

## Chapter 1 Introduction

### *Contributing Authors:*

Jim Puckridge, Justin Costelloe, Janet Pritchard, Julian Reid, Peter Hudson

### **1.1 Aims and objectives**

Increased demand for water resources is resulting in attention being directed towards the unregulated rivers of the arid zone (cf. the “Currareva” proposal (Hawkins et al. 1995), the “Farmhand” scheme (2002). The intermittent rivers of the Lake Eyre Basin (LEB) are unregulated, have highly variable flow regimes and retain high levels of ecological health. Improved understanding of the ecological functioning of these rivers is critical as land and water resource managers seek to balance the environmental needs of the rivers with current and future demands on their water resources. However, little is known of the basic biology and hydrology, let alone the hydrology-ecology relationships operating in these rivers, although spectacular booms and busts of fish (Puckridge et al. 2000) and waterbirds (Kingsford 1995; Kingsford et al. 19499) have been observed during major flood cycles.

Understanding the ecosystem processes at work in the rivers of the LEB is a particularly challenging task due to the inherent complexity of biology-hydrology relations (cf. Puckridge et al. 1999) and the extreme seasonal, interannual and interdecadal variability of the flow regimes of arid zone rivers (Puckridge et al. 1998).

The ARIDFLO project was instigated to help provide this understanding. ARIDFLO is a collaborative project between the University of Adelaide, the University of Melbourne, CSIRO Division of Sustainable Ecosystems, the CRC for Freshwater Ecology, the CRC for Catchment Hydrology, the South Australian Department of Water, Land and Biodiversity Conservation, the Queensland Environmental Protection Agency/Parks and Wildlife Service and the Queensland Department of Natural Resources and Mines. The project has been funded through the Natural Heritage Trust as part of the Environmental Flows Initiative of Environment Australia.

The objectives of ARIDFLO are to:

- Develop a method using satellite imagery, rainfall, geomorphology and discharge data to model the hydrologic regimes of poorly gauged and ungauged arid zone rivers (IMAGHYD);
- Using existing data and the DRY/WET model (Puckridge et al. 1999), predict environmental responses to flows in the Cooper, Diamantina and Neales-Peake river systems;
- Evaluate predicted environmental responses against data collected;
- Establish the basis for an environmental monitoring program on the LEB Rivers;
- Develop a generic model of relationships between flow regime, ecological processes and biodiversity for Australian arid zone rivers (ARIDFLO).

## **1.2 Approaches**

To obtain hydrological information for the ungauged and sparsely gauged rivers of the LEB, the ARIDFLO project has developed a hydrological model (IMAGHYD). IMAGHYD is a modelling approach that divides the modelled reach into a grid and moves both rainfall and streamflow from cell to cell to allow for the prediction of patterns of floodplain inundation and hydrological data for any cell within a given reach. Each grid cell has an area of 0.05 by 0.05 degrees (approximately 5km\*5km). To ensure historically realistic output for these grid cells, the predictions from IMAGHYD models are constrained and calibrated against four different sources of data. The principal data source used in this calibration process was gauging station data but other non-traditional data sources of satellite imagery; geomorphological data and local landowner's records were also employed.

In concert with the development of IMAGHYD, biological data from the same river reaches and over a wide range of biotic groups were collected (algae, zooplankton, macroinvertebrates, fish, waterbirds, littoral vegetation). The patterns of river flow described by IMAGHYD were then related to biological processes (such as algal, zooplankton and macroinvertebrate blooms, waterbird breeding, fish breeding and colonization) using a range of analytic and modelling techniques. This approach builds on the DRY/WET model (Puckridge et al. 1999), which related hydrological patterns in the lower Cooper to biological responses in the Coongie Lakes wetlands. However it tests the predictions of the DRY/WET model over a much larger geographic area, over a greater range of biotic assemblages, and using a greater range of modelling techniques. It also extends the range of biology-hydrology relations studied, and adds studies of interactions between biotic groups and of biological responses to waterbody geomorphology. From these results and in collaboration with pastoralists, industry representatives, interest groups, water resource managers and other wetlands experts, the project team developed a general model (ARIDFLO) of environmental responses to flow for Australian arid zone rivers over several temporal and spatial scales, and a number of qualitative modelling tools for determining these responses.

ARIDFLO therefore will allow qualitative prediction of the impacts that upstream water resource proposals are likely to have on fundamental ecosystem processes. It will also be useful in the management and monitoring of existing water use projects in the arid zone, and in the restoration of arid zone rivers already affected by water resource use. In addition, the project critically evaluates the suitability in such highly variable river systems of various approaches to the quantitative modelling of biological responses to hydrological change.

ARIDFLO placed a strong emphasis on community consultation in the development of the aims, methodology and results of the project. In addition, hydrological and biological observations by the local community were incorporated into the ARIDFLO analysis. An ARIDFLO report aimed at the general community is also being produced in hard copy and CDROM for general public release.

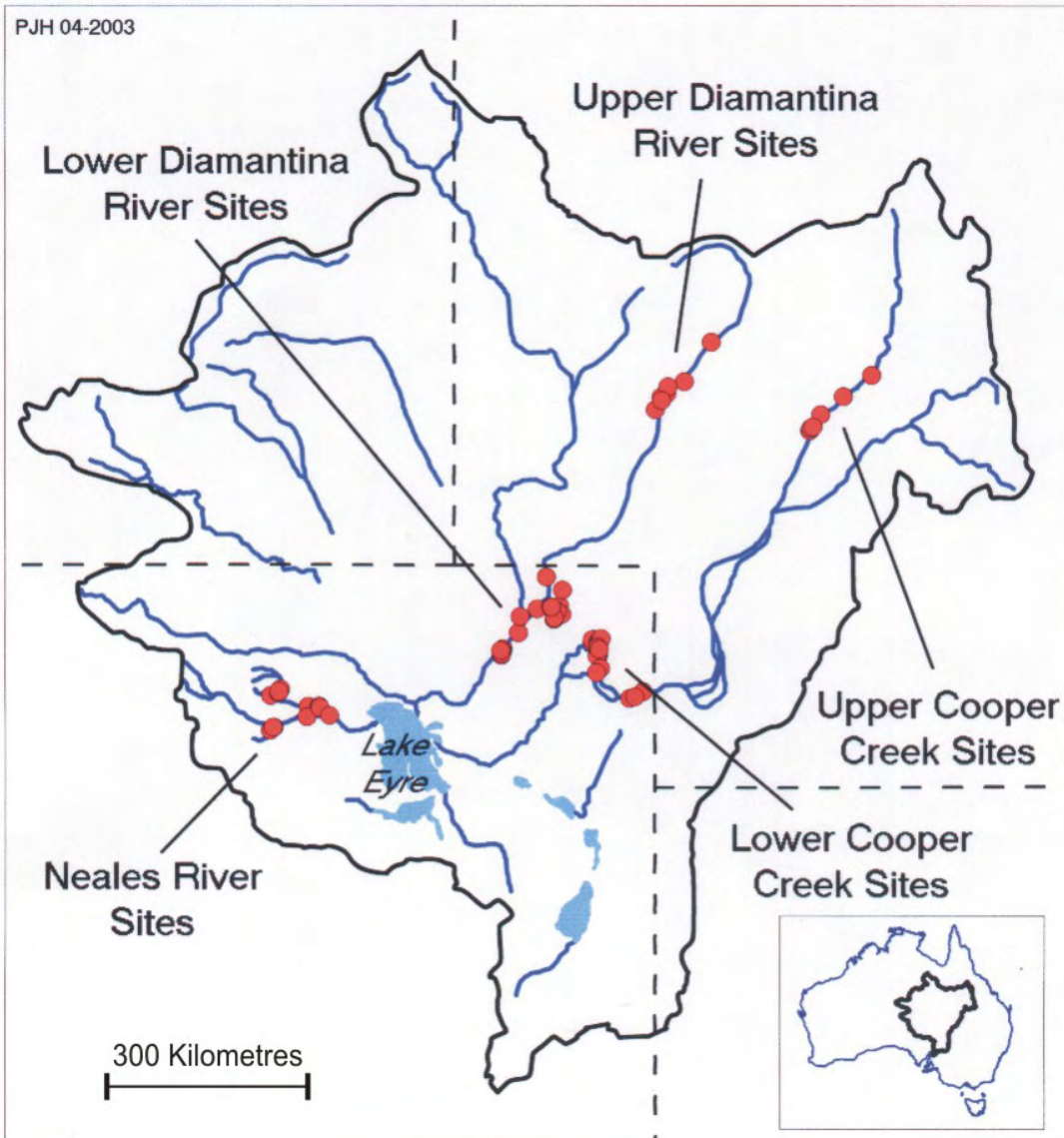
## **1.3 Scope**

### **1.3.1 Spatial**

The Lake Eyre Basin (LEB) has an area of 1,140,000 km<sup>2</sup> (Kotwicki 1986), is similar in size to the Murray-Darling Basin (MDB), and includes large iconic river systems such as Cooper Creek (catchment area 306,000 km<sup>2</sup>, river length 1500 km) and the Diamantina River (catchment area 160,000 km<sup>2</sup>, river length 1000 km). To encompass the spatial diversity of the LEB rivers, samples were collected from five reaches distributed over three river systems. The three river systems chosen were Cooper Creek, Diamantina River and the Neales River (Figure 1-1).

The Cooper Creek and Diamantina River sampling was further stratified into downstream and upstream reaches (Coongie Lakes and the Thomson River on Cooper Creek, Goyder Lagoon and Diamantina Lakes on the Diamantina River). The Neales River, a smaller ungauged river (length 430km, catchment area 35,000 km<sup>2</sup>) from the western LEB was also sampled. This spatial sampling structure allows for comparisons between upstream and downstream reaches within a river catchment, between catchments and also between major river systems and smaller systems. The inclusion of the Neales River also allows for the methodology to be tested on an ungauged river system with no previously recorded hydrological data, a common situation for many Australian arid zone rivers.

Within each of the river reaches (Figs 1-1, 2-1) between 6 and 12 waterbodies were sampled (including lake, swamp, main channel, subsidiary channels and floodplain waterbody types) and within each waterbody, replicate samples for each biotic community group were collected (Table 2-1). Over the course of the project, 56 different waterbodies were sampled. However the number of waterbodies sampled per reach and per trip, and the number of replicates taken per waterbody varied with hydrological conditions, waterbody size, habitat complexity and the biotic group sampled.



