# Consequences of past hydrological disturbance and emergent issues for water resources in Australia

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## INTRODUCTION

Australia is a large, megadiverse, island continent undergoing environmental change on a huge scale. Water is a central part of this landscape change and is also essential for future societal well-being. This paper describes the origins of hydrological disturbance, the ensuing consequences and emerging issues for water in Australia.

Australia is a large and varied island continent with a land mass of 7 682 300 km$^2$ and a coastline of 37 000 km. The land is ancient and flat with an average altitude of only 300 m a m.s.l. The country spans a range of climatic zones, from the wet-dry tropics in the north to the arid centre to temperate and mediterranean climates in the south.

The mean annual rainfall is 465 mm, making Australia the driest of all the permanently inhabited continents. Some 80% of the land has an annual rainfall < 600 mm, whilst only 4% is above 1200 mm per annum. The continent has high evaporative potential, with annual pan evaporation rates > 2000 mm. The combination of low rainfall and high evaporation results in a modest mean annual runoff of 52 mm.

## CULTURAL HISTORY OF AUSTRALIA'S WATER

### Aboriginal relationship to water

There are few accounts of Aborigines's relationship to water, most being restricted to the use of fish traps. Contemporary accounts from the 1840s describe the gatherings of several hundred Aborigines at fish trapping sites which were seasonal events of social significance. It is now understood that Aboriginal occupation over many millennia has led to an affinity with water and land that is unmatched by European settlers (Smith, 1998). Networks of waterholes and rock pools were known and maintained across even the driest parts of the continent. The Aboriginal way of life was intimately linked to the biophysical environment and involved spiritual relationships centred on ancestral beings who created the form of the land and the people. The impact of Aboriginal occupation on rivers and water resources was minimal compared to the changes they caused to native flora and fauna.

### 19$^{th}$ century

Explorers Oxley, Sturt, Mitchell, Hume, Leichhardt, and botanists John and Allan Cunningham, all repeatedly reported that watercourses ceased in reed barrier ponds (billabongs). The Darling, Macquarie, Gwydir, Namoi, Lachlan, Murrumbidgee, Goulburn and Murray rivers 'died' in the plains. They reported that watercourses were unlike any other and had a total absence of worn banks. Cod and other species of fish lived in the cool reed barrier ponds and were observed moving up the catchment in times of flood.

Captain Cadell was commissioned by the NSW Government to clear a river up the Murray. He developed a steam powered saw machine for cutting trees below the water line and went on to clear the Goulburn, Darling and other rivers between 1856 and 1863. Settlers and squatters also burnt reeds for their cattle and sheep and cleared areas adjacent to watercourses. When floods occurred, new river courses were cut into the soft soil far from the prior watercourses, undercutting and dropping large stretches down several feet. The prior streams and billabongs drained to the new lowered rivers.

Australian water histories frequently cite the occurrence of droughts as shifting social attitudes. The severe Victorian droughts of 1877–81 led to water being the key social and political issue of the time. The *Water and Conservation District Act (1880, amended 1883)* was the first to *"conserve and distribute water not only as a means of preserving life, both animal and human, but also as a means of increasing the yield of soil, giving some security to agriculturalists in districts where rainfall is precarious"*. The *Irrigation Act 1886* was based on the recommendations of Alfred Deakin, regarded as the founder of Australian water law, whose main recommendation was that the State should exercise supreme control of ownership over all rivers, lakes, streams and sources of water supply except springs rising upon private lands.

### 1900–1950

The Federation of Australia was proclaimed on 1 January 1901 but natural resources remained a State responsibility. In the first half of the century, water engineering works were fostered by large, powerful and well-resourced state government agencies. The movers and shakers who drove these bodies were, almost without exception, engineers backed by influential politicians whose policies and attitudes reflected the national drive for increased agricultural production. The 'art' of economics received little recognition. Dam engineering and irrigation were pre-eminent and any adverse effects were rarely mentioned.

### 1950s to the 1980s

Infrastructure for water resource development grew dramatically over this period. The national goal of development was supported with new injections of federal government funds. Throughout all water sectors the major developments were planned and implemented by state agencies run by engineers. Australia had entered a phase of development that was to lead to an era of mega-projects founded on even larger dams. The best known of these schemes are the Snowy Mountains Scheme, the Ord River development; hydro-electricity in Tasmania and the Burdekin Dam in Queensland.

