

Chapter 16

Drought and Climate Change in the Murray-Darling Basin: A Hydrological Perspective

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Abstract The Murray-Darling Basin experiences frequent droughts and, at the time of this writing, parts of it are in the grip of the worst drought in the 110 years of comparatively high-quality records. In this chapter, we consider the term drought to be several years with less than median rainfall. The combined impacts of drought and over-allocation of water for irrigation use have led to severe stress on floodplains and wetlands. Climate change projections suggest that the Murray-Darling Basin will be on average drier in the future. The recent drought period has experienced lower autumn and winter rain and higher temperatures than past droughts, resulting in the lowest runoff totals on record in recent years. While these features may be associated with climate change, they may equally be a result of large, long-term climate variability. The recent drought and declining river health have exposed the inadequacy of current water management to cope with the variability of water availability in the Murray-Darling Basin. Future water management strategies should involve consideration of a range of scenarios, including those incorporating climate change.

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16.1 Introduction

Australia is, in the words of one of the country's best loved poems, a land "of drought and flooding rains".¹ Drought, often associated with El Nino events, is interspersed with wetter periods. Australia experiences a major drought about once every 10 years (Bureau of Meteorology 2004).

The southeastern part of Australia, including the Murray-Darling Basin (shown in Fig. 16.1), has recently experienced a drought more severe than any previously experienced (Timbal 2009). The drought is compounded by water diversions, which by about 1995 had risen to nearly half of the water resource available in an average year in the Murray-Darling Basin. The consequent decline of water available to the environment has led to declining river health (MDBC 2002), which has been much exacerbated in the last few years of drought. In 2002, the Murray-Darling Basin Commission (MDBC) reported that the average annual discharge to the sea from the Murray had fallen to 27 % of its natural, pre-development value (MDBC 2002). For the last few years, the discharge has been effectively zero: the lower lakes, which are separated from the sea by a series of barrages are now about 0.8 m below sea level, and expected to fall to more than 1 m below sea level over the summer (MDBA 2009). The health of the floodplain and wetlands continues to decline, with the lower part of the Murray having experienced 13 years at the time of this writing without a significant flood (many ecosystems depend on periodic floods).

The responses to the declining river health and rising diversions have included: a cap on diversions since 1995 (MDBA 2009); water reform under the National Water Initiative, particularly market-based measures, to increase the efficiency of use and provide for greater certainty for investment and for the environment (NWC 2009); and the Water for the Future plan of the Commonwealth Government which, amongst other things, aims to restore water to the rivers by upgrading leaky irrigation systems and acquiring water entitlements to provide water for the environment (DEWHA 2009). The policy and economics of these responses are covered in other chapters in this book.

The aims of this chapter are to set the hydrological scene: to characterize historic droughts, to compare the recent drought, and to show scenarios of possible future droughts under climate change. We also aim to identify some hydrological limits to policy and management—what is possible and what is not. The scope of the chapter is surface water resources, which are most immediately affected by drought.

¹ A line from "My Country," by Dorothea Mackellar, first published in 1908.

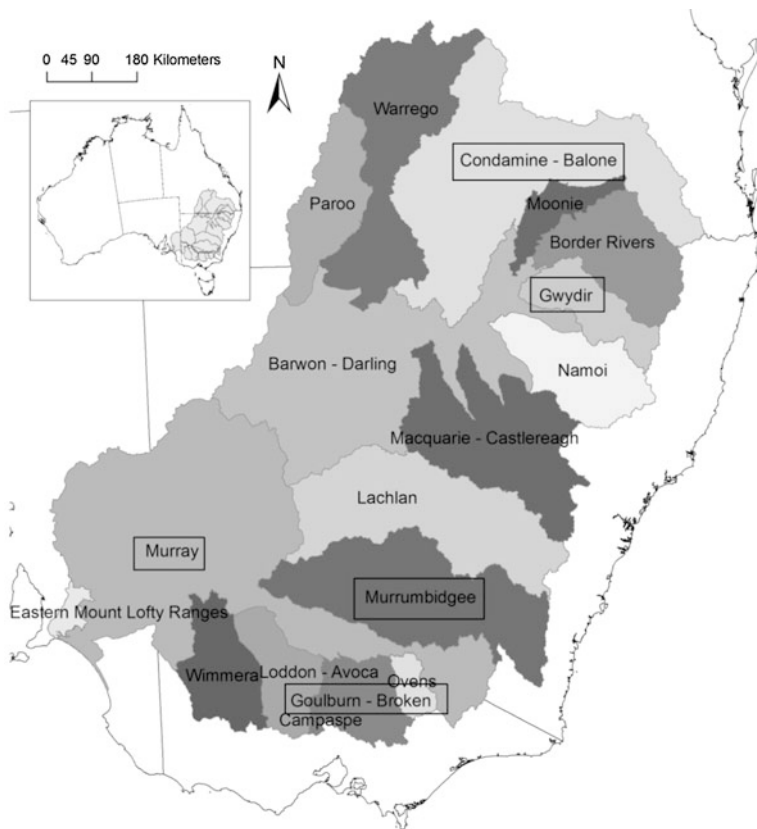


Fig. 16.1 The Murray-Darling Basin, with the regions used in the CSIRO sustainable yields project. The five regions described in this chapter are shown in *boxes*

16.2 What do We Mean by Drought?

We outline some general features of Murray-Darling Basin rainfall in Fig. 16.2. The figure shows the whole Murray-Darling Basin annual rainfall (i.e., the spatial average of annual totals). Superimposed are a five-year moving average, and averages for earlier and later periods showing the well-known drier first part of last century and the wetter later part (until 1995, or so). Also shown is the median rainfall for the whole period, and the droughts that are generally considered as major droughts in Australia (Bureau of Meteorology 2004). All of the droughts have a long run of years below the median, or a year well below the median, or both.

