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Part I. Water and the Basin

1. Understanding the Basin and its Dynamics

John Williams

Introduction

The competing tensions between water extraction for immediate human use and water essential to the long-term ecological function and sustainability of the rivers and groundwater systems in the Murray–Darling Basin (MDB) sit at the centre of public policy debate on water reform. Yet it is much more than this. The people of the Basin are faced with the enormous challenge of transforming themselves into more resilient communities. This requires managing and reconstructing the conflict between the climatic and biophysical realities of the Basin and the earlier private and public policy aspirations of the European settlers that have dominated for the past 150 years. Water reform is, then, a social process by which communities work to align land use and economic industries so that they work more in harmony and within the capacity of the hydrological and ecological processes operating in the landscape and thereby are able to harvest a wider range of ecosystem services than they currently do. For water reform to be embedded in such a process, it is critical, however, that the dynamics of the biophysical processes operating within the geological and geomorphic form of the ancient Basin be fully appreciated and understood. Without an understanding of the Basin's form and functionality, water-reform implementation will probably solve one problem while creating several others. This must be done against a backdrop of climate change which is impacting on the very high climatic variability that over the past decade has seen a severe, nine-year drought and a year of large floods. These extreme events — both very wet and very dry — are what characterise the Basin of the past and they can be expected to be an increasing part of a climate-change future (Francis and Hengeveld 1998; Min et al. 2011; Pall et al. 2011).

The biophysical nature of the Basin's rivers and groundwater systems, coupled with this climatic variability and change, calls for water reform to be implemented in innovative ways that will test the fabric of our society and stretch our scientific knowledge to the limit. For it is management of greater extremes — the floods and the droughts — in accord with the ecological functional requirement of these rivers and the increasing demand for water extraction to satisfy human need that call attention to the need for radical water reform in the light of failure of current policy and practice. Present-day problems that confront the Murray–Darling Basin (MDB) can be related to the way the societal narrative, cultural values and knowledge have clashed with the climatic and geological history of the ancient Australian continent.

The MDB heritage we have today is the result of an unfortunate coincidence between human action and the set of geological and climatic forces that formed the Basin. Human activity over the past 150 years has exacerbated geological, hydrological and ecological processes driven by a history of changing and highly variable climate through time and across the Basin (Williams and Goss 2002). The Basin is ancient. What we see today bears residual features and the overprinting of a long history of climate changes, involving many sequences and oscillations between very humid and extremely arid environments. Clearing of forest and woodland vegetation, in conjunction with the application of irrigation water, has produced in less than 200 years a change in groundwater equilibrium and river flow regimes that in many ways mimic the changes that have resulted in the past from climatic oscillations (Bowler 1990). These changes brought by Europeans through grazing, clearing of forests and woodlands and the development of irrigation have resulted in the return of conditions that existed about 18 000 years ago — once again we have high saline water tables discharging to rivers. The flow regimes of the rivers have been drastically changed so that the floodplain ecosystems that drive much of their ecological function are disconnected, and the flows to flush out salt and refresh the system are far too infrequent. Innovation, problem solving, and the managerial capacity of farmers have sustained an impressive productivity growth through the twentieth century, particularly in cereal production. Great wealth from the production of food and fibre has been fundamental to the wealth and wellbeing all Australians now share. The Basin has yielded much and has a heritage of place and natural history that is very important to Australians everywhere. The Basin is our heartland and holds symbols of our rural heritage, upon which Australian identity has been built. But now we see much of what has been built under threat from economic, social and environmental change and decline.

Water reform in the Basin is cast against this background of the ancient bio-geophysical processes that must be understood and managed while finding new expressions and narratives within which the Basin's communities recast and rebuild more resilient futures. This chapter seeks to examine the nature of the Basin's geology, hydrology and ecology, and to weave into this the interaction of the human aspirations, values and visions that have shaped our communities and that generate the human and physical heritage within which water reform must take place.

Biophysical Background

Geological History and Basin Structure

The Murray–Darling Basin's streams and rivers sit in a shallow basin, which is very old, very flat, contains large stores of salt, and with respect to groundwater is very nearly blind in that it has no outlet to the sea.

In geological terms, the Basin has a very ancient foundation. The oldest rocks (pre-Cambrian), which outcrop in the western margins, date back at least some 600 million years. Most of the Basin has a basement of ancient (Palaeozoic age of 230–540 million years) rocks that were eroded to a palaeo-plain. Over this ancient platform, sedimentary rocks formed basins during the Mesozoic age (some 60–250 million years ago) in the case of the Great Artesian Basin (GAB), and, later, during the Caenozoic age (less than 60 million years), the Murray Basin was laid down (Ollier 1995). These two basins are separated by a system of tectonic warp axes that corresponds to the drainage divides. These are the two major sedimentary groundwater basins over which the Murray–Darling Basin catchment is located (Ollier 1995). Within both basins there has been broad down-warping, subsidence or sinking of these sedimentary rocks. This has resulted in sedimentary rocks infilling a low-lying, saucer-shaped depression (Evans et al. 1990), rimmed and underlaid by folding and partly metamorphosed ancient basement rocks. These ancient (Palaeozoic) rocks now form the subdued mountain ranges around most of the Murray–Darling Basin — apart from the south-western rim, where concealed basement rocks just beneath the surface form the Padthaway Ridge. This separates the MDB from the Southern Ocean.

Whilst the Murray Basin is very large, the sedimentary rocks are relatively thin. The maximum thickness is 600 m, found over the region of most subsidence, while at the margins of the Basin the thickness of the sediments is less than 200 m. They form a pancake-like veneer over the older basement rocks (Evans et al. 1990). Because the sedimentary rocks are quite thin, the Basin has a relatively small capacity for groundwater storage. This saucer-shaped structural configuration with subsidence just south of the centre, covered by a thin layer of sediments, has important implications for the nature of the Basin and the way surface and groundwater must be managed. The MDB is essentially a closed groundwater basin within which groundwater drainage is directed internally towards the central subsidence and thicker sediments, rather than towards the side where the Murray connects to the sea.

Because the Basin is blind and because the sediments in which groundwater can be stored are relatively thin they offer a relatively small storage capacity as the sedimentary rocks are largely water saturated. Thus, there is little capacity in the groundwater system for the storage of additional recharge. Thus, if the groundwater systems receive increased recharge as they have since European settlement, the additional recharge cannot escape. The water tables must rise.

These features all point to a most important conclusion. Minimal groundwater recharge will drive a rapid water table rise, and because the Basin is essentially blind and therefore has a small discharge capacity, the response of groundwater levels to reductions in recharge rate will be very slow. When the additional recharge is reduced, the water table fall will be very slow largely determined by the small discharge capacity via the Murray or by evaporation from land-surface discharge regions in the depressions and lakes of the landscape. Thus, groundwater systems can be filled easily, but must empty and discharge very slowly. This is a most unfortunate fundamental fact about the MDB and it is essential to understand that the Murray River needs to have large flushing flows to carry salt to the oceans where it came from (Evans et al. 1990).

About 40–60 million years ago, the central area of the MDB subsided as the eastern highlands were uplifted. This subsidence formed two distinct regions of sedimentation and later groundwater accumulation. The southern area is known as the Murray Groundwater Basin, which is not fully synonymous with the catchment but it does underlie a great deal of it. The northern area, over which the Darling River and its tributaries now flow, is the southern part of the Great Artesian Basin. The climate of the early Tertiary (40–60 million years ago) was very much wetter than at present and the Murray Basin then contained large swamps and bogs, and thick sediments that were laid down in broad valleys. With increasing subsidence and eastern highlands uplift, stream dissection and incision in the highlands resulted in sand and gravel deposition in fans as the rivers entered the plains.

During the Miocene (26–7 million years ago) the sea level rose relative to the land, and the inland sea covered the south-western corner of the Murray Groundwater Basin. Marine materials were deposited in sand sheets. In the past two million years, the sea retreated, leaving a succession of stranded beach ridges and relic coastlines. Following the sea's retreat, a huge freshwater lake developed, as there was a blockage across the Murray. During the Quaternary glacial period about two million years ago, the climate became very arid, with dry and windy conditions prevailing. Another set of dunes — this time Aeolian — was built by the wind action. In the past 30 000 years, a thick blanket of fine alluvium has been laid down over coarse sediments in the old bedrock of the central area of the Murray Basin. A similar process took place in the Darling.

The sea once occupied the Mallee and most of the Murray Basin, extending to Balranald in New South Wales, with thin reaches stretching to Kerang, Victoria, at its peak, before retreating from about three to four million years ago. Whilst the salt associated with this intrusion has long since left the Basin through leaching, the retreat of the sea established the ultimate gradient and outlet for the Basin and the modern (past 500 000 years) landscape development of the Basin. This retreat of the sea had a number of other important consequences.

Not only did the climate dry from the extensive wet rainforest period (12–30 million years ago), but earth movements dammed the Murray outlet to result in the huge Lake Bungunnia. The lake formed about 2.5 million years ago and continued to exist for about two million years, until about 500 000–700 000 years ago when the outflow point was deepened sufficiently to drain the lake and permit the Murray River to cut a deep gorge through earlier sediments to provide an outlet to the sea.

Modern Features of the Landscape, Waterways and Vegetation

Within the time frame of the Murray–Darling's origins, there are four factors (Evans et al. 1990) that control the modern landscape features

1. the low level of tectonic activity over long periods
2. a strong east–west gradient of increasing aridity
3. the marine influence on the south-western corner of the Basin
4. the prevailing south-westerly winds.

Compared with other continents, Australia has been remarkably free of volcanic or mountain-building activity in recent time. While the Australian continent has drifted north from Antarctica over the past 60–80 million years, very minor changes in topography have occurred (Bowler 1990; Ollier 1995). The Great Dividing and Flinders ranges and the extensive plains between were already present from at least 20 million years ago. These ranges are very subdued features compared with the mountains of other continents. The late-Quaternary (past million years) history of the Murray–Darling Basin has been of minor tectonic movement and the evolution of landforms under increasingly arid conditions (Wasson 1987). The major subdivisions such as the Eastern Upland, Cobar Plains, Murray and Upper Darling basins have largely remained as they are, but within these, landform changes have occurred to produce the rivers, dunes, alluvial plains and slope colluvium as they are today (Wasson 1987).

The closed nature of the Murray Basin results in a strong interaction between groundwater and surface water. In the west, the River Murray is an efficient drain providing the natural pathway for removing groundwater and its dissolved salts. In fact, the lower sections of the river have always been a salt drain. The changes that have occurred in the groundwater system of the southern Murray Basin over the past 150 years of European settlement appear to mirror in magnitude the changes that would have occurred over thousands of years as a result of climate oscillations that characterised periods over the past 500 000 years.

The result is that old groundwater recharge structures and mountains of salt sitting dormant for maybe 18 000 years are being reactivated. This implies that an increase in groundwater flow to streams and rivers as has happened in the geological past will again occur — with an accompanying increase in movement of salt to land and rivers. Large quantities of saline groundwater enter the Murray as it moves through the channel that is deeply incised into the sediments underlying the Mallee. Reversal of the process that caused the rising water tables will not halt the discharge of salt to land and river until the high water tables are able slowly to discharge. This is a critical matter to take note of when determining the sustainable-flow regimes of these river systems under any water-reform agenda. Failure to give attention to these issues will further damage the river function and further reduce the options for those communities dependent on healthy river and floodplain function.