The NSW government started stream channel protection and rehabilitation in 1948 under the Rivers and Foreshore Improvement Act. Stream frontage land owners were mainly concerned with flooding problems. Streams (rivers, creeks and gullies, both perennial and ephemeral) were considered wild or 'faulty' and landowners requested that they be tamed or trained to reduce flooding or 'improved' for human use. Works such as channel straightening and clearing of riparian vegetation were carried out across southern and eastern Australia. Some of these practices persisted through to the mid-1980s (Department of Water Resources 1987, Outhet *et al*., 1999).

### 1980s onwards — emergence of environmental values

The Tasmanian dams issue is a symbolic turning point in Australian history (and to some extent internationally) in galvanising the environmental movement. The first signs of conflict arose with the proposal to construct the Gordon River power scheme. This involved flooding Lake Pedder which had been designated a National Park a few years earlier. The 'Save Lake Pedder' campaign resulted in the first large coordinated environmental demonstrations seen in Australia. Whilst the dam went ahead and the lake was flooded, the campaign spawned the United Tasmanian Group, the first environmental political party in the world. The subsequent battle over the proposed damming of the Franklin River was resolved in 1983 in the High Court in favour of the Commonwealth over the Tasmanian state government to stop the dam. Since that time dam building has been in serious decline, with only two significant dams constructed in the 1990s.

From this complex history of water and river management in Australia, today's perceptions and values have emerged and are evolving.

## HISTORICAL DRIVERS OF HYDROLOGICAL CHANGE

Historically the major impacts on the quality and health of aquatic ecosystems in Australia have been caused by land clearance and water resource developments, both primarily for establishing agriculture (Schofield *et al*., 2000). Due to the small population and manufacturing base, point source pollution has been a much smaller problem than broad-based landscape activities.

### Land clearing for agriculture

In 1788, forest covered about 10% and woodlands about 23% of the Australian continent (Carnahan, 1986). By 1990 this had been reduced to 5 and 15% respectively, with an average loss of more than 500 000 ha per annum of woody vegetation (CSIRO, 1990). In the south, native vegetation has been replaced principally with annual pastures and crops. This has led to a severe degradation of riparian zones, increased sediment loading and turbidity in rivers, surface water nutrient enrichment and land and stream salinisation.

Riparian vegetation is poorly protected in agricultural areas as these zones are predominantly privately owned, with little active management for protection of riparian values (Bunn *et al*., 1993). In a major national assessment of riparian vegetation (NLWRA, 2002), 65% or 120 000 km of the river length assessed was cleared.

### Water resource developments

More than 447 large dams have been built for a variety of purposes, including irrigation (primarily), urban water supply, hydroelectric power generation and flood mitigation (ANCOLD, 1990). Until very recently, dams, weirs, channels and levees were designed on engineering and water supply criteria alone, with little thought given to ecological impacts (Kingsford, 2000). As a result, most dams have been designed without fish ladders and impede upstream fish migration (Harris and Gehrke, 1997).

Australia is now winding back its large dam building; however, the agricultural landscape contains several million small farm dams (ICAM/SKM, 1999). These dams have mixed environmental outcomes, on the one hand modifying river flows and reducing water quality but at the same time providing refuge for native flora and fauna.

There are 24 inter-basin transfer schemes in Australia, the best known being the Snowy Mountains Hydro-electric Scheme. As with dam releases, water transfers may increase bank erosion and sediment transport, adversely affect the source river through reduced flows and transfer biotic material, thereby disrupting river basin biotic integrity (Davies *et al*., 1992).

### Irrigated agriculture

Irrigated agriculture in Australia covers about 2 million ha, mostly concentrated in the south-east (80% in the Murray-Darling Basin). Many irrigated areas are suffering raised water tables and soil salinisation. The drainage of irrigated land to rivers often contributes significant loads of sediment, salt, nutrients and pesticides. Irrigation accounts for about 70% of Australia's harnessed water resources and has a major impact on river hydrology, both through direct abstraction and storage and delivery operations (Schofield, 1996a; Schofield and Simpson, 1996; Schofield, 2000). Irrigation water use increased by about 5% pa over the period 1984 to 1997 (NLWRA, 2000).

