water from the surface to below the root zone of plants and crops which contributes to groundwater supplies

Sand slugs: large deposits of sand or other fine material lying in the bed of rivers. The material comes from gully erosion in the catchment. These sand deposits fill up the river channel, smother the original form of the riverbed and move slowly downstream.

Stygofauna: animals inhabiting underground aquifers and caves