The cycles of saline/non-saline associated with rising/falling water tables were driven by oscillations in climate, and current 50-year cycles can be seen in shallow groundwater today (Rancic et al. 2009). Within an otherwise geologically stable basin, a central feature of the landscape was the erosion/deposition/transportation of salt and sediments within the Basin. Very little material left the Basin. The sediments and salts were recycled, reworked and accumulated. These oscillations in climate to both wetter and drier than at present were sufficient to move sediments from shallow groundwater and saline environments to non-saline environments. This is a salutary characterisation of the Basin to be better managed under water reform.

While the onset of regional salinity was a relatively rapid response to changing climatic conditions, the recovery from the saline lakes and rivers was a much slower process. About 13 000 years ago, trees and shrubs returned to the landscape, and shallow groundwater levels fell, enabling other, more bio-diverse vegetation to establish on the once salinised land. Although the evidence of the recovery is clear, the mechanism that brought the recovery remains unclear (Bowler 1990).

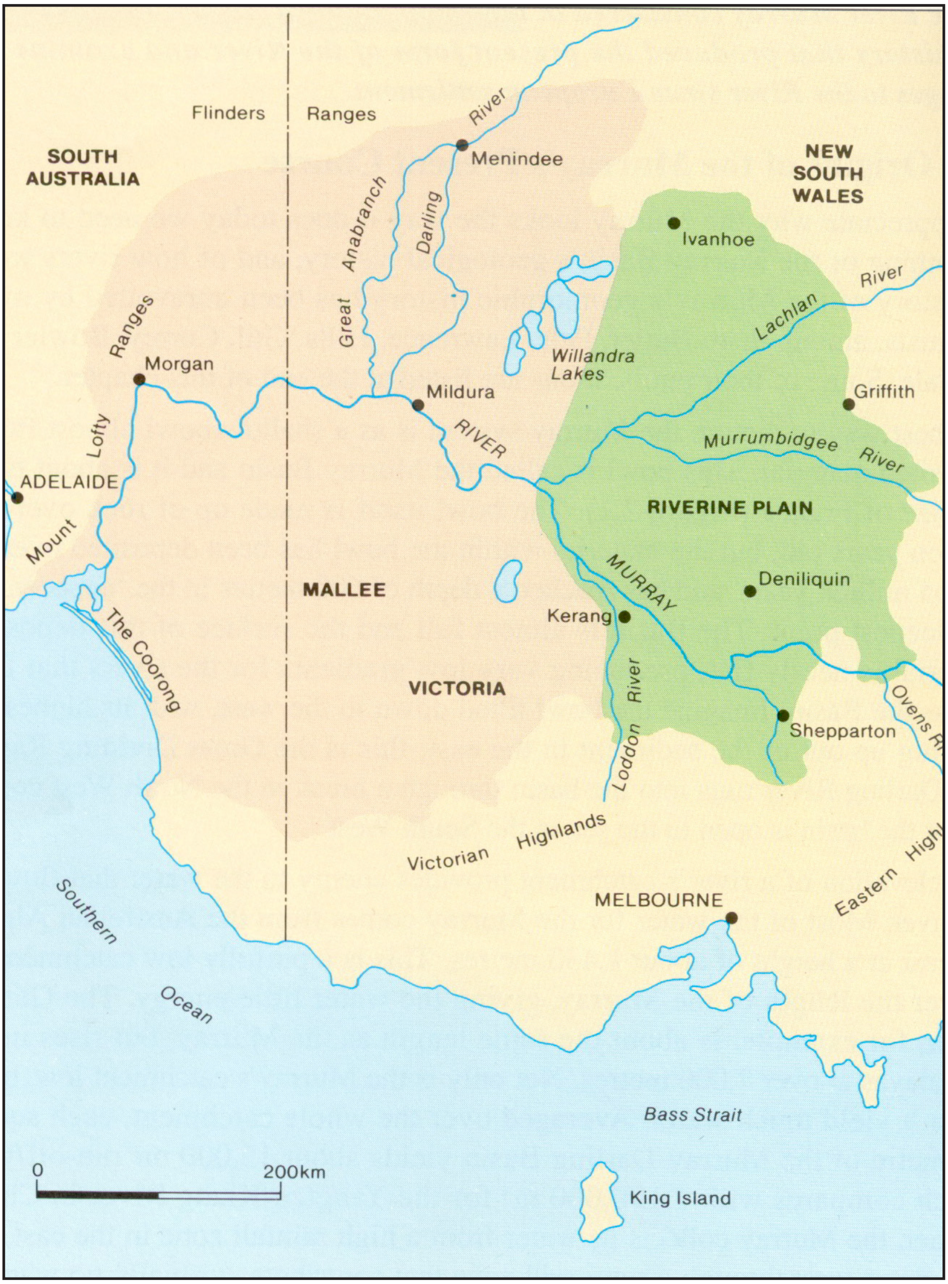

Figure 1.1 The large geomorphic features of the Murray–Darling Basin

Source: Rutherford (1990:18).

River Form, Hydrology and Ecological Functionality

The rivers in the Murray–Darling Basin as we know it today occupy — and are substantially controlled by — a catchment formed by the interactions of geology, erosion and depositional processes driven by oscillating humid and arid climates over many millions of years. An appreciation of these processes and the history is critical to understanding the context in which water reform must be cast. If water reform is not cast to address how the Basin works, it will fail and will need to be redone in years to come.

The MDB encompasses some 14 per cent of the Australian continent, stretching from the subtropics of central Queensland to the southern alps of Victoria, across the extensive floodplains of the Murray River to the Lower Lakes at its mouth and, ultimately, to the Great Southern Ocean (see Figure 1.1).

The Basin's boundaries to the east and south are provided by the Great Dividing Range including the Australian Alps while in the north, west and south-west, the boundaries are much less distinct. For instance, in the Wimmera in the south-east and the Bulloo Basin in the north-west, where the Darling rises, the boundaries are subdued watersheds with catchments dominated by internal drainage, which thus contribute very little to surface-water flow. Elsewhere low to medium-altitude ranges mark the Basin's limits: the Mount Lofty Ranges are in the south-west, the Grey and Barrier ranges to the west and the Chesterton and Warrego ranges in the north. Extensive plains and low uplands that are less than 200 m above sea level dominate most of the Basin. Thus, low relief and very low gradients dominate the flow regimes and the movement of floods and pulses of flow in the rivers for the greater part of their length. The three largest rivers of the Basin — the Murray, the Murrumbidgee and the Darling — are not only the three longest rivers on the Australian continent, but more importantly they are central components of our folk law and our history for both Aboriginal and European settlers. These rivers — their red gums, the wetlands and the arid lands of the west — are welded into the array of Australian icons and culture.

The MDB is essentially a shallow bowl almost full of deposited material (Rutherford 1990). Two large depositional geomorphic forms dominate the Basin. In the west, the rivers have carved channels and anabranches over ancestral channels and troughs of the ancient Mallee plains (Figure 1.1). This Mallee plain in the west is characterised by extensive sequences of sand ridges of both marine and Aeolian origin with no tributary stream junctions except those of the Murray and the Darling. To the east, a large proportion of the Basin consists of very large riverine floodplains of 200 m or less in elevation, characterised by meandering river systems of multiple channels, anabranches, billabongs and wetlands (Rutherford 1990). The riverine plain is essentially a complex network of river channels and floodplains overprinting on ancient river channels and floodplains, with alluvial deposits interspersed with widespread and complex patterns of Aeolian depositions. Present-day drainage often breaks up into complex distributor systems extending across the plain to form a mosaic of ancient and modern channels, which generally rejoin forming the Murray trunk stream near the junction between the riverine plain and the Mallee sands. All the streams of the Riverina are characterised therefore by very low gradients with enormous year-to-year and decade-to-decade variability in flow, and the movement of water, nutrients and sediments between the floodplain and the network of ancient and modern channels.

The oldest of the ancient river systems (MDBMC 1987:10) are the '*deep leads*' — deeply buried channels now filled with sands and gravels. The next are the 15–30 000-year-old structures known as '*prior streams*', and their sediment-filled channels are slightly elevated above the surface of the current floodplain. The most recent are the '*ancestral rivers*' because of their close relationship with the present drainage networks — showing up as winding depressions across the landscape. The interlinking of these systems of sands and gravels, which now contain groundwater, is critical to the present hydrology of the Basin.

The riverine floodplain of the Murray and the Murrumbidgee has a remarkable network of drainage lines, channels and wetlands. Many other, much older systems have evidence that these streams carried much more water and sediment than they do today. The earlier streams were responsible for the depositions of the alluvial plains. In the post-glacial period (the past 15 000 years), stream discharge has moderated and sediment loads have become finer, muddier and with slower stream velocities. Stream banks, slopes and dunes have stabilised, groundwater has fallen and lakes have dried up. The windblown *parna* and riverine alluvium have been deposited during the Quaternary across the riverine plain and along the eastern slopes (Butler 1958) — a consequence of a wet, stable period of soil formation — followed by wind erosion and deposition of the previously mentioned material to be reworked once again in the soil-forming process that characterises the Riverina floodplains.

Middle Murray Rivers carried sandy bed loads and built larger meadow scrollbars, a process which is no longer occurring. Flow from the rivers was very much greater than at present, probably fed by snow-melt from glaciers and large areas of permanent snow in the eastern uplands. There were periods of much greater flow than this prior to extraction for irrigation.

The river channels have evolved to be connected regularly to these over-bank ecosystems via a range of flood events interspersed with long periods of droughts under historical and recent highly variable rainfall sequences, as set out in Figure 1.2.

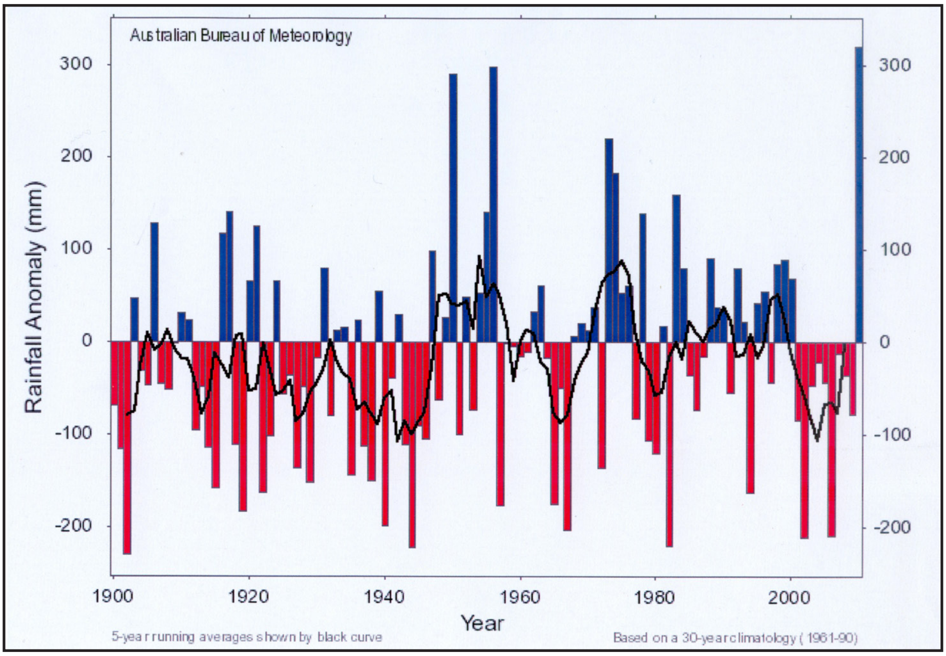

Figure 1.2 Annual rainfall anomaly for the Murray–Darling Basin, 1899–2010

Source: <http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rranom&area=mdb&season=0112&ave_yr=5>

The highly variable climate means that water availability varies greatly from season-to-season as does its quality during the seasons and between seasons. The highly variable flow of the rivers has led to large storages being built to reduce the variability of supply. The impact of such large storages on the river-flow regime, water quality and ecological functioning of the rivers have been very great indeed (NRC 2009b).