### Forestry

The impact of forestry operations on rivers has generally been minor in the long term when compared with agriculture. Examples of increased river sediment and salinity have been cited where extensive clearfelling has taken place, but these problems diminish rapidly with regeneration (Schofield, 1996b). Short-term and long-term effects of forest silviculture (Stoneman and Schofield, 1989, Ruprecht *et al*., 1991) and fire on stream yields have been recorded. Forest management impacts on rivers are often reduced by the inclusion of riparian buffer zones, and the retention of riparian forest and understorey. Some transient ecological impacts of forestry pesticide spraying have been recorded (Davies *et al.*, 1994).

### Mining

Mineral resources are a mainstay of the Australian economy but mining has generally had little impact on rivers because of the small area developed (<1%). Some important mineral deposits do occur, however, within high value ecosystems (e.g. Kakadu National Park, Northern Territory; Jarrah Forest, Western Australia) and potential riverine impacts are a concern (Schofield and Bartle, 1984; East *et al*., 1988). Extraction of sand and gravel deposits from river channels does occur and effects of these activities are well documented (e.g. Warner, 1995). Australia's most notable water-related mining disaster is the pollution of the King and Queen rivers in Tasmania (Davies *et al*., 1996).

### Industry and urbanisation

Most of Australia's other industrial activity is concentrated within or close to urban and coastal areas. Large-scale industrial point-source pollution to rivers is rare. Similarly, urbanisation has had only local impacts on rivers (Thoms *et al.,* 1999), although a number of small to medium towns discharge significant effluent loads to rivers in the Murray-Darling Basin thus contributing to blue-green algal blooms (Thoms and Flett, 1993).

## MAJOR CONSEQUENCES OF HYDROLOGICAL DISTURBANCE

Human activities of many kinds can disturb the hydrological cycle or water balance, and this disturbance can in turn create additional unforeseen environmental problems. In Australia, land clearing and water resource development have to date had the greatest impacts on landscape hydrology which in turn has led to secondary salinisation, soil erosion, eutrophication and degradation of water regime dependent ecosystems.

### Salinisation

The first detailed account of secondary (human-induced) salinisation (Wood, 1924) arose from the observation that railway water supplies were going saline a few years after the clearing of native vegetation. Wood conceptualised that rising groundwater tables brought about by the replacement of deep-rooted native vegetation by short-rooted annual crops and pastures was mobilising salt stored in the soil profile. This hypothesis was validated much later through detailed research in the 1970s, by which time stream salinities were rising and salt scalds expanding across agricultural areas of south-west Western Australia (Schofield and Ruprecht, 1989).

Salinity in Australia is a long-term problem for dryland farming, irrigated agriculture, river water quality, native vegetation, wetlands, biodiversity and human infrastructure (roads, railways, towns) (PMSIEC, 1999; Williams *et al.*, 2001). An estimated 5 m ha of agricultural land, 12 000 km of rivers, 80 important wetlands and 630 000 ha of perennial vegetation is currently affected or at risk of salinity. These figures are estimated to rise by 290%, 350%, 160% and 320% respectively by 2050 (NLWRA, 2002).

Given the size of the problem, there has been surprisingly little research on the ecological impacts of salinisation (Bailey and James, 1999). Observations indicate the impacts are likely to be severe. Preliminary research on macroinvertebrates shows community structure is altered and diversity decreased when salinities rise to the 1000–2000 mg $L^{-1}$ range, whilst reproductive capacity of macrophytes is impaired as salinities rise to 6000 mg $L^{-1}$ (Hart *et al*.. 1991; Bailey and Warwick, 1998).

Actions to control salinity, primarily through using vegetation to restore the hydrological balance (Schofield, 1992) and by engineering works have been developed and trialed since the 1970s. Successes to date include the reduction of salinity in the Murray River by expensive groundwater interception schemes which pump saline water to land disposal sites (PMSIEC, 1999) and the reduction of salinity in the Denmark river through almost complete reforestation of the cleared land.

#### Erosion

Another major response to land clearing has been accelerated soil erosion, leading to increased sediment loads, turbidity and nutrients in rivers. Removal of riparian and in-stream vegetation is frequently accompanied by radical changes to channel geomorphology. Further habitat modifications are caused by infilling of river pools. Erosion rates in agriculturally developed landscapes are typically 1–5 times natural rates, but exceed 50 times in hot spots (NLWRA, 2002).