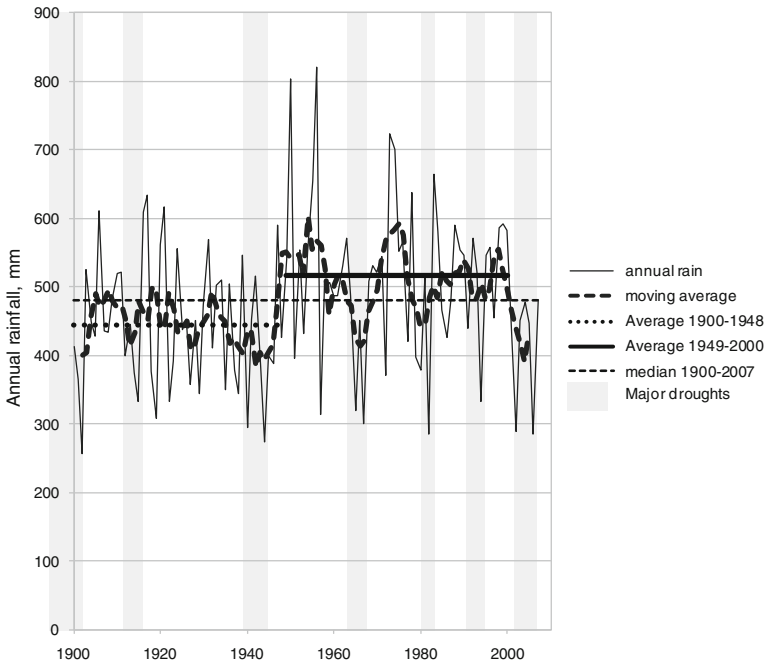


Fig. 16.2 Spatially averaged annual rainfall for the Murray-Darling Basin. *Sources* Rainfall record, Hennessy et al. (2008); drought periods (*vertical stripes*), Bureau of Meteorology (2004)

16.2.1 Some Simple Metrics: Long, Dry Periods

The aim in this chapter is to build upon the information gleaned from the Murray-Darling Basin Sustainable Yields (MDBSY) project² results and look more comprehensively at the dry years and, in particular, at runs of dry years. There are several drought indices, and different ways of defining drought. Hounan (1976) notes that perceptions of drought differ among meteorology, agriculture, hydrology, and economics, and lists 29 indices relevant to meteorological and agricultural drought. Maher (1973) suggests that a generally acceptable, though nevertheless inadequate, definition is “severe and prolonged water shortage.” We

² The Murray-Darling Basin Sustainable Yields project was a major project commissioned by the Australian Federal Government, and undertaken by CSIRO in association with relevant state agencies and leading consultants (See Kendall et al. for further details). The project assessed water availability in the Murray-Darling Basin under four main scenarios: historic climate, the current severe drought, climate change (with dry, median and wet sub-scenarios), and climate change plus some anticipated developments which could change water availability (but which did not include changes to the locations or allocations of irrigation water use). The project modeled the water availability under current rules of water sharing, and linked surface water and groundwater use. The project was completed in 2008, the results of which are available in a series of reports (CSIRO 2008).

make use of this definition, but rather than appealing to a single index of drought, we work directly with the length and severity of dry periods, where the severity is defined as a departure (on the dry side) from the median.

We chose five regions from the MDBSY project as a north–south transect: Condamine, Gwydir, Murrumbidgee, Murray and Goulburn (Fig. 16.1). For each region, we examined the modeled runoff for the headwater regions above the major dam or dams (respectively: Chinchilla Weir; Copeton; Burrinjuck and Blowering; Hume and Dartmouth; Eildon), dam storage levels, diversions and end-of-system flows. For the Murray, we also examined the flows at an intermediate point (Wakool). We examined the full length (111 years) of the MDBSY modeled results, for the historical and three main climate change scenarios—a median projection and a wet and a dry extreme.

The MDBSY modeled climate change projections were obtained by scaling the historic climate sequences. The scaling was performed to vary historical daily and seasonal rainfall (and other climate variables) to match their distribution in the IPCC AR4 modeled rainfall (or other climate variables), while preserving the overall annual totals (or averages) expected in 2030 in the IPCC results. The key point for this study is that the sequences of rainfall are given by the historical records being scaled. Droughts, therefore, occur in the same sequence and have the same general order of severity (that is, the deepest drought in the record is the most recent, and the deepest in the modeled scenarios is that at the end of the modeled period). Other forms of climate change projection will result in drought results that differ from those presented here.

16.2.2 Length of Dry Runs

For every region and measure (runoff, flows, etc.) and the historical scenario, the first step is to identify the median value for the 111-year record. The next step is to identify all years that are drier than the median, and to count how often there are 1, 2, 3, 4, etc. dry years in a row (i.e., a run unbroken by a year wetter than the median). This is done for the historic and climate change scenarios, always with reference to the median of the historic scenario. Thus we identify in our future projections whether there are fewer or more dry runs than in the historic record, and whether the runs are longer or shorter.