For the rivers, groundwater, wetlands, floodplains, lakes and estuaries to regain their ecological function and become healthy, they must regularly have over-bank flows that connect the channel to the floodplains, billabongs and wetlands. Plants and algae in these places transfer and enrich the river water with energy, carbon, nutrients and food-web elements, which then move back over time to the channel and drive the ecological activity along the length of the river (Overton and Saintilan 2010). These critical exchanges are represented for red-gum communities in Figure 1.3.

This process might be repeated many times along the path of these floodplain rivers. The flow of water through all these components of the river system is fundamental to the ecological health and function of the Basin. River regulation and over-allocation have severed these vital connections. It is in the interests of all water users that these functions be restored (NRC 2009b).

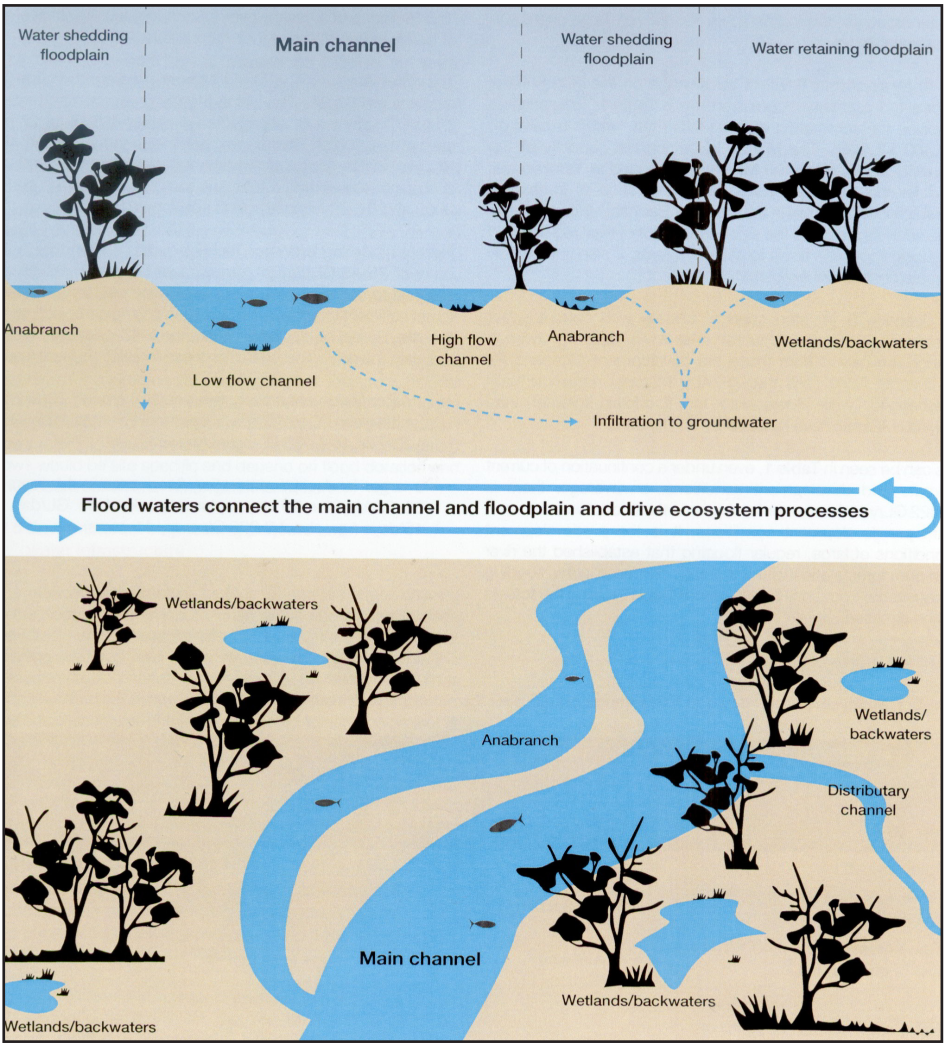

Figure 1.3 Cross-section and oblique views, respectively, of ecological function and the floodplain hydrology of river red-gum forests

Source: NRC (2009b:165).

This is how our Murray–Darling floodplain rivers work. They must be connected regularly to the over-bank ecosystems (Doody et al. 2009). Not only do these surface-dependent ecosystems in billabongs, floodplains and wetlands supply to the river much of its photosynthetic-driven ecosystem function, these places are also where many of the groundwater aquifers are recharged. Floods over floodplains are important to the recharge of groundwater. Our river channels, floodplains and groundwater systems are nearly always interconnected. Water flows from flooding rivers into the underground water and quite often flows through these groundwater aquifers back to the river to provide the base flow of our rivers in dry times. These connections and flow to and from the river channel are critical to the health of the river system (NRC 2009b). They need to be regularly fed and connected.

This floodplain geomorphology has shaped the ecosystem function of the river, maintained key habitats and ensured bird and fish-breeding events. The sequences of flooding events across these floodplains created over 30 000 wetlands in the MDB, 11 of which are listed under the Ramsar Convention on Wetlands of International Importance.

The environmental challenge is that current extractions are such that the frequency of low-flow years associated with closure of the Murray mouth has increased from about 5 per cent prior to European settlement to more than 60 per cent. The biggest impact is in the Lower Lakes, the Coorong and Murray mouth at the end of the system, but assets throughout the Basin are in a major state of decline (Senate Standing Committee on Rural and Regional Affairs and Transport 2008:39). In addition to reductions in flows due to high rates of extraction and drought, river regulation has reduced the variability and frequency of low to medium over-bank or flood events so that floodplains are now much drier and more saline as a result of evaporation from off-river pools (NRC 2009b:102–99). Far fewer regular flood events and minimal flows during dry periods along with stream salinisation mechanisms interact to produce acid-sulphate sediments in substantial parts of the Basin (Hall et al. 2006; Lamontange et al. 2006; McCarthy et al. 2006). These can cause permanent damage to the benthic habitat, create acid waters and release heavy metals, which can result in total collapse of ecological functions in these ecosystems.

Overall, the ecological health of 20 of the 23 river valleys in the Basin is classified as either poor or very poor (Davies et al. 2008).

Managing erosion and deposition processes to maintain healthy refuges within the channels and the floodplain through floods and droughts is a critical issue which must be addressed in successful water reform.

The Murray–Darling rivers need both floods and drying regimes that restore healthy ecological function across the whole Basin. Peter Cullen wrote:

> This is a challenging area for science, but current thinking indicates that the goal of ecological management is to restore or maintain resilience so the systems can cope with the shocks of climate or other factors they experience. It takes extreme events like droughts and floods to let us see whether we have kept resilience in our systems. We are not managing these systems for some benign 'average' condition, but so they can cope with the extremes that characterize the Australian climate and our agricultural markets. (Cullen, forthcoming).

Water reform will need to pioneer ways to go forward with management that can make river systems resilient to the shocks of the droughts and massive floods that are often amplified by our engineering interventions. To do that with current climate variability will challenge our science and our society, but to add the impacts of climate change on variability and changed probability distributions for our rainfall will stretch both science and society to their limits.

Climate History and Future Change

Climate is Highly Variable in Space and Over Time

Inflows to the Darling River in the north of the Basin are derived from highly variable episodic summer rainfall, often driven by monsoon depressions. The Murray River and its tributaries have their source in the Australian Alps and receive most of their inflows from rain and snow in winter and spring (Figure 1.4).

This steep decline in rainfall features a complementary increase in evaporation. Most of the Basin west of the Wagga Wagga–Dubbo axis has an annual water deficit; it is only in the eastern margins — maybe 15 per cent of the Basin (Crabb 1997:6) — that there is a water surplus that can drive the river flows in the Basin. In fact, today some 37 per cent of the flow is driven from about 3 per cent of the Basin.

This is illustrated in Figure 1.5 (Donohue et al. forthcoming), which provides the average Budyko-modelled annual run-off across the Murray–Darling Basin for the 1981–2006 period, the distribution of basin run-off expressed as a percentage of total run-off and the percentage of basin run-off for a given percentage of basin area. Clearly, the hydrology of the Basin is characterised by eastern upland headwaters contributing most water for very long, low-gradient rivers meandering through semi-arid and arid plains. There are, however, summer flows from monsoon influences and depressions that attach to these, which can give high flows in the Darling River. The consequence is a river system with very high spatial and temporal variability in flow regimes where floods and droughts are important to the ecological systems that have evolved over long periods of geomorphic stability.

It is in this landscape of extraordinary tectonic stability that the modern climate (past 500 000 years) operated to drive the erosion, depositional and fluvial features of the Basin. Whilst the geological foundation is old and stable, the climate, in contrast, has been highly variable and has oscillated between very humid and extremely arid periods, with strong gradients across the Basin — perhaps much greater than we see today (Butler 1958).

