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Water – where, when, how much? Challenges in understanding and managing flow in rivers of the Lake Eyre Basin

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Introduction

The floods and zero flow periods of the unregulated rivers of the Lake Eyre Basin drive spectacular booms and busts in ecosystem responses (Kingsford *et al.* 1999; Puckridge *et al.* 2000). In addition to their renowned environmental value, the rivers are central to the economy of the arid zone, sustaining pastoralism (see Chapters 10 and 11) and tourism (see Chapter 13), and their flow patterns affect the infrastructure of important energy industries (oil, gas and geothermal). While the rivers are unregulated and currently experience only minor water resource use (see Chapter 20), they are experiencing constantly changing pressures on land use and increasing demands on water resources, particularly from expanding energy industries (Kingsford *et al.* 2014; see Chapter 19).

Arid zone river systems are significantly challenging for describing the basics of flow – where, when and how much? Traditionally, hydrological analysis occurs when there is either a potential for substantially changing the river for human use, such as building a dam, or for managing a river where there are already significant diversions for human use. It could be argued that detailed observations of flows and construction of complex hydrological models are not warranted for Lake Eyre Basin rivers, but this ignores the ever-present management challenges. Natural resource managers need to be able to identify changes in the flow regime of these rivers from stressors, including water extraction, floodplain modifications and climate change. Hydrological models are essential for estimating how proposed changes may affect the rivers and their biota. Therefore, monitoring of flows and flooding patterns in these rivers is not an academic exercise – both are central to the sustainable management of Lake Eyre Basin rivers.

Current state of monitoring

One of the major challenges for the management of the water resources of the Lake Eyre Basin is the paucity of conventional hydrological data. The Lake Eyre Basin is a similar size to the Murray–Darling Basin, both just over 1 million km^2, but there are only 13 gauging stations (Fig. 2.1) in the Lake Eyre Basin, with records of more than 15 years of data compared to more than 160 gauges in the Murray–Darling Basin (Kennard *et al.* 2010). The number of gauging stations shrank in the 1990s in the Lake Eyre Basin (see Table 2.1), but there has been a recent resurgence due to increased investment by the Bureau of Meteorology and the Queensland and South Australian governments, and some industry monitoring (e.g. Santos

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Fig. 2.1. Cullymurra waterhole in South Australia, near Innamincka, is the site of one of only 13 river gauges in a river of ~1300 km (photo, R.T. Kingsford).

Limited). This scarcity of monitoring data makes understanding the hydrology of these complex rivers extremely difficult. And yet major decisions that depend on this understanding and being able to determine the impacts of flow regime changes on downstream landholders and the environment need to be made about the future of these rivers.

Where – spatial variability

Spatial variability is a major feature of Lake Eyre Basin river flows. Rainfall, run-off and river flow vary considerably across the Lake Eyre Basin (McMahon *et al.* 2008a; McMahon *et al.* 2008b). Measurement of the most important input into any hydrological model, rainfall, is also particularly difficult, given the relatively few rain gauges in the Lake Eyre Basin (McMahon *et al.* 2008a). This contributes to the uncertainties of measuring the flow in Lake Eyre Basin rivers, an important area for research. Added to this, the complex flow paths and channel networks on the large, spectacular floodplains of the major Lake Eyre Basin rivers are confronting to monitor and model. The few gauging stations (Table 2.1) are naturally where flow convergence most efficiently measures flow volumes. But we have little information about what is happening to flow between these monitoring points, often hundreds of kilometres apart.

In the magnificent Channel Country of Cooper Creek, between the junction of the Thomson and Barcoo Rivers and South Australia, flow can follow incredibly complex, anastomosing channels and floodplain paths, as it slowly moves downstream (Fig. 2.2). The

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Table 2.1. Changes in the number of stations in state government gauging station networks in major catchments of the Lake Eyre Basin during different periods.

Unrated and non-telemetered water level logger sites installed since 2000 as part of research projects or the Lake Eyre Basin Rivers Assessment (LEBRA) monitoring project were not included.