To illustrate the steps so far, Fig. 16.3 shows the modeled historic runoff record for the Condamine, and Fig. 16.4 shows the analogous record for the dry climate scenario. By inspection, it can be seen that there are more dry years (years with runoff less than the historic median) in Fig. 16.4 than in Fig. 16.3, and that the runs of dry years are longer. (We may also note that the runoff reflects the generally drier period in the first part of the record and the generally wetter period in the second part of the record. All regions and measures reported here show this general pattern.) Figure 16.5 plots the frequency of the dry runs, and shows that there are more single dry years in the historic scenario, but more long runs of dry

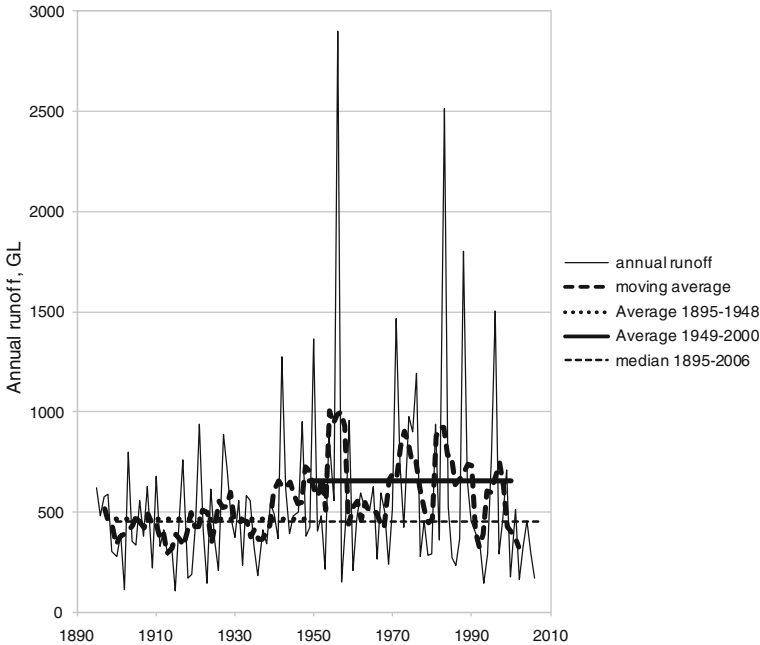


Fig. 16.3 Modeled historic runoff for the Condamine above Chinchilla weir

years (particularly runs of 5 years or more) in the dry extreme and median climate change projections. For ease of presenting the information, we will hereafter refer mainly to the number of runs of 5 years or more, which for the runoff in the Condamine are one for the historic scenario, five for the dry extreme, three for the median, and one for the wet extreme projection.

The total number of years in the 111-year Condamine sequence in runs of 5 years or more is six for the historic scenario, 28 for the dry extreme, 16 for median, and six for the wet extreme projection.

The two numbers above—number of runs of 5 years or more, and total number of years in the 111-year sequence in runs of 5 years or more—are calculated for all regions, scenarios and measures (runoff, flow, etc.), and together indicate the length of long dry runs.

16.2.3 Severity of Dry Runs

To indicate the severity of a dry run, we calculated the average reduction of the measure in a run of dry years. The average reductions in runoff for dry runs are plotted in Fig. 16.5 as percentages. The average reductions in runs of dry years of 5 years or more are taken to indicate the severity of long dry runs.

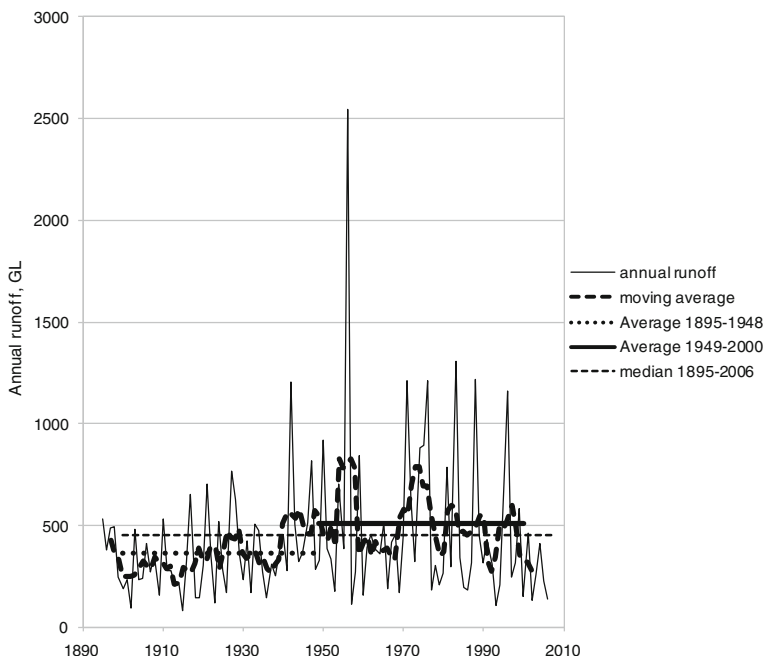


Fig. 16.4 Modeled dry extreme climate change runoff for the Condamine above Chinchilla weir (based on scaling the historic rainfall, and presented as if for the same years as the historic modeled period in Fig. 16.3). The median is the historic median (i.e., the same as in Fig. 16.3)

16.3 Past, Present and Projected Droughts in the Murray-Darling Basin

16.3.1 Historic and Projected Droughts: Length and Severity

Figure 16.6 shows the results for runoff. The top two charts show that:

- there is a general trend to lengthier long dry runs going from the Condamine in the north to the Goulburn in the south (that general trend is reversed in the Gwydir and the Murrumbidgee);
- long dry runs in dry extreme and median climate change projections are projected to be longer, more frequent or both than those in the historic scenario, strongly so in the case of dry extreme, and in all regions;
- the long dry runs in the wet extreme scenario are of the same length as those in the historic scenario for all regions (except in the Murrumbidgee); and
- the Murrumbidgee has no dry run of five or more years in the wet extreme scenario.