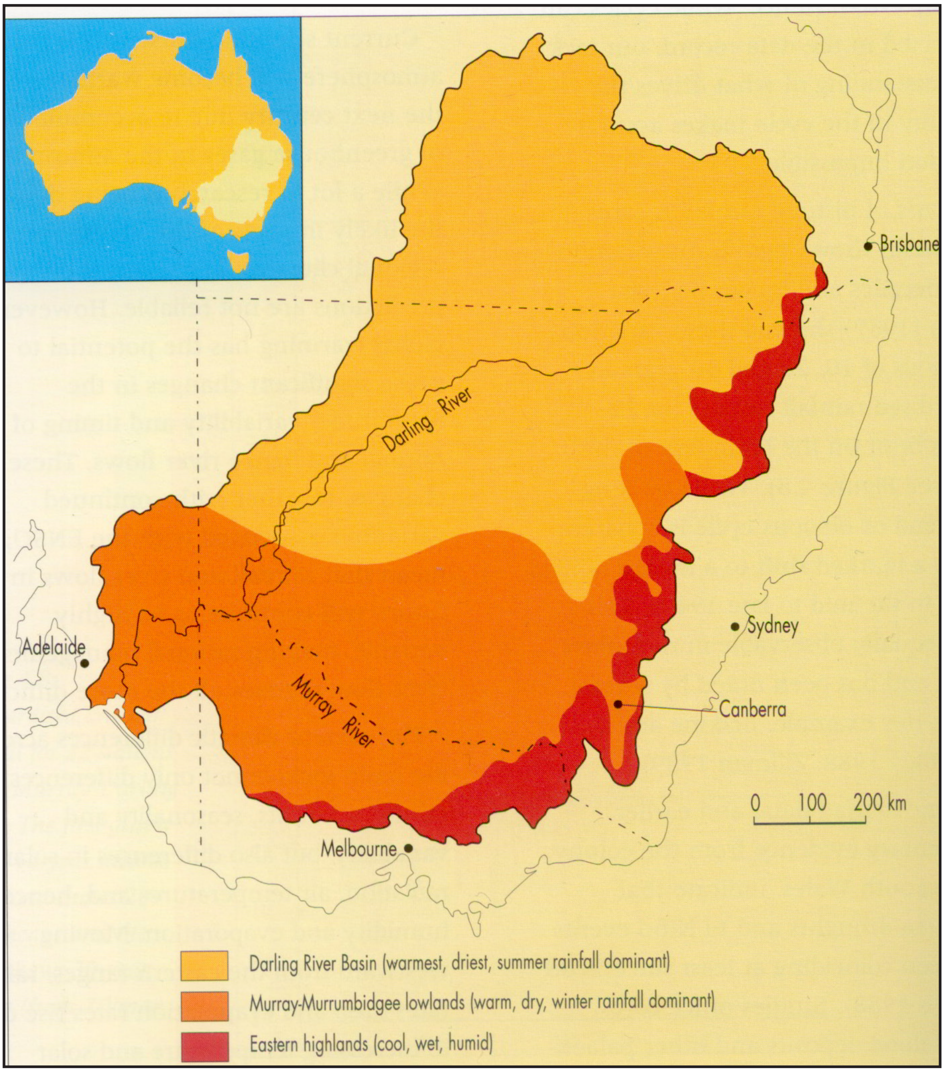

Figure 1.4 The three major climatic regimes of the Murray–Darling Basin

Source: Nix and Kalma (1982), reproduced with permission © CSIRO

Winds blowing across the continent from the south-west have been a major influence on landscape formation. Lakes have been formed by wind erosion of dry clays from valley floors. Along with the formation of lunettes, great clouds of dust laden with salt were lifted aloft by strong westerly winds to be transported and redeposited downwind to the east. Thus, the dust and salts are recycled up the valleys by the wind and the salt in clay aggregates, blown from the lake floors. Westerly winds have formed the west–east dune patterns that constitute the most distinctive feature of the Mallee region: long, low-gradient rivers with highly variable flow regimes are sourced from small upland regions.

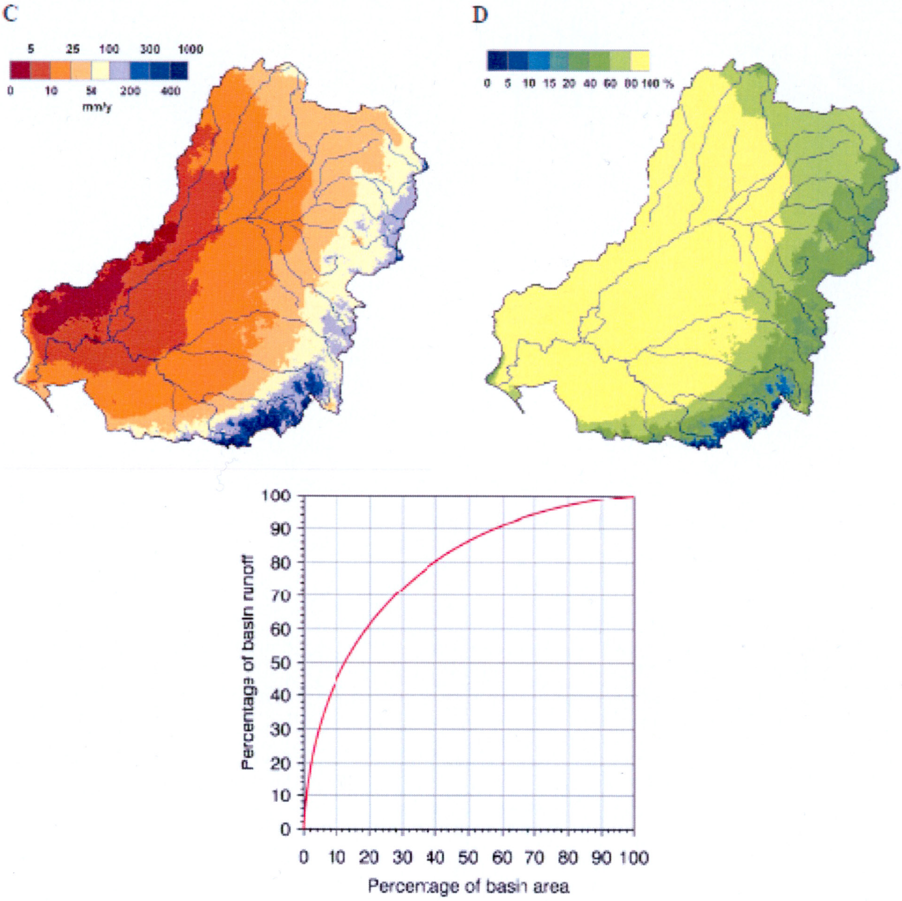

Figure 1.5 Average hydrological fluxes across the Murray–Darling Basin, 1981–2006

Notes: Plot C is Budyko-modelled annual run-off, and plot D is the distribution of basin run-off expressed as a percentage of total run-off. The lower plot shows the percentage of basin run-off for a given percentage of basin area.

Source: Donohue et al. (forthcoming).

The Murray River and its tributaries rise in the well-watered areas of the south-eastern highlands and flow westward through the dry interior. It is similar for the Darling, where the headwaters are in relatively well-watered, summer-dominant rainfall regions, in contrast with the winter-dominant snow-fed flow of the Murray Basin's rivers. In the Darling, as rivers pass from east to west and move into more arid regions, residual salts are concentrated in these arid landscapes where little surface run-off contributes to flow. The entry of groundwater — much of it very saline — to the Murray system as it moves through these arid lands is, however, significant. As mentioned earlier, this groundwater discharge to the Murray is the only mechanism by which groundwater can exit the Basin.

The MDB is large in area, yet very small in discharge, characterised by extreme events and thus very high variability. Over the period 1894–1993 the annual discharge from the Murray and the Darling ranged from a low of 1626 to 54 168 GL (Maheshwari et al. 1995).

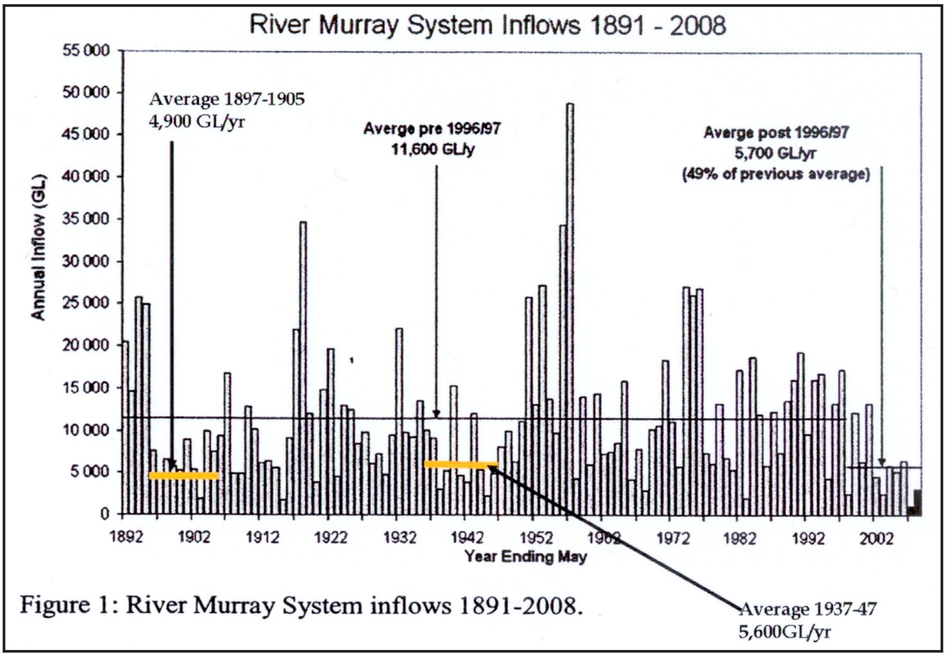

Figure 1.6 Murray River inflow, 1891–2008

Source: MDBC (2008:78).

Climate-Change Impacts on Drought, Floods and Water Use

The latest modelling indicates that Australian average temperatures are projected to rise between 0.6 and 1.5°C by 2030, and, with business as usual in terms of global greenhouse gas emissions, the warming is projected to be between 2.2 and 5°C by 2070. In the southern MDB, it is projected that there will be decreases in rainfall, especially during winter and spring, which are traditionally the times of the highest precipitation (Bureau of Meteorology 2010).

This large reduction from 10 to 20 per cent by 2030 under median climate change for the southern catchments is a trend consistent with a southward shift in the Southern Annular Mode (Meneghini et al. 2007) and is what would be expected with global warming. The central and northern river systems are expected to have smaller reductions, particularly where summer rainfall dominates the generation of water yield. It is also expected that ocean-warming patterns and the expression of La Niña influences on the northern Basin might increase summer rainfall and contribute to large flooding events across the Basin. Even in the south, where the mean is expected to decrease, the distribution of rainfall around that mean is less certain and could indicate an increase in extremes of both severe droughts and large floods (Min et al. 2011; Pall et al. 2011). In line with the work of Khan (2008), we can expect that climate-change impacts will change the statistical distribution of rainfall. While means are helpful, the task for best-practice river management will be to manage the extremes of droughts and floods and work with statistical probability distributions of both historical and predicted rainfall using models that incorporate the climate-change drivers attributed to anthropogenic greenhouse gas (Min et al. 2011; Pall et al. 2011).

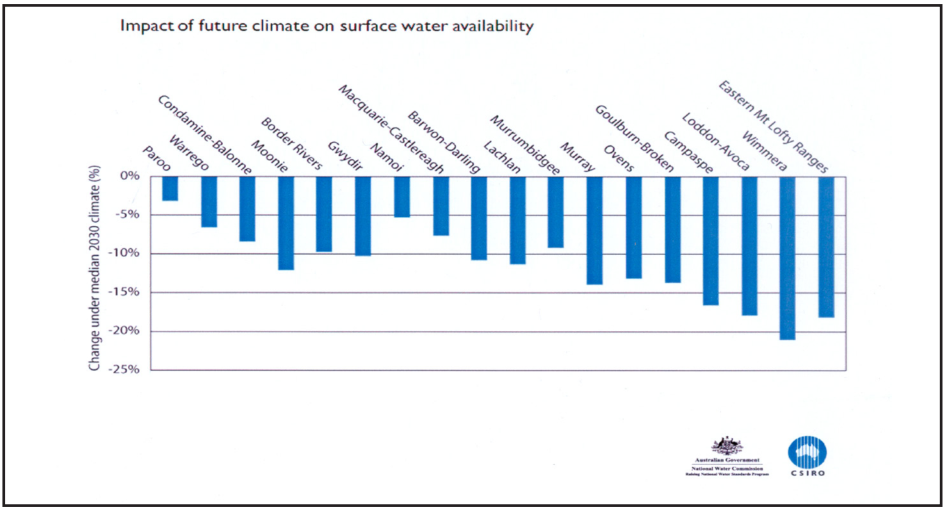

Figure 1.7 Predicted impacts of future climate on surface-water availability in the river systems of the Murray–Darling Basin

Source: CSIRO (2008:34).

Climate-change projections (CSIRO 2008:26) on run-off for the MDB are set down in Figure 1.8 and highlight the large uncertainty in future run-off projections. Averaged over the whole Basin, the median estimate under a mid-range climate-change scenario is a reduction in average annual run-off of 9 per cent by 2020, 15 per cent by 2050 and 23 per cent by 2070 (CSIRO 2008:26). Critically, the fall in surface-water availability over the past decade of the millennium drought in the southern part of the Basin has been much greater than the worst-case climate-change scenarios for 2030, as autumn rainfall has fallen by as much as 30 per cent (Proctor et al. 2009:9) and annual run-off relative to 1990 by nearly 40 per cent (CSIRO 2008:26). Overall in the Basin, we can expect a general drying, but also associated with a declining mean we can expect increases in variability and thus an increase in extreme dry periods and extreme wet periods.