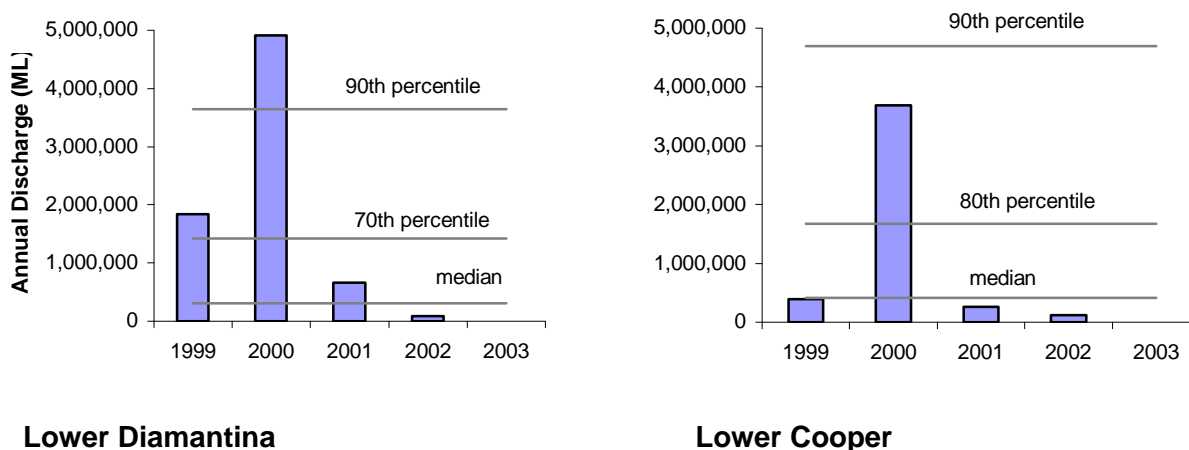
**Figure 1-1 ARIDFLO Sampling Sites**

The five river reaches sampled by ARIDFLO project contain 56 different waterbodies. See Fig. 2-1 for detailed location maps.

### 1.3.2 Temporal

The sampling design called for three samples per year, preferably evenly spread across the year in late spring, late summer and during winter. This within-year replication was proposed for two reasons: firstly, to give a better than interannual temporal resolution to track biotic community response to hydrological events, and, secondly, to enable partitioning of biotic community variation into separate seasonal and hydrological components. However, due to a delay in the decision to provide a third year of funding, the winter sampling in 2001 was omitted. Replication was therefore not possible for all seasons, but the project did encompass 2 early summer and 4 late summer sampling events. The timing of the field trips was April 2000, August 2000, December 2000, April 2001, November 2001, April 2002, and February 2003.

The project spanned three and a half years, from 01/01/2000 to 30/06/2003, and so included part or all of four separate flood seasons (December to April) and a major drought (2002-2003). The study was fortunate to sample during major floods in 2000 (all reaches) and in 2001 (lower Diamantina only) and in low flow years 2002-2003 (Figure 1-2). Each field sampling (which included consultation with landowners in the field) took approximately one month.



**Figure 1-2. Annual discharges for Lower Diamantina and Lower Cooper reaches**

*These annual discharges demonstrate the wide range of flood conditions that occurred during and immediately before (1999 flood year) the ARIDFLO project. Also displayed are various percentiles of annual flow for the two reaches calculated from the gauging station record (29 years for lower Cooper and 35 years for lower Diamantina). Note that no flow was recorded at either gauging station for the 2003 flood year, up to February 2003.*

### 1.3.3 Biotic

The ARIDFLO project is unique in achieving near-simultaneous sampling of all the major elements of the aquatic food web in the LEB. These elements included: riparian and littoral vegetation, aquatic algae, zooplankton and littoral microfauna, macroinvertebrates, fish, and waterbirds. The range of biotic assemblages sampled and measured by the ARIDFLO project is discussed further in Section 2.2.3.

### 1.3.4 Hydrologic and geomorphic

A large range of predictor variables was derived from the hydrological modelling and field collection of data. These were used in the analyses of biological responses to hydrological events. The predictor variables described aspects of the recent flow history (up to three years prior to the sampling date) and the long-term flow regime of the waterbody. Geomorphological variables describing the waterbody and its position in the catchment were also derived for each waterbody. Some examples of the variables are provided in Table 1-1 and more detailed descriptions of the variables are contained in Chapter 2 of the report.

**Table 1-1. Groups of hydrological and geomorphological predictive variables used in hydrology-biology modelling**

TYPE	PARAMETER EXAMPLES
Flow duration	Duration of previous three flows (days), duration of cessation of flow (days).
Magnitude of pulse	Peak daily volume of flow pulse (ML/day), total volume of flow pulse (ML).
Pulse timing	Timing relative to mean peak timing ( $\pm$ months), time since last peak flow (days).
Depth variations	Last max and min depths (m), present standard depth (m) of waterbodies.
Monthly to annual discharge	Flow volume for preceding 1-12 months and 1-3 years (ML).
Waterbody geomorphology	Cease-to-flow depth (m), bankful depth:width ratio.
Physico-chemical	Conductivity (EC), temperature ( $^{\circ}$ C), Secchi depth (cm).

## **1.4 Previous work in the Lake Eyre Basin**

### **1.4.1 Hydrological**

The rivers of the LEB are characterised by a general paucity of data on streamflow and water quality. Cooper Creek is the best served of the major river systems and has eight operating (including three re-established in 1999) and six inoperative gauging stations. The Diamantina River has only one operating and two inoperative gauging stations (one of these only measured stage data), while the Georgina River has no operating gauging stations but does have four inoperative stations. To further compound the paucity of data, many of the inoperative gauging stations are only rated at low flood levels and so confidence levels in the accuracy of the discharge data for the larger floods are low. These deficiencies are even more severe for the smaller river systems where frequently no gauging station data have ever been recorded. Many even lack any basic systematic flood height data, and prior to the ARIDFLO surveys, this was the case for the Neales-Peake catchment.

The following studies have addressed some aspects of the modelling, or analysis, of the hydrological processes for the rivers of the LEB. Analysis of gauging station data to determine transmission losses in a 420km reach of Cooper Creek in the LEB (Knighton and Nanson, 1994a) demonstrated that the losses were extremely large and varied non-linearly with discharge within the 'Channel Country' reach of Cooper Creek. Further analysis of a number of gauging station records from the LEB by Knighton and Nanson (2001) defined further broad-scale characteristics of the hydrological regimes of the major LEB rivers. The same authors have published seminal papers on the geomorphological and hydrological characteristics of waterholes on Cooper Creek (Knighton and Nanson 1994b, 2000, 2002). The variability of the hydrological regime of Cooper Creek has also been demonstrated by Puckridge et al. (1998; 2000).

In terms of hydrological modelling, a simplified, whole-of-basin modelling approach was taken by Kotwicki (1986), using the RORB model (Laurenson and Mein 1990). The most relevant modelling approach previously applied in the LEB was the modelling of most of the Cooper Creek catchment by Schreiber (1997). That approach used the Sacramento model to generate runoff from sub-catchments, which were then routed through the main river network using the IQQM model. An interpolated rainfall dataset was used as input to the Sacramento model with the daily rainfall of each subcatchment being the mean value of all rainfall grid cells contained within that subcatchment. This same rainfall dataset is used as input to the ARIDFLO hydrological models and is discussed in Section 2.4.2. Streamflow was routed along a link-node representation of the channel system using a modified Muskingum routing procedure where the 'k' parameter varied as a function of discharge. The approach allowed for explicit flow routing through a simplified channel system and incorporated non-linear routing and transmission loss behaviour as discharge increased. The impact on transmission losses of variable flow paths used by different sized flood events was not addressed as the defined flow paths remained invariant for all flood sizes.

The Cooper Creek model achieved reasonable calibration results when simulated versus measured discharge plots and flow duration curves were compared. However, the inability of the model to simulate changes in flow distribution for different discharge ranges was a major impediment to accurately simulating discharge at a number of points (waterbodies) spread over the river system, particularly in the mid and lower reaches where the complex flow paths were greatly simplified.

In addition, the separate natures of the rainfall-runoff model (Sacramento) and the routing model (IQQM) resulted in a cumbersome and inflexible structure. The relative complexity of the Sacramento model was also probably over-parameterised given the streamflow data available for calibrating the model. In the simulation of the Cooper Creek catchment, the Sacramento model was calibrated on the gauging station record of a single subcatchment (Darr River) and these parameters were then applied across the entire catchment. This limited the ability of the model to simulate, or investigate, the effects of variability in catchment characteristics on runoff across this very large catchment. For these reasons, it was considered that an alternative hydrological modelling approach should be applied to the reaches that were sampled by the ARIDFLO project.

As part of the DRY/WET study (Puckridge et al. 1999), the spatial patterns of inundation within the lower Cooper reach (downstream of Innamincka), during the period 1986-1992, were analysed using satellite data (NOAA-AVHRR and Landsat MSS images). The spatial patterns of flooding were related to flood events of characteristic size, both in terms of peak discharge and total volume, as measured at Cullyamurra gauging station (Costelloe 1998; Costelloe et al. 1998, Puckridge et al. 1999). This involved the identification of key threshold discharges (measured at Cullyamurra) for flow into the major flow paths of the lower Cooper reach and estimation of threshold volumes for the outflow from sequentially linked lakes of the Coongie Lakes wetlands.

This methodology was successful in providing a framework for analysing and predicting the highly complex flow patterns in the lower Cooper for flow events grouped into categories according to size and catchment source. In addition, the mapping of spatial patterns of flow allowed the calculation of time series of area inundated for specified reaches and wetland groupings, and these were used as input to the modelling of ecological responses to flood events in the DRY/WET study.

This approach to providing hydrological data for the ARIDFLO project was originally advocated in the project proposal. However, this approach (using satellite images to calculate changes in inundated area) had a number of deficiencies that limited its usefulness.

- The area inundated for a given reach was difficult to accurately measure using satellite images across the scale of flow events. The methodology was most suited to large floods in reaches with broad, low gradient floodplains. Flow events (particularly in-channel flows) resulting in the area of inundation of a reach being significantly less than the satellite image pixel size could not be accurately measured.
- The temporal resolution of satellite images was limited by the overpass frequency and cloud cover. Even using satellite images with daily overpass frequency (e.g. NOAA-AVHRR), the geometry between the sensor and the land surface limited the temporal resolution to approximately weekly for quantitative mapping of flooded area. Practically, it was found that the combination of cloud cover and image geometry limited the available images to approximately two to three per month.
- As a result of the spatial and temporal scale problems, in reaches with limited floodplain width and faster flood passage (e.g. upper Diamantina, Thomson and Neales), it was difficult to obtain sufficient images to effectively map inundation patterns.
- During the period of the ARIDFLO project, increased technical expertise, advice and software from the Department of Civil and Environmental Engineering, University of Melbourne, allowed the development of rainfall-runoff models for all sampled reaches. These were used to supply data on the flow regime and recent flow history of all waterbodies sampled during the ARIDFLO project. The rainfall-runoff modelling approach (see Section 2.4) superseded the use of the DRY/WET methodology although extensive use was made of satellite images in identifying flow paths in the lower reaches and to assist in the spatial calibration and validation of the modelled discharge. Of the five reaches sampled by ARIDFLO, only the Thomson River has publicly available documentation concerning hydrological models developed for the reach (Schreiber 1997).