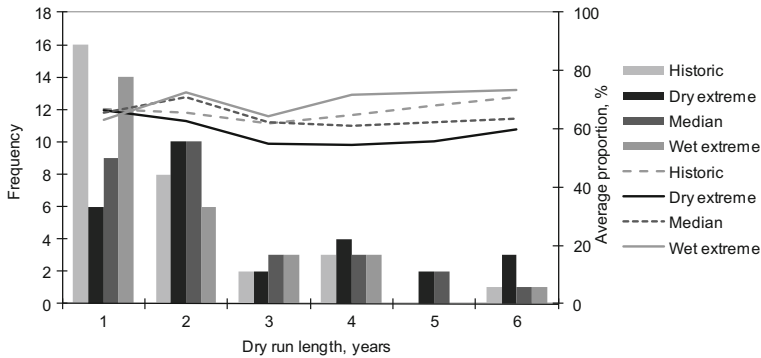


Fig. 16.5 Frequency of runs of dry years of different length, and average proportion of historical median (as a percentage) for each run of dry years, for runoff in the Condamine region

In terms of the severity, Fig. 16.5 shows the average reduction in modeled runoff was greatest for the dry extreme scenario, followed by the median projection and historic scenarios, and least for the wet extreme scenario. The average reduction in any scenario did not vary greatly with the length of the dry run.

The bottom part of Fig. 16.6 shows that, for runoff:

- there is no particular north–south trend in severity in the historic, median, or wet extreme climate change scenarios;
- the dry extreme scenario indicates more severe long dry runs in the south (with a reversal from the Gwydir to the Murrumbidgee);
- in the dry extreme and median climate change scenarios, long dry runs are more severe than the historic for all regions except the Gwydir; and
- the wet extreme projection long dry runs are less severe than the historic for all regions except the Goulburn.

This general pattern was repeated for dam storages, diversions and end of system flows (except that the general north–south trends of increasing length and severity are not reversed at Gwydir–Murrumbidgee for these measures). What differed with these other measures was the size of the average reduction (i.e., how much less water was stored, diverted or flowed, compared to the reductions in runoff).

Figure 16.7 shows the average reductions during long dry runs in storage, diversions and flows. Whereas modeled runoff was generally reduced to between about 50 and 75 % of the median historic value, storage was reduced to between about 35 and 70 %, and flows to between about 20 and 70 %. The reduction in modeled end-of-system flows is particularly pronounced in the Murray, Murrumbidgee, and Goulburn. Flows at the intermediate point on the Murray, at Wakool, were reduced to between about 60 and 70 %. Generally, then, the reduction in flows were greater than the reduction in storage, which in turn were greater than the reduction in runoff. van Dijk et al. (2008) showed this pronounced

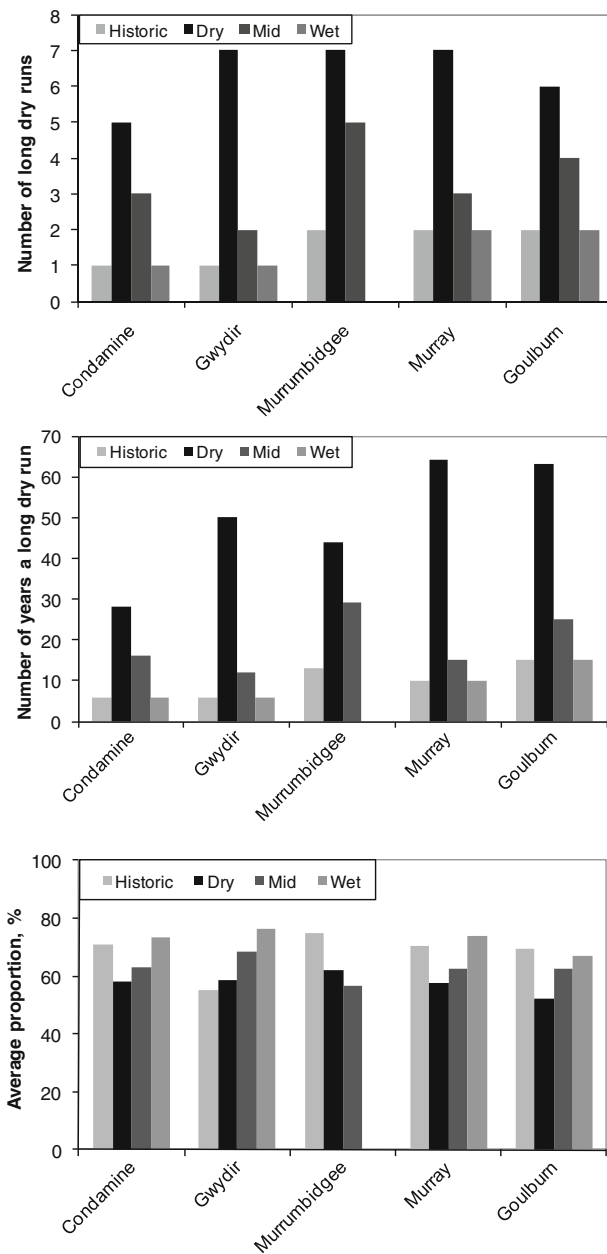


Fig. 16.6 Runoff in long dry runs: *top*—number of long dry runs; *middle*—total number of years in 111 in a long dry run; *bottom*—average proportion of the median historic value in long dry runs. A long dry run is a dry run of 5 years or more