The historical high variability and the likelihood that this might be further enhanced in ways unknown set a very exacting context for implementing water reform. The reform must be able to address this variability in that droughts and large floods are part of the Basin's history. The ecological functionality of the Basin has evolved to require this variation in flooding and drying. Such a pattern of flow regimes does not readily accommodate water-resource development and irrigated agriculture. This is the nub of the difficulties that will need to be addressed by water-reform policy and its implementation catchment by catchment, community by community.

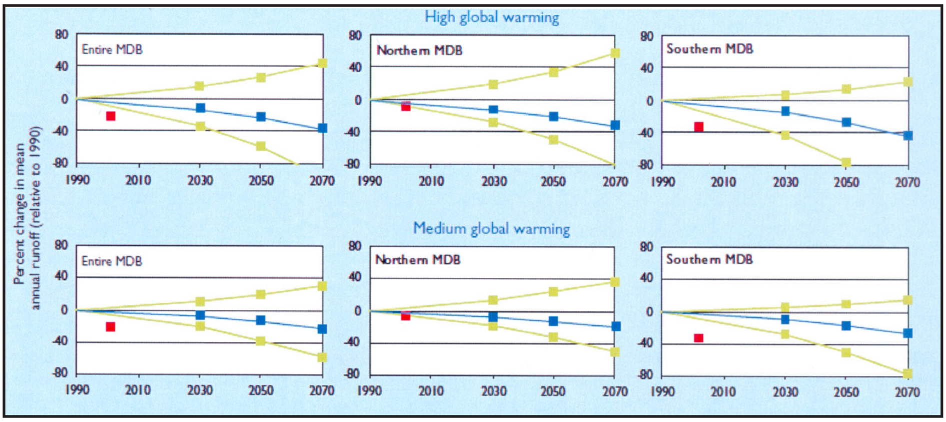

Figure 1.8 Run-off projections for 2030, 2050 and 2070 relative to 1990 for the entire Murray–Darling Basin, the northern Basin and the southern Basin under high and medium global-warming scenarios

Notes: The lines represent the upper and lower ranges and the median predictions of change to run-off. The squares locate the percentage change in run-off associated with the recent, 1997–2006 climate.

Source: CSIRO (2008:26).

In light of these circumstances, river-basin management is faced with greatly over-allocated rivers with water extraction that has not taken account of the huge climatic variability (see Figure 1.2), where a 40 per cent reduction in run-off is part of history. In addition, the climate-change projections for temperature, rainfall and run-off are alarming given the current dire straits of many environmental assets and ecosystems in the MDB. Fortunately, the millennium drought was broken by a major flood-producing rainfall event in 2010 (see Figure 1.2) — largely as the consequence of the El Niño event of 2009 transitioning into a very significant La Niña event in 2010 and 2011. If the nine-year dry had continued in the southern MDB then the sustainable diversion limits (SDLs) proposed under the Basin Plan could have been 'too little, too late'. The challenge is threefold: 1) immediately to reduce extractions to levels that prevent key ecosystems crossing critical thresholds; 2) ensuring environmental flows adjust to reduced inflows in ways that do not risk the long-term sustainability of key environmental assets; and 3) developing environmental watering that mimics pre-development frequency of flows and ensures episodic flooding events.

The European Aspirations

For the first European settlers, Australia was, indeed, a lucky country. The natural conditions were very conducive to pastoralism: extensive grasslands with minimal clearing required, mild temperatures and large areas. And the economic conditions were favourable, too: capital and convict and other cheap labour flowing from Great Britain and a rich market for the dominant product — wool. The early European settlers in Australia had no choice but immediately to adapt to the unique environment of high climate variability, low soil fertility and scarce water resources. In fact, the early settlers were arguably better adapted to Australian conditions than the assisted settlers of the twentieth century. They had large farming leases and relied heavily on what nature provided in natural-resource inputs, and it would seem they had a respect and even admiration for the natural environment (Cathcart 2009; Idriess 1993:7–238).

The frontier was born with the westward push over the Blue Mountains — opportunity mixed with risk to personal safety. By 1860, most of the economically useful land in the Murray–Darling Basin had been taken up, but, significantly, it was in the hands of a few settlers on extensive leases. The path to the natural riches of the Basin was led not only by explorers but also by squatters seeking new grasslands. Again, it was the promise of material gain that was a dominant factor, and the productivity and resource security of the Basin entered the national psyche (Powell 1993). The squatters' values and beliefs are still remnant in rural Australia today and can be traced to these times: man against the odds, heroism and scorn of authority (Connell 2007:7–47; Gray and Lawrence 2001).

In time, land administration caught up with expansion, and, under the policies of the day, agriculture was transformed to a system based on small proprietors drawing financial and labour resources from largely within the family (Gray and Lawrence 2001). Pastoral land use gave way, in part, to cropping. As in the United States, in Australia, the closer-settlement policy was built on a 'yeoman ethic'. In Powell's words:

> [T]he reassuring picture [was] of small freehold properties owned and controlled by industrious families for their own immediate and essentially non-commercial benefit. The implication of self-sufficiency entailed the requirement that each freehold be carefully cultivated to some significant extent, and the undisguised moral injunction suggested that the land be 'passed down' by successive generations, like heirlooms. This imagery has been a primary influence in [the] economic and political life of Australia since the mid-nineteenth century. (Powell 1993:24)

This imagery remains strong today.

There have been waves of closer-settlement schemes since the end of World Wars I and II. The policies of the day placed great store on the family farm as the instrument of community development and assumed viable farm sizes in times of agricultural prosperity.

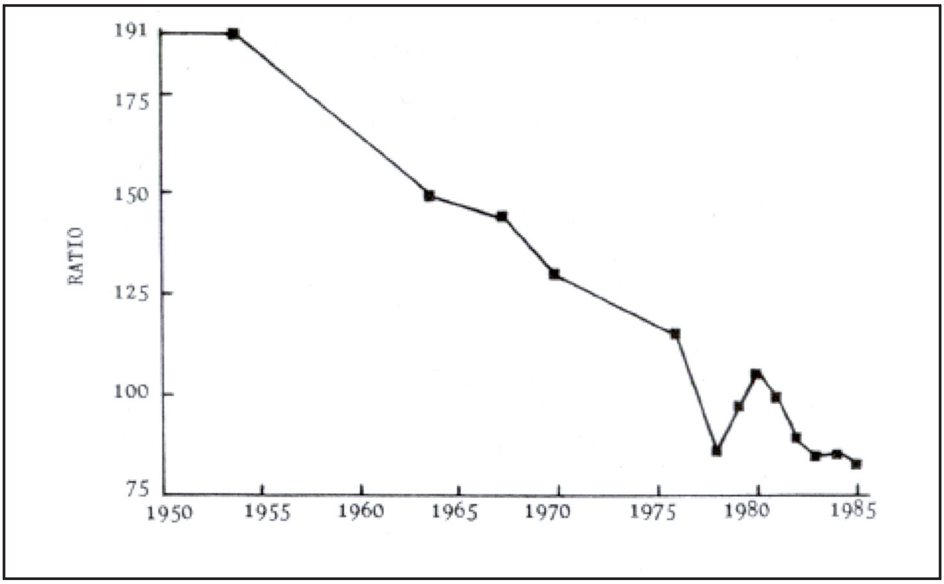

Figure 1.9 Farmers' terms of trade, 1950–85 ratio of prices received to prices paid

Note: B.A.E. data with 1980–81 = 100.

Source: Crofts (1985).

The early years of rapid expansion of both dryland and irrigated agriculture in the MDB were characterised by very favourable terms of trade, as in Figure 1.9 (Crofts 1985) — reflected in relatively cheap energy, fertilisers and agricultural chemicals coupled with rail transport systems tailored to the pattern of expansion. Most importantly, this was characterised by sequences of high rainfall that filled newly constructed dams and gave favourable seasons that favoured the establishment and utilisation of exotic pasture systems based on the greatly improved grain genetics arising from the 'green revolution'. Unfortunately, the very favorable terms of trade were not long lasting (see Figure 1.7). Wool, grain and meat prices declined rapidly relative to rising costs of production. Steeply declining terms of trade continue to plague most agricultural industries in the Basin. Only those industries with the ability to lift efficiency gains at rates that exceed the declining terms of trade have been able to build improving enterprise equity and profit. The trends in commodity prices and generally rising costs of production generate long-term financial pressure upon many farm families in broadacre dryland industries (Barr 2002, 2009).

From 1970, when commodity prices and market growth plummeted, the legacy of this policy was apparent: farms becoming marginal in profitability in the face of declining terms of trade, and, within a generation, rural reconstruction then rural adjustment schemes were introduced. This concentration in settlement and decline in farm profitability had many implications besides economic ‘belt tightening’ by the occupying families. Specifically, there has been a great environmental cost and a legacy where farm business units do not have the resources to address it — hence the expression ‘you can't be green while you're in the red’.

But in contradiction with this policy position, Australian agriculture — from its European beginnings and quite unlike that of the United States — was largely export oriented. From first settlement, it was subjected to commercial forces both in an expectation of returns on the capital brought from abroad and in the relative lack of dependency on domestic consumption. It was not long before the natural resource and environmental constraints had to be tackled. They were successful, through raw innovation by farmers and sustained assistance by public investment in research and development, extension and education. This is where Australia did follow the US model, as early as the 1890s. Under pro-development policies of the day, science and technology were applied to ‘problem solving’: fallowing to conserve moisture, the application of phosphate fertilisers, or the exploitation of groundwater, which clearly was in response to recognised limits in dryland production at the time. The greatest legacy today is from the clearing of native vegetation and its replacement with introduced crops and pastures, aided by all manner of innovative engineering devices to prepare the ground for farming. The European ‘land-use model’ changed from extensive grazing where the adapted plant species remained largely intact, although often over-grazed, to an economic incentive to cultivate and crop all the arable area.

Innovation, problem solving, and the managerial capacity of farmers have sustained an impressive productivity growth through the twentieth century, particularly in cereal production. At the same time, evidence of the land-degradation impacts was mounting (Williams 2001). Retention of significant portions of land under native vegetation was advocated as early as the 1890s (Powell 1993). Concern within the scientific community about soil erosion grew, until the twin events of the Depression and the ‘dust bowl’ in the United States gained widespread attention. There were policy and institutional responses — typically, soil-conservation legislation and government research and advisory programs. But the form of land degradation that remained elusive was dryland salinity. Surprisingly, the association between vegetation clearing and the onset of salinity — in Western Australia — was first published in a scientific journal in 1924. In the Murray–Darling Basin, dryland salinity remains an ongoing threat, not only to farmland but to river water quality and water supplies, thus placing dryland and irrigation farming in an awkward relationship.

Irrigation development in the southern Basin dates back to the 1880s and was driven early by the need to overcome the variability of the Australian climate. Damming and regulating rivers are synonymous with water conservation and a new development frontier — '*making the deserts bloom*' (Cathcart 2009; Powell 1993; Williams 2003). While the earliest farmers used their own resources to exploit groundwater, this was soon followed in Victoria by State-funded infrastructure and closer-settlement schemes. Again, there was a policy objective on inland settlement, community development and, during the war years, population dispersal for national security reasons. Subsequently, the level of exploitation of River Murray water became a source of interstate conflict (Cullen 2002) and its value reached a point where a River Murray Commission's Report could state that '*water is of such inestimable value in an arid country like Australia that the State of people allowing it to go to waste or not effectively using it forfeits the moral although not of course the legal right to the enjoyment of the prospective privileges derived from these rights*' (Powell 1993:62).