### 1.4.2 Biological

The aquatic biology of the LEB has generally been neglected. No basin-wide studies of overall aquatic biology or detailed studies of any biotic group across the basin have been done. However, there are some foundation studies, which although restricted in spatial coverage, looked in detail at the aquatic ecology of the Coongie Lakes system in the lower Cooper reach over the period 1984-1992 (Mollemans et al. 1984; Reid and Gillen 1988; Puckridge et al. 1989; Puckridge et al. 1998; Puckridge et al. 1999; Puckridge 1999; Puckridge et al. 2000; Reid and Puckridge 2000; Sheldon et al. 2002). In addition to the detailed studies of Coongie Lakes, one biodiversity study was made of the aquatic ecology of Goyder Lagoon on the lower Diamantina (Puckridge et al. 1999), and two studies are currently underway of the aquatic ecology of the Queensland /NSW border rivers which include sites in the upper Cooper Channel Country (viz. Bunn and Davies 1999) and the River Refugium project of the CRC for Freshwater Ecology. Pioneering studies of the fish of the LEB, including much of their own work, were summarized by Glover and Sim (1978a).

These studies were fragmentary and intermittent, and directed principally at taxonomy and distribution, with some preliminary work on physiological tolerances (Glover and Sim 1978b). Glover (1982) provided the first overall account of fish species' distribution by river system in the LEB, and summarized what was known of their habitat preferences. Glover (1990) supplemented the above work with a checklist of the fishes and their habitat preferences in the north eastern South Australian deserts (so principally in the lower Cooper system), and commented on some of the more unusual ecological characteristics of these species.

The Flood Pulse Concept (FPC - Junk et al. 1989) stands as an oft-cited model of how rivers connect laterally with their floodplains during floods and how this linkage influences aquatic ecology. Puckridge (1999) trialed this model for understanding the ecology of large, arid zone, floodplain rivers such as Cooper Creek and identified a number of limitations. The study provided justification, at the flow regime (long temporal scale) and whole river (large spatial scale), for extending the range of significant flow events in the FPC model beyond the restricted "flood pulse" to the more general "flow pulse" – that is, to all phases of flow including zero flow. This thesis laid the foundations for a "**Flow** Pulse Concept", a Flood Pulse Concept extended in the range of flow amplitudes and the variety of facets of flow events considered significant for river ecology.

In the course of this work, Puckridge (1999) also confirmed that the flow regimes of dryland rivers, particularly the Cooper and Diamantina, are exceptionally variable and unpredictable. This variability was shown to be multi-faceted and led to the general recommendation that a multivariate approach should be taken to modelling hydrology-biology relations for all rivers. The description of extreme flow variation was taken one step further when Puckridge et al. (2000) demonstrated that multiannual flow cycles in Cooper Creek, partly driven by the ENSO phenomenon, promote long-term cycles of "boom and bust" in the fish populations of the river, but may also inhibit recruitment of exotic fishes in favour of native fish. This result suggested the "Flow Pulse Concept" in arid zone rivers should be extended to include longer-term patterns of flow such as multiannual flood clusters.

In addition to the exceptional hydrological variability of the LEB rivers, there are other respects in which these rivers appear to function in distinctive ways. Studies of primary production in waterholes of the upper Cooper Creek indicate that a “bathtub ring” or littoral layer of algal biofilm appeared to be responsible for most primary production in these waterholes (Bunn and Davies 1999; Bunn et al. 2003, see also 1.6.2.2). This finding suggested that the enormous extent of littoral habitat in the multi-channel systems of the Cooper and Diamantina could be vital for sustaining high primary production in these rivers. However primary production is also driven by the alternation of flooding and drying phases on the floodplain that allows the accumulation and decay of organic material.

In addition to examining flow variability, Puckridge (1999) described, at the flow regime (long temporal scale) and river reach (medium spatial scale), the distinctive environmental characteristics of lower Cooper Creek. His thesis summarized the current knowledge of the Cooper Creek fish fauna, and characterised the Cooper Creek fish assemblage as more *r*-selected and showing less parental investment in offspring than the assemblage of Magela Creek (a variable but more predictably variable river in the wet-dry tropics). Puckridge also demonstrated the relatively low fish species count in the arid zone Cooper Creek, in comparison with the fish faunas of tropical northern Australian rivers. In fact, on Welcomme’s (1985) regression of log species count against log basin area for the world’s major rivers, the Cooper system, with its catchment area of 300,000 km<sup>2</sup>, is exceptionally depauperate.

This is likely to be attributable to the extreme selective pressures imposed on fishes by an exceptionally variable hydrologic regime. In contrast, see species richness of waterbirds (Section 1.6.2.6). Further, as the results below will demonstrate, total species count can be misleading as an indicator of effective species richness (number of species captured per unit of effort). For example, species count may be inflated by the presence of exotic species, must be standardized with respect to sampling effort, and gives no indication of the relative abundances of species. Thus a river like Cooper Creek, with a species count of 12, may give an impression of greater effective species richness than a river like the Murray, which has approximately twice the species count but where catches are dominated by carp and goldfish.

The above work, while valuable, has been restricted in geographic range and in taxonomic scope. ARIDFLO has provided an invaluable extension of both, so that in terms of baseline information alone, ARIDFLO has radically transformed our biological and hydrological knowledge of the second largest river basin in Australia. As importantly, ARIDFLO has employed state of the art modelling techniques to provide a comprehensive understanding of the crucial relations between arid zone river hydrology and biological responses over most major aquatic assemblages.

## **1.5 Similar projects outside the LEB**

The only Australian biological river survey comparable in spatial and temporal scale to ARIDFLO is the NSW Rivers Survey (Harris and Gehrke 1997) but that project sampled on only four occasions over two years. Further, the NSW survey focused solely upon the fish assemblage, whereas ARIDFLO achieved near-simultaneous sampling right across the aquatic food chain, covering littoral vegetation, aquatic algae, zooplankton, macroinvertebrates, fish and waterbirds. ARIDFLO therefore provides a database that allows inter-reach and inter-catchment comparisons of biological responses to flow events, to geomorphology and to other biota. Moreover, ARIDFLO provides this coverage in a river basin previously largely unstudied, and it therefore represents a foundation contribution to Australian river ecology.

## **1.6 Background on the LEB**

### **1.6.1 Hydrology**

#### **1.6.1.1 Climatic controls**

The headwaters of the major three river systems of the LEB lie along the north-eastern margin of the basin and are within the zone of influence of the North Australian Monsoon (Allan 1985). As a result, most runoff is generated in these better watered upper reaches and the river systems flow through progressively more arid and lower gradient areas. The terminus of these floods is either in wetland systems of the lower reaches, or - in years of large floods - Lake Eyre North. Rainfall events causing significant runoff are strongly summer dominant but are highly variable, partially because of the basin's position on the fringe of the North Australian Monsoon Zone (NAM). The variability in the flow regime of the major rivers of the LEB can be largely attributed to the position of their headwaters immediately to the south of the North Australian Monsoon shear line.

The headwaters are within the zone of influence of summer seasonal rainfall and shifts in the NAM shear line to the south can result in very large floods developing in one or more of the major rivers (Allan 1985). In addition, transient tropical depressions, such as tropical cyclones making landfall and moving south, can also result in large flood events. The large flood events of Cooper Creek show a small but significant correlation with the ENSO cycle (Puckridge *et al.* 2000). The southward shift of the monsoon shear line or the increased possibility of transient local depressions may be more likely during positive phases of the ENSO cycle ("La Niña" episodes) but the latter phenomenon also has a strong random (stochastic) component. As a result of these quasi-periodical and random influences, the flow regime of the LEB major rivers is marked by very high inter-annual variability.

In the lower reaches of the major rivers and for the rivers of the western side of the LEB (e.g. Neales-Peake River) rainfall is still summer dominant but is even more variable than in the headwaters (Bureau of Meteorology). Large floods are often associated with higher rainfall occurring down into the lower reaches and the western catchments derive most of their large rainfall events from transient depressions sourced from the northwest coast of Australia (Allan, 1985, Croke et al. 1999). Although LEB rivers are dependent upon flows from upstream, the importance of localised small runoff events occurring in isolation from upper reach streamflow should not be understated. These localised events are very important in topping-up and maintaining some of the aquatic refugia in the periods between larger (regional) flows.

The ecological ramifications of high rainfall variability in central Australia generally (Stafford Smith & Morton 1990), and the LEB particularly (Morton et al. 1995a; Roshier et al. 2001a,b) have been explored in terms of the redistribution of runoff and its consequences, across multiple spatial and temporal scales.

### **1.6.1.2 Streamflow and catchment characteristics**

Streams in the arid and semi-arid zones (i.e. those with catchments confined to these zones, *sensu* Farquharson *et al.* 1992) are characterized by strongly skewed distributions of flow and large transmission losses downstream (Rodier 1985). McMahon (1979), in a worldwide comparison of hydrological variability, illustrates some aspects of the variability of discharge of arid zone streams, although over a narrow range of time-scales. However, arid zones differ in their degree of variability on McMahon's criteria, and the above characteristics are much more pronounced for the arid zone rivers of Australia (Alexander 1985; McMahon and Finlayson 1991, Puckridge et al. 1998). Topographic, vegetation and evaporation characteristics of arid zones in these continents tend to amplify rainfall variability in its translation to runoff.

Such rivers - i.e. with catchments confined to the hot arid and semi-arid - should be distinguished from rivers like the Senegal, Nile, Chari, Niger and Orange-Vaal of Africa, the Columbia and Colorado of North America, the Indus of Asia and the Murray-Darling in Australia, all of which flow through arid zones but derive most of their discharge from remote, humid catchments, and retain the hydrological characteristics of those catchments (Rodier 1985, Comin and Williams 1994). Similarly, rivers such as the Ob and Lena in the CIS and the McKenzie in Canada have dry catchments, but because their climates are sub-arctic, their flow patterns are different from those of hot, semi-arid catchments (Farquharson et al. 1992).

Arid zone rivers have complex channel morphologies, in which a single channel operates at low flow conditions and a wider, often braided channel or channel of complex cross-section operates at high flows (Graf 1987, Nanson et al. 1986). Rare, large floods play a dominant role in shaping these morphologies (Pickup et al. 1988). The geomorphology of arid zone rivers also tends to be more dynamic than that of humid zone rivers. For example, the preponderance of unconsolidated sediment and sparse riparian vegetation promote aeolian transport of sediment during drought, instability in channel profile and channel re-routing during large floods (Graf 1987, Kresan 1988, Puckridge et al. 1999).