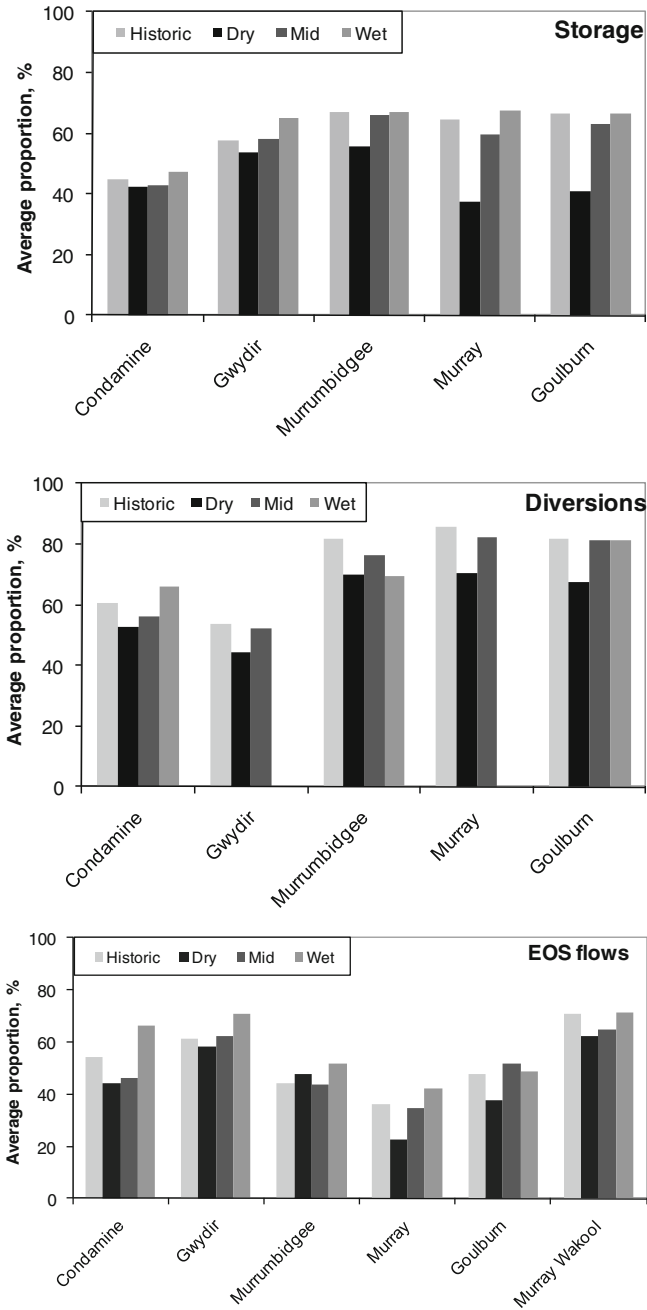


Fig. 16.7 Average proportion of the median historic value in long dry runs: *top*—storage; *middle*—diversions; *bottom*—end-of-system flows, plus the flow at Wakool, an intermediate point on the Murray

effect on flows and lesser effect on diversions for all of the regions in the Murray-Darling Basin for average (not drought) conditions in the MDBSY results. We discuss the reasons for this in the section “Rainfall, runoff, river flows and diversions” below.

The behavior of the modeled diversions differed, however, particularly in the south of the basin (Murrumbidgee, Murray, and Goulburn). The modeled reduction in diversions (using the assumption of current water-sharing rules) in these three regions was between about 70 and 85 % of the median, somewhat less than the reduction in runoff. This is consistent with a general finding of the Murray-Darling Basin Sustainable Yields study (reported for all years, not just drought years) (CSIRO 2008; Young and Chiew 2009), that the current rules of allocation and diversion shelter irrigation from the impacts of reductions in water availability.

16.3.2 The Recent Drought

The recent drought was the worst in the last 110 years (Timbal 2009), which is the period of high-quality records available for such comparisons.

A significant feature of the recent drought is the greater temperatures than those experienced in past droughts (Murphy and Timbal 2007), and the seasonal pattern of the reduced rainfall (Timbal 2009). In addition, inflows into the River Murray in the last 10 years have been about half the historic average (MDBA 2009, and Fig. 16.8), and those in 2006 were considerably less than the previous historic minimum. Inflows during the main inflow period from June to October were in 2006 less than 10 % of those in the long-term mean. Note that reduction in runoff for the worst single year of the recent drought is not comparable to the average reductions over a run of dry years shown in the bottom plot in Fig. 16.6.

Figure 16.9 shows the anomaly (departure from the long-term mean) in the annual mean temperature, averaged across the Murray-Darling Basin (Hennessy et al. 2008). The temperature anomaly (and therefore the actual mean temperatures) has risen over the last few decades, and is now about 1 °C greater than the long-term mean.