The continued, then rapid expansion of irrigation development from the 1950s has resulted in a dilemma even more stark than dryland farming: enormous economic development but at major environmental cost to rivers. The Murray–Darling Basin Ministerial Council responded with some of the most interventionist natural-resource policies in Australian history: the Cap on diversions in 1995, and the Salinity and Drainage Strategy of 1989 (Connell 2007). What was overlooked post-1950 for 30 years was that all this expansion took place in the same high-rainfall climate sequence that drove the expansion of dryland agriculture (Khan 2008).

Figure 1.10 depicts this coincidence between irrigation expansion, as reflected in storage capacity and diversions in the Basin, with a large number of years with large positive rainfall anomalies over the 1950s to 1980s, with the exception of four drier years in the 1960s. This period is perhaps the wettest period in our recent history (Khan 2008).

Unfortunately, it came to a shuddering halt with the millennium drought from 2000 to 2009. Irrigated agriculture suffered a very large reduction in water availability over these nine years. But a reduction of up to 40 per cent in water use across the irrigation industries resulted in the gross value of irrigated agricultural production in the Basin falling only from $5.5 billion to $5.1 billion. This, however, masked large impacts on profit margins and enterprise equity despite the benefits of water trading, which has cushioned substantially the economic impact. These industries now have been weakened such that both the economic and the social wellbeing of the irrigation communities have deteriorated (Chapter 11).

The declining financial strength of dryland agriculture has been coupled with the impaired economic and social conditions of irrigated agriculture resulting in many communities in the MDB being under significant economic and social stress (Grafton and Jiang, 2010; Chapter 14).

Prior to the millennium drought, it was assumed that, unlike dryland farming — which we have seen is increasingly under price–cost pressures and has limited capital accumulation through profits — irrigation industries have a greater capacity to address their ecological footprint. This must now be seriously questioned.

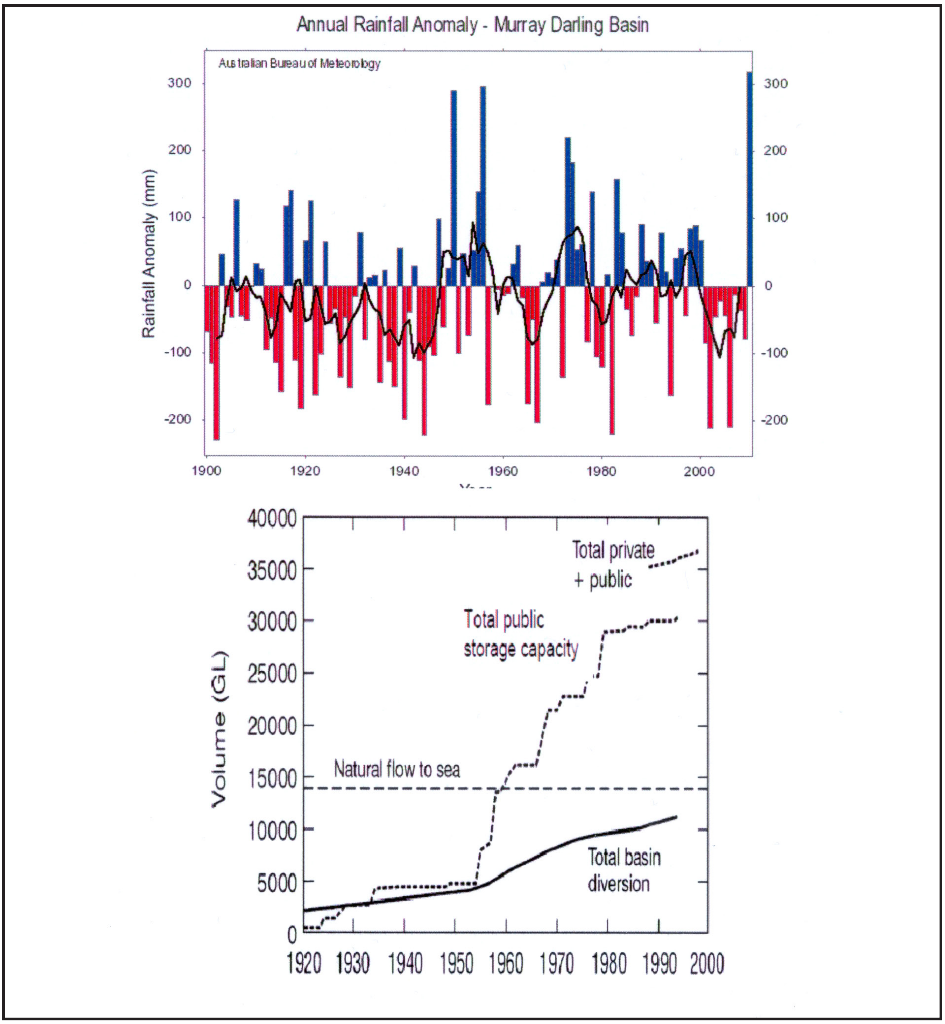

Figure 1.10 The annual rainfall anomaly for the Murray–Darling Basin, 1891–2010, and the storage capacity and diversions in the Basin, 1920–94

Source: Williams (2004).

The water-reform agenda that is urgently needed to restore some fundamental ecological functions to the river system and the groundwater now must be cast in a context of communities of the MDB suffering declining economic and social capacity. In such context, is water reform achievable? If it is to be achieved, how can this take place within the limited social and economic capacities of the MDB communities?

Human Interaction with the Bio-Geophysical Realities must be Managed in Successful Water Reform

Water Reform is About People, Policy and Practice

Irrigation industries by their nature are more intensive than others in their land use, and one of their productive resources — water — is amenable to tight management. In fact, in recent years, even with the bold national government policy (the water-reform agenda) — including the Cap on diversions in the Basin and water trading — there is still considerable scope to maintain or improve economic output from a scarce and increasingly scarcer natural-resource base. In fact, the Government can boast a pretty good track record—for instance, bringing off-farm impacts of pesticide use under control, and limiting or even reversing groundwater rise on farms. The serious impact on river health of the over-extraction of water from rivers to support these industries was, however, not addressed. This fundamental resource was taken for granted. Initially, it was believed that irrigation industries do not suffer the extremes of capital risk and income decline that the dryland industries experience. In general, they were thought to have the capacity to reinvest in their future and respond positively to the pressure to reduce their environmental footprint. The millennium drought has now thrown those assumptions into serious question. Failure to use historical data from equally severe droughts in the first 50 years of Federation (see Figure 1.10) blinded policy makers, water managers and communities alike to the fact that climate variability was very important to the water supply and how it was allocated, and that irrigation industries were just as vulnerable as the dryland industries.

Long-term average surface-water extractions in the Basin are about 12 000 GL/year, while the nominal total surface-water entitlements are approximately 16 000 GL. Long-term average surface-water availability is about 14 500 GL/yr.

The Basin is home to two million people, including 18 000 irrigators and more than 40 000 primarily dryland farmers (ABS et al. 2009), who collectively farm more than 80 per cent of land in the Basin. As we have seen, irrigated agriculture was actively encouraged through most of the twentieth century by State governments in the form of land grants and subsidised off-farm infrastructure and water storage (Connell 2007). To provide reliable flows for irrigation — especially during dry years — large public dams with total capacity in excess of two years of average flows were built and now account for about 80 per cent of water-storage capacity in the Basin (see Figure 1.10). The largest were constructed in the second half of the twentieth century — a period (as shown in Figure 1.10) that coincided with relatively wet conditions and large flooding sequences (Khan 2008; Vives and Jones 2005) — and water extractions more than doubled from the 1950s to the 1990s (Productivity Commission 2010).

Consequently, by the 1990s, the nominal volumes of surface water allocated to water entitlements that varied in terms of their reliability of supply by type, catchment and State, were about one-third greater than what was usually available. More than 90 per cent of the volume is diverted to water annual crops such as pasture, cotton and rice, and also perennials such as grapes and fruit trees (Productivity Commission 2010). By the 1980s, there was increasing concern over the effects of extractions on the health of the rivers and their ecosystems. A spectacular algal bloom in the summer of 1991–92 that extended along more than 1000 km of the Darling River gave the issue international prominence and led, ultimately, to a freeze on further growth in surface-water extractions at 11 600 GL against a long-term natural flow to the sea of approximately 14 000 GL (Chartres and Williams 2006:Figure 4). This became known as 'the Cap'. An unfortunate failure of public policy was that the Cap did not apply to groundwater extractions and groundwater use rapidly accelerated after its imposition on surface water (SKM 2003).

While the Cap limits surface-water extractions to what irrigators would have received given the infrastructure and management rules in place in 1993–94, assuming the same hydrological and climactic conditions, it does not address the over-allocation of the Basin's rivers. Simultaneous with the establishment of the Cap, the States in the Basin agreed to allow water trading by separating rights to land and water so that while total diversions were capped, individual irrigators could increase their extractions if they purchased water entitlements from others. Water trading in terms of permanent water entitlements came into being as part of the National Water Initiative in 2003 and was part of an accord to return water to over-allocated rivers. When water licences of various durations and forms were converted to indefinite water entitlements which became a tradeable water right this represented a large transfer of public assets to the private sector. The accord and social contract was in light of this transfer to be a return of water to the public to provide the water for over-allocated rivers systems of the Basin. The nature of this social contract is the foundation for the water reform process in which we are currently involved. This should not be forgotten.

Trade in these entitlements — and to a greater extent trade in the annual allocations of water assigned to each entitlement every irrigation season — has grown rapidly, with the trade in entitlements increasing more than twenty-fold since implementation of the Cap. Nevertheless, rules still remain that effectively prevent the trade of water entitlements across State boundaries (ACCC 2009).

The Cap was implemented with the water-management rules that operate separately in each State and that are counter-cyclical. Namely, they provide for a greater proportion of inflows to irrigators in dry years than in wet periods. These rules were justified, in the belief that the environment would get its 'fair share' of the water during flood events, and this would be consistent with the natural flows to which the Basin's ecosystems had evolved. A drying trend in the southern part of the Basin that began shortly after the implementation of the Cap (Vernon-Kidd and Kiem 2009), coupled with an increase in decadal mean temperature of between 0.2 and 0.3°C since 1960 in many parts of the Basin (Bureau of Meteorology 2010), has reduced water availability, and made the Cap a non-binding constraint in many parts of the Basin, as water-sharing agreements were suspended in most States. In contrast, the counter-cyclical water rules have become much more important, as they have reduced environmental flows in the MDB by much more than the actual declines in inflows during the recent millennium drought.

Agriculture and associated development in the past 213 years have contributed to economic growth and population wellbeing which is as good as you will find anywhere in the modern world; however, the exploitation of natural resources beyond their rates of replenishment and out of line with ecological functioning of the river systems has been a cost associated with this economic growth. Costs include declining river health, increased surface and groundwater use, rising salinity and acidity, loss of soil structure and condition; and environmental impacts that are quite stark — measured in the invasion of environmental weeds and feral animals, in flora and fauna species loss, and in ecosystem breakdown.