The arid zone floodplain rivers of the LEB (one of the world's largest internally draining basins) have arguably the most variable flow regimes in the world (Puckridge et al. 1998). The rivers develop over very low gradients and commonly have complex flow paths with extensive braided/anastomosing channel systems, resulting in floods with slow travel times (weeks to months). The rivers have greatly varying widths of active channel and floodplain. During large flood events, floodwaters can inundate tens of thousands of square kilometres and the floodplain can be up to 60km wide. The rivers predominantly transport clay-sized particles, so floodplains are covered by cracking clays (Nanson et al., 1986). Floodplain infiltration losses may be limited by the sealing of the swelling clay floodplain substrate once their crack capacity is exceeded (Knighton and Nanson 1994).

### **1.6.1.3 Limnology**

Arid zone rivers are characteristically more turbid and more variable in physico-chemistry than humid zone rivers (Comin and Williams 1994, Williams 1987a). A record of physicochemical data from a permanent channel reach on the lower Cooper, (probably the most physico-chemically stable habitat in the river (Glatz 1985) illustrates that even at this site, physico-chemical factors are highly variable. In the shallower, more ephemeral waterbodies typical of the LEB, waters are similarly warm, fresh, turbid, alkaline and nutrient-rich, but variability is more pronounced.

## **1.6.2 Aquatic Biology of the LEB**

### **1.6.2.1 General**

The biota of arid zone streams are generally tolerant of extreme environmental conditions (Williams 1987a, Comin and Williams 1994), are spatially and temporally patchy in community composition and abundance (Comin and Williams 1994, Puckridge and Drewien 1988), flexible in life-history strategies (Kodric-Brown 1981), opportunistic in response to flow variation (Deacon and Minckley 1974), and dependent on drought refugia (Shmida et al. 1986, Stafford Smith and Morton 1990, Morton 1990, Briggs 1992).

### **1.6.2.2 Algae**

Macrophytes are generally species poor in central Australian large river systems (e.g. Roberts 1988) and restricted to a narrow range of habitats. Algae on the other hand, form a fundamental part of the food chain in these systems and are considered to play the predominant role in fixing carbon in the aquatic ecosystem (Bunn et al. 2003). Most of the scant attention given to algal studies has been paid to the trophic role of algae in biofilms (Reid and Brooks 2000; Burns and Ryder 2001; Bunn et al. 2003) and to the composition of the epipellic diatom assemblages and their environmental constraints (Gell et al. 2002). By comparison there has been limited, if any, documentation of entire phytoplankton assemblages in arid rivers of Australia. More than mere inventory though, description of the temporal and spatial variability in the diversity and composition of phytoplankton assemblages is required to enhance the understanding of how these intermittently productive ecosystems of the arid zone function.

Regional surveys of freshwater algae in Australia have largely been restricted to areas outside the arid zone. Tropical wetlands, such as the Alligator Rivers region of northern Australia, have been found to have very high algal diversity, with 530 taxa, mostly identified to species level but not including diatoms, reported from this area (Ling and Tyler 1986), and with 850 species identified from eight small samples collected primarily for the study of rotifers (Thomassen 1986). In sub-tropical south-eastern Queensland, 727 species of freshwater algae were identified over a one year period (McLeod 1975). Within the semi-arid Murray-Darling Basin there have been studies on the hydrological and physico-chemical controls on the epipelagic diatom assemblages (Gell et al. 2002) and of the phytoplankton of the River Murray and its major tributaries. Over 150 taxa were recorded from 1980-1985 (Sullivan et al. 1988).

It is difficult to compare these studies or to contrast their results with those of ARIDFLO because of different sampling techniques and their biases in effective survey of floating, in-column, benthic and littoral components of the total algal flora. Within the Australian arid zone the algal assemblage has been little documented, with the exceptions of the collection of 33 diatom taxa, mostly identified to species, from a large salt lake (Lake Eyre South: Blinn 1991) and a study of primary production from freshwater algae in the upper reach of Cooper Creek, a major river of the LEB (Bunn et al. 2003). In Cooper Creek, the study by Bunn et al. (2003) found that a narrow band of filamentous algae occupying the shallow littoral zone of waterholes was responsible for much of the primary production within the waterhole. That study also noted that large diurnal variations in the dissolved oxygen saturation in the open surface water suggested high rates of primary production from the phytoplankton assemblage, but its contribution was not further explored.

### **1.6.2.3 Zooplankton and littoral microfauna**

A single report summarized biogeographical affinities of the microfauna of Lake Eyre (Williams and Kokkin 1988), however there have been no comprehensive studies of the zooplankton from the LEB. Comparable basin-scale surveys of ephemeral floodplain waterbodies of the Murray-Darling Basin (Shiel et al. 1998) and of a range of wetland types (river-fed, lakes, claypans) of the Carnarvon Basin, WA (Halse et al. 2000) reported approximately 500 microfaunal species on each of these surveys, with up to 75% regional endemism in some groups (e.g. Copepoda). Other studies in arid/semi-arid Australia are recent, documenting, *inter alia*, the zooplankton assemblages of southwest WA (Storey et al. 1993; Halse et al. 2000; Pinder et al. 2000) and intermittently filled lakes on the Darling (Jenkins and Boulton 1998) and Paroo (Timms 1998) Rivers in western NSW.

#### 1.6.2.4 Macroinvertebrates

There have been relatively few studies of the aquatic macroinvertebrate fauna of Cooper Creek or the Diamantina and Neales Rivers. Of the South Australian studies, the account of the macroinvertebrate fauna in the Coongie Lakes study (Puckridge and Drewien 1988) was somewhat preliminary as the identification of all the taxa collected had not been completed. Reid and Puckridge (1990) gave a brief account of the macroinvertebrates of Coongie Lakes, which was based largely on Puckridge and Drewien (1988). Sheldon and Puckridge (1998) examined the macroinvertebrate assemblages of Goyder Lagoon on the Diamantina River. They sampled about two years after a major flood and so water levels were low. They found 54 macroinvertebrate taxa, most of which were insects. Their sampling revealed quite different assemblages from the same type of macrohabitats. Sheldon et al. (2000) investigated the significance of variable connectivity to the aquatic invertebrates of the Coongie Lakes region.

This sampling was done shortly after protracted regional flooding with only two of the 12 sites disconnected. They collected 70 taxa, most of which were insects, and found that the taxon richness differed significantly between lake, connecting channel and main channel macrohabitats. As part of the AUSRIVAS program, Madden et al. (2002) documented the various macroinvertebrate taxa collected from watercourses feeding Lake Eyre (including the Cooper, Diamantina, Neales, Peak and Macumba systems). At species level resolution they recorded over 200 taxa. Of the Queensland studies, Choy et al. (2002) investigated the ecological condition of the Georgina, Diamantina, Cooper-Thomson and Bulloo Rivers using several criteria including AUSRIVAS. In 72 samples collected from 30 sites they recorded a total of 74 taxa at the family level of resolution (ca. 200 species).

Although riparian and bank damage due to stock access was common at sampling sites, they considered the sites to be only moderately impacted by this. Most of the taxa collected were considered to be opportunists and tolerant of wide ranging conditions. The Dryland River Refugia project (CRC Freshwater Ecology) is focussing on Cooper Creek, Warrego River and Border Rivers, and various taxa are being studied in this. For example, Cook et al. 2002 have conducted a genetic study of the widespread shrimp, *Macrobrachium australiense* to examine its population structure and dispersal.

The role of increasing salinity and its impacts on riverine fauna has not been widely studied. During the ARIDFLO fieldwork, a number of the sampled waterbodies in the South Australian reaches (e.g. Neales, lower Diamantina, lower Cooper) showed large fluctuations in salinity, reaching hyper-saline levels (i.e. salinity greater than seawater) in a number of water bodies. These fluctuations in salinity were found to have profound effects on the assemblages of most of the biotic groups and this is discussed further in Chapter 4. In salt lakes Williams et al. (1990) found that species richness and salinity were negatively correlated over a broad range of salinities. Williams (1983) describes three major groups of salt-adapted fauna, most of which have evolutionary links with freshwater species. The 'halobionts' (>50 gL<sup>-1</sup>) include isopods (e.g. *Haloniscus searlei*), chironomids (*Tanytarsus barbitarsis*), ostracods, copepods and the brine shrimp *Parartemia*. The 'halophiles' (10-60 gL<sup>-1</sup>) include the water-flea *Daphniopsis pusilla* and the snail *Coxiella* as well as rotifers, ostracods and some insects. The 'salt-tolerant' (<20 gL<sup>-1</sup>) fauna are the most diverse and include many insect species.

The LEB rivers, particularly in their lower reaches, are subject to markedly fluctuating salinities. With respect to increasing salinity on normally freshwater river and wetland habitats Bailey and James (2000), suggested that salinities in excess of 0.8 gL<sup>-1</sup> would adversely affect some species. Their conclusions, however, were qualified as they

suggested the available information on the effects of salinity on invertebrates had serious limitations. Hart et al. (1991) reviewed the salt sensitivity of normally freshwater biota and suggested that an increase in salinity to about  $1 \text{ gL}^{-1}$  would result in direct adverse biological effects. Most of this work, however, has focussed on the impact of increasing salinity on habitats and fauna not normally subjected to high or fluctuating salinities. For example, in the wheatbelt wetlands of south-western Australia most halophilic species are found in the naturally saline wetlands rather than in those subjected to secondary salinisation (Pinder et al. in press). This study suggests that as secondary salinisation becomes more extensive the distribution of the halophilic species will contract, which means that secondary salinisation of freshwater habitats does not replace naturally saline habitats (Pinder et al. in press).

#### **1.6.2.5 Fish**

In the lower Cooper, Puckridge and Drewien (1988) found that there was insufficient evidence to conclude that the fish assemblage was exceptionally generalist. However, timing of reproduction in most species suggested they responded to both seasonal and hydrological breeding cues, so there was some evidence for reproductive opportunism. Further, in 1987 it was observed that three common fish species had swum one km against the flow out onto the floodplain in response to runoff from local rain, and were stranded in an ephemeral pool. This suggested that these species at least were highly opportunistic in their movement responses to flows. This observation was reinforced by Puckridge et al. (1999) who observed that during the exceptional 1989-91 flood cluster on the lower Cooper, *Ambassis mulleri*, a small-growing species previously only recorded several hundred kilometres upstream, migrated downstream into the lower Cooper and established itself as a major component of the downstream assemblage.

Some elements of this assemblage are therefore highly mobile – a useful adaptation in a system as hydrologically variable as the LEB. Further, Puckridge (1999), in a comparison between the lower Cooper and the Magela Creek fish assemblages based on publications on the respective species, found that the lower Cooper assemblage was considerably more r-selected – i.e. was more strongly adapted (e.g. in terms of early maturation and high fecundity) for a variable environment.