Figure 16.10 shows the mean monthly rainfall and runoff averaged over the southern Murray-Darling Basin (Potter et al. 2008) for 1895–2006, and for three 10-year dry periods. During the recent drought, the greatest reduction in rainfall was during the autumn and early winter, whereas the earlier dry periods had reduced rainfall spread more throughout the year (Fig. 16.10a). This has led in the recent drought to soils being less saturated, and subsurface water storage being lower, at the start of the winter. Consequently, the winter rain in the recent drought mostly just refilled the soil, with little being leftover for runoff. Since winter and early spring are the periods of greatest runoff (Fig. 16.10b), the reduction during these periods has a disproportionate effect. Thus, the recent drought has seen reductions in runoff greater than those in previous dry periods (Potter et al. 2008, and Fig. 16.10b). Potter and Chiew (2009) show that, for the Campaspe region in

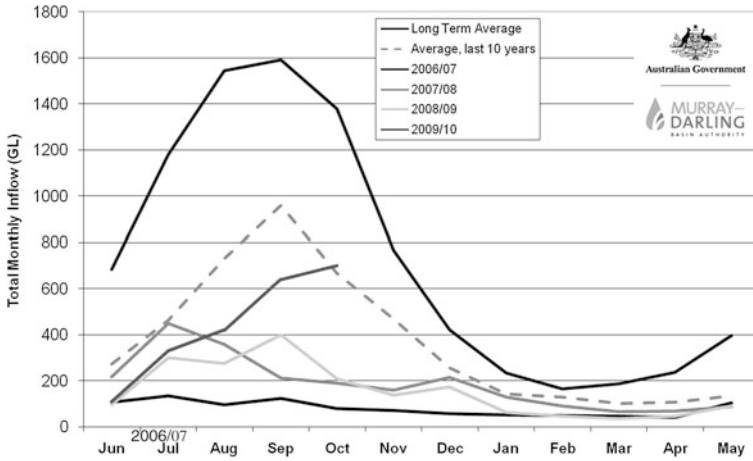


Fig. 16.8 Murray system inflows (excluding Snowy and Menindee inflows). *Source* MDBA (2009)

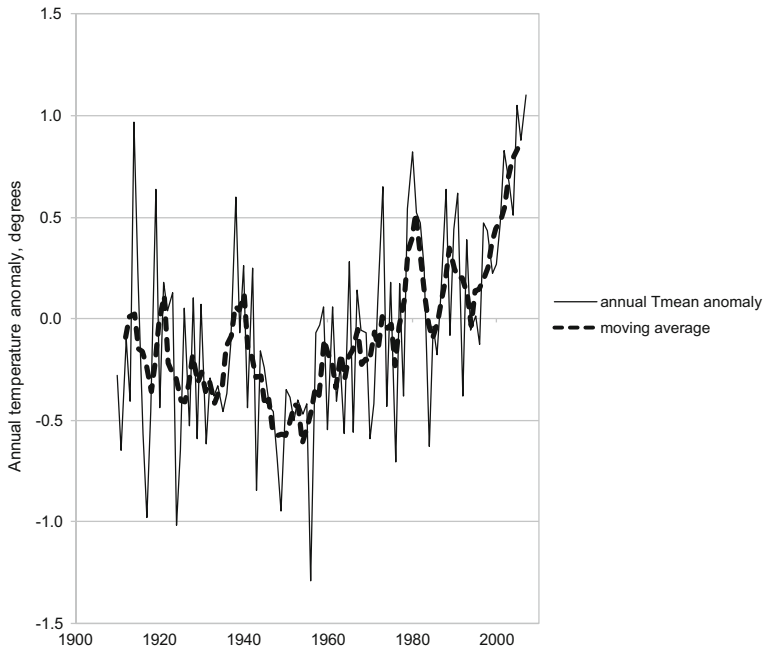


Fig. 16.9 Annual temperature anomaly (departure from the 1961–1990 mean) for the Murray-Darling Basin. *Source* Hennessy et al. (2008)

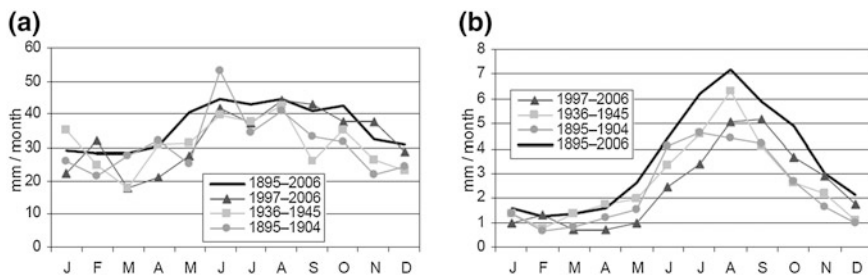


Fig. 16.10 **a** Monthly rainfall and **b** monthly runoff for the southern Murray-Darling Basin averaged across selected time periods. *Source* Potter et al. (2008)

the south of the Murray-Darling Basin, the reduction in runoff was caused primarily by the reduction in mean annual rainfall, followed by the changed seasonality and lack of high rainfall years in the past decade, then by the change in evapotranspiration (related to the elevated temperatures).

We made use above of the Murray-Darling Sustainable Yields project results of modeled runoff, storages, diversions, and flows, which were for the years up to 2006. We have modeled these results for the Murray alone up to 2009, to show the extreme nature of the recent drought (Fig. 16.11). All four measures drop in 2006 below the previous record low. We discuss this further in the next section.

Chiew et al. (2009) review evidence whether the current drought was associated with global warming, and conclude that it is not currently possible to separate a global warming signal from large, natural, long-term climate variability. Thus, the drought could be associated with a global warming, or a return to the conditions of the first half of the last century.