For industries that are largely dependent on natural resources, the over-allocation or overuse of resources gives very masked signals because of the long-run nature of the response to development and the year-to-year variability obscuring the trends. On the other hand, there are much sharper signals of environmental impact and these are readily observed and communicated widely and forcefully by conservation advocates on the fringe of these mainstream industries.

These environmental impacts are an early indicator of a loss of resilience in ecosystem function in the natural resources base that underpins our land-based industries — that is, the biophysical processes and systems are moving from the complex to the simple. These changes are foretelling a decline in the natural-resource base and ultimately in economic productivity.

It is clear that this negative interaction between people and their land, water and biodiversity is fundamental to the task that must be resolved for water reform to take place. Water reform is only one component of a whole complex of issues confronting communities in the MDB. From the brief and inadequate analysis here, it is clear that the social, economic and political fabric of the MDB communities is at a critical stage of change. The economic foundations and social fabric for both dryland and irrigated agriculture are no longer as they were when settlement was established. There is evidence that many communities are suffering serious financial and social difficulties. Many sense a serious threat to their existence. Water reform, then, is cast at a time in the history of the Basin when it is extremely difficult to understand and analyse the tensions and contradictions between the cultural values and social and economic aspirations of communities both in the Basin and outside with the necessary future actions, dictated by the bio-geophysical realities, necessary to restore resilience in the function of ecosystems upon which all ultimately depend. The narrative — the mix of values, aspirations and visions — for the MDB can no longer be cast as the one that served the past, but the new narrative for the Basin and its communities has yet to emerge.

This clash between bio-geophysical reality, economic reality, and social and cultural values demands a policy response. It is difficult and progress is slow. Australians have been at it in the Murray–Darling Basin for nearly 150 years. Why has it come to this? Why are we incapable of turning around the long-run environmental impacts of food and fibre production and associated development, measured symptomatically as declining river health and ecological function of rivers, the loss of wetlands, dryland salinity, decline in the quality of our soils and increasing loss of native species?

The challenge to us all is quite confronting now.

Our Future

For more than 100 years, Australians have fought over the waters of the Murray–Darling Basin. Water is a scarce resource, and, as we have developed the extraction industries of the Basin, we have not left enough water in the rivers to sustain a healthy river system. This will challenge our science and our society to find management solutions that can yield river systems resilient to the shocks of drought and massive floods which are often intensified by our engineering interventions. This is daunting enough with current climate variability, but then to add to this mix the impacts of climate change on climate variability and changed probability distributions for our rainfall will stretch us to our limits.

A new Basin Plan is being developed to address this blight on our history. Under the *Water Act 2007*, the job of the Plan is to provide for limits on the quantity of water that may be taken from the Basin water resources as a whole. It is part of a broader set of water reforms designed to bring balance back to the Basin (Wentworth Group 2010).

As we have seen, irrigated agriculture is the biggest consumer of the water we take out of the Basin. It uses the water to produce high-quality food and fibre. It produces valuable exports. It also provides jobs and is a foundation industry in the economies of communities along the rivers of the Basin. For the river to work, however, there must be enough water in the system to connect the wetlands and floodplains, and flush the salts, nutrients and sediments through the lakes, estuaries and the Murray mouth.

The changes the new Basin Plan brings can be delivered in different ways. They can be done badly, as we have seen in the past. Or they can be achieved in ways that provide the water to meet the environmental needs of the river system and at the same time help businesses and communities to optimise opportunities and adapt to a future with less water.

Perhaps the narrative we need is that the current crisis in the Murray–Darling Basin provides the best opportunity since Federation for Australians to work together to rebuild our Murray–Darling heartland, resulting in more resilient communities and healthier rivers. We must accept that we have a future with less water and a system that is currently over-allocated and is also confronted by climate change.

In the past 50 years, the majority of Australians — whether we live in the city or the country — have benefited greatly from the development of irrigated agriculture in the Murray–Darling Basin. In a relatively short time, we have developed an industry that produces much of the top-quality food and fibre we all enjoy at a cost the majority of us can easily afford. This growth in irrigation has been achieved largely as a result of families and individuals investing their time, money and aspirations into their farms, infrastructure and businesses. Industries that support irrigation have developed and employed people. In turn, service industries — ranging from the pub to the newsagent — have been set up, or expanded, to service the needs of the growing population. People have built their livelihoods; they have fed and clothed their families, paid school fees and mortgages — all off the back of irrigation and the industries it supports. Regional towns have grown as a result of the people irrigation brought. More people has meant social groups and sporting teams have been set up or expanded. Trophies have been won and lost and community spirit and identity have evolved.

The gold that fed this rush was water.

But we took too much and we did not take note of our history of droughts that could bring these industries to a halt. We now must do that: look to our climate history and to our climate future and rebuild our communities so that they have resilient futures in light of our climate and bio-geological heritage.

The current approach to the adjustment — although beginning to return some water to the system — has a fundamental flaw. Irrigation communities already suffering see it as another attack on their livelihoods. People cannot see a positive vision for themselves and their community in a future with less water.

In some areas, those who can see a vision for themselves and are willing to sell must struggle with the negative judgements of the rest of the community many of whose members are conscious of the importance of the water and the income it potentially but indirectly generates for them. A large proportion of the community that relies on irrigation-related activities for its income has no water to sell and does not benefit from its sale out of their region.

The social implications of the adjustment are massive, and if we do not address them we will not make the adjustment. We will instead fight amongst ourselves to protect our livelihoods. Rules limiting trading volumes, embargoes on trade and bickering between States highlight this reality.

In this challenge, however, lies opportunity.

With the right social processes in place, the irrigation communities of the Murray–Darling Basin could develop a new vision for their future. For some communities, the vision might be a future without irrigation. These local visions could integrate into a broader vision for a sustainable and profitable Murray–Darling Basin with healthy rivers, wetlands and floodplains.

Implementation of part of this process of water reform, and the $12.9 billion the Government has allocated, could be the catalyst to deliver a new future rather than the threat to communities it is currently seen as.

Other, existing nation-building and rural-development programs could be integrated with the water reforms to deliver services and infrastructure to help communities develop new opportunities. To deal with this, we will need a well-balanced, three-legged-stool approach to water reform. Currently, we have only two legs: buyback and infrastructure improvement to lift efficiency. Without the third leg of support to help regional communities plan for a future with less water and structurally adjust, the stool will fall over. This third leg is missing, and our communities are being expected to make these huge adjustments with little support from government.

Australian society as a whole has played a role in the development of this catastrophe through our government's over-allocation of water extraction from our rivers and groundwater. It seems only fair that all Australians take responsible action to assist our communities to make the required adjustment so that water extraction is in line with the capacity of the rivers and groundwater.

Ultimately, this will give us all an assurance of a more sustainable future. To support communities in the Basin and build on this legacy it will be increasingly important that Australians build a regulatory framework around food and fibre production in the Basin that enshrines its sustainability credentials as the water reform is implemented. Williams and McKenzie (2008) argue for a regulatory framework in Australia that ensures that all food reaching the consumer is produced in ways that minimise the damage to natural resources and the environment. Environmental management systems and proper labelling of food and its footprint are first steps and are currently maturing. But this alone is not sufficient. A regulatory framework is required that establishes that, for food and fibre to be marketed, it must have been produced by means which meet an Australian standard for sustainable food or fibre products. Such a standard must apply to both Australian grown and imported products. The water reforms when implemented have the potential to make the MDB one of the most sustainable food and fibre production basins on the planet. Australians will need to then maximise the benefits of such an achievement by ensuring we have a regulatory framework which enables Basin communities to capture of this competitive advantage on local and overseas markets.

For communities to begin to shape futures, it is so important that there be honesty and transparency in the magnitude of the reduction in water extraction that is compatible with a healthy Murray–Darling. Most regional cities, towns and communities within the Murray–Darling Basin face massive social and economic impacts of a water-reform agenda designed to improve the health of over-allocated rivers and groundwater. This upheaval comes at a time of severe drought and against a backdrop of climate change. Communities are faced with making tough and painful decisions.

There is ample evidence that regional communities and industry are actively taking responsibility for planning to live with less water and accept the need to return water to the river.

Certainly, the government buyback of water allocations and entitlements is a critical part of the solution, as is the government investment in water and irrigation infrastructure. But there is an urgent need to bring together these two elements in the water-reform agenda with a third element involving a strong focus on and commitment to community and industry planning as part of a package for regional development.

Governments have put some $12 billion on the table to address water reform in the Murray–Darling Basin. This investment should be a key plank in the regional development, rebuilding and revitalisation of the communities of the Murray–Darling. It is a magnificent opportunity to support, facilitate and resource our communities to find their own solutions for a more resilient future. Elsewhere in this book (Chapter 11; Hoggett et al. 2008; Miller 2010; Wentworth Group 2010) a number of writers explain how to empower individuals and groups of people by providing the skills they need to effect change in their own communities. These skills are often concentrated around building social cohesion through the formation of large social groups working for a common agenda.

We must support regional communities in a number of different ways to help them plan for a future with less water and provide the structural-adjustment support that will be required. History suggests that many attempts to assist autonomous adjustment backfire. Structural adjustment can be done very well or very badly. Funds skilfully applied to target areas can greatly speed up adjustment processes, especially if there are substantial public benefits at stake.

The whole water-reform package could be seen as an opportunity for major regional development based on community assistance for planning, building new futures and making the necessary structural adjustment. With this focus, the most effective use can then be made of water buybacks coupled with investment in infrastructure and on-farm innovation to drive water-use efficiency. Putting the focus on community development and the assistance required by communities who are faced with major change and adjustment could turn the current crisis into an opportunity for Australians to work together to rebuild our Murray–Darling heartland, resulting in more resilient communities and healthier rivers.

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Bibliography

Australian Bureau of Statistics (ABS), Australian Bureau of Agricultural and Resource Economics (ABARE) and Bureau of Rural Sciences (BRS) 2009, *Socio-economic context for the Murray–Darling Basin*, Descriptive report, MDBA Technical Report Series: Basin Plan, BP02, Murray–Darling Basin Authority, Canberra.

Australian Competition and Consumer Commission (ACCC) 2009, *Water Trading Rules: Draft advice*, Australian Competition and Consumer Commission, Canberra.

Barr, N. 2002, 'Structural change in Australian agriculture: implications for natural resource management', in *People Strategies and Outcomes 1986–96*, Australian Natural Resources Atlas, Department of Sustainabililty, Environment, Water, Population and Communities, Canberra, <http://www.anra.gov.au/topics/people/strategies-outcomes/index.html>

Barr, N. 2009, *The House on the Hill: The transformation of Australia's farming communities*, Land & Water Australia, Canberra, <http://lwa.gov.au/products/pn20461>

Bowler, J. 1990, 'The last 500,000 years', in N. Mackay and D. Eastburn (eds), *The Murray*, Murray–Darling Basin Commission, Canberra, pp. 96–110.

Bureau of Meteorology 2010, *State of the Climate*, Bureau of Meteorology, Canberra.

Butler, B. E. 1958, *Depositional systems of the riverine plains of southeastern Australia in relation to soils*, Soils Publication No. 10, CSIRO Division of Soils, Canberra.

Cathcart, M. 2009, *The Water Dreamers—The remarkable history of our dry continent*, Text Publishing, Melbourne.

Chartres, C. J. and Williams, J. 2006, 'Can Australia overcome its water scarcity problems?', *Journal of Developments in Sustainable Agriculture*, vol. 1, pp. 17–24.

Commonwealth of Australia 2007, *Water Act 2007*, No. 137 (2007), Department of the Attorney-General, Canberra.