Catchment	Pre-1966	1966–1990	1990–2010	Post 2010
Cooper	5 (3[a])	11	9	13 (4[a])
Diamantina	1	2	1	4 (1[a])
Georgina	0	4	0	2
Finke	0	8 (5[a])	8 (5[a])	3
Macumba	0	0	0	1[a]
Neales	0	0	0	2[a]

[a] gauging stations with no rating curve (only flow levels monitored and not discharge).

hydrology and geomorphology of this reach are reasonably well known after 20 years of research, which shows that small flows follow channelised pathways and experience low 'transmission losses', compared to the medium to large floods, which cover more of the floodplain and hence experience higher proportional losses (Knighton and Nanson 1994; Knighton and Nanson 2001; McMahon *et al.* 2008a). A 'transmission loss' means the water doesn't progress further downstream, but in fact it is not a loss at all because the water is critically important to the spectacular ecology of the floodplain and landholders who graze

Fig. 2.2. During floods Cooper Creek breaks out of its major channels and spreads out along complex flow paths across the floodplain (photo, R. T. Kingsford).

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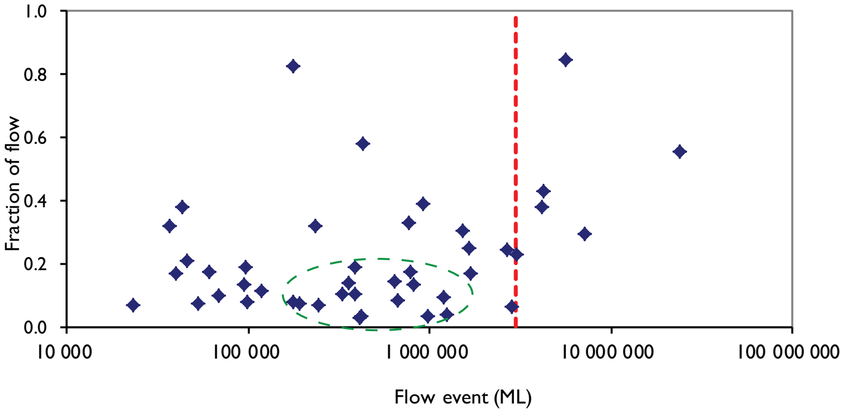

Fig. 2.3. Fraction of flow in the Channel Country of Cooper Creek reaching the border of South Australia (measured at the Nappa Merrie gauge), relative to total flood event volume (log scale) measured at the Currareva gauge (near Windorah). Daily flow data supplied by the Queensland Department of Natural Resources and Mines (1950–88). The dashed oval shows the medium volume floods that experience some of the highest relative volume reductions in this reach.

their livestock on these highly productive floodplains (see Chapters 10 and 11). These 'transmission losses' can be huge. For instance, for some medium-volume floods which return every one to three years, 90–95% of the volume that passes the town of Windorah does not flow into South Australia (see the circled flood data in Fig. 2.3). This water evaporates, infiltrates the channel (where it can recharge groundwater; Cendón *et al.* 2010) and the floodplain, or lies on the floodplains (Knighton and Nanson 1994), where it fuels an ecological boom cycle (see Chapter 1). Understanding the fate of this floodwater is challenging. Adding to the complexity of estimating transmission losses is accounting for inflows to the reach from rainfall and tributary flow. Some flood events may be entirely composed of run-off generated in the Thomson and Barcoo catchments while others (e.g. those with flow fractions greater than 0.3 in Fig. 2.3) can receive substantial contributions from local rainfall and run-off in the Channel Country (Fig. 2.4).