16.4 Rainfall, Runoff, River Flows, and Diversions

Decreased rainfall leads to decreased runoff, which in turn leads to decreased river flows. In Australia, in common with other arid and semi-arid environments, the decreases are amplified: the decline in runoff varies from 2 to 3.5 times the decline in rainfall (Chiew 2006).

Raupach et al. (2009) show that the average flow at the River Murray at Wentworth has, since 2002, been 23 % of its pre-2002 value. They conclude that this results mostly from a decline in the fraction of rainfall that becomes runoff (to 41 % of its earlier value), followed by a decline in the fraction of runoff that reaches the river gauge (i.e., an increase in fractional losses in the river system) (to 68 %), followed by a decline in the rainfall (to 81 %). We showed above, and in Figs. 16.6 (bottom) and 16.7 that the reduction in modeled flows was greater than that in runoff, consistent with the amplification noted by Raupach et al. (2009). The result is also consistent with the amplification factors given in van Dijk et al. (2008) for average conditions.

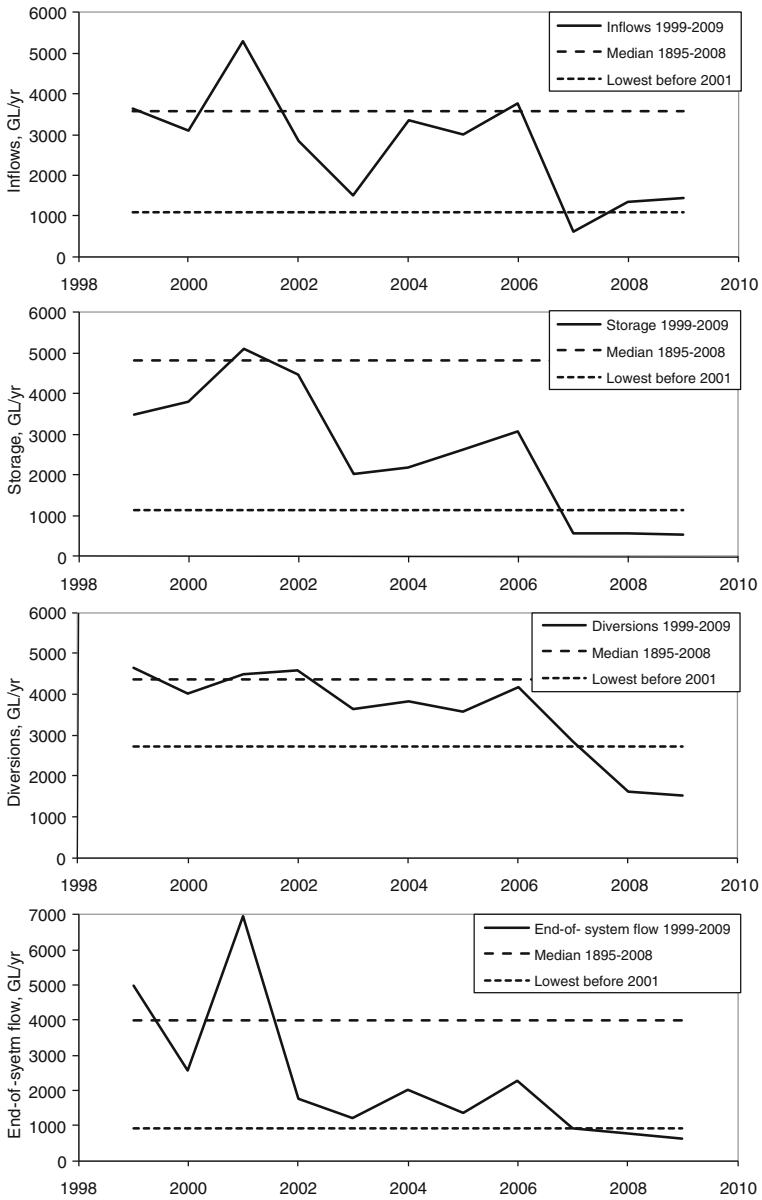


Fig. 16.11 Impact of the current drought on the River Murray: top, inflows to the Hume and Dartmouth reservoirs; middle top, storage volumes in the Hume and Dartmouth reservoirs; middle bottom, diversions; bottom, flows at the end of the system (Lock 1). The year is the year to the end of June—thus 2007 is the year July 2006 to June 2007

The amplification of rainfall declines into runoff declines are mostly a result of the hydrology of the situation—in drier landscapes and drier times, natural water storages (in the soil, the subsoil, wetlands, and so on) dry out more, so a greater proportion of the rain may be retained and become evapotranspiration, leaving less to runoff. The amplification of runoff declines to river flow is partly a result of the hydrology—in a flat, arid landscape, rivers lose water to evaporation and seepage—and partly a result of managed diversions.

The reductions in diversions in the south of the basin, in contrast, were less than the reductions in the runoff. This is solely a result of the current rules of water sharing, and the way the rules allocate water to irrigation. The impact of the water-sharing rules is also seen in Fig. 16.11. The irrigation diversions showed little response to the lower inflows in 2003, because the reservoir storage levels were adequate to maintain supplies; the end-of-system flows, however, dropped dramatically. The 3 years from July 2004 to June 2006 saw inflows approaching the long-term median (slightly above in 2005–2006), sufficient under the water-sharing rules to supply irrigation at near median levels, but insufficient to either refill the reservoirs or provide for flows (Fig. 16.11). Finally, the unprecedented dry year of 2006–2007 saw storage levels, diversions, and flows fall to considerably less than their previous minimums. Hayman and McCarthy (2010) describe how this led to the first “irrigation drought” for irrigators near the downstream end of the system.