Refugia (or deep permanent waterbodies) in a system of rivers as prone to drought as the LEB are self-evidently important to their fish fauna, particularly to an assemblage that has no capabilities for aestivation. However Puckridge et al. (1999) found that impermanent waterbodies also play vital roles in fish ecology. When flooded they harbour the highest abundance of macroinvertebrates (and so of fish food) and allow fish to escape from the higher incidence of fish disease characteristic of the permanent refugia.

### **1.6.2.6 Waterbirds**

Nomadism and extreme fluctuations in population sizes of many species characterise the boom-bust response of this diverse terrestrial faunal component of the LEB's riverine aquatic systems (Reid et al. 1990; Kingsford and Porter 1993; Kingsford 1995; Kingsford and Norman 2002; Roshier et al. 2001a, 2001b, 2002). Unlike the instream fauna, birds have the capability to undertake dramatic movements into and out of the Basin in response to prevailing rainfall patterns throughout the Australian continent (Roshier et al. 2002; Kingsford and Norman 2002). Basically, it has been concluded – if little observed directly – that Australian waterbirds flock into interior wetlands after flooding rains and huge inundation events, with an exodus again upon the return of the next inevitable dry period (Matheson 1974, 1978; Frith 1977; Badman 1989; Reid et al. 1990; Briggs 1992; Marchant and Higgins 1990, 1993; Kingsford and Halse 1999; Kingsford and Norman 2002). Arid Australia including the LEB has a surprisingly diverse waterbird fauna. Over 80 species have been recorded in the SA portions of the LEB alone, with more than 50 species reported breeding (Badman 1989; Reid et al. 1990; Reid and Puckridge 2000). A similar sized waterbird fauna – and indeed it comprises most of the same species – occurs in temperate regions to the south and across the tropical north of the continent (J. Reid, unpubl. data).

Occasionally, spectacularly large concentrations of nesting waterbirds have been reported from wetlands in the LEB, such as the Banded Stilt at Lake Callabonna (McGilp and Morgan 1931), and Australian Pelican at Lake Eyre (Paine 1976; Waterman and Read 1992). Moreover, while it has been assumed that large breeding events of many species must occur in the LEB wetlands during big flood events because of the spectacular eruptions that occur after dry conditions return, [e.g. Black-tailed Native-hen (Matheson 1974, 1978) and Freckled Duck (Parker et al. 1985; Martindale 1986)] – but more duck species besides (Frith 1977; Parker et al. 1985; Marchant and Higgins 1990) – few detailed reports of widespread breeding exist in the primary literature, largely because of the inaccessibility of the region in flood conditions. However, sufficient primary (if sometimes anecdotal accounts, e.g. Duncan-Kemp 1933; Paine 197; Reese 1925, 1930; Cox and Pedler 1977; Badman 1979, 1989; Cox 1982; Mollenmans et al. 1984; Reid 1988, 1992), do exist and these have been reviewed by Parker et al. (1979, 1985), Reid (1984, 2000), Storr (1984), Badman (1989), Reid et al. (1990), Marchant and Higgins (1990, 1993) and Reid and Puckridge (2000) to lend credence to the claims of substantial breeding activity occurring across many species when conditions are suitable.

While no detailed ecological studies of waterbird habitat use and diets have been undertaken in the LEB, assemblage-wide population censuses in specific wetlands, wetland complexes, or prescribed portions of large wetlands have occurred over the past two decades, and descriptive accounts of habitat use exist (Cox 1982; Badman and May 1983; Mollenmans et al. 1984; May 1986; Badman 1987, 1989; Reid 1988, 1992; Reid and Puckridge 2000). The eastern Australian aerial waterbird surveys, which commenced in October 1983 (Braithwaite et al. 1985) and which have been repeated each October since (e.g. Kingsford et al. 1990, 1996), include a selection of wetlands in the eastern LEB (parts of the Cooper and Diamantina systems).

These counts have indicated large abundances of waterbirds in some years. Additional aerial surveys by Kingsford and colleagues along the lower Cooper of SA and Lake Eyre (Kingsford and Porter 1993; Kingsford et al. 1999) have revealed waterbird assemblages probably exceed a million birds at times during drying conditions after sizeable floods, when birds are forced off the floodplain and temporary lakes onto the few remaining deeper or more permanent lakes. Reid and Jaensch (1999) undertook a survey of the Coongie Lakes (Cooper Creek, SA) by helicopter in December 1998, and estimated from ground surveys with limited access to the district's vast spread of wetlands there were >100,000 birds on the nine lakes counted, and reported that a year earlier J.R.W. Reid (in Reid and Jaensch 1999) had estimated 250,000 waterbirds present there in November 1997.

Reid and Puckridge (2000) summarised a number of ground counts from the Coongie Lakes system (by land and boat) undertaken by J.R.W. Reid and colleagues between November 1986 and November 1997. Actual total waterbird abundances enumerated from incomplete counts of the lakes' system varied from lows of 20,000 (Reid 1988) to 120,000 in 1977 (from which the above estimate of 250,000 derives), except that Reid (1988) reported much lower totals from two counts immediately following heavy local rain events when the majority of the waterfowl had apparently vacated the lakes to take advantage of adjacent casual waters (Reid and Puckridge 1990). Thus the structure and abundance of waterbird assemblages can vary greatly over short periods in response to varying local conditions. Again, it is this characteristic of not being physically tied to the instream environment as is the case with most aquatic biota, that allows waterbirds to capitalise on resources and events not directly connected to the riverine system, but that also may serve to lessen the strength of their relationships with the hydrology of the LEB rivers.

In excess of 20,000 waterbirds have been reported from a number of other wetlands and wetland complexes in the lower Cooper in SA, including the Kanowana Lakes (Holmes 1992), Lake Hope and Lake Blanche (Kingsford et al. 1999), as well as Lake Eyre mentioned already. The 'Directory of Important Wetlands in Australia' (ANCA 1996) lists several wetlands in Queensland and South Australian sections of the wider LEB, specifically noting waterbirds as a Ramsar criterion for listing in most of them. Kingsford and Halse (1999) compiled a list of arid-zone wetlands that have at least once supported at least 20,000 waterbirds, and some lie within the LEB. Most of these wetlands are river fed and so part of the LEB drainage network.

There are no prior studies that have aimed to describe the statistical relationships between various facets of the waterbird assemblage of the LEB and the hydrology of major rivers in the Basin – apart from, that is, the very general observation summarised above, that large floods generally result in large concentrations of waterbirds on the few remaining large waterbodies at the tail end of the event. It will also be apparent from the foregoing material that weather patterns both within and outside of the LEB have the potential to influence the movements of inland Australian waterbirds, and that these influences will need to be considered should the statistical models developed by the ARIDFLO study linking waterbird responses directly to hydrological variables fit poorly.

## **1.7 Key Research Questions and Hypotheses**

The original ARIDFLO proposal set forth a series of hypotheses that would be tested by the data collection and analyses conducted during the project. Broadly, ARIDFLO seeks to extend and test the generality of the findings of the Dry/Wet study in a different time period within the same reach (Coongie Lakes on the Lower Cooper in SA) and across different reaches and rivers in the LEB. In addition, because the project encompasses a greater range of biotic groups than Dry/Wet and has access to resources that allow a wider range of technologies to be used, ARIDFLO sets out many other testable propositions derived from ecological experience and theory. The original grant proposal formally set out null hypotheses; however, the view of the peer reviewers was overwhelmingly negative about this 'clumsy' structuring of hypotheses, and so the 'testable assertions' format was adopted.

A case can be made that slavish devotion to the purist scientific method of falsification may be inappropriate, given both the non-experimental survey methodology employed by ARIDFLO and the exploratory nature of investigations such as ARIDFLO. Accordingly, we also temper our conclusions with respect to the driving forces structuring biotic patterns and responses. Many of the original hypotheses arising from Dry/Wet (and as stated in null hypothesis format in the funded ARIDFLO application) are described again here, as well as other questions and expectations that ARIDFLO seeks to address.

### **1.7.1 Hydrological Hypotheses**

Three hypotheses were set out in the ARIDFLO proposal (see below) relating to the methodology of deriving hydrological data ("IMAGHYD") for use in the analysis of biological responses to flood events. As stated in Section 1.4.1, the proposed methodology was based upon that used in the DRY/WET study. During the course of ARIDFLO, it became obvious that the DRY/WET methodology had deficiencies when applied at the extended geographic scope of ARIDFLO, particularly for the upper reaches and smaller rivers (see Section 1.4.1). Instead, an approach using rainfall-runoff models was considered to provide a more accurate and flexible methodology (see Section 2.4). As a result, the eventual IMAGHYD method employed in ARIDFLO, using rainfall-runoff models, differed substantially from the method of deriving hydrological data for the DRY/WET project. In the latter project, rainfall-runoff modelling was not used and hydrological data were derived from satellite images measuring flooded area and lagged, monthly totals of streamflow measured at the upstream gauging station at Cullyamurra.

The IMAGHYD method of the ARIDFLO project improved greatly on the derivation of hydrological data used by the DRY/WET project. The development of hydrological models allowed for daily streamflow data to be modelled at the scale and location of individual waterbodies. As such, the hydrological hypotheses framed in the original proposal (see below) have been superseded and should be considered in terms of how effectively the IMAGHYD method has succeeded in producing modelled discharge data for each waterbody location in an arid zone basin characterised by highly variable flow regimes and a paucity of measured hydrological data describing the flow regimes of these rivers. The development and validation of hydrological models for the five sampled reaches is further discussed in Chapters 2 and 3.

**Hypothesis 1.** (Temporal changes in spatial patterns of inundation)

The method developed for predicting spatial patterns of inundation on the lower Cooper Creek for the period 1986-1992 will provide a consistent framework for describing the inundation patterns of flow pulses on lower Cooper Creek during the period 2000-2003.

**Hypothesis 2.** (Spatial changes in patterns of inundation – gauged rivers)

The method of integrating remote sensing, gauge station data, onground hydrological monitoring, rainfall and topographic data to determine spatial patterns of inundation on lower Cooper Creek will be effective in determining inundation patterns on the Diamantina River for the period 2000-2003.

**Hypothesis 3.** (Spatial changes in patterns of inundation – ungauged rivers)

The method of integrating remote sensing, onground geomorphic and hydrological measurements, rainfall data, rainfall-runoff modelling, and local knowledge will be effective in determining inundation patterns on the Neales River for the period 2000-2003.

