An assessment of the research requirements to support effective provisions of environmental water in the South Australian Murray–Darling Basin: 

*Part 2 – Development of hydro-ecological conceptual models and identification of knowledge gaps in current understanding of flow–biota relationships*

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Acknowledgements

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Executive summary

Riverine flora and fauna are intrinsically linked with the river flow regime, with spatio-temporal variability in flow driving ecosystem structure and function. The flow regime of the Murray-Darling Basin (MDB) in south-eastern Australia has been significantly altered to the detriment of natural riverine processes and native biota. A central tenet of contemporary management in the MDB, as in other large river systems globally, is the restoration of ecologically important aspects of the natural flow regime to achieve positive environmental outcomes. Such approaches rely on knowledge of cause-effect relationships between hydrological variability and aquatic biota.

Significant research on flow-ecology relationships has been conducted in the lower River Murray, in South Australia (SA), in the past three decades, spanning a broad range of hydrological conditions (e.g. low flow to flood) and investigating a range of processes (e.g. matter transport) and biota (e.g. vegetation). Nevertheless, significant gaps in our understanding remain. To best support and guide future hydrological and ecological restoration in the lower River Murray there is a need to summarise contemporary understanding of flow-ecology relationships and in doing so highlight knowledge gaps and priority areas of future research.

This report summarises the development of a series of hydro-ecological conceptual models on the response of a range of different ‘biotic/abiotic ecosystem components’ to flow in the SA MDB. Biotic/abiotic components considered as part of the project were: 1) nutrients, carbon, biofilms and microbes, 2) microbiota, 3) vegetation, 4) macroinvertebrates, 5) frogs, 6) fish and 7) waterbirds. The objectives of the project, through the development of these conceptual models, were to:

1) Provide a readily accessible and easy to understand summary of current understanding on ecosystem response to flow in the SA MDB to support decisions regarding environmental water provisions; and
2) Aid in identifying knowledge gaps in current understanding to be the subject of future research, to better support environmental water provisions.

Development of conceptual models followed a ‘flow band’ approach, in line with contemporary approaches adopted by agencies involved in the management of environmental water in the MDB (i.e. the Murray–Darling Basin Authority (MDBA) and Commonwealth Environmental Water Office (CEWO)). As such, conceptual models of response were developed for each biotic/abiotic component for flows representative of the following flow bands in the lower River Murray: 1) winter entitlement (~3,000 ML.day\(^{-1}\)), 2) summer entitlement (~7,000 ML.day\(^{-1}\)), 3) ‘freshest’ (~20,000 ML.day\(^{-1}\)), 4) ‘bank-full’ (~40,000 ML.day\(^{-1}\)), 5) ‘small overbank’ (~60,000 ML.day\(^{-1}\)) and 6) ‘large overbank’ (~80,000 ML.day\(^{-1}\)). Hydrological and physico-chemical conditions (e.g. within-channel hydraulics, floodplain inundation and salinity) under each of the flow bands were described for two distinct regions of the SA MDB: 1) the ‘lower River Murray channel and floodplain’: from the New South Wales (NSW) border downstream to Wellington (this includes all habitats, both instream and floodplain, below the 1956 flood level) and 2) the ‘Lower Lakes and Coorong’: from Wellington to the Murray Mouth, including the Coorong lagoons. Conceptual models of ecological response were then developed for each of these regions.
A total of 12 Conceptual models were developed (i.e. six flow bands across two regions) and took the form of a series of statements or predictions of ecological patterns and processes that would occur under given flow scenarios. These statements are summarised for each conceptual model in ‘synthesis diagrams’. Each statement was assigned a ‘certainty score’, to reflect the level of support (i.e. ranging from 4 (very certain) – based upon abundant published literature, to 1 (very uncertain) – based upon expert opinion with little consensus) for that prediction. All statements that received ‘uncertain’ or ‘very uncertain’ scores were deemed to reflect a knowledge gap in contemporary understanding of flow-related ecological response. These statements were collated and synthesised into coherent knowledge gaps, grouped by defined ‘ecological/biological themes’ and presented for each biotic/abiotic component.

In total, 71 knowledge gaps were identified for the seven biotic/abiotic components across six ecological/biological themes (Table 0-1). The greatest numbers of knowledge gaps were identified under the themes of trophic dynamics (41 knowledge gaps) and population dynamics and community structure (22 knowledge gaps). Whilst the theme of trophic dynamics is broad, this result highlights a substantial lack of understanding of diets, trophic pathways and food web structure in relation to flow in the lower River Murray. Furthermore, there appears a need for greater understanding of the life history of native biota in relation to flow. Whilst all knowledge gaps identified represent priorities for future research, these two general ecological/biological themes are perhaps most pertinent.

Table 0-1. Summary of the number of knowledge gaps identified as priorities for future research in relation to each ecosystem component and ecological/biological theme.

<table>
<thead>
<tr>
<th>Ecological/biological theme</th>
<th>Trophic dynamics</th>
<th>Population dynamics and community structure</th>
<th>Distribution</th>
<th>Condition</th>
<th>Movement</th>
<th>Habitat use</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic/abiotic component</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrients, carbon</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Microbiota</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Vegetation</td>
<td>4</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Frogs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Fish</td>
<td>1</td>
<td></td>
<td>6</td>
<td></td>
<td>3</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Waterbirds</td>
<td>1</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
<td>22</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>71</td>
</tr>
</tbody>
</table>

This report provides a comprehensive summary of contemporary knowledge on the flow-related ecology of the lower River Murray and represents a readily accessible repository of knowledge to support decisions regarding environmental water provision and ultimately, hydrological and ecological restoration in the SA MDB. Through the process of developing the hydro-ecological conceptual models around the selected flow bands, we have quantified the rigour of our knowledge and identified key deficiencies in contemporary ecological understanding. These deficiencies in current understanding form priority hydro-ecological research questions in the SA MDB. The
conceptual models and knowledge gaps developed in this project should not be viewed as exhaustive. Indeed as new research becomes available, conceptual models and knowledge gaps should be updated.
1 Introduction

Flow variability is the key driver of riverine ecosystem structure and function, influencing floodplain inundation, hydrodynamics, sediment and nutrient transport, productivity, physico-chemical conditions, physical habitat availability and biotic life history processes, and ultimately, the distribution and abundance of biota (Poff et al. 1997). Nevertheless, the flow regimes of the majority of the world’s large rivers have been significantly altered (Nilsson et al. 2005) to the detriment of natural riverine processes and native biota (Bunn and Arthington 2002). Subsequently, a central tenet of contemporary river management is hydrological restoration with a focus on re-instating ecologically important aspects of natural flow regimes to achieve positive environmental outcomes (Arthington et al. 2006). Detailed understanding of the relationships of riverine processes and biota with different aspects of the flow regime is fundamental to providing environmental water and flow management that generates positive environmental outcomes.

Substantial research effort has focused upon flow-ecology relationships in South Australia’s (SA) Murray–Darling Basin (MDB) (e.g. Walker and Thoms 1993, Walker et al. 1994, Blanch et al. 1999a, Walker 2006). In particular, in the 1980s and 1990s, considerable attention was given to the ecological effects of regulation of the lower River Murray (Walker 1985, Walker et al. 1992, Walker and Thoms 1993, Sheldon and Walker 1997). Over the last decade, variable hydrology has enabled further investigations of the relationships of a range of ecosystem processes (e.g. matter transport, Aldridge 2013) and biotic components (e.g. vegetation, Nicol et al. 2013) to substantial hydrological variability (i.e. drought, Brookes et al. 2009b; and flood, Ye et al. 2014). As such, contemporary understanding of the relationship between the flow regime of the lower River Murray and biotic/abiotic patterns and processes has improved greatly. Nevertheless, significant gaps in understanding remain. To support and guide future environmental water delivery and river management there is a need to collate and summarise the contemporary understanding of flow-ecology relationships and in doing so highlight gaps in understanding which may require further research attention.

Ecological and life history conceptual models are commonly used in natural resource management. By utilising empirical data and expert knowledge, conceptual models simplify complex systems, identifying links between causal factors and ecological patterns and processes. Conceptual models typically summarise current ecological understanding and thus represent a readily accessible repository of such knowledge to support decisions around natural resource management. Secondly, as ecological conceptual models present ideas on ecological function or life histories, they can highlight gaps in ecological understanding and thus aid in identifying priorities for future research and monitoring.

This report forms a component of a larger project which aims to assess research requirements to support effective provision of environmental water in the SA MDB, including assessment of current decision support tools and ecological knowledge, and the development of an indigenous engagement framework (Hemming and Rigney 2014, Kilsby 2014). This report presents the assessment of current ecological knowledge, the specific objective of which was to collate existing information on the influence of flow on a range of biotic/abiotic ecosystem components (i.e. 1) nutrients, carbon, biofilms and microbes, 2) microinvertebrates, 3) vegetation, 4)
macroinvertebrates, 5) frogs, 6) fish, and 7) waterbirds) and then to summarise this contemporary understanding in the form of hydro-ecological conceptual models. The aim of developing these conceptual models was two-fold:

1) To provide a readily accessible and easy to understand summary of current understanding on ecosystem response to flow in the SA MDB at the landscape scale to support decisions regarding environmental water provisions; and

2) To aid in identifying knowledge gaps in current understanding for future research, to better support environmental water provisions.
2 Methods

2.1 Biotic/abiotic components and spatial scope

At the initiation of the project, a team was assembled comprising experts on the ecology of the selected ecosystem biotic/abiotic components. Selected biotic/abiotic components included 1) nutrients, carbon, biofilms and microbes, 2) microinvertebrates, 3) macroinvertebrates, 4) vegetation, 5) frogs, 6) fish and 7) waterbirds (Table 2-1). Each of the experts was asked to develop conceptual models detailing the current ecological understanding of the response of each biotic/abiotic component to flow.