16.5 Implications for Policy and Management

The experience of the recent drought, the knowledge of the long-term cycles of water availability over the last 110 years or so, and the projections for climate change, have serious implications for the future management of the rivers and irrigation of the Murray-Darling Basin. The over-riding conclusion is that current water management approaches are inadequate to deal with the high variability in water availability (Chiew et al. 2009). Neither the irrigation sector nor the environment can be sustained at desired levels in droughts as severe as the recent one or those that we may expect in the future. New water sharing arrangements are the subject of much debate at the time of writing.

The recent drought had features absent in previous droughts. It is possible that the dominant hydrological processes may have changed: the connections between surface water and subsurface stored water may have been lost, such that rainfall amounts that historically would have led to runoff appear now to lead to little or no runoff (Chiew et al. 2009). Milly et al. (2008) explored this issue in greater detail. Thus, policy and management are best developed for scenarios that describe a range of possible futures (Chiew et al. 2009), and should not rely solely on past experience.

Projected future dry runs are longer and more severe in the median and dry extreme scenarios than those in the historic record, so if these scenarios are realized in the future, it is likely that there will be future droughts **worse** than the

recent drought. A return to the drier conditions in the first half of last century, even in the absence of global climate change, would lead to long dry runs that are longer and more severe than those in the second half of last century. A combination of the drier conditions in the first half of last century with global climate change would lead to long dry runs that are very long and severe by historic standards. In the Goulburn region in particular, the situation would, by historic standards, be more or less a perpetual drought in the dry extreme scenario.

The projected increase in long dry runs affects the flows (and hence the prospects of maintaining river health and other flow-dependent environmental assets) and the storages and diversions. In the recent drought, there was insufficient water for either the environment or irrigation. This situation would be exacerbated under projected climate change. The situation would also be exacerbated should there be a return to the drier conditions in the first half of last century.

The current management rules for operating the river and allocating water favor irrigation over the environment (although this appears not to be the intent of various water acts). Changing this requires a change in management or ownership by an environmental agent of entitlements (which is envisaged under the Water for the Future plan; DEWHA 2009).

16.5.1 Options for Dealing with Drought: Some Hydrological Constraints

Looking to options to deal with droughts, we leave economic and policy considerations to the other chapters in this book. Here, we comment on some hydrological possibilities.

- Larger dams would be irrelevant in the projected longer and more severe long dry runs.
- Migration of irrigation downstream, if the current (slow) trend were to result in similar volumes of water being used as at present but further downstream, would overall leave irrigation vulnerable to projected longer and more severe long dry runs. This is because river losses are greater in dry years, as shown by the more severe declines in flows at the end of the River Murray than at Wakool (Fig. 16.7).
- Conversely, migration of irrigation upstream such that similar volumes of water were used as at present but further upstream (closer to water storages) would leave irrigation somewhat less vulnerable to projected longer and more severe long dry runs. This is because river losses are less at upstream locations, and also because rainfall is higher so less irrigation is required (for a given crop, soil, etc.). However, this would also leave less water in the river for flows downstream. In any event, other factors (primarily economic) are driving irrigation

downstream. Any provision of water to downstream environmental assets would also mean there is little to gain under this strategy.

- Improving irrigation canals to minimize leaks and improve conveyance efficiency (one strategy under the Water for the Future plan, DEWHA 2009) is appealing, but is not equally effective under all circumstances. The leaks all go somewhere. There is little gain from stopping a leak that returns water to the river or some other use, although there are gains from stopping leaks to saline or otherwise unusable groundwater, and from reducing evaporation. Qureshi et al. (2009) show that return flows significantly diminish the economic benefit of infrastructure improvement.
- Purchasing access entitlements may be more effective (Productivity Commission 2009; Qureshi et al. 2009), and are most effective when they take account of where the water is required (Mainuddin et al. 2007). This is because losses of water from the river (through seepage or evaporation) can render an acquisition less effective than another, seemingly more expensive, purchase. As discussed by Mainuddin et al. (2007), acquisition strategies sometimes leave this factor out.
- Improving irrigation efficiency, such as changing from flood to drip irrigation, can lead to greater irrigation productivity from less water. However, it may also diminish return flows, leading again to the problem noted above of diminished water to the river and diminished benefit (Qureshi et al. 2009).
- There may be opportunities to manage environmental water more effectively to achieve multiple targets. Thus, an environmental flow might be used to both water some flood-dependent wetlands and reduce salinity in a sensitive stretch of the river.

16.6 Conclusions

The recent drought exposed the inadequacy of our water policy and management: current arrangements cannot deliver water to both irrigation and the environment at desired levels in droughts like the recent one. We cannot return water to the environment and keep irrigation going in its current form. New water sharing arrangements are the subject of much debate at the time of writing.

The recent drought was in some ways comparable to extreme droughts in the past, but also contains some features that suggest, but do not prove, that climate change may be influencing southeastern Australia. More importantly, these features show that past droughts do not provide a sufficient guide to future management: a range of scenarios including climate change scenarios must be considered.

Policy and management should be prepared to cope with future droughts more severe than that which we recently experienced. Climate change projections are uncertain, and climate variability will no doubt result in wet and dry periods, but such preparations are prudent and will leave us able to cope with whatever the future holds.

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