**1.7.2 Biological Hypotheses****1.7.2.1 Introduction**

Relations between hydrological drivers selected by Dry/Wet (Puckridge et al. 1999) and biological responses in the lower Cooper Creek over 1986-1992 were reframed as hypotheses for the original ARIDFLO proposal. These hypotheses could only be strictly tested for the fish assemblage, which used the same sampling techniques and similar sites as Dry/Wet. For the other biotic groups sampled by ARIDFLO, either they were not sampled by Dry/Wet (e.g. algae, waterbirds), sampled at much coarser taxonomic resolution by Dry/Wet (e.g. zooplankton, macroinvertebrates), or used different sampling techniques (e.g. for macroinvertebrates). The broader range of biotic groups, higher taxonomic resolution and improved sampling techniques (i.e. sampling littoral zone for macroinvertebrates rather than open water) adopted for ARIDFLO provides greater insight into the functioning of the LEB rivers while the Dry/Wet dataset provides the opportunity to test specific hypotheses over different time periods, spatial scales and geographic areas. For the biotic groups where the Dry/Wet study does not provide testable hypotheses, the following section lists some of the major research questions and expectations that are addressed by the ARIDFLO study.

**1.7.2.2 Algae**

Sampling and analysis of the phytoplankton assemblage was not part of the original ARIDFLO proposal but an offer from Joan Powling (Freshwater Biology, Melbourne), to compile an inventory of recognisable algal taxa, was accepted. Prior to ARIDFLO, remarkably little was known of the phytoplankton of the LEB rivers. Previous work on Cooper Creek (Bunn et al. 1999) had identified littoral algae as a key element in the primary production of waterholes. Given the possible importance of this biotic group and the paucity of existing data on the phytoplankton element of the algal assemblage, the aim of the algal component of ARIDFLO was to provide critical information on such basic questions as;

- What phytoplankton occur in LEB rivers?
- Is the phytoplankton assemblage depauperate in taxa compared to other arid and semi-arid catchments in Australia, particularly the Murray-Darling Basin?

- What is the nature of the blue-green algae (cyanobacteria) assemblage in LEB rivers? What is the extent and frequency of occurrence of potentially toxic species? For instance, in undisturbed catchments it is expected that the occurrence of toxic cyanobacteriae taxa is uncommon. Is this the case in the LEB?
- What factors are correlated with changes in the diversity, composition and relative abundance of the phytoplankton assemblage?

### **Generic Richness of all algal groups**

**Hypothesis 1.** Algal generic richness is significantly positively correlated with higher water temperatures and the summer season.

**Hypothesis 2.** Algal generic richness is significantly higher in floodplain and main channel waterbodies than in lakes and outer-channel waterbodies.

**Hypothesis 3.** Algal generic richness is significantly higher in floodplain macrohabitat than in refuge waterholes.

**Hypothesis 4.** Algal generic richness is significantly negatively correlated with waterbody bankfull depth. (This would accord with hypothesis 3 in that the waterbodies with the greatest bankfull depth are refuge waterholes).

**Hypothesis 5.** Algal generic richness is significantly positively correlated with the upstream connected river length. The 'upstream connected river length' variables have the largest values for the downstream reaches of the large rivers (Cooper and Diamantina), and so such a correlation would indicate an increase in algal generic richness following large floods in the lower reaches.

**Hypothesis 6.** Algal generic richness is more highly positively correlated with waterbodies (like the Coongie Lakes) that remain connected up- and downstream for a long time after they have stopped flowing.

**Hypothesis 7.** Algal assemblage composition is significantly correlated with salinity (measured as conductivity) such that, as salinity rises, assemblage composition changes from domination by salinity-intolerant to domination by salinity-tolerant taxa.

**Hypothesis 8.** Algal generic richness is significantly correlated with previous and current flows of various sizes and over various time lags. A variety of hypotheses arise from this general one: e.g. algal generic richness is significantly positively correlated with low rates of rising and falling limbs of the flood pulse and algal generic richness is significantly positively correlated with increasing water depth (i.e. with volume of river flow and flood size).

### **Cyanobacteriae generic richness**

**Hypothesis 1.** Cyanobacteriae generic richness is significantly positively correlated with higher water temperatures and the summer season.

**Hypothesis 2.** Cyanobacteriae generic richness is significantly positively correlated with pH.

**Hypothesis 3.** Cyanobacteriae generic richness is significantly correlated with flow events. Whether the correlation is positive or negative depends on the timing, volume and extent of these events, their temporal relation to preceding and succeeding events, and to longer-term hydrological patterns. Thus again a variety of hypotheses arise from this general one.

**Hypothesis 4.** Cyanobacteriae generic richness is significantly higher in main channel and floodplain waterbodies than in lakes and outer channels.

**Hypothesis 5.** Cyanobacteriae generic richness is significantly correlated with maximum waterbody depth.

## Algal abundance

**Hypothesis 1.** Algal abundance and community composition are significantly correlated with previous and current flows of various sizes and at various time lags. Several specific null hypotheses arise from this general one: e.g. algal abundance is significantly correlated with hydrological persistence (flood clustering), algal abundance is significantly positively correlated with low rates of rising and falling limbs of the flood pulse and algal abundance is significantly positively correlated with increasing water depth (i.e. with river flow).

**Hypothesis 2.** Algal abundance is significantly positively correlated with higher water temperatures and the summer season.

## Inter-biotic relationships: algal assemblage composition

**Hypothesis 1.** Algal assemblage composition is significantly correlated with hydrology and zooplankton assemblage composition and abundance.

### 1.7.2.3 Zooplankton and littoral microfauna

Similar to algae, the zooplankton assemblage was not part of the initial ARIDFLO proposal but again the project was extremely fortunate to receive an offer of the services of Dr Russ Shiel (University of Adelaide), an expert on Australian microfauna. Prior to ARIDFLO, remarkably little was also known of the zooplankton and littoral microfauna of the LEB rivers. This biotic group forms a fundamental part of the food chain but there had been no comprehensive surveys or studies from the LEB. So, similar to the algal assemblage, the zooplankton component of ARIDFLO set out to provide data and insights into such basic questions as;

- What microfauna taxa occur in LEB rivers?
- Is the microfauna assemblage depauperate in taxa compared to other arid and semi-arid catchments in Australia, particularly the Murray-Darling Basin? Or in light of previous surveys of other semi-arid and arid zone basins (Shiel et al. 1998; Halse et al. 2000), will the microfauna assemblage of the LEB be diverse but show high regional endemism?
- What factors are correlated with changes in the diversity, composition and relative abundance of the zooplankton and littoral microfauna assemblage?

Zooplankton taxa have life cycles of days to weeks - much shorter than the temporal scale of ARIDFLO. However, it is possible to test hypotheses about broad patterns of zooplankton response to hydrological events and other environmental variables.

## Zooplankton Taxon Richness

**Hypothesis 1.** Zooplankton taxon richness differs significantly between seasons, and in particular differs between winter and summer, or between early and late summer.

**Hypothesis 2.** Zooplankton taxon richness is significantly correlated with time since the peak of the last flow pulse.

**Hypothesis 3.** Zooplankton taxon richness is significantly correlated with distance downstream in the river catchment.

**Hypothesis 4.** Zooplankton taxon richness is significantly correlated with size or duration of current or recent flooding.

**Hypothesis 5.** Zooplankton taxon richness differs significantly between the falling limb of a flood, the rising limb or during conditions of no flow.

**Hypothesis 6.** Zooplankton taxon richness is significantly different between waterbody types (viz. main channels, lakes, refuge waterholes, off channel waterbodies).

**Hypothesis 7.** Zooplankton taxon richness is significantly correlated with the ratio of frequency of flooding to frequency of drying.

**Hypothesis 8.** Zooplankton taxon richness is significantly correlated with conductivity.

**Hypothesis 9.** Zooplankton taxon richness is significantly correlated with Secchi depth.

### **Zooplankton relative abundance**

**General hypothesis:** Zooplankton relative abundance does not differ significantly from zooplankton taxon richness in its correlations with season, hydrology, waterbody geomorphology or conductivity.

### **Zooplankton assemblage composition**

**Hypothesis 1.** During or soon after periods of flow, taxon richness and relative abundance of rotifers are significantly higher than taxon richness and relative abundance of microcrustaceans.

**Hypothesis 2.** During winter and early summer (when flow is nonexistent or minimal and waterbodies are disconnected) rotifer taxon richness and abundance significantly decline.

**Hypothesis 3.** During winter and early summer (when flow is nonexistent or minimal and waterbodies are disconnected) microcrustacean taxon richness and abundance significantly increase.

**Hypothesis 4.** Hatching of zooplankters from resting stages in the sediment egg bank contributes significantly to changes in zooplankton taxon richness over extended periods after a flood event.

**Hypothesis 5.** Hatching of different components of the zooplankton eggbank is significantly correlated with salinity changes. (This would account for any differences in species composition at LEB sites in which there was no appreciable inflow but significant variation in salinity).

**Hypothesis 6.** Compositional changes in zooplankton assemblages are significantly correlated with the receding limb of the flood, and most significantly with the period after waterbodies become disconnected.

### **Inter-biotic relationships: zooplankton assemblage composition**

**Hypothesis 1.** Zooplankton assemblage composition is significantly correlated with hydrology and algal assemblage composition.

#### **1.7.2.4 Macroinvertebrates**

The macroinvertebrate assemblage has been comparatively little studied in the arid zone of Australia. In common with many biotic groups (e.g. algae, zooplankton), basic research needs to identify what factors drive variations in the diversity, composition and abundance of this assemblage. The Dry/Wet study found that the open water macroinvertebrate abundance increased in waterbodies that were less frequently inundated while fish abundance decreased (Puckridge et al. 1999). This was interpreted as representing the top-down predation effects of fish on macroinvertebrate abundance but also highlighting the importance of more ephemeral waterbodies as food sources for fish during flood events. The applicability of this finding to another component of the macroinvertebrate assemblage (littoral instead of open water) during a different time period and to different reaches is investigated by ARIDFLO.

As the macroinvertebrate assemblage was not sampled by the same techniques in the ARIDFLO and Dry/Wet projects, quantitative hypotheses established from Dry/Wet cannot be tested with ARIDFLO data. However, studies in Murray-Darling wetlands have shown the importance of ephemeral waters to high levels of macroinvertebrate production (e.g. Maher & Carpenter 1984; Crome 1986), and so this issue could be explored, and hypotheses postulated, testable using the ARIDFLO data set, particularly in relation to prior hydrological events such as complete draw down of waterbodies and the size of the most recent event.

Several hypotheses were posed to provide insight into the major 'drivers' of community composition of the macroinvertebrates. They tested for differences in community composition and taxon richness at temporal and various spatial scales, as well as for the influence of current and previous flow events and water chemistry (conductivity). These hypotheses were tested on a suite of systematically collected macroinvertebrate samples from each of the reaches.

#### **Reach effects**

Through biogeographical differences (historical and current environmental conditions), it is reasonable to assume there will be differences in macroinvertebrate communities. Although reach effects can be explicitly tested for, the role of hydrology in contributing to the varying histories and current riverine conditions found across the studied reaches may be influential – its role is difficult to test, however. Similar considerations apply to macrohabitat and microhabitat differences – obviously the role of hydrology is paramount in shaping both fluvial morphology and the distribution of perennial and ephemeral vegetation.