Commonwealth of Australia 2004, *Intergovernmental Agreement on a National Water Initiative*, Commonwealth of Australia, Canberra.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) 2008, *Water availability in the Murray–Darling Basin*, A report from CSIRO to the Australian Government, Murray–Darling Basin Sustainable Yields Project, CSIRO, Canberra.

Connell, D. 2007, *Water Politics in the Murray–Darling Basin*, The Federation Press, Sydney.

Crofts, F. C. 1985, 'Thirty years of pasture research which changed Australia', *Proceedings of 3rd Agronomy Conference 1985 Hobart, Tasmania, Australia*, <http://www.regional.org.au/au/asa/1985/invited/p-01.htm#TopOfPage>

Crabb, P. 1997, *Murray–Darling Basin Resource*, Murray–Darling Basin Commission, Canberra.

Cullen, P. W. 2002, 'The common good', in D. Connell (ed.), *Unchartered Waters*, Murray–Darling Basin Commission, Canberra, p. 138.

Cullen, P. (forthcoming), 'Facing up to the water crisis in the Murray–Darling Basin', in V. Cullen (ed.), *This Land Our Water*, ATF Press, Adelaide.

Davies, P., Harris, J., Hillman, T. and Walker, K. 2008, *Sustainable rivers audit: a report on the ecological health of rivers in the Murray–Darling Basin*, Prepared by the Independent Sustainable Rivers Audit Group for the Murray–Darling Basin Ministerial Council, Canberra.

Donohue, R. J., Roderick, M. L. and McVicar, T. R. (Forthcoming), 'Assessing the differences in sensitivities of runoff to changes in climatic conditions across a large basin', *Journal of Hydrology*.

Doody, T., Overton, I. and Pollock, D. 2009, 'Floodplain inundation mapping', in I. C. Overton, M. J. Colloff, T. M. Doody, B. Henderson and S. M. Cuddy (eds), *Ecological outcomes of flow regimes in the Murray–Darling Basin*, Report prepared for the National Water Commission by CSIRO Water for a Healthy Country Flagship, Canberra.

Evans, R., Brown, C. and Kellett, J. 1990, 'Geology and groundwater', in N. Mackay and D. Eastburn (eds), *The Murray*, Murray–Darling Basin Commission, Canberra, pp. 75–95.

Francis, D. and Hengeveld, H. 1998, *Extreme Weather and Climate Change*, Climate and Water Products Division, Atmospheric Environment Service, Canadian Ministry of Supply and Services, Ontario.

Grafton, R. Q. and Jiang, Q. 2010, *Economics of drought, water diversions, water recovery and climate change in the Murray–Darling Basin*, CWEEP Research

Paper 10-01, Centre for Water Economics, Environment and Policy, The Australian National University, Canberra, <http://cweep.anu.edu.au/pdf/publications/research_papers/10-01_WaterEconomics.pdf>

Gray, I. and Lawrence, G. 2001, *A Future for Regional Australia: Escaping global misfortune*, Cambridge University Press, UK.

Hall, D., Baldwin, S., Rees, G. and Richardson, A. 2006, 'Distribution of inland wetlands with sulfidic sediments in the Murray–Darling Basin, Australia', *The Science of the Total Environment*, vol. 370, pp. 235–44.

Hoggett P., Mayo M. and Miller C. 2008, *The dilemmas of development work: Ethical challenges in regeneration*, Policy Press, Bristol.

Idriess, I. 1993, 'The cattle king', in *Ion Idriess's Greatest Stories*, HarperCollins, Sydney, pp. 1–238.

Khan, S. 2008, 'Managing climate risks in Australia: options for water policy and irrigation management', *Australian Journal of Experimental Agriculture*, vol. 48, pp. 265–73.

Lamontange, S., Hicks, W. S., Fitzpatrick, R. W. and Rogers, S. 2006, 'Sulfidic materials in dryland river wetlands', *Marine and Freshwater Research*, vol. 57, pp. 775–88.

McCarthy, B., Conalin, A., D'Santos, P. and Baldwin, D. 2006, 'Acidification, salinisation and fish kills at an inland wetland in south-eastern Australia following partial drying', *Ecological Management and Restoration*, vol. 7, pp. 218–23.

Maheshwari, B. L., Walker, K. F. and McMahon, T. A. 1995, 'Effects of regulation on the flow regime of the River Murray, Australia', *Regulated Rivers: Research and Management*, vol. 10, no. 1, pp. 15–38.

Meneghini, B., Simmonds, I. and Smith, I. N. 2007, 'Association between Australian rainfall and the Southern Annular Mode', *International Journal of Climatology*, vol. 27, pp. 109–21.

Miller, C. 2010, 'Developing capacities and agency in complex times', in *Challenging Capacity Building*, eds. M. Clarke and S. Kenny, Palgrave Macmillan, Melbourne.

Min, S.-K., Zhang, X., Zwiers, F. W. and Hegerl, G. C. 2011, 'Human contribution to more-intense precipitation extremes', *Nature*, vol. 470 (17 February), pp. 378–81.

Murray–Darling Basin Authority (MDBA) 2010, *Guide to the proposed Basin Plan*, Murray–Darling Basin Authority, Canberra, <http://thebasinplan.mdba.gov.au/guide/guide.php?document=the-murray-darling-basin>

Murray–Darling Basin Commission 2008, Annual Report 2007-2008, Murray-Darling Basin Commission, Canberra, p.78. <http://publications.mdbc.gov.au/download/MDBC-AR-0708.pdf>

Murray–Darling Basin Ministerial Council (MDBMC) 1987, *Murray–Darling Basin Environmental Resources Study*, NSW State Pollution Control Commission, Sydney.

Natural Resources Commission (NRC) 2009a, *Riverina Bioregion Regional Forest Assessment: River red gum and other woodland forests*, NSW Natural Resources Commission, Sydney, <http://www.nrc.nsw.gov.au/content/documents/Red%20gum%20-%20FAR%20-%20Complete.pdf>

Natural Resources Commission (NRC) 2009b, 'Implications of changes in climate for water availability and flooding regimes', in *The Final Assessment Report on Riverina Bioregion Regional Forest Assessment: River red gums and other woodland forests*, NSW Natural Resources Commission, Sydney, <http://www.nrc.nsw.gov.au/content/documents/Red%20gum%20-%20FAR%20-%20Ch%208.pdf>

National Water Commission (NWC) 2009a, *National Water Commission Australian Markets Report 2008–2009*, National Water Commission, Canberra.

National Water Commission (NWC) 2009b, *Australian Water Reform 2009: Second biennial assessment of progress in implementation of the National Water Initiative*, National Water Commission, Canberra.

Nix, H. A. and Kalma, J. D. 1982, 'The climate of the Murray-Darling Basin,' in *Murray–Darling Basin Project Development Study*, Stage 1 Working Papers, CSIRO Division of Water and Land Resources, Canberra.

Ollier, C. D. 1995, 'Tectonic and landscape evolution in Southeast Australia', *Geomorphology*, vol. 12, no. 1 (April), pp. 37–44.

Overton, I. and Saintilan, N. (eds) 2010, *Ecosystem Response Modelling in the Murray–Darling Basin*, CSIRO Publishing, Melbourne.

Pall, P., Aina, T., Stone, D. A., Stott, P. A., Nozawa, T., Hilberts, A. G. J., Lohmann, D. and Allen, M. R. 2011, 'Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000', *Nature*, vol. 470 (17 February), pp. 382–6.

Powell, J. M. 1993, *The Emergence of Bioregionalism in the Murray–Darling Basin*, Murray–Darling Basin Commission, Canberra.

Proctor, W., Hosking, K., Carpenter, T., Howden, M., Stafford Smith, M. and Booth, T. 2009, *Future research needs for climate change adaptation in the Murray–Darling Basin*, Report to the Murray–Darling Basin Authority, Canberra.

Productivity Commission 2010, *Market Mechanisms for Recovering Water in the Murray–Darling Basin*, Productivity Commission, Melbourne.

Rancic, A., Salas, G., Kathuria, A., Acworth, I., Johnston, W., Smithson, A. and Beale, G. 2009, *Climatic Influences on Shallow Fractured-Rock Groundwater Systems in the Murray–Darling Basin, NSW*, NSW Department of Environment and Climate Change, Sydney South, <http://www.environment.nsw.gov.au/resources/salinity/09108GroundwaterMDB.pdf>

Rutherford, I. 1990, 'Ancient river, young nation', in N. Mackay and D. Eastburn (eds), *The Murray*, Murray–Darling Basin Commission, Canberra, pp. 17–36.

Senate Standing Committee on Rural and Regional Affairs and Transport 2008, *Water Management in the Coorong and the Lower Lakes*, Parliament of Australia, Canberra.

Sinclair Knight Merz (SKM) 2003, *Projections of groundwater extraction rates and implications for future demand and competition for surface water*, Murray–Darling Basin Commission Publication 04/03, Sinclair Knight Merz, Melbourne.

Vernon-Kidd, D. C. and Kiem, A. S. 2009, 'Nature and causes of protracted droughts in southeast Australia: comparison between the federation, WWII, and big dry droughts', *Geophysical Research Letters*, vol. 36, no. L22707, <DOI:10.1029/2009GL041067>

Vives, B. and Jones, R. 2005, *Detection of abrupt changes in Australian decadal rainfall (1890–1989)*, Technical Paper No. 73, CSIRO Department of Atmospheric Research, Aspendale, Vic.

Wasson, R. J. 1987, 'Geology, geomorphology and mineral resources of the Murray–Darling Basin', in *Murray–Darling Basin Project Development Study*, Stage 1 Working Papers, CSIRO Division of Water and Land Resources, Canberra, pp. 1–9.

Wentworth Group 2003, *Blueprint for a national water plan*, A report from the Wentworth Group of Concerned Scientists, Sydney, <http://www.clw.csiro.au/new/WWF0703-02%20A4%20Horiz.pdf>

Wentworth Group 2010, *Sustainable Diversions in the Murray–Darling Basin—An analysis of the options for achieving a sustainable diversion limit in the Murray–Darling Basin*, Wentworth Group of Concerned Scientists, Sydney, <http://www.wentworthgroup.org/blueprints/sustainable-diversions-in-the-murray-darling-basin>

Williams, J. 2001, 'Farming without harming—can we do it?', *Agricultural Science*, vol. 14, no. 1, pp. 20–4; vol. 14, no. 2, pp. 34–7.

Williams, J. 2003, 'Can we myth-proof Australia?' *Australasian Science*, vol. 24, no. 1 (January/February).

Williams, J. 2004, 'Wealth from water: a national perspective', in G. Batten and J. Kent (eds), *Proceedings of the Wealth from Water Conference*, Wagga Wagga, NSW, 14 March 2003, Charles Sturt University and Wagga Wagga Chamber of Commerce and Industry, NSW, pp. 24–35, <http://www.clw.csiro.au/staff/WilliamsJ/Wealth_from_Water.pdf>

Williams, J. and Goss, K. 2002, 'Our difficult bequest: the collision of biophysical and economic reality, cultural values and public policy', in D. Connell (ed.), *Unchartered Waters*, Murray–Darling Basin Commission, Canberra.

Williams, J. and McKenzie, F. 2008. 'Agriculture' in *10 Commitments: Reshaping the Lucky Country's Environment*. Lindenmayer, D.B., Dovers, S., Hariss Olsen and Morton, S. (eds). CSIRO Publishing, Melbourne.