The composition of floodwaters flowing into South Australia shows relatively little change to that measured at Windorah (Larsen 2012), indicating that some flow channels are very efficient in transporting water downstream (i.e. without much evaporative loss and concentration of the ionic composition) while others move water onto the floodplain. This suggests that most of the water loss measured at the downstream gauging station is due to pooling of water on the floodplain or wetlands (i.e. no longer connecting with downstream flow). This water then evaporates, infiltrates the sediment of the floodplain where it supplies plant transpiration, or recharges groundwater (Cendón *et al.* 2010). Surprisingly, the actual channels that convey flow during flood events of different magnitudes have never been accurately mapped nor their different functions identified. This is an important knowledge gap and a focus for our research (e.g. Mohammadi *et al.* 2017) because, for instance, if there was irrigation extraction from an efficient pathway, there would be a much greater downstream effect (in terms of flow reaching South

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Fig. 2.4. Local storms in the Lake Eyre Basin make a contribution to the flow of the rivers in the Lake Eyre Basin into waterholes, floodplains and lakes (photo, A. Emmott).

Australia) than the same volume and rate of extraction from a pathway which predominantly supplied the floodplain, where the impact would be predominantly on the ecosystem and landholders, depending on the floodplain.

A second example of spatial variability is in South Australia, where the Cooper changes from an anastomosing channel system to a distributary channel system. Here, the Cooper splits into three distinct flow paths: Strzelecki Creek (only receiving flow from Cooper Creek during very large floods), the Main Branch (with two subsequent branches) and the North-west Branch (Fig. 2.5). The latter flow path supplies the iconic, Ramsar-listed Coongie Lakes (Fig. 2.6). To estimate how changes in the flow regime would affect inflows to Coongie Lakes, we need to know the thresholds and how much water flows down each of the flow paths for the range of different events. During April 2012, the flood pulse from Queensland (see Fig. 2.7) had approximately an annual recurrence interval and the North-west Branch received 53% of the channel flow while the rest (47%) went down the two channels that form the Main Branch. However, a flow double this volume in 2011 pushed a higher percentage of flow down one of the Main Branch channels (see Fig. 2.5): 34% compared to 20% of the flow in 2012. Flood conditions prevented the other Main Branch channel and the North-west Branch channel from being measured in 2011. Clearly, the percentage of flows down the different channels varies with the volume of the flow, but this is difficult to determine even in a medium volume flood, requiring substantial effort to collect such critical data in this remote and challenging environment. Unless these changes in the percentages in

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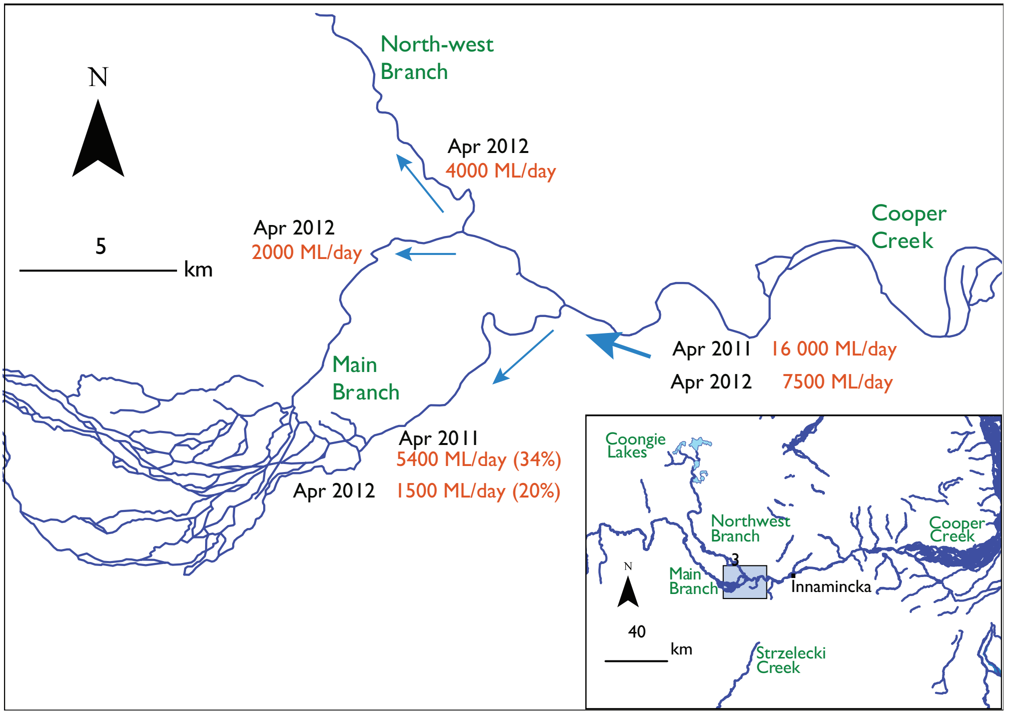