#### **Hypothesis 1A: Assemblage composition by reach**

Given the vast separation and the nature of each of the reaches, it is expected that the composition of macroinvertebrate fauna differs across reaches.

#### **Hypothesis 1B: Taxon richness by reach**

Following on from Hypothesis 1A above it is also expected that there are differences in taxon richness between reaches.

## **Macrohabitat effects (hydrological regime)**

### **Hypothesis 2A: Assemblage composition and macrohabitat**

Each of the river reaches is a complex composite of various macrohabitats such as lakes, channels and floodplains. These experience different flooding regimes due to their size, depth, location and connectivity to the main stem. They also provide variable physical environments for the biota. Accordingly, it is expected that the macrohabitats support different macroinvertebrate assemblages.

### **Hypothesis 2B: Taxon richness and macrohabitats**

Following on from Hypothesis 2A above it is also expected that there are differences in taxon richness between macrohabitats.

## **Microhabitat effects (recent hydrological events)**

### **Hypothesis 3A: Community composition and microhabitat**

Each macrohabitat contains a variety of microhabitats such as emergent vegetation, snags or bare mud. Each species and functional group of emergent vegetation has its own characteristics and the environment and the resources available to macroinvertebrates living within these microhabitats vary considerably. Accordingly, macroinvertebrate assemblage composition differs across microhabitat.

### **Hypothesis 3B: Taxon richness and microhabitat**

Following on from Hypothesis 3A above it can be expected there are differences in taxon richness between microhabitats.

## **Most recent flow size**

### **Hypothesis 4: Taxon richness and abundance and size of previous flow**

The boom-bust dynamics of these systems are often referred to, yet is this phenomenon demonstrable with systematically gathered macroinvertebrate samples? A suitable Hypothesis for testing this is: Does size of last flow influence taxon richness and abundance.

## **Prior flood events, draw down**

### **Hypothesis 5A: Abundance and hydrological events before the current/most recent event**

Macroinvertebrate abundance is greater in waterbodies that experienced a greater degree of drying/draw down prior to the next flow.

### **Hypothesis 5B: Chironomid abundance and prior hydrological events**

Crome's (1986) study identified chironomids as showing classic boom-bust dynamics in wetlands that dried completely. Accordingly chironomid abundance is greater in waterbodies that experienced a greater degree of drying/draw down prior to the next flow.

### **Hypothesis 5C: Macroinvertebrate abundance and within-reach gradients**

The Dry/Wet study showed that pelagic invertebrate abundance increased downstream within the Coongie Lakes reach along the gradient of increasing frequency of drying of waterbodies (Puckridge et al. 1999). We speculate whether the same responses will be exhibited by littoral macroinvertebrates, and whether it is a general phenomenon in the wider Lake Eyre Basin, or a phenomenon peculiar to the Coongie Lakes themselves with their unique hydrology (staggered filling sequences) and morphology (repeating channel-lake-sill sequence). Specifically, was the observed Dry/Wet response due to geographical sequence position or frequency of drying? A speculative hypothesis is: littoral macroinvertebrate abundance increases downstream within reaches.

## **Salinity**

### **Hypothesis 6: Taxon richness and water conductivity**

The influence of high evaporation rates, saline groundwaters and the phenomenon of declining discharge downstream causes salinity fluctuations within waterbodies through time and systematically along a reach's length. Macroinvertebrates can be expected to show a broad range of tolerances to saline conditions, and some species and groups will be more tolerant to salinity fluctuations than others. Accordingly, macroinvertebrate assemblage composition and richness differs in response to variations in salinity.

#### **1.7.2.5 Fish**

Fourteen fish ecology hypotheses were investigated with the ARIDFLO data and their relevance is briefly summarised below. Of particular note is the greater temporal scope of the fish dataset, compared to the other biotic groups, due to the availability of catch data from Coongie Lakes relating to an earlier period (Dry/Wet 1986-1992 – Puckridge et al 1999). As the fish assemblage was sampled at the same sites by the same techniques by both the ARIDFLO and Dry/Wet projects, hypotheses derived from the latter study can be tested with data from the ARIDFLO project

#### **Hypothesis 1 - Fish species can be organised into a variety of functional groups**

*Relevance* – Species can be placed into functional groups according to their ecology, such that species sharing similar suites of traits are likely to respond to important features of the environment in similar ways (Wiens 2002). Through identifying functional groups, the complexity in the structure and ecology of the fish community can be simplified.

*Section to refer to for results and more information* – 4.5.2.3

#### **Hypothesis 2 - The ARIDFLO sampling methodology adequately captures the full range of fish species.**

*Relevance* – There are many factors that influence how many individuals of different fish species are caught when sampling. Establishing potential biases in catch data before analyses is a pre-requisite for any fisheries study. Thus an evaluation is required of how well the ARIDFLO sampling regime captures different fish species and their life history stages by investigating gear selectivity, relative rarity, nocturnal activity- and microhabitat- preferences.

*Section to refer to for results and more information* – 4.5.3

#### **Hypothesis 3 – Variation in species richness is correlated with regional, hydrological and geomorphological effects.**

*Relevance* – Determining species richness (number of species) and how this changes across different temporal and spatial scales is a basic objective of many field studies researching community ecology (Boulinier et al. 1998). A first step is to develop an understanding of how many species there are in different regions, in different types of waterbodies and under different hydrological conditions. A pattern-analysis and lines of evidence approach will allow us to identify significant associations between specific features of the environment and the structure of fish communities. Recognising what features of the environment might structure fish communities is essential to understand how they might respond under changing environments and/or with increasing anthropogenic pressure

*Sections to refer to for results and more information* – 4.5.2, 4.5.4 and 5.5.4.1

**Hypothesis 4 – The fish community of Coongie Lakes is similar in composition between Dry/Wet, 1986-1992 (Puckridge et al. 1999) and ARIDFLO, 2000-2003.**

*Relevance* – Long-term ecological studies have often found that species richness tends to be relatively constant through time even though the abundance of individual species and the assemblage composition can change quite markedly (e.g. Holbrook et al. 1994). The ARIDFLO study provides an opportunity to test whether or not assemblage composition and species abundances vary through time for LEB rivers given their widely varying levels of productivity and resource availability driven by the boom and bust cycle. This can be done by comparing the catch data from the ARIDFLO Coongie Lakes reach (2000-2003) with the Dry/Wet study of Puckridge et al. (1999) carried out over the earlier time period 1986-1992.

*Sections to refer to for results and more information* – **4.5.4.4 and 4.5.5.4**

**Hypothesis 5 – Variation in species abundance is correlated with regional, seasonal, hydrological and geomorphological factors.**

*Relevance* – The abundance (number of individuals) of different species is an important measure of ecosystem health. Reduced abundances and contracting distributions are often the first warning signs of a deleterious response to environmental degradation (Burgman and Lindenmeyer 1998). Fortunately, most threatening processes are not yet in force in the minimally-regulated LEB, and with such a situation comes the opportunity to better categorise and quantify how abundances of different species change naturally in relation to their relative position within the riverscape, season, flow regime, and macrohabitat.

*Sections to refer to for results and more information* – **4.5.5 and 5.5.4**

**Hypothesis 6 – Native fish recruitment ramps up in response to flood clusters.**

*Relevance* - Puckridge et al. (2000) suggest that it is the cluster of floods across years that is of greater biological significance than the actual size of the individual floods. Therefore, it is hypothesised that hydrological persistence, or the occurrence of flood clusters across years, will have significant effects on fish species richness and abundance.

*Sections to refer to for results and more information* – **4.5.4.2, 4.5.5.2, 5.5.4**

**Hypothesis 7 – Exotic species do not dominate native populations in the ecologically intact LEB rivers.**

*Relevance* - In disturbed catchments in Australia and overseas, exotic species are increasing at the expense of natives. But is the increase in exotic species a symptom of poor river health or a cause of decline in native species? The large spatial scale of ARIDFLO and relatively long temporal scale of study of the Coongie Lakes reach provide a unique opportunity to study the controls on abundance and distribution of exotic fish in the virtually natural LEB rivers, free of significant hydrological alteration.

*Sections to refer to for results and more information* – **4.5.2, 4.5.4, 4.5.5 and 6.8**

**Hypothesis 8 – Under naturally variable hydrologic conditions, exotics are unable to capitalise on flood clusters as effectively as native species (Puckridge et al. 2000).**

*Relevance* –The lack of response of exotics to floods (increase in abundance) has been previously reported from the Dry/Wet study of the Coongie Lakes reach, 1986-1992 (Puckridge et al. 1999). The ARIDFLO study has the opportunity to test this hypothesis over a different time period (2000-2003) for the same and different reaches of LEB rivers.

*Sections to refer to for results and more information* – **4.5.5.4 and 6.8**

### **Hypothesis 9 – Undertaking long distance movements are important**

*Relevance* – It is hypothesised that long-distance fish movements are common in LEB fishes, acting to connect populations, allow opportunistic re-colonisations, buffer the fish community against perturbations, and increase resilience to environmental variation (Holbrook et al. 1994). The capture of fish moving through waterbodies during flow (non-residents) can be considered an ecological ‘mass effect’, as individuals captured are vagrants outside their original habitat (Burgman and Lindenmeyer 1998). Sampling fish communities during flow gives important information about which fish species migrate, what sizes of fish migrate, what sort of distances they migrate over, and an understanding of how the typically fragmented LEB fish community can be reconnected during periods of flow.

*Sections to refer to for results and more information* – 4.5.4.2, 4.5..2 and 5.5.4

### **Hypothesis 10 – A wide variety of native species actively use ephemeral floodplain habitats, particularly juvenile life-history stages.**

*Relevance* – There has been some recent dispute about the significance of lateral connection between the main river channel and its floodplains for native fish in the Murray-Darling Basin (MDB). Particularly, Humphries *et al.* (1999) claim a lack of widespread evidence for floodplain use by any life-history stage of any Murray-Darling fish species. In contrast to the MDB, floodplains in the Lake Eyre Basin are still functionally intact, retaining their natural connectivity and ecological function. Thus this allows the contributing role of floodplain macrohabitats to LEB fish ecology to be assessed without the confounding influences of anthropogenic disruption.

*Sections to refer to for results and more information* – 4.5.4.3 and 4.5.5.3

### **Hypothesis 11 – There is a correlation between the size and timing of fish disease outbreaks and flood events.**

*Relevance* – Large-scale fish disease outbreaks are natural occurrences in LEB rivers, but it is not well understood what conditions lead to the development of stressful conditions and disease. It is hypothesised that flooding may be both beneficial and stressful for freshwater fish. Although flooding may open up new habitats and food resources for fish, flooding can also result in stressful environmental conditions that can leave individuals susceptible to disease and fish kills. Identifying if fish disease and fish kills are correlated with flooding may aid in the discrimination between natural events and those exacerbated by human action (directly or indirectly).