Table 2-1. Biotic/abiotic components for which hydro-ecological models were developed and relevant experts, including affiliations (UoA, University of Adelaide; CSIRO, Commonwealth Scientific and Industrial Research Organisation; SARDI, South Australian Research and Development Institute; DEWNR, Department of Environment, Water and Natural Resources).

<table>
<thead>
<tr>
<th>Biotic/abiotic component</th>
<th>Expert (affiliation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrology</td>
<td>Nadine Kilsby (UoA)</td>
</tr>
<tr>
<td>Nutrients, carbon, biofilms and microbes</td>
<td>Todd Wallace (UoA) and Rod Oliver (CSIRO)</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Jason Nicol (SARDI)</td>
</tr>
<tr>
<td>Microinvertebrates</td>
<td>Deborah Furst (UoA)</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>Sally Maxwell (DEWNR)</td>
</tr>
<tr>
<td>Frogs</td>
<td>Rebecca Turner (DEWNR)</td>
</tr>
<tr>
<td>Fish</td>
<td>Brenton Zampatti and Chris Bice (SARDI)</td>
</tr>
<tr>
<td>Waterbirds</td>
<td>Dan Rogers (DEWNR)</td>
</tr>
</tbody>
</table>

The spatial scope of this project was the SA MDB, which we define as all habitats below the 1956 flood level from the SA–New South Wales (NSW) border to the Murray Mouth (Figure 2-1). The SA MDB is characterised by a series of distinct geomorphic zones (i.e. the ‘floodplain’, ‘gorge’, ‘swamps’, ‘Lower Lakes’ and ‘Coorong’), but for the purpose of developing conceptual models of biotic/abiotic response to flow, this project considered two distinct ‘regions’:

1) The ‘lower River Murray channel and floodplain’: from the NSW border downstream to Wellington. This includes all habitats, both instream and floodplain, below the 1956 flood level; and
2) The ‘Lower Lakes and Coorong’: from Wellington to the Murray Mouth, including the Coorong lagoons.

We consider there are fundamental distinctions in the hydraulic and physicochemical nature of these two regions and key ecological drivers. For instance, within-channel hydraulics, water level and
subsequently floodplain inundation are important factors influencing ecological response throughout the ‘lower River Murray channel and floodplain’. In contrast, within-channel hydraulics and floodplain inundation are of less importance in the ‘Lower Lakes and Coorong’, but rather, salinity, water level variability and physical connectivity are the primary drivers of ecological response. Furthermore, the biota of the Coorong are fundamentally different from those typical of the ‘lower River Murray channel and floodplain’. We propose that intra-regional spatial variation in flow-related drivers of ecological response will have less influence on biota and the scale of this influence is beyond the scope of this investigation.

Figure 2-1. Map of the South Australian Murray–Darling Basin, including Locks 1–6 and demarcation of regions (the ‘lower River Murray channel and floodplain’ blue shading and the ‘Lower Lakes and Coorong’ red shading) considered in the development of hydro-ecological conceptual models.

2.2 Hydrology

In order to develop hydro-ecological conceptual models, the hydrologic regime (i.e. hydrology and hydraulics) of the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’ was characterised in relation to six specific ‘flow bands’, namely:

1) ‘Lower base flow’ (winter entitlement) – 3,000 ML.day⁻¹;
2) ‘Upper base flow’ (summer entitlement) – 7,000 ML.day⁻¹;
3) ‘Freshes’ – 20,000 ML.day⁻¹;
4) ‘Bank-full’ – 40,000 ML.day⁻¹;
5) ‘Small over-bank’ – 60,000 ML.day\(^{-1}\); and
6) ‘Over-bank’ – 80,000 ML.day\(^{-1}\).

These flow bands were selected to represent disparate phases of the river hydrograph in regards to hydraulics (depth and velocity), inundation and, potentially, biological/ecological processes (e.g. fish spawning) in the SA MDB or as they represent artefacts of management and subsequently, conspicuous phases in the hydrograph of the contemporary regulated river (e.g. winter and summer entitlement flows). This approach is in line with hydrological templates (Figure 2-2) being utilised by agencies charged with the management of environmental water in the MDB (i.e. the Murray–Darling Basin Authority (MDBA) and Commonwealth Environmental Water Office (CEWO)), to describe flow scenarios in relation to environmental water delivery (MDBA 2011).

![Figure 2-2. Conceptual diagram of different flow bands considered overlaid on river geomorphology (MDBA 2011).](image)

Detailed description of the flow bands is presented for each of the regions (i.e. ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’). Each flow band is placed in a hydrological context (e.g. return intervals), before hydraulics (e.g. velocity and water level) and floodplain inundation are described for the ‘lower River Murray channel and floodplain’, and salinity and water level are described for the Lakes and Coorong.

Discharge data were sourced from MSM–BigMOD (MDBA 2010) modelling for current and pre-regulation conditions. Information presented for each flow band includes the frequency of flows of that magnitude under pre-development and post-regulation conditions. Velocity data were sourced from a combination of field studies (Kilsby 2008, Bice et al. 2013) and contemporary models, including a calculated mean cross-sectional velocity model (Gippel 2011) and a 2D MIKE model with a 15 m grid (Watertech 2011, Bice et al. 2013, Wallace et al. 2014).

Water level data are presented for the ‘lower River Murray channel and floodplain’ for all flow bands and were sourced from a combination of 2D modelling (DEWRN 2012a) and water level charts (E&WS 1975). River channel depth data were extracted from the River Murray Digital Elevation Model (DEM) as the lowest point in a 100 m grid centred at each river kilometre. Inundation data are
presented in several ways, including the total area and proportion of inundation of different vegetation classes, and the total area and proportion of wetland area inundated. These data were sourced from the River Murray Flood Inundation Model (RimFIM) (Overton et al. 2006b) and a 2D MIKE model (DEWNR 2012b). Vegetation classes are defined by the dominant species in that assemblage: 1) river red gum (*Eucalyptus camaldulensis* var. *camaldulensis*), 2) black box (*Eucalyptus largiflorens*), 3) river red gum/black box, 4) saline shrubland, 5) lignum (*Duma florulenta*) and 6) river cooba (*Acacia stenophylla*) (Overton et al. 2006b).

The hydraulic and physico-chemical characteristics of the ‘Lower Lakes and Coorong’ under the different flow bands are described in relation to water level and salinity. These data were sourced from a combination of modelled (Webster 1997) and measured data (Water Connect 2013).

For the purpose of the current project, the timing and duration of the predetermined flow bands, and antecedent conditions were not explicitly considered. Whilst the timing, duration and frequency of flow are fundamental components of river flow regimes (Poff et al. 1997) and have a large influence on biotic response, the inclusion of these parameters would have resulted in an inordinate number of different flow scenarios, consideration of which was beyond available resources. Instead, for each of our scenarios, it was considered that flows would be of duration sufficient to elicit an ecological response and that our experts would consider this, along with timing and antecedent conditions when developing hydro-ecological conceptual models. Despite exclusion of explicit flow durations in the conceptual models it should be noted that the response of biota to flows of varying duration is an important knowledge gap in ecological understanding and thus, the provision of environmental water allocations.

### 2.3 Conceptual models

#### 2.3.1 Current understanding and model development

A summary of hydrologic information was distributed to all members of the project team, as well as a range of documents that had previously described ecological understanding of the responses of different biotic/abiotic ecosystem components to flow in the SA MDB. These documents were provided to the relevant experts to assist in compiling and synthesising contemporary understanding of ecological response to flow and to provide examples of currently available ecological conceptual models. The package included the following reports:


Experts were then asked to use the hydrologic information provided and their understanding of the ecology of their assigned biotic/abiotic components (using the documents provided, any other relevant contemporary literature, expert opinion and consultation with peers) to develop hydro-ecological conceptual models regarding patterns and processes likely to occur at each of the proposed flow bands.

Conceptual models may take a variety of forms but generally utilise empirical data and expert understanding/opinion to simplify complex systems, identifying links between causal factors and ecological patterns and processes. Ecological conceptual models of system function or species lifecycles often take the form of ‘spaghetti’ diagrams linking various patterns and processes and, whilst informative, are often complex. Additionally, such models often treat well understood ecological relationships (i.e. cause–effect mechanisms supported by abundant scientific literature) equally with those that are less well understood or hypothesised (i.e. supported by anecdotal evidence only). Thus, in the current project, conceptual models were developed in the form of statements or predictions of ecological patterns and processes that would occur under given flow scenarios, and each statement was allocated a certainty score to reflect the level of confidence in that prediction. Assigning a measure of certainty to predictions of ecological patterns and processes in relation to flow variability is vital for identifying knowledge gaps in conceptual understanding.
Table 2-2 was adapted from Mallen-Cooper et al. (2011) and presents the process for scoring the certainty of predictions made in the hydro-ecological conceptual models. The conceptual models provided by each expert were then synthesised into simplified conceptual diagrams presenting key patterns and processes occurring at each flow band.

Table 2-2. ‘Certainty’ scoring system used to define confidence in predictive statements of response to flow in the hydro-ecological conceptual models. Adapted from Mallen-Cooper et al. (2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very uncertain</td>
<td>No available data. Diverse views/conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Uncertain</td>
<td>No available data. Expert opinion. Consensus on conceptual understanding</td>
</tr>
<tr>
<td>3</td>
<td>Moderately certain</td>
<td>Supported by indirect, observational or limited scientific data</td>
</tr>
<tr>
<td>4</td>
<td>Very certain</td>
<td>Supported by direct or abundant scientific data. Published peer-reviewed literature</td>
</tr>
</tbody>
</table>

Conceptual models for the different biotic/abiotic ecosystem components of the SA MDB were developed using the same general principles. Nevertheless, due to inherent differences in ecology and the influence of flow on different biotic groups, there were differences in the development of the conceptual models between components. Experts of components with relatively few species (e.g. frogs) typically took an individual species approach, whilst experts of components with a relatively large number of species (e.g. vegetation, birds) typically utilised ‘guild’ approaches, grouping species based on similarities in life histories, feeding modes, etc. Such an approach assumes that species with similar traits will respond in the same manner to the same ecological conditions (Growns 2004). Each biotic/abiotic group, however, includes a general description of biology/ecology and justification for the use of guilds or species approaches.