Fig. 2.5. Changes in flow volume in 2011 and 2012 at the split in Cooper Creek between the North-west Branch (flowing towards Coongie Lakes) and the two channels of the Main Branch (flowing towards Lake Eyre). The inset figure shows the lower Cooper where it changes from an anastomosing channel system to a distributary system downstream of Innamincka. The shaded rectangle in the inset figure shows the location of the North-west Branch and Main Branch split.

flow between the major flow paths of the lower Cooper are known, we will be unable to represent this behaviour in a hydrological model.

When – temporal variability

In addition to the spectacular spatial variability of the Lake Eyre Basin rivers, their flows rank highest among the most temporally variable large rivers of the world (Puckridge *et al.* 1998; McMahon *et al.* 2008b). In particular, this high variability in flows between years (interannual variability) drives the boom–bust ecological response to flow events. Very large floods (e.g. those in 2010) inundated greater than 10 000 km^2, but this shrinks in relatively dry years (e.g. 2013), with more than an order of magnitude lesser flow volume (Fig. 2.7).

For many parts of Lake Eyre Basin, we have no records of when rivers flowed. There is improvement with expansion of the monitoring network (Table 2.1), but the available records are short, relative to the high interannual variability of these rivers. For instance, monitoring of flows in the 34 000 km^2 catchment of the Neales River (western Lake Eyre Basin) from March 2000 to November 2009 identified an average of 2.5 flows per year, with one or two flows in any one reach of the river. However, there were another 22 flows between November 2009 and April 2011, coinciding with a La Niña episode (Fig. 2.8a). This increased the average

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Fig. 2.6. The spectacular Coongie Lakes, an internationally important wetland, are supplied by the North-west Branch of Cooper Creek and support high biodiversity, particularly during dry periods when fish and waterbirds congregate (photo, R. T. Kingsford).

number of flow events to 4.2 events for the period 2000–2011. Observed flow events in the Neales River, for 2000–09, were significantly higher than for modelled flows during the pre-2000 period (Fig. 2.8b; see also Costelloe *et al.* 2005), emphasising the necessity for multi-

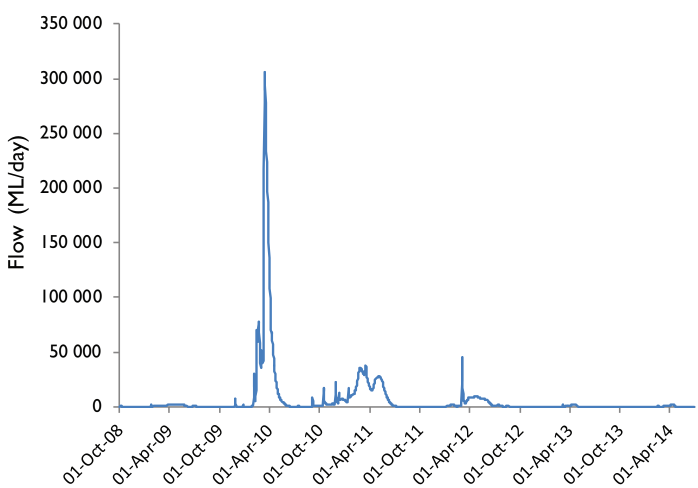

Fig. 2.7. The interannual variability of Cooper Creek is illustrated using daily flow data from Cullyamurra gauging station, near Innamincka (South Australian Department for Environment, Water and Natural Resources, Fig. 2.1), 2009–13. Note the small volume of the 2009, 2013 and 2014 floods compared to the period 2010 to 2012.