*Section to refer to for results and more information* – 4.5.7

### **Hypothesis 12 – Do the predictive neural network models developed for Coongie Lakes over the 1986-1992 period (Dry/Wet study of Puckridge et al 1999) fit the 2000-2003 period (ARIDFLO study) equally well?**

*Relevance* – Neural Network modelling of the Dry/Wet (1986-1992) and ARIDFLO (2000-2003) datasets (2m seine) from Coongie Lakes allow predictive models developed from one time period to be tested on a later time period to determine their broadscale applicability and stability. Factors used to predict fish community composition in Dry/Wet include various hydrological variables (including measures of hydrograph shape as well as flow volume and lagged at various time intervals), macrohabitat type, season and environmental variables (e.g. temperature and conductivity).

*Section to refer to for results and more information* – 5.3

**Hypothesis 13 – Sites with similar assemblages are strongly correlated with sites of similar hydrology and the assemblage patterns of other biotic groups.**

*Relevance* – To understand the dynamics of LEB aquatic ecosystems, individual species or even assemblages, cannot be considered in isolation for they are parts of an ecological web. Interactions between species, biotic groups and the environment take many different forms and produce multiple patterns. Thus, Mantel tests were carried out to analyse the degree of commonality in patterns of assemblage composition between biotic groups and other factors such as hydrology, reach and trip.

Section to refer to for results and more information- 5.6

**Hypothesis 14 – The ecological condition of LEB fish communities can be assessed with a modified index of biotic integrity.**

*Relevance* – The index of biotic integrity (IBI) is an effective- and rapid- status reporting tool used to assess river health (Karr 1981, 1987). The IBI developed during the NSW Rivers Survey (Harris and Gehrke 1997; Harris and Silveira 1999) was used in ARIDFLO as a template for the preliminary assessment of health of the LEB fish communities. The IBI is most commonly used to assess biotic integrity response across a gradient of *anthropogenic* disturbance. However, ARIDFLO used the IBI to assess biotic integrity response across a gradient of *natural* disturbance. The implicit assumption with this approach is that the most naturally disturbed sites have lower biotic integrity scores (“Naturally disturbed” is interpreted in terms of the supra-seasonal sequence of floods and droughts, *sensu* Lake 2000, Lake 2003).

Section to refer to for results and more information- 7.4

#### 1.7.2.6 Waterbirds

##### 1. Waterbirds – macro scales (recent here relates to events in the previous 3-6 months)

**Hypothesis 1:** Waterbird abundance and reproductive effort in relation to the size of the current/most recent flood

Although there is some evidence to suggest that waterbirds flock into the LEB wetlands from outside the Basin in response to large floods for the purposes of breeding (Reid and Puckridge 1990, 2000; Waterman and Read 1992; Roshier et al. 2002), the twin propositions are actually quite difficult to test. First, around the time of peak flooding, there is such an extensive area of inundation during larger floods that birds are likely to be dispersed at low densities.

Therefore, even though their total population in the wider region may be large to very large, observations taken at individual waterbodies may detect very low numbers and densities of waterbirds. In fact the very large concentrations of waterbirds may occur on a few remaining deeper or more permanent lakes towards the end of a flooding cycle, and by which time the most recent event may have been a small flow or flood. Nevertheless, *a priori*, the expectation that waterbird abundance should increase through immigration and subsequent recruitment in response to larger floods still stands and can be formally tested. In particular the level of breeding activity should be maximal immediately after the largest floods.

The count data collected from aerial surveys over the broader area, if they can be analysed to yield valid population estimates over the wider region, should be amenable to detecting trends in total population size, while both ground and aerial surveys are expected to detect more breeding activity after larger floods than smaller floods.

An hypothesis can be stated thus: Waterbird abundance and reproductive effort at the river reach scale are related to the size of the current/most recent flood.

**Hypothesis 2:** Waterbird abundance at the river reach scale in relation to size of floods in the focal river catchment, and in relation to size of floods in adjacent catchments within and outside of the LEB

Roshier et al. (2002) demonstrated that the abundance of the general duck guild in the Paroo River wetlands of north-western New South Wales varied inversely to a significant degree with the size of floods in the Cooper Creek catchment over a three-year period based on quarterly counts. Roshier et al. (2002) also demonstrated that the abundance of the fish-eating guild in the Paroo River wetlands varied directly with the size of floods in the Paroo, Bulloo River and Cooper Creek catchments (flooding patterns in these three catchments are tightly positively correlated due to ENSO effects being experienced over much of the continent contemporaneously). Accordingly, there are no certain *a priori* expectations about total waterbird assemblage abundances in relation to flood magnitude within the LEB and its separate river catchments.

An hypothesis can be stated thus: Waterbird abundance at the river reach scale may be partly related to the aggregate size of current/most recent floods in major arid and semi-arid catchments other than the catchment under study.

**Hypothesis 3:** Waterbird abundance and reaches' position in catchment in relation to water residence time

The two upstream Queensland reaches are characterised hydrologically by steeper gradients and consequent faster flow rates than the downstream South Australian reaches. Waterbird populations accumulate at high densities in shallow, stagnant or slowly flowing waters, and so the expectation is for higher densities and larger concentrations in the two South Australian reaches on the Cooper and Diamantina systems; furthermore, waterbird numbers ought to be greater in the downstream waterbodies within the Neales reach.

An hypothesis can be stated thus: Maximum waterbird abundance, within a given flood event or cluster of floods, is affected by water residence time across reaches on the Diamantina River and Cooper Creek and within the Neales River reach.

**Hypothesis 4:** Invariant waterbird community structure and habitat relationships across catchments?

Being near the top of the aquatic food chain, and far removed from the scum at the bottom of the pond, any major differences in the instream trophic structures across the three rivers studied for ARIDFLO should be reflected in the guild composition and abundance of the waterbird assemblages. Also, their relationships with hydrologically defined habitat resources could be expected to differ between large and smaller catchments. Habitat, in this sense, can be defined as the range of values of hydrological and other environmental variables expressed in the different reaches. For instance, the Neales catchment is much smaller than the Cooper and Diamantina catchments, and spatially it is further removed from the large waterbird centres in the south-east and far north of the Australian land mass; accordingly, a smaller, less diverse waterbird fauna is expected to occur in the Neales.

An hypothesis can be stated thus: Waterbird community structure and some habitat relationships will differ between the different river catchments.

## **2. Waterbirds – meso scales**

A paradigm shift occurred in Australian waterfowl ecology in the 1980s when it was revealed that a super-abundance of critical food resources for Australian ducks is generated in wetlands after complete draw-downs and upon subsequent refilling (e.g. Maher and Carpenter 1984; Crome 1986). Extensive or complete draw-down of wetlands liberates nutrients which are immediately available to fuel biological production on refilling, while a rapid burst of production of detritivores (Crome 1986) capitalising on organic material accumulated during the draw-down may also occur (Kingsford and Norman 2002). Shallow waterbodies are also generally more productive for a variety of waterbirds than deep waters, and so floodplains when seasonally inundated are favoured foraging habitats for Australian waterbirds. Within the Coongie Lakes system, Reid and Puckridge (1990, 2000) observed that abundance of waterbirds increases downstream, that is as the lakes' dry periods and frequency of complete draw-down increase; also abundance increases on the lakes as the surrounding casual waters (following rain) and floodplain wetlands dry out completely – birds are forced off the more productive floodplains and back onto the lakes. Consequently, three null hypotheses relating to these observed patterns can be framed.

**Hypothesis 1:** Waterbird abundance on discrete waterbodies, such as well-defined waterholes and lakes, increases after maximum flood stage within a flood event.

**Hypothesis 2:** Waterbird abundance within a river reach is related to waterbody depth.

**Hypothesis 3:** Waterbird abundance within a river reach is inversely correlated with the frequency of waterbody inflows and degree of permanence.

### 3. Altricial Colonial Nesting Waterbird Requirements

(These hypotheses can only be tested over longer time scales than the duration of this project but an important contribution to gathering the necessary data can be made.)

**Hypothesis 1:** Altricial and colonial nesting waterbird reproductive effort tied to a minimum threshold period of inundation of emergent nesting sites and the presence of extensive inundated floodplain

Briggs (1992; *personal communication*, March 2000) suggested that based on experiences in the Murray-Darling Basin wetlands, the altricial colonially nesting waterbirds (ibis, egrets and spoonbills) require an extended time for courtship, pairing, nest selection, nest building, incubation and rearing of nestlings to fledging – perhaps for as long as nine months to complete a large breeding event successfully. Other waterbird experts have suggested a much shorter time is required, at least to expect some recruitment, e.g. four months of floodplain inundation may be the minimum time to expect some (if limited) successful recruitment, with greater productivity achieved the longer the period of inundation (e.g. Maher and Braithwaite 1992; Scott 2001), i.e. a threshold effect and ramping-up effect. Because of higher evaporation rates (shorter inundation times) and greater productivity in warmer waters of the LEB, it could be conjectured that this group of birds in the LEB might be geared to completing a highly successful colonial breeding event in a shorter period than nine months, and that the threshold period may be less than four months.

An hypothesis can be stated thus: Successful reproduction by the altricial and colonial nesting group of waterbirds can be completed in less than nine months of floodplain inundation, and that there is a minimal prior period of inundation required before the colony settles and begins nesting.

**Hypothesis 2:** Reproductive effort of piscivores that specialise on larger fish (large cormorants, pelican) and hydrological persistence

On the basis of the senior author's detailed observations of fish synecology in the Coongie Lakes over a six-year period, Puckridge *et al.* (2000) erected the 'hydrological persistence' hypothesis, that instream biological production 'ramps up' over the course of consecutive larger than average floods such that native fish densities, well adapted to boom-bust conditions of the Australian inland, steadily increase despite the massive dilution effect of successive floods. The abundance of large individuals (sub-adult to adult size) of the larger species of fish in the community (e.g. bony herring, golden perch, Barcoo and Welch's grunters) also steadily increases over these two to three year *La Nina* driven events, thereby potentially providing the largest members of the fish-eating guild (Australian pelican, great and pied cormorant) with an increasing food base for greater reproductive output. Reid (1992) observed a major increase in the size of the Australian pelican colony nesting at the Coongie Lakes over the three years of hydrological persistence documented by Puckridge *et al.* (1999, 2000), despite actual annual discharge declining in the final year.

An hypothesis can be stated thus: Reproductive effort of piscivores that specialise on larger fish (large cormorants, pelican) is partly dependent on consecutive years of large floods to promote a cumulative growth in abundance of adult large fish.