2.3.2 Identifying knowledge gaps

One of the primary aims of the current project, through development of hydro-ecological models, was to identify key knowledge gaps to inform research and ultimately better support decisions regarding environmental water provision. To facilitate this, we assigned certainty scores (Table 2-2) to predictive statements of flow-related ecological responses to identify hypothesised relationships that require further research and validation.

All predictive statements in conceptual models that received certainty scores of 1 (very uncertain) or 2 (uncertain) (Table 2-2) were assumed to reflect a knowledge gap in contemporary conceptual understanding of flow-related ecological response. These statements were synthesised into coherent knowledge gaps by relevant experts and grouped by ‘ecological themes’ (e.g. population dynamics, movement, trophic dynamics, etc.) for each biotic/abiotic component. The final knowledge gaps for each biotic/abiotic component are presented in Section 11.
3 Hydrology of the SA MDB

The aim of this and subsequent ‘hydrology’ sections is to describe hydrological conditions relevant to the response of biotic/abiotic ecosystem components at each specified flow band. As such, these sections provide a general overview of hydraulics (e.g. velocity and water level), floodplain inundation and salinity in the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’, as expected under a given discharge (i.e. flow band). They do not provide a definitive review of the multiple factors influencing hydrology and hydraulics in the two regions, but rather present the range of conditions that may exist under a given discharge.

3.1.1 Lower River Murray channel and floodplain

On average, flow to the SA border (QSA) follows a seasonal pattern, peaking in spring with low flows through autumn (Figure 3-1). Regulation of the River Murray, including the construction of dams, weirs and barrages, and extraction of water for irrigation and consumptive purposes, has impacted mean flow volumes in SA. While the typical spring peak has been retained, the mean magnitude of the peak has more than halved (Maheshwari et al. 1995) (Figure 3-1). Despite river regulation and typically seasonal flow patterns, inter-annual flow to SA remains highly variable; for example, in the past 35 years, annual flow at the SA border has ranged from 1,015 GL in 2007 (minimum daily flow of 767 ML.day\(^{-1}\) in June) to 15,600 GL in 1993 (maximum daily flow of 111,620 ML.day\(^{-1}\) in November) (Figure 3-2).

Flow at the SA border is governed by the MDBA and Department of Environment, Water and Natural Resources (DEWNR). Under the Agreement, SA is entitled to a maximum of 1,850 GL.year\(^{-1}\), regardless of water availability in the Basin, with daily entitlement flows varying from 3,000 ML.day\(^{-1}\) in May–June to 7,000 ML.day\(^{-1}\) in December–February (Figure 3-3). The hydrograph under entitlement flow differs from the natural hydrograph in both magnitude (1,850 GL.year\(^{-1}\) compared to modelled mean of 6,172 GL.year\(^{-1}\); Maheshwari et al. 1995) and timing (low flow over winter and peak flow over summer compared to low flow over autumn and peak flow over spring) (Figure 3-1 and Figure 3-3). In addition to entitlement flow, SA might receive ‘Additional Dilution Flows’ of up to 3,000 ML.day\(^{-1}\), based on a series of storage rules for both Menindee Lakes and combined Hume and Dartmouth Dams, or targeted environmental flows. Additional flow above these volumes is considered ‘unregulated’ by the MDBA and is based on catchment-scale water availability.

As flow varies both seasonally and annually, flows of given volumes for given durations occur at different return intervals. Figure 3-4 describes the frequency of different flow events (discharge \(y\) or greater for a duration of \(x\) or greater days) under modelled current conditions. The data were modelled using MSM–BigMod with 118 years of climate data. For example, a flow event of \(>7,000\) ML.day\(^{-1}\) for \(>60\) days occurs in 90% of years, compared to only 47% of years for a flow event of \(>20,000\) ML.day\(^{-1}\) for \(>60\) days. The effect of varying flow volumes is manifested in variable hydraulics, notably depth (e.g. inundation) and flow velocity.
Figure 3-1 Mean monthly discharge into South Australia (QSA): entitlement flow under the Murray–Darling Basin Plan, modelled natural discharge and modelled current discharge (Maheswari et al. 1995).

Figure 3-2 Calculated daily discharge at the South Australian Border (QSA) (Station A4261001), 1977–2013 (Water Connect 2013).
Figure 3-3 Daily entitlement discharge into South Australia (QSA), assuming equal discharge on all days of the same month.

Figure 3-4 Frequency of events – how often (% of years) and event of a flow event of 3,000, 7,000, 20,000 and 40,000 ML.day$^{-1}$ or greater occurs for $y$ days or longer, under current conditions. For example, a flow of 20,000 ML.day$^{-1}$ or greater, lasting for 60 days or longer, will occur in 47% of years (47 out of 100 hundred years). Modelled using MSM–BigMod with 118 years of climate data. Data only available up to 40,000 ML.day$^{-1}$. 
Hydraulics

Water level

River regulation has significantly impacted water levels in the River Murray in SA (Walker 2006); water levels at lower discharges (i.e. <30,000 ML.day$^{-1}$) in the River Murray channel and Lakes Alexandrina and Albert are primarily controlled by the barrages and Locks 1–6, rather than by flow magnitude. At these lower discharges, the weirs are operated to maintain a steady ‘pool level’ (Table 3-1). At higher discharges (e.g. ~60,000 ML.day$^{-1}$), the Locks are ‘drowned out’, navigable passes are removed and water levels are controlled by the discharge magnitude. Table 3-1 shows some details of the locks and weirs and barrages in SA.

Table 3-1. Details on Locks and Weirs 1–6 on the River Murray in South Australia. There are five barrages (Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere) separating the Lower Lakes (Lakes Alexandrina and Albert) from the Murray Mouth. Water levels are given in m AHD (Australian Height Datum).

<table>
<thead>
<tr>
<th>Lock and Weir</th>
<th>River km</th>
<th>Distance to next upstream lock (km)</th>
<th>Top of piers level (m AHD)</th>
<th>Upstream pool level (m AHD)</th>
<th>Downstream pool level @ 5,000 ML.day$^{-1}$ (m AHD)</th>
<th>Downstream pool level @ 30,000 ML.day$^{-1}$ (m AHD)</th>
<th>Discharge navigable pass removed (ML.day$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>274.3</td>
<td>87.8</td>
<td>4.3</td>
<td>3.2</td>
<td>0.8</td>
<td>1.9</td>
<td>70,000</td>
</tr>
<tr>
<td>2</td>
<td>362.1</td>
<td>69.3</td>
<td>7.2</td>
<td>6.1</td>
<td>3.3</td>
<td>5.1</td>
<td>55,000</td>
</tr>
<tr>
<td>3</td>
<td>431.4</td>
<td>84.8</td>
<td>10.4</td>
<td>9.8</td>
<td>6.3</td>
<td>8.0</td>
<td>64,500</td>
</tr>
<tr>
<td>4</td>
<td>516.2</td>
<td>46.2</td>
<td>14.3</td>
<td>13.2</td>
<td>10.3</td>
<td>12.2</td>
<td>64,500</td>
</tr>
<tr>
<td>5</td>
<td>562.4</td>
<td>57.4</td>
<td>16.8</td>
<td>16.3</td>
<td>13.4</td>
<td>14.7</td>
<td>68,500</td>
</tr>
<tr>
<td>6</td>
<td>619.8</td>
<td>76.8</td>
<td>19.9</td>
<td>19.3</td>
<td>16.4</td>
<td>18.4</td>
<td>62,000</td>
</tr>
<tr>
<td>Barrages</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.8</td>
<td>0 (sea level)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wellington</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*equivalent to ‘normal pool level’

The influence of a weir on water level is related to distance from the weir; the further upstream from a weir, the lesser the influence of the weir and more variable the water level (e.g. Figure 3-5). Water levels immediately upstream of a weir are generally very stable, in contrast to the highly variable water level immediately downstream of a weir (Figure 3-5 and Figure 3-6). While daily (short-term) water level fluctuations downstream of weirs have increased since river regulation, the long-term water level regime (including continuous periods of water level falling and rising over longer time periods) has become more regular and less diverse (Maheshwari et al. 1995).
Figure 3.5. Water level (m AHD) upstream side of Lock 3 (station A4260516), at Loveday pump station (station A4260624) and downstream side of Lock 4 (station A4260515), 1986–present (Water Connect 2013).

Figure 3.6. Water levels immediately above and below Lock 1 at Blanchetown (stations A4260902 and A4260903 respectively) (Water Connect 2013).
**Velocity**

Velocity in the River Murray channel is a function of both discharge and water level, which is controlled by the operation of the weirs; nevertheless, in general, velocity increases with discharge (Figure 3-7 and Figure 3-8). Data from a 2D MIKE hydraulic model indicate a number of velocity patches are present within the Lock 5 to Lock 7 reach for any specified discharge but velocity magnitude increases with discharge (Figure 3-8). For example, at flows of $<7,000$ ML.day$^{-1}$, >50% of the channel area exhibits velocities $<0.17$ m.s$^{-1}$, whereas at flows $>40,000$ ML.day$^{-1}$ velocities $>0.31$ m.s$^{-1}$ are predominant throughout the reach.