Stream bank, gully and hillslope erosion occur in different combinations across the landscape (Rosewell, 1997). Stream bank erosion is widespread in all agricultural landscapes. Gully erosion is common in southern and eastern Australia and is particularly intense in the south-east. The rate of gully erosion is characteristically high following clearing and then slows. Hillslope or sheetwash and rill erosion are dominant and reach very high rates in tropical northern Australia (NLWRA, 2002). In tropical areas, large sediment loads are often generated from farmed land during cyclonic events (Hunter *et al*., 1996) and on the north-east coast results in massive plumes discharging from the river mouths into the Great Barrier Reef lagoon (Furnas, 2003).

In regulated rivers, short-duration flow releases have been associated with river bank slumping, whilst in unregulated systems such slumping may reflect increased rates of water level fall associated with irrigation diversions (Thoms and Sheldon, 2000).

#### Eutrophication

The frequency and severity of algal blooms in Australia's rivers, lakes, estuaries and reservoirs indicates the decline of aquatic health (Banens and Davis, 1998; Harris, 2001). Action was catalysed by the 1000 km long bloom of toxic cyanobacteria in the Barwon-Darling River in 1991/92: it was so severe that a state of emergency was declared and water had to be trucked to rural homesteads and cattle herds.

Many dams frequently experience eutrophication, with the build-up of nutrients in the sediments and water column, which may stimulate the proliferation of green or toxic blue-green algae and aquatic weeds (Mitchell and Rogers, 1985; Harris, 1994). Severe eutrophication and the release of algal toxins have repeatedly prevented the utilisation of water storages in several areas (CRCWQT, 1998).

Sources of nutrients include sewage effluent, fertilisers, soil erosion and sub-surface colloidal movement. In south-east Australia, the fine clay component of eroded soil is moderately high in phosphorus and is a significant contributor to riverine eutrophication (Donnelly *et al*., 1996). Fertilisers are strongly implicated in highly transmissive sandy soils such as the Swan Coastal Plain in Western Australia (Schofield and Birch, 1986).

#### Water regime dependent ecosystems

River regulation has caused the decline of riparian forests, invasion of dewatered river channels and wetlands by vegetation, changes in aquatic plant community structure in regulated river reaches and weirs, population and species diversity declines of invertebrates, fish and waterbirds and several invertebrate extinctions (Schofield *et al.*, 2003). Water extraction from the Murray River is approaching 90% of mean annual runoff, with discharge to the ocean becoming a rare event (MDBC, 1995). Seven lacustrine invertebrates disappeared when Lake Pedder in Tasmania was flooded as part of a hydropower scheme, and leeches previously collected from River Murray wetlands by Victorian hospitals at 25–30 000 per annum have seldom been seen since the 1970s.

Australia's regulated rivers have also been prone to invasions of exotic species of plants such as water hyacinth, *Hymenachne,* and willows, and fish, especially the European carp (Arthington and Bluhdorn, 1995). Rivers and wetlands have been degraded in ways that prevent them from sustaining natural aquatic ecosystems and their high levels of biodiversity (Kingsford, *loc. cit.)*. They have been replaced with simplified systems of lower diversity dominated by exotic species that will be much less useful to humans in the future.

Wetlands in Australia have been altered by draining, infilling, river regulation and conversion to other uses. This has caused extensive loss of wetlands — 90% of floodplain wetlands in the Murray-Darling Basin, 50% of coastal wetlands in New South Wales, 75% of wetlands on the Swan Coastal Plain in south-west Western Australia (Bunn *et al*., 1997).

Six types of groundwater-dependent ecosystems are under threat of hydrological disturbance (Hatton and Evans,1998): terrestrial vegetation; river base flow systems; aquifer and cave ecosystems; wetlands; terrestrial fauna; and estuarine and nearshore marine ecosystems. Terrestrial vegetation communities are among those most threatened by changes in groundwater level associated with irrigated and dryland agricultural land use. This is particularly true for small patches of remnant vegetation and those in areas where regional groundwater levels have risen substantially since European settlement.