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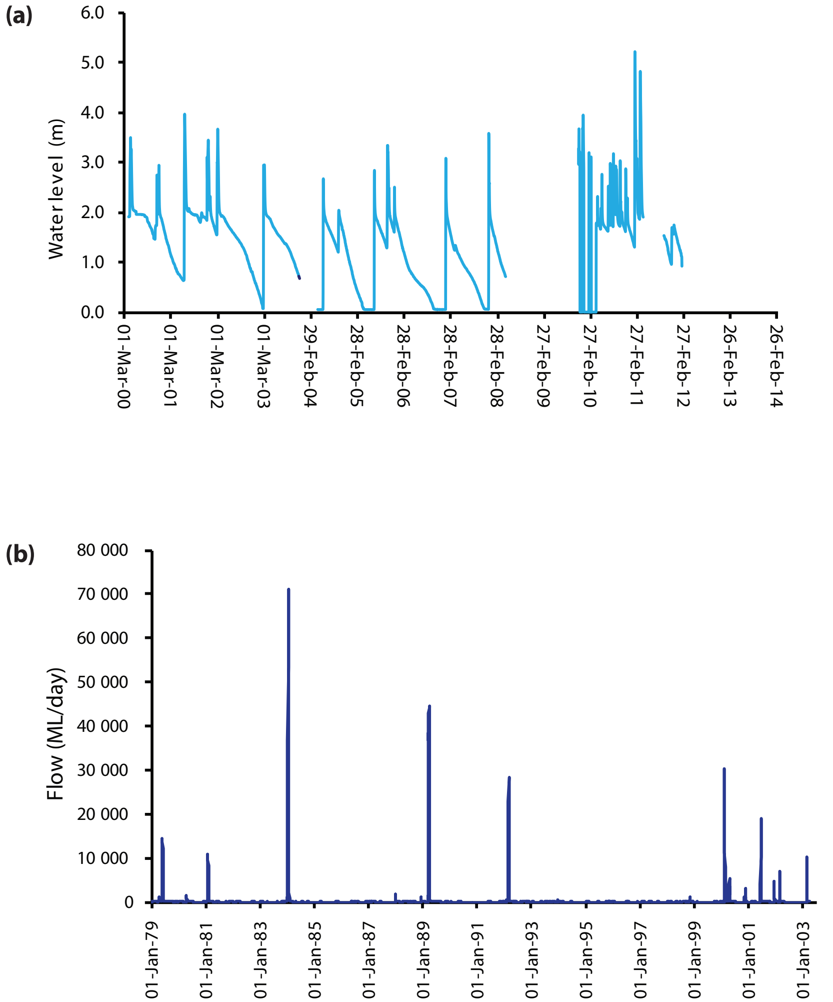

Fig. 2.8. Algebuckina Waterhole on the Neales River showing (a) observed water level with increased frequency of flows, 2009–2011 and (b) modelled daily flow (Costelloe *et al.* 2005), illustrating that the period of observed data (post-1999) had more frequent flow events than the preceding 20 year period.

decadal records before temporal variability can be quantified. We need to have knowledge of flow variability for infrastructure development adjacent to the river or its tributaries. This information can be generated by developing rainfall run-off models, but without observed flow data to calibrate or evaluate the model, there will be a large degree of uncertainty in the results. The consequences of inaccurate estimation of flood frequencies can affect estimates of impacts on ecosystems, ecosystem services and infrastructure (e.g. roads).

The high interannual flow variability of Lake Eyre Basin rivers has implications for extraction of water from the rivers. Variability in magnitude and timing means that water extraction would be relatively unreliable for agricultural or mining requirements using flow-based thresholds. For example, current extraction rules for inactive irrigation licences in the

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Windorah–Nappa Merrie reach of Cooper Creek require that the river has a minimum flow of 3220 ML per day before extraction can occur, with a maximum extraction allowed of 120 ML per day without a storage. This means that no water could be extracted in the driest 10–20% of years of the flow record at the Currareva gauge. These extraction rules minimise the effects of potential water extraction. However, once established an operation could lobby for increased access to reliable, rather than opportunistic, water extraction.