Hydraulic conditions also differ along the length of a weir pool. Water velocity immediately below each lock is generally higher than immediately above each lock (e.g. Figure 3-7 and Figure 3-9). Again the 2D MIKE hydraulic model is used to model water velocity in the lower (immediately upstream Lock 3), middle (equidistant between Lock 3 and 4) and upper weir pool (immediately downstream Lock 4) from Lock 3 to Lock 4; a greater range of velocities is present at all discharges immediately downstream of Lock 4 compared to immediately upstream of Lock 3 (Figure 3-9).

![Figure 3-7](image1.png)

**Figure 3-7.** The mean cross-sectional velocity at different discharges, downstream of Lock 3 and upstream of Lock 2 (in the same weir pool). Velocity calculated from a cluster of cross-sectional areas (Gippel 2011).

![Figure 3-8](image2.png)

**Figure 3-8.** Percent of the main channel in the reach from Lock 5 to Lock 7 in different velocity classes for different discharges. For example, at 7,000 ML.day$^{-1}$ the channel is 9% $0.04–0.1$ m.s$^{-1}$, 48% $0.11–0.17$ m.s$^{-1}$, 33% $0.18–0.3$ m.s$^{-1}$ and 10% $>0.31$ m.s$^{-1}$. Modelled data from Watertech (2011) in Wallace et al. (2014), based on a 15 m x 15 m 2D grid MIKE model. Note the variable velocity class categories.
Figure 3-9. Percent of the a) lower (immediately above Lock 3), b) mid and c) upper (immediately below Lock 4) reaches between from Lock 3 to Lock 4, in different velocity classes, for different discharges. For example, at 7,000 ML.day\(^{-1}\) in the lower reach (a) the channel is 53% 0.0–0.09 m.s\(^{-1}\), 46% 0.1–0.19 m.s\(^{-1}\) and 1% 0.2–0.29 m.s\(^{-1}\). Modelled data based on a 15 m x 15 m 2D grid MIKE model in Wallace et al. (2014).
Inundation

Under normal weir operation, as discharge increases, water reaches the top of the main channel and starts to spill over onto the floodplain. The exact discharge that the floodplain commences to become inundated depends on local channel capacity and varies between lock reaches. Figure 3-10 shows the percentage of the floodplain for the different lock reaches that are inundated under different discharges (data from RiMFIM; Overton et al. 2006b). In general, water starts spilling onto the floodplain at around 40,000 ML.day$^{-1}$, and much of the floodplain is inundated at 100,000 ML.day$^{-1}$.

Normal weir pool operation has artificially elevated water levels, particularly immediately upstream of locks, which has led to permanent inundation of many wetlands. Figure 3-11 shows that, in most reaches (except Lock 6–7), >70% of wetland area (as defined by GIS data from the Murray–Darling Basin Commission; Overton et al. 2006b) is inundated at discharges as low as 5,000 ML.day$^{-1}$. Nevertheless, total wetland area inundated still increases with discharge.

Figure 3-10. Percent of the total floodplain (including wetlands) between locks inundated under different discharges. 100% inundation occurs at an unknown discharge (>100,000 ML.day$^{-1}$), and varies between floodplains. Data from RiMFIM (Overton et al. 2006b).
Figure 3-11. Percent of wetland area inundated on the floodplain between locks under different discharges. Data from RiMFIM (Overton et al. 2006b).

3.1.2 Lower Lakes, Coorong and Murray Mouth

Salinity and water level are the key ecological drivers of the Lower Lakes, Coorong and Murray Mouth ecosystem (Paton 2010) (Figure 3-12). In general, the greater the outflow from the barrages the lower the salinity across both the lakes and Coorong (Lester et al. 2011), although the pattern of flow delivery and flow history are important factors in determining salinity; ‘widely different barrage flows were capable of producing either completely healthy ecosystem states or completely degraded ecosystem states in the Coorong’ (Lester et al. 2011).

Barrage discharge and salinity in the Lower Lakes from 2002–2012 are presented in Figure 3-13. Barrage discharge ceased from 2007–2010, due to reduced inflows from the River Murray and consequently salinity in the lakes increased. Subsequently, high volume flows in 2010/11 and recommencement of flow through the barrages resulted in reduced salinities in the lakes (note that hydrological connectivity between Lake Alexandrina and Albert (sample location Meningie) was disrupted in 2007 and only restored in 2011). As such, extremes of flow, both low and high, influence lake salinities. Nonetheless, Figure 3-14 compares measured salinity across the lakes at different barrage discharges using all data from 2002–2012 (noting again that barrage discharge ceased from
2007 to 2011, and Lake Albert (location Meningie) was not connected to Lake Alexandrina for much of that period) and indicates that at low to moderate flows (e.g. <40,000 ML.day\(^{-1}\)) a wide range of salinities are associated with a given barrage discharge. This is likely due to salinity being driven by a combination of lake inflow and barrage discharge (Lake Alexandrina), as well as water level and evaporation (Lake Albert) (Heneker 2010).

Barrage discharge and salinity in the Coorong from 1984–2012 are shown in Figure 3-15. In general, increased discharge through the barrages causes decreases in salinity near the Murray Mouth. Reduced or zero discharge typically results in increased salinity in the Murray Mouth area, but salinity generally remains around marine levels due to tidal exchange through the Murray Mouth (note dredging was intermittently required over this period to keep the Murray Mouth open). Salinity in the Coorong 100 km from the mouth shows a strong seasonal pattern, with long-term responses to barrage discharges; a period of high discharge over 1987–1993 resulted in an overall reduction in salinity, and conversely the period of low discharge over 2002–2011 resulted in a steady increase in salinity (Figure 3-15). Figure 3-16 compares the salinity in the Coorong at different barrage discharges. While close to the Murray Mouth there is a general decrease in salinity with increase in discharge, at 100 km away the pattern is not so clear.

Barrage operations, influenced by lake inflows, evaporation and at times mouth condition and sea level, control discharge and are the primary driver of water level in the lakes. Figure 3-17 shows that water level in the lakes, during normal operation, ranges from about 0.5 m AHD (Australian Height Datum) to 1 m AHD. During the drought of 2007–2010, however, water levels dropped to almost a metre below sea level (-1 m AHD), but then returned to normal levels following widespread flooding in the lower River Murray in 2010/11. The effect of barrage operations on lake water levels is also demonstrated in Figure 3-18. Water levels of 0.5–1 m AHD are recorded over a wide range of barrage discharges (1,000–160,000 ML.day\(^{-1}\)).

Water levels in the Coorong appear to follow an annual pattern independent of barrage discharge (Figure 3-19), although higher discharges may have the effect of increasing the water level along the length of the Coorong (as shown by the slightly higher water levels associated with higher barrage discharges in the Coorong at 100 km from the Murray Mouth; Figure 3-20).

In addition to salinity and water level, mouth openness is considered another important ecological driver in the Coorong. Mouth openness is the degree of connection with the Southern Ocean, and determines the level of tidal exchange and influence of sea-level variation. Historically, the mouth has varied from closed to several hundred metres wide (Webster 1997). Again, while in general the greater the barrage outflows the more open the mouth, Lester et al. (2011) stated ‘no one single volume can be identified that is sufficient to keep the Mouth ‘open’ as there is an increasing relationship between flow volumes and the relative openness of the mouth’.
Figure 3-12. Map of the Lower Lakes and the Coorong showing locations of salinity and water level data stations.

Figure 3-13. Barrage discharge and salinity in different locations in the Lower Lakes (see Figure 3-12 for locations) from 2002–2012. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Poltalloch Plains (station A4261031), Narrung Jetty (station A4260583) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from the MDBA.
Figure 3-14. Salinity at different barrage discharges in different locations in the Lower Lakes (see Figure 3-12 for locations) from 2002–2012. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Poltalooch Plains (station A4261031), Narrung Jetty (station A4260583) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 3-15. Barrage discharge and salinity in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.
Figure 3-16. The salinity at different discharges in the Coorong near the Murray Mouth (Coorong − 0 km) and in the Coorong at a point 100 km from the mouth (Coorong − 100 km) (see Figure 3-12 for locations) from 1984−2012. Salinity data from Webster (1997). Barrage discharge data from the MDBA.

Figure 3-17. Barrage discharge and water levels in different location in the Lower Lakes (see Figure 3-12 for locations) from 2002−2012. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from the MDBA.
Figure 3-18. The water level at different barrage discharges in different location in the Lower Lakes (see Figure 3-12 for locations) from 2002–2012. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 3-19. Barrage discharge and water level in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Water level data from Webster (1997). Barrage discharge data from the MDBA.
Figure 3-20. The water level at different discharges in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Water level data from Webster (1997). Barrage discharge data from the MDBA.
4 Ecology of the biotic/abiotic components of the SA MDB

Prior to developing hydro-ecological conceptual models the general flow-related ecology of the different biotic/abiotic components in the SA MDB are described below. In particular the use and justification of guild approaches are outlined where applicable.

4.1 Nutrients, carbon, biofilms and microbes

General introduction

Natural organic matter (NOM) is a significant energy source in aquatic systems (Wetzel 2001) and originates either from terrestrial sources within the catchments of creeks, rivers and lakes (allochthonous organic matter) or from organisms within the aquatic ecosystem (autochthonous organic matter). The primary sources of allochthonous (externally derived) material are plant (Robertson et al. 1999, McKnight et al. 2003) and to a lesser extent soils (Nelson et al. 1996). These external supplies of terrestrially produced organic carbon are transported into rivers from the surrounding catchment, largely as a result of increased river flows and floods. Although larger fragments of organic material are transported during high flows and may form food items for some organisms, most of the organic carbon is delivered as dissolved or fine particulate forms that cannot be utilised by larger organisms (Jansson et al. 2007, Brett et al. 2012).

Phytoplankton, periphyton (biofilms), bacteria, and macrophytes represent the major autochthonous (internally derived) sources of organic carbon. In the River Murray the extent of macrophytes and biofilms is curtailed as a consequence of increased water depths due to flow regulation, and reduced light penetration because of water turbidity. De-snagging of the river channel is also likely to have dramatically reduced the available surface area available to support biofilms (Baldwin et al. 2013). As a result, primary production is predominantly carried out by microscopic phytoplankton comprised of microalgae and cyanobacteria (Oliver and Merrick 2006, Gawne et al. 2007).