Groundwater-dependent wetland ecosystems are those that are at least seasonally waterlogged or flooded. Examples include mesophyll palm vine forests, paperbark swamp forests and woodlands, swamp sclerophyll forests and woodlands, swamp scrubs and heaths, swamp shrublands, sedgelands, swamp grasslands, swamp herblands and mound springs ecosystems. Changes in water table level may have important implications for these communities (Hatton and Evans, 1998). Prolonged lowering or raising of the water table are likely to cause change in the composition of species, favouring species adapted to drier or wetter conditions, respectively. As with terrestrial vegetation, the development of more shallow saline groundwaters may result in the salinisation of plant root zone and the subsequent collapse of ecosystems.

## FUTURE ISSUES FOR AUSTRALIAN WATER RESOURCES

### Facing increasing water scarcity

Despite Australia having 5% of the global freshwater resources and only 0.3% of the population, water scarcity will become an increasing issue due to distributional effects. In simple terms, Australia's population and production systems are in the drier southern half of the country, and irrigation, the largest water consumer, is located in semi-arid environments. Most of the country's water resources are in the tropical north where significant agricultural development and population growth, relative to other parts of the country, is unlikely. Currently 26% of surface water catchments and 34% of groundwater units are close to or over-allocated in their water resources (NLWRA, 2002). Competition for water resources will increase rapidly due to increasing demand and decreasing supply (Greenwood, 1992).

Increasing demand will arise from two quarters. Firstly, increasing population will lead to increasing domestic, agricultural and industrial requirements for water. Population forecasts are wide ranging, but the current immigration policy would see a 20% increase, to 25 m, by 2050 (Foran and Poldy, 2002). In the past, water use has been correlated to population growth. Surface water use has increased by 69% from 1983 to 1997, whilst groundwater use has increased by 88% over the same period (NLWRA, 2002). Secondly, pressure to allocate more water for environmental benefits will reduce allocation for consumption. A major test case for the Murray River is in progress with between 500 GL and 1500 GL being negotiated for reallocation to environmental water.

Decreasing supply will also arise from two drivers. Firstly, climate change is predicted to reduce runoff across most areas of southern Australia. The combination of increased temperatures, increased evaporation and decreased rainfall lead to reduced stream runoff. Flow reductions across the Murray-Darling Basin of 16–25% by 2050 and 24–48% by 2100 have been estimated by Beare and Heaney (2002). Secondly, revegetation and regeneration of cleared catchments will reduce stream yields. Revegetation is occurring for commercial plantations and farm woodlots, for control of erosion and salinity, and to combat biodiversity decline. This 'water squeeze' implies substantial trade-offs for Australian society in the future.

### Preserving environmental values

The Australian continent is in a phase of rapid environmental change. This has occurred due to the fragility of its landscapes when perturbed by traditional agricultural and water resource development practices. These problems are now being exacerbated by the onset of climate change. Nevertheless Australia is extraordinarily diverse — which should be matched by equally extraordinary efforts to reduce further decline.

The Wild Rivers survey of the Australian Heritage Commission showed that very few river systems can be classified as truly 'wild rivers'(Stein *et al*., 1997). There are, however, a number of systems that have so far escaped major perturbations and should now become the focus of protection.

The majority of land in Australia is in private ownership and improved land use and land management controls and incentives continue to be minimal. The administrative situation today is far from ideal, with no national water or river management agency, and few coherent water laws at either national or state levels (Schofield and Price, 1999; LWRRDC. 2000). In the future Australia will need to improve its legal, policy, regulatory and institutional systems to achieve better outcomes.

## CONCLUSIONS

The hydrological cycle in Australia has been disturbed dramatically by agricultural and water resource development over the past 200 years. This disturbance has in turn led to environmental degradation via soil erosion and salinity; water quality decline in the forms of increased salinity, nutrients, sediments and turbidity; water regime decline in terms of quantity and flows; habitat loss and fragmentation; and concomitant decline in native species populations and biodiversity. These consequences will continue to play out in the Australian landscape for decades and centuries to come.

Climate change predictions indicate that increasing temperatures, increasing evaporation and decreasing runoff could exacerbate dramatically the negative impacts of these landscape trends over the next 50 years and beyond. Competition for declining water resources will be brought into sharp focus this century, with potentially significant social and economic impacts.

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