How much – future requirements of monitoring and modelling for the Lake Eyre Basin

The rivers of the Lake Eyre Basin experience water extraction volumes that are very low (see Chapter 20), compared to the far more heavily regulated rivers of the neighbouring Murray–Darling Basin (Kingsford 2000). In the Murray–Darling Basin, Commonwealth and state governments are spending more than $13 billion on water management and environmental flows to redress historical over-allocation of water resources (Murray–Darling Basin Authority 2012). The overriding management paradigm in the Murray–Darling Basin is to identify and provide the minimum amount of environmental water, and appropriate temporal patterns of flow, that will maintain acceptable levels of ecological health for the rivers. In contrast, essentially all of the river flow in the Lake Eyre Basin rivers is needed to support its natural patterns of boom and bust and the current good state of ecological health (Leigh *et al.* 2010). Therefore, the management paradigm in the Lake Eyre Basin should determine how any development (and associated change in flow regime) will affect the present ecological health of the rivers (see Chapter 22), and use this understanding to guide acceptable levels of extraction or changes to flow patterns, rather than aiming to define minimum environmental flow requirements.

Conclusion

The 'where' and the 'when' issues for rainfall and flow illustrate the complexities and challenges in determining a sound response to the 'how much water?' question for the rivers of the Lake Eyre Basin. The most difficult aspect of 'how much?' lies in answering the question of 'how much effect would water extraction, or infrastructure development that changes flow patterns, have on the flow regime and ecology of downstream ecosystems?' This is particularly hard to answer because of the difficulty in identifying hydrological and ecological change in this highly variable system with short and incomplete flow records. Changes are likely to have the most effect on the smaller flow events, depending on extraction rules or placement of pumps, weirs and dams. For this reason, modelling of the large Lake Eyre Basin rivers must include the capacity to accurately simulate small flow events, rather than concentrating on simulating mean or large flow events. It is not acceptable to make broad policy and management decisions based on insufficient modelling, given the potential long-term consequences. Modelling of small flow events requires more emphasis on which flow paths are activated, and the relationship between flow volume and how much water is required by floodplains. Modelling flows in the small rivers of the Lake Eyre Basin must also address acceptable accuracy when simulating smaller flows. Here, the challenge is not so much the spatial variability of flow paths, as

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typically these smaller rivers have simple channel systems, but whether the rainfall data can capture the spatial variability of rainfall patterns. For instance, is the rainfall station network capable of accurately measuring rainfall from isolated thunderstorms (Fig. 2.4) in comparison to widespread rainfall from fronts or larger tropical weather systems?

The Lake Eyre Basin presents considerable, but not insurmountable, challenges to hydrological modelling. Despite the lack of extensive monitoring infrastructure, we can make targeted use of satellite data to improve our capacity to model the flow regimes of these rivers with improved accuracy and predictive power. For instance, rigorous mapping of flood patterns across a range of flood volumes, using existing satellite systems, can be combined with the new generation of digital elevation data (e.g. Karim *et al.* 2012; Mohammadi *et al.* 2017). This approach would allow the gathering of important information on flow paths that occur between the gauging stations. We can also add value to the increased government and private industry investment in flow-monitoring stations of the past few years. A commitment to gathering discharge (i.e. river flow) data at these newly monitored locations would greatly contribute to the capacity of hydrological models to manage these rivers by allowing the quantitative estimation of flow into different parts of the river systems.

A combination of a long-term commitment to data gathering and targeted research will greatly increase our capacity to confidently analyse or model the effects of changing flow regimes on the magnificent arid-zone rivers of the Lake Eyre Basin and their dependent ecosystems and ecosystem services. While we move towards steadily improving our hydrological understanding of the system, we need to be mindful of current limitations when assessing the effects of water resource use and floodplain infrastructure developments. Our capacity to monitor or model changes to the smaller volume flow events is prone to considerable uncertainty and hence our confidence in analysing the effect of flow regime changes on particular assets is presently poor.

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