The extent of primary production by phytoplankton is dependent on the availability of light for photosynthesis and the supply of major nutrients especially nitrogen, phosphorus and silica. If light does not limit plant growth, nutrient availability is the factor that is next most likely to limit growth (Udy et al. 2001). Environmental conditions that influence the availability of these growth requirements will affect the supply of organic material generated by the phytoplankton.

Existing conceptual models on the relative importance of allochthonous–autochthonous NOM and lateral–longitudinal connectivity include the river continuum concept (Vannote et al. 1980), serial discontinuity concept (Ward and Stanford 1983, Stanford and Ward 2001), flood pulse concept (Junk et al. 1989), riverine productivity model (Thorp and Delong 1994) and pulse reserve model (Noy-Meir 1973, Reynolds et al. 2004). None of these conceptual models were developed for, or based on Australian river systems, although their limitations have been considered with respect to the River Murray (Puckridge et al. 1998, Gawne et al. 2007). A conceptual model for lowland rivers in the southern MDB may predict that the dominant source of dissolved organic carbon (DOC) would shift
dynamically between periods of low flow, moderate flow and flood periods. During periods where flows are constrained to the river channel, the majority of energy is likely to be derived from in-stream sources, as the exchange of material between the floodplain and the river channel is limited. The relative importance of allochthonous carbon will increase when enhanced catchment discharge increases lateral connectivity through floodwaters that inundate and mobilise the stores of allochthonous material on the floodplain. The store of nutrients and NOM available to be released to the water column will increase with the inter-event duration between flooding. The following information outlines the state of knowledge and basis for such a conceptual model.

**Relationship between discharge, inundation extent and the load of carbon and nutrients**

When floodwater first enters a floodplain there is rapid (within hours) leaching of carbon and nutrients from inundated material (Baldwin 1999, O’Connell et al. 2000, Francis and Sheldon 2002) and soils. This is referred to as the ‘Birch effect’ (e.g. Scholz et al. 2002). The concentration and quality of carbon likely to be mobilised is positively correlated to the inter-flood duration (Baldwin and Mitchell 2000, Wilson et al. 2011).

Within the MDB, several studies have demonstrated that periods of elevated flows that create lateral connectivity increase the concentration of carbon and nutrients in the river, including studies in the lower River Murray, (Aldridge et al. 2012, Oliver and Lorenz 2013), lower Macintyre River (NSW–Queensland border) (McGinness and Arthur 2011), and Lachlan River (NSW) (Moran et al. 2013). Moran et al. (2013) demonstrated a positive correlation between DOC and flow, and DOC limitation during low flows. Westhorpe and Mitrovic (2012) recorded a positive relationship between discharge and DOC coupled with slightly higher terrestrial carbon signatures during flood events in the Namoi River (NSW). Robertson et al. (1999) predicted that a flood inundating 44 km² would provide as much allochthonously derived carbon as produced from autochthonous sources (i.e. phytoplankton) in one year. Gawne et al. (2007) considered that this effect could be produced by a smaller flood (34 km²).

In the lower River Murray, organic loading is not likely to be as high during within-channel flows (40,000 ML.day⁻¹) as for flows that inundate a substantial amount of the mid-floodplain where tree density is relatively high. However, Oliver and Lorenz (2013) present data from the 2010/11 flood that indicates that flow ≥ 20,000 ML.day⁻¹ can induce an increase in DOC and a depletion in dissolved oxygen. Assessments undertaken at the Chowilla Floodplain have demonstrated that partial return of environmental water allocations from individual managed wetlands to the creek system generates a measurable carbon and nutrient pulse and a stimulation of heterotrophic activity in the receiving waters (Wallace and Lenon 2010, Wallace 2013a). Therefore, marked changes in carbon and nutrient concentrations may occur without inundating extensive areas of river red gum or black box woodland. Furthermore, ephemeral creek channels that connect at sub-bank-full flows have been identified as important sources of NOM in other lowland rivers in the MDB (McGinness and Arthur 2011). Return flows containing high loads of readily available DOC is considered to be one of the most important sources of carbon in lowland rivers (e.g. Findlay and Sinsabaugh 1999).

An estimate of the load of carbon and nutrients that will be released as discharge increases can be made using data on carbon and nutrient release from a mesocosm study undertaken by Brookes et al. (2007) (see Table 4-1 for release values). Mean leaf litter loading recorded in that study was 2,564 ±506 g.m⁻² in river red gum woodland areas and 475 ±224 g.m⁻² in temporary wetland/flood-runner
channels. The area of each habitat type and resultant loads of filterable reactive phosphorus (FRP) total phosphorus (TP), and DOC for flows in the range 20,000–100,000 ML.day$^{-1}$ are shown in Figure 1.1 and 1.2, respectively.

Depending on growth conditions within the channel these nutrients may be utilised by biota, stored within sediments and behind structures such as weirs, or transported downstream. Aldridge et al. (2012) reported very high retention of dissolved FRP and TP in the lower River Murray during low flow periods, and low retention during overbank flow. Those authors concluded that during low flows, the reach between Lock 9 and Lock 1 is a sink for nutrients and during high flows is a source of TP, total nitrogen (TN) and DOC. In contrast, the lower River Murray is a sink for nitrate and nitrite (NOx) during both high and low flows. During very high flows and floods in the lower River Murray significant loads of nutrients, carbon and other materials are transported downstream to the Lower Lakes and Coorong region (Cook et al. 2008).

Table 4.1. Release rate of carbon and nutrients from leaf litter collected from ephemeral wetlands at Chowilla Floodplain. Mean leaf litter loading = 475 ±224 g.m$^{-2}$ in ephemeral wetland/floodrunner channels; 2,564 ±506 g.m$^{-2}$ in river red gum woodland areas; 391 ±62 g.m$^{-2}$ in black box woodland areas. Data from Brookes et al. (2007).

<table>
<thead>
<tr>
<th>Resource</th>
<th>Temporary wetlands</th>
<th>River red gum</th>
<th>Black box</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg.g$^{-1}$ leaf material</td>
<td>tonnes. ha$^{-1}$</td>
<td>mg.g$^{-1}$ leaf material</td>
</tr>
<tr>
<td>Filterable reactive phosphorus</td>
<td>0.39</td>
<td>1.85</td>
<td>0.04</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>0.59</td>
<td>2.80</td>
<td>0.12</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>1.74</td>
<td>8.27</td>
<td>1.61</td>
</tr>
<tr>
<td>Nitrate+nitrite</td>
<td>0.19</td>
<td>0.90</td>
<td>0.51</td>
</tr>
<tr>
<td>Dissolved organic carbon</td>
<td>12.7</td>
<td>60.33</td>
<td>23.8</td>
</tr>
</tbody>
</table>
Figure 4-1. Flow–area inundation plot for river red gum woodland and ephemeral wetlands. Figure from Wallace et al. (2014).

Figure 4-2. Flow–nutrient load plot for a) filterable reactive phosphorus (FRP) and total phosphorus (TP) and b) DOC. Load is in kilotonnes.
Potential influence of river regulation on the relative role of allochthonous and autochthonous material

The basal supplies of organic material underpinning river food webs are influenced by a range of inter-connected environmental conditions including land use and river hydrology. The influence of vegetation type on potential loads of NOM is outlined in the preceding sub-section. Regulation of the River Murray has increased the proportion of time under low flow conditions and decreased lateral connectivity between the river channel and floodplain (Maheshwari et al. 1995).

The 11 low level (~3 m head) weirs on the River Murray between Mildura and Blanchetown have little impact on discharge (ML.day\(^{-1}\)), because 1) discharge is primarily controlled via management of storages and 2) the weirs offer little scope to re-regulate discharge due to the low storage within each weir pool (from 64 GL at Lock 1 to 13 GL at Lock 7). However, they do have a significant impact on water levels (river stage) (Cooling et al. 2010). Prior to river regulation, levels in the river were characterised by sustained rises and falls that occurred over days–weeks. Under current standard operating regimes, the weirs are managed in response to changes in flow to provide relatively stable water levels (±50 mm) upstream of the structures. In the weir tailwaters, levels fluctuate daily by about ±200 mm (Maheshwari et al. 1995). The weirs have also dramatically altered velocity, resulting in a marked reduction in velocity, particularly in the lower third of the weir pools (Wallace et al. 2014).

Robertson et al. (1999) hypothesised that increasing the proportion of time rivers are in low flow conditions has led to an unnatural dominance of algal production in Australian floodplain rivers. The reduced frequency and duration of lateral connectivity limits the opportunity for transfer of energy between the river and floodplain wetlands, biasing the riverine food web towards autochthonous sources (Hadwen et al. 2009). In separate studies, Gawne et al. (2007), Oliver and Merrick (2006) and Oliver and Lorenz (2007) demonstrated that during within-channel flows the River Murray is energy constrained with net production close to zero. A study in the MacIntyre River (NSW) concluded that a 55% reduction in river–floodplain connectivity led to a decrease in importation of DOC from anabranch channels of up to 98% (Thoms et al. 2005).

Pathways for trophic upsurge

Carbon and nutrients can be rapidly incorporated into microbial and algal biomass (Schimel 2004). The assimilated carbon and nutrients are subsequently cycled through the food web to higher trophic level organisms (e.g. birds and fish). This process is referred to as ‘trophic upsurge’ (e.g. Furch and Junk 1997). The two primary pathways for transfer of basal resources to higher organisms are:

1) The classical food chain: phytoplankton→zooplankton→macroinvertebrates→fish; and
2) The microbial pathway: bacteria→protists→nanoflagellates→ciliates→zooplankton.

The microbial pathway feeds into, and can enhance energy transfer through the classical food chain, the critical connection occurring at the level of the zooplankton (Jansson et al. 2007, Brett et al. 2012). The community composition of heterotrophic and phototrophic species and the resulting food web connections are determined by environmental characteristics and understanding their influences is important to ecosystem management and fisheries production (Brett et al. 2012).
Influence of discharge on the euphotic zone and autotrophic productivity

The extent to which light penetrates the water column is determined by the absorption and scattering of light as a result of dissolved colour and suspended particles (Kirk 1994). These water quality attributes are a function of discharge, although they may increase with flow due to the resuspension of sediments and increasing connectivity with the floodplain. They are also influenced by landscape characteristics including geology and land use, and hydrological characteristics such as flood frequency, which determines the period that material can accumulate on the floodplain. Consequently, it is difficult to relate colour and turbidity directly to river discharge and usually their fluctuations and influence on optical water quality are assessed through monitoring data. Discharge more directly influences the underwater light climate through its effect on water depth and for a given optical water quality, the influence of depth on primary production can be assessed.

Light energy declines exponentially with depth through the water column confining the growth of photosynthetic organisms to the well-illuminated upper layers. The depth of the water column over which phytoplankton photosynthesis is possible and the bottom area over which attached benthic algal production can occur, are delimited by the depth to which 1% of incident sunlight penetrates, commonly called the euphotic depth. This approximate light limit is used for both planktonic and benthic algal production and is based on extensive field measurements (Reynolds 1984). This is also a reasonable estimate for the limits of macrophyte growth (Blanch et al. 1998, Cottingham et al. 2010).

Unlike attached organisms that grow within the light zone, phytoplankton are circulated through the water column and moved in and out of the illuminated zone by mixing, so that assessing their light conditions is more complicated. Changes in water depth influence the light climate encountered by phytoplankton by altering the ratio of the euphotic depth to the mean depth of the water column. This ratio determines the time that cells mixed through the water column spend in the upper illuminated zone where photosynthesis can occur, relative to the time spent in the deeper unilluminated zone where respiration of cellular reserves produced by photosynthesis provide the energy for continued activity (Talling 1957, Reynolds 1984). Models developed from empirical data and describing integral daily photosynthesis and respiration rates have demonstrated that a shift from light sufficiency to light limitation occurs when this ratio is <~0.2–0.3, (Reynolds 1984, Oliver et al. 2000). At lower ratios the respiration requirements exceed the carbon fixed by photosynthesis and growth is constrained or ceases.

At a given discharge and water depth, the ratio of the euphotic zone to the mean depth of the water column will be influenced by the optical water quality. If the extent of light penetration decreases due to increases in dissolved colour or turbidity then the ratio will decrease and phytoplankton production will be less. A decrease in the depth of light penetration will also reduce the area of illuminated sediment that can support production by attached biofilms and macrophytes. Changes in optical water quality may be brought about by 1) increased rainfall washing in catchment material, 2) floods that mobilise and transport material from the floodplain or 3) flows from upstream catchments of water that differs in its optical characteristics. Turbidity in the Darling River is usually high (>100 NTU) (Sherman et al. 1998, Oliver et al. 2000) and flood waters from the Darling River can reduce the photic depth in the lower River Murray to <0.2 m (Mackay et al. 1988), limiting the growth of aquatic plants (Brookes et al. 2009a). In the late 1980s, water in the lower River Murray included disproportionate contributions from the Darling River via Lake Victoria, and turbidity was
high. When this management practice stopped, turbidity decreased and there were dramatic recoveries in the distribution and diversity of littoral plants and associated invertebrates (Walker et al. 1994, Blanch et al. 1999b, 2000).

**Influence of velocity on autotrophic productivity**

Discharge affects the ability of organisms to maintain themselves within the river channel through its influence on water velocity and retention time. Attached organisms are influenced by the shear force generated by water velocity, for example, biofilm biomass and species richness decline at velocities >0.3 m.s\(^{-1}\) (Biggs et al. 1998, Ryder et al. 2006) as does macrophyte biomass (e.g. Biggs 1996). Lower flows enhance the accumulation of phytoplankton biomass as increases in the effective retention time enable extended periods of growth to occur before cells are transported downstream. Possible causes of increased retention include changes in the presence of slack water zones due to altered crenulations of the bank, altered connectivity with larger wetlands, changes in the occurrences of large low flow pools within the river, or even the degree of in-stream flow reversals due to stream-bed structures (Cottingham et al. 2010). Biomass production in the River Murray was found on average to increase exponentially as velocity declines <0.2 m.s\(^{-1}\), with these reduced velocities largely associated with weirs (Oliver and Lorenz 2010). Similar observations of the influence of water velocity on phytoplankton biomass accumulation have been reported for other large rivers (Reynolds 1988).

Concomitant with a reduction in discharge is the increased likelihood of thermal stratification, especially during summer. Most phytoplankton rely on mixing to enhance their suspension in the water column as they are heavier than water and the onset of thermal stratification decreases water mixing causing increased population losses through sinking. Conversely, thermal stratification has the potential to improve the light climate and so favour the growth of phytoplankton able to maintain themselves within the illuminated layers. Important amongst this group are the buoyant cyanobacteria that cause significant water quality problems. The interaction between flow, water turbulence and thermal stratification has been studied in lowland rivers in south-eastern Australia and persistent stratification generally occurs in the major rivers during summer at mean cross-sectional velocities of ~0.05–0.1 m.s\(^{-1}\) (Bormans and Webster 1997, Mitrovic et al. 2003). However, cyanobacterial blooms can occur at higher water velocities if thermal stratification is intermittent but sustained for several days. Typical discharge rates associated with the occurrence of particular phytoplankton groups at Morgan on the lower River Murray indicated dominance by diatoms at flows >10,000 ML.day\(^{-1}\), while the cyanobacteria *Anabaena* spp. was restricted to flows <6,000 ML.day\(^{-1}\) (Burch et al. 1994, Aldridge et al. 2010). Wind shear across the water surface also influences mixing and so the discharge rate at which thermal stratification occurs can be modified by the influence of wind. In many river reaches the wind influence is small due to high banks and short reaches aligned with the wind direction, but in the wide and exposed Lower River Murray wind does have an effect (Aldridge et al. 2010).

In the flowing reaches of the River Murray production measurements have suggested that light is most often limiting to growth and that nutrients are available in excess of the growth requirements (Oliver and Merrick 2006). However, once flow declines and nutrients become incorporated into the increasing phytoplankton biomass, the nutrient supply can be drawn down so that population growth becomes nutrient limited. In the highly regulated lower River Murray this can occur within the weir pools and in the river below Lock 1. The likelihood of nutrient limitation is increased if
thermal stratification occurs as the resupply of dissolved nutrients to the surface layers from stores in the bottom sediments is reduced, although higher levels of nutrients may be released from the sediments as anoxia increases. Phytoplankton that are able to sustain themselves in the illuminated layers yet access nutrients in the deeper layers are successful under these conditions, the most common groups being the cyanobacteria.

Role of heterotrophic microorganisms

There is a very large pool of allochthonous NOM that can be mobilised during periods of high flows and therefore represents a large pool of energy for those organisms adapted to its uptake. However, it is often proposed that a large proportion may not be assimilated into higher-order trophic levels because allochthonous material typically contains a high carbohydrate content with median C:N ratios of autochthonous and allochthonous material being ~6 and >5 times higher than their potential consumers (invertebrate herbivores) (Elser et al. 2000). A high C:N ratio reduces the efficiency of utilisation and growth rates, and may reduce the flow of allochthonous material through the food web. There is evidence that indicates that some consumers such as macroinvertebrate shredders preferentially select food sources with C:N ratios closest to their body tissue (Deegan and Ganf 2008). However, the relative flow on effects of high C:N ratios is likely to depend on the pathways through which resources are assimilated (Brookes et al. 2005, Douglas et al. 2005). Assimilation of soluble carbon and nutrients via the microbial food web may represent the main pathway through which allochthonous NOM enters the food web (Sherr and Sherr 1988).

The heterotrophic microorganisms of river ecosystems are comprised of bacteria (prokaryotes) and a diverse array of microeukaryotes including protozoa (flagellates, ciliates, amoeba), fungi, microzooplankton (<200 µm), and mesozooplankton (200–2,000 µm). These form the components of the microbial loop, where production results from the respiratory metabolism and regeneration of organic materials into forms that can be transferred along trophic pathways (Jansson et al. 2007, Brett et al. 2012). Bacterial production is supported by dissolved and particulate organic carbon generated both internally and externally to the river. Of particular importance are algal exudates (Fenchel 2008) and dissolved terrestrial organic carbon (Jansson et al. 2007).

Bacteria are efficiently grazed by phagotrophic microorganisms (e.g. flagellates and ciliates) (Dillon and Molot 1997) and by filter-feeding microzooplankton, particularly rotifers. The mesozooplankton (size range: 200–2,000 µm) predominantly feed on phytoplankton, microzooplankton, other mesozooplankton and detritus. Generally bacteria are too small for mesozooplankton to efficiently graze and although some crustacean mesozooplankton are known to consume living or dead particles (Vrede and Vrede 2005), particulate organic carbon and bacteria are generally regarded as low quality food resources at this trophic level (Martin-Creuzburg et al. 2011, Taipale et al. 2012). Consequently, the effective utilisation of bacterial biomass requires additional protozoan trophic links in the food web (Berggren et al. 2010).

Microscopic eukaryotes are abundant in freshwater, but due to their size and a lack of taxonomic knowledge for these groups (Creer et al. 2010, Zingel et al. 2012) monitoring their response to changing environmental conditions has been restricted. Advances in DNA sequencing have enabled complex environmental samples to be analysed for microorganisms, providing information on changes in diversity, community composition and trophic structure, and developing a basis for linking biotic assemblages to environmental factors (Bradford et al. 2013). These methods have been
used in the lower River Murray in combination with traditional identification and enumeration of phytoplankton, and zooplankton, to describe microeukaryote community composition. The molecular identification of phytoplankton and zooplankton provided similar patterns of responses to those obtained from traditional microscopic enumeration. However, the molecular methods reported on a broader range of eukaryotic microorganisms including protists, ciliates and fungi, which is more difficult to achieve using traditional methods and rarely attempted. The molecular analyses identified a significant range of eukaryotic microorganisms present in the river and described changes in community composition in response to environmental influences including environmental flows that increased lateral connectivity between the river and floodplain (Bradford et al. 2013). The increased diversity of microeukaryotes was assumed to be in response to the increased quantity and complexity of the allochthonous organic material transferred from the floodplain.

**Biofilms**

Biofilms are comprised of microorganisms (algae, bacteria, fungi) that adhere to submerged surfaces including inorganic (e.g. rocks, gravel, sediment) and organic substrates (e.g. wood, aquatic macrophytes). Biofilms serve an important biogeochemical role, altering nutrient cycles and providing food to invertebrates and other animals (Burns and Walker 2000a, Vink et al. 2005, Watts et al. 2009b). DOC and nutrients assimilated into biofilms may short-circuit the path from microbial loop → microinvertebrates → higher trophic levels, as biofilms may be grazed directly by large macroinvertebrates (e.g. prawns, shrimps, snails) that are prey for fish.

In systems with variable water levels and flows, biofilms are maintained in early- to mid-successional stages, dominated by diatoms and unicellular algae (Steinman and McIntire 1990). Low variability in water depth and stable photic zones will promote late-successional biofilms and where light is >1% of the surface irradiance filamentous green algae and cyanobacteria dominate (Burns and Walker 2000b). The balance between heterotrophic and photosynthetic organisms is also influenced by nutrient availability and physical disturbances such as scouring, grazing and desiccation (Burns and Ryder 2001, Ryder et al. 2006). High flows may reduce algal biomass and shift composition toward early-successional diatoms (Watts et al. 2009a, 2009b). Selective grazing of palatable algal species by invertebrates also may skew biofilm composition (Burns and Walker 2000a).

Burns and Walker (2000b) demonstrated that the variation in amplitude and duration of water level in the Lock 1 tailwater during routine weir operations was not sufficient to support maintenance of early-mid successional biofilms. Sheldon and Walker (1997) hypothesised that in the lower River Murray reduced water level variation associated with regulation has caused a shift from heterotrophic (bacteria and fungi) to autotrophic (algae) dominance of biofilms. Algal dominated biofilms may be an inadequate food resource for some biota, and it has been suggested that this shift in biofilm composition may explain the disappearance of snail species from the lower River Murray (Wishart 1994, Sheldon and Walker 1997, Stevens 2005). C:N ratios increase between diatoms (Bacillariophyta), non-filamentous and filamentous green (Chlorophyta) algae. High C:N ratios (≥10:1) in biofilms may reflect dominance of filamentous green algae (Burns and Walker 2000a) and can be considered an indicator of algal dominated biofilms. However, this needs to be interpreted with caution; cyanobacteria have lower C:N ratios than Chlorophyta due to the absence of structural tissue (Sheldon and Walker 1997, Burns and Walker 2000a). Hence a mid- or late
successional algal biofilms with a high proportion of cyanobacteria may have a low C:N ratio. This pattern was reported in a study on biofilm in the lower Darling River (Wallace 2013b).

**Interactions and competition**

There is likely to be direct interactions between the classical and microbial food chains that influence the extent of their relative impacts on river food webs during periods of high flows and floods in the lower River Murray (Aldridge *et al.* 2012). The balance between the classic and microbial pathways will shift as availability of resources changes (Staehr *et al.* 2012), driven by variability in discharge that alters 1) within-channel hydraulic conditions (water column depth, velocity, turbulence and mixing depth) and 2) lateral and longitudinal connectivity. Water clarity (turbidity) and season will have a moderating influence on outcomes via euphotic depth, water temperature, leaf litter loads, day length and sunlight intensity. During periods of high flow, the increased organic loads stimulate the activity of heterotrophic microorganisms causing large increases in respiration and reductions in dissolved oxygen concentrations (Oliver and Lorenz 2013). Under some circumstances, hypoxic blackwater events can occur with oxygen concentrations low enough to be lethal to many aquatic biota (e.g. Howitt *et al.* 2007). The two most important factors that determine outcomes are water temperature and carbon loading (Baldwin and Wallace 2009).

During high flows and floods, particularly if a substantial proportion of the water is derived from the Darling River, phytoplankton production is likely to be curtailed due to reductions in euphotic depth (Oliver and Lorenz 2013). Bacteria may benefit from the reduced competition for inorganic nutrients during periods of reduced photosynthetic activity. With an increasing input of allochthonous material, bacteria are less reliant on autochthonous material via phytoplankton such that the basal energy source of the pelagic food web becomes dominated by bacterial production (Jansson *et al.* 2007, Lefebure *et al.* 2013), and the microbial pathway may dominate the transfer of organic material to higher organisms in the aquatic food webs. This may be a valuable food resource for fast growing organisms such as zooplankton and some macroinvertebrates.

Depending on the area, duration and timing of the flooding, and the extent of organic matter accumulation on the floodplain, conditions within the shallow floodwaters on the floodplain may be conducive to the growth of phytoplankton and zooplankton. These organisms can grow profusely in the flood waters (Oliver and Lorenz 2013, Furst 2014), and in conjunction with the eukaryotic microorganisms utilising the terrestrial organic material, generate food resources that can be delivered to larger organisms through both the classical and microbial pathways. Staehr *et al.* (2012) report that this pattern of shallow zones tending to net autotrophy and subsidising respiration in adjacent deeper zones occurs in a wide range of aquatic ecosystem types.

These periods of enhanced productivity are likely to be short-lived, but may be critical to particular life stages of organisms, in which case the timing of events is important. For example, a critical stage in the life cycle of fish is when larvae switch from endogenous to exogenous feeding. This is a time when the availability of suitable prey can determine their survival and significantly influence fish year-class strength. Zooplankton is often considered to be major food resources for fish larvae but recent studies have shown that ciliates can account for 60% of the total carbon biomass consumed (Zingel *et al.* 2012). Ciliates are fragile and easily digested so are often not identified in traditional studies. A lack of knowledge of the food web position of larvae and juveniles of native fish in the
River Murray makes it difficult to identify their requirements for particular basal supplies of organic materials that, although not directly consumed, support the development of suitable food items.

The more links in the food web that carbon must pass through before reaching the highest trophic levels implies higher carbon losses. Therefore there will be reduced efficiency of energy transfer to higher trophic levels in bacterial dominated food webs (Sommer et al. 2002, Jansson et al. 2007, Lefebure et al. 2013). Substantial supplies of allochthonous organic materials are required if overall support is to be sustained for high trophic level organisms (Brett et al. 2012). Consequently, it is likely that the period over which heterotrophic food chains associated with microorganisms dominate the transfer of organic material to higher organisms will be short-lived unless access to flood delivered organic material extends beyond the period of flooding. This could occur if enhanced populations of microorganisms develop and remain in the river, or if transported organic material accumulates in river sediments or around flow barriers and provide continued support to the microbial pathway. Oliver and Lorenz (2013) demonstrated that heterotrophic activity reduced rapidly following a major flood in the lower River Murray, with little indication of substantial reserves of organic material to fuel the microbial loop being left in the river channel following the flood occurrence. Nevertheless, the microbial loop provides access to organic materials otherwise unobtainable by larger organisms.

The Lower Lakes

Much of the material transported by floods in the lower River Murray makes its way to the Lower Lakes, Coorong and Murray Mouth. The Lower Lakes are managed through the regulation of inflows from the river and of discharge through five barrages that separate the lakes from the river mouth and ocean influences. These large and shallow lakes are generally well mixed and often turbid due to frequent wind resuspension of sediments. Under the prevailing management regime, lake water levels and flushing rates are managed within set bounds. The hydrology of the lake varies annually according to water availability and seasonal conditions, interrupted occasionally by drought periods and wet years when uncontrolled floods moved through the river system. The longest recorded perturbation was due to the prolonged impact of the Millennium Drought (2000–2010) when inflows were minimal for almost a decade and lake depths fell to unprecedented levels, dramatically changing the environmental characteristics of the lakes and reducing the connectivity between the River Murray, Lower Lakes, Coorong and Murray Mouth.

The general patterns of occurrence of phytoplankton were reviewed by Aldridge et al. (2010). Although mixed communities of phytoplankton species occur in the lakes, particular groups are more likely to be dominant under certain conditions. During periods of high turbidity, low light availability and high nutrient availability, the filamentous green alga Planctonema lauterbornii has been dominant. In Lake Alexandrina from 1975 to 1978, P. lauterbornii accounted for >95% of algal cells (Geddes 1988, Baker 2000). Conversely, cyanobacterial blooms of Nodularia spumigena, Anabaena spp. and Aphanizomenon spp. occurred regularly in Lake Alexandrina and Lake Albert between 1990 and 1995 and were associated with extended periods of low flow, low turbidity, low turbulence, and high light availability. More specifically, the blooms of N. spumigena in the summer and autumn of 1990/91 and 1995 were associated with low flows (<10,000 ML.day⁻¹), moderate turbidity (<50 NTU), low conductivity (400–1,100 EC units) and variable nutrient concentrations (Baker 2000, Aldridge et al. 2010).
Towards the end of the Millennium Drought, between August 2008 and September 2009, when river inflows were minimal and lake depths fell to unprecedented levels, both Lake Alexandrina and Lake Albert regularly experienced blooms of picocyanobacteria, notably *Aphanocapsa* spp., *Planktolyngbya* spp., *Aphanizomenon* spp. and *Pseudanabaena* spp. (Aldridge et al. 2010). It was also during the extended drought period that the first recorded bloom of *Cylindrospermopsis raciborskii* occurred in the Lower Lakes in 2006 (Cook et al. 2008).

Although the data available for analyses are limited, it clearly demonstrates a strong influence of river flows on the types of phytoplankton that predominate within the Lower Lakes. However, there is essentially no information on 1) changes in phytoplankton production under different conditions, 2) heterotrophic populations that make up the microbial food chains, or 3) utilisation of the loads of organic carbon that are delivered with the river flows. As a result, the influence of flow on the basal sources of organic carbon within the lakes, and their importance in the food webs, cannot be determined at the current time.

**Coorong and Murray Mouth**

The biogeochemical conditions within the Coorong are influenced by the balance between freshwater flows over the barrages from the lakes and oceanic exchanges through the Murray Mouth. The Coorong is a long, closed coastal lagoon with the freshwater and oceanic inputs situated at the northern end. Conditions along the lagoon are strongly influenced by the longitudinal exchange of water and effects of evapoconcentration on the distal reaches where water exchange is particularly restricted. One outcome of these conditions is that very strong salinity gradients are set up along the lagoon, in extreme situations ranging from brackish at the northern end to six times seawater concentrations at the southern end (Brookes et al. 2009b).

There are several influences of River Murray inflows on the phytoplankton community of the Coorong. Water flowing through the lakes and over the barrages transports freshwater phytoplankton species into the Coorong. These flows also directly affect the hydrodynamic conditions and salinity levels in the Coorong. During periods of low or no flow over the barrages, usually associated with reduced river inflows to the lakes, the phytoplankton of the Coorong are dominated by estuarine and marine species of diatoms and flagellates (Geddes and Butler 1984, Geddes 1987). During a period of prolonged barrage closure in 2004–2005, when the Coorong was operating as a marine coastal lagoon two predominant marine diatoms, *Chaetoceros* and *Asterionella*, made up approximately 56.6% and 33.3%, respectively (collectively 89.9%) of the mean total cell number (Geddes and Francis 2008) and no freshwater species were observed (Geddes and Tanner 2007). Under these conditions a significant salinity gradient developed along the lagoon and halophytic species appeared, dominated by green algae of the genera *Nannochloris* particularly in the hypersaline southern sites where cell numbers were in excess of 1 million cells.mL\(^{-1}\) (Geddes and Tann 2007). Chlorophyll \(a\) levels increased in a north-south direction (low to high salinity) indicating increased productivity along the lagoon, but detailed hydrodynamic analyses suggested this resulted in part from the transport and concentration of cells down the lagoon due to water flow (Grigg et al. 2009). In contrast, during a period of high flow from the River Murray (1983–1984 mean flow of approximately 800 GL.month\(^{-1}\)) *Planktonema lauterbornii* was dominant at sites closest to the barrages, presumably transported in with the water from Lake Alexandrina, but as flows slowed, marine diatoms and flagellates became dominant again (Geddes 1987). Even after a small release in 2004 of Lake Alexandrina water into the Coorong (approximately 30–40 GL over 15 days in
2004), abundant numbers of freshwater phytoplankton (*Aphanocapsa, Monoraphidium, Crucigenia, Planktonema, Oocystis* and *Planktolyngyba*) were found in the North Lagoon (Geddes 2005) but decreased with distance from the barrage outflow.

Changes in the balance of inflows will also influence nutrient concentrations, organic carbon inflows, and turbidity within and between the Lower Lakes and Coorong region. High river flows, especially floods, transport large amounts of suspended and dissolved materials, most of which will be captured in the Lower Lakes (Cook *et al.* 2008). The organic material transported into the system is likely to make a significant contribution to productivity through the microbial food chain, but this cannot be assessed with current information. Primary production within the lakes is considered to be largely due to phytoplankton, although benthic biofilms may make significant contributions at times due to the extensive areas of shallow water, but there is no data to assess this. A similar lack of data exists for the Coorong, both of which are likely to have significant phytoplankton and biofilm production, and that also are influenced by the influx of organic material from upstream. Consequently the significance of the classical and microbial food chains in supporting the food webs of these systems is unknown, and the influence of inflows from the river under different flow conditions can only be surmised because of the important influences that depth, turbidity and water velocity have in addition to water quality and flow itself.

**Summary**

Studies in both marine and freshwater systems have investigated whether a connection of the microbial loop to the classical food chain provides a link between allochthonous organic carbon and the rest of the food web (Azémar *et al.* 2007). Some studies have provided support for the role of microorganisms as a link between allochthonous organic carbon and the classical food chain (Jansson *et al.* 2007), and as a major source of food for the larger organisms (Schmid-Araya and Schmid 2000, Pernthaler and Posch 2009), but debate still remains about their significance (Brett *et al.* 2012). It is generally accepted that the total production at the base of the food web largely determines the productivity at the top, but the organic carbon delivered to larger organisms will depend on the nature of the trophic links and the efficiency of transfers (Brett and Goldman 1997, Sommer *et al.* 2002, Lefebure *et al.* 2013). What is still poorly understood is the extent to which heterotrophic microbial pathways increase overall food web production in response to inputs of terrestrial dissolved organic matter (Jansson *et al.* 2007). In the River Murray, where external supplies of organic material are at times large, the role of heterotrophic microbial pathways is likely to be significant, but there is currently no direct information to assess this.
4.2 Microbiota

In riverine ecosystems microbiota provide a critical link within the aquatic food web. They feed on bacteria, phytoplankton and organic material (e.g. Jumars et al. 1989), and are preyed upon by organisms such as other microbiota, macroinvertebrates, fish, amphibians and birds (Lynch 1979, Crome 1985, Ranta and Nuutinen 1985, Arumugam and Geddes 1988, Meredith et al. 2003). The community is comprised of two main spatially distinct assemblages that often vary significantly in species composition and abundance, and thus their role within the ecosystem. These are 1) zooplankton that inhabit the open water and 2) littoral microfauna, which inhabit areas of fringing or submerged vegetation (Shiel 1995). Both of these assemblages contain a range of plankton that can be divided into two broad groups: namely, rotifers and a suite of microcrustaceans dominated by cladocerans, copepods and occasionally ostracods. These groups differ in their size ranges, life cycles and anatomical structures and will be used to classify and simplify the complex assemblages that occur within riverine ecosystems. These groups are defined below.

Group 1: Rotifers

Rotifers are present within all temporary and permanent habitats of the River Murray channel, Lower Lakes and Coorong (e.g. Geddes 1984, Shiel 1985, Boulton and Lloyd 1992). Examples of commonly found genus include Asplanchna, Anuraeopsis, Brachionus, Keratella, Collotheca, Conochilus, Hexarthra, Lecane, Colurella, Lepadella, Cephalodella, Synchaeta, Trichocerca and Filinia. Of all the numerous zooplankton groups, rotifers are the smallest in body size with most species <200 μm. The greatest rotifer biodiversity is found in ephemeral waters, where >100 co-occurring species have been collected in single net tows (Shiel et al. 1998). In anticipation of unfavourable conditions rotifers produce a resting egg, capable of undergoing a prolonged diapause through a range of unfavourable conditions (Allan 1976). Therefore rotifers can not only survive but thrive in ephemeral habitats. The resting eggs of all species do not respond to the same cues, therefore a succession of hatching events occurs, with associated assemblage changes over time (Tan and Shiel 1993). The life span of a female rotifer varies from approximately two days to three weeks. Rotifer abundance often reaches its maxima in spring to early summer.

Group 2: Microcrustaceans

The microcrustacean community of the lower River Murray is dominated by cladocerans, copepods and ostracods. Cladocerans are present within all temporary and permanent habitats of the River Murray channel and Lower Lakes (e.g. Geddes 1984, Shiel 1985, Boulton and Lloyd 1992). Examples of common genus include Bosmina, Chydorus, Daphnia, Ceriodaphnia and Moina. Mature females produce eggs that develop rapidly into miniature versions of the parent and lastly into mature reproductive females, completing the parthenogenetic stage. Due to overcrowding or other environmental stimuli that may signal impending unfavourable conditions, eggs are produced that develop into males while other eggs develop into sexually reproducing females. Following fertilization, resting eggs (ephippia) are produced. Time between the occurrence of stimuli indicating the onset of unfavourable conditions and production of a resting egg is longer for crustaceans than rotifers, making them more susceptible to rapidly changing conditions. Adults range in size from
approximately 500–3,000 μm and life span ranges from weeks to several months. Cladoceran abundance often reaches its maxima in late spring.

Copepods are also present within all temporary and permanent habitats of the River Murray channel and Lower Lakes (e.g. Geddes 1984, Shiel 1985, Boulton and Lloyd 1992). Copepods are commonly abundant in reservoirs, billabongs, weir pools and downstream reaches of the River Murray. Three groups of copepods occur within the River Murray: calanoid, cyclopoid and harpacticoids. The most abundant are calanoid copepods of the family Centropagidae (usually Boeckella and Calamoecia). Within the river main channel, cyclopoid copepods are less abundant, yet can be seasonally diverse and abundant in billabongs and ephemeral habitats (usually Australocyclops, Mesocyclops, Microcyclops and Eucyclops) (Shiel 1982, Geddes 1984). Harpacticoids are generally benthic in habitat, rarely occurring within the pelagic zone. Through sexual reproduction, copepods sometimes lay eggs directly into the water while others enclose them within a sac attached to the female’s body until they hatch. Some eggs have a tough shell and can lie dormant for extended periods of time. Copepods range approximately 800–8,500 μm in body length and life span ranges from weeks to several months. Copepod abundance has been found to be highly seasonal, reaching its maxima in summer (Shiel 1982).

Ostracods are sometimes abundant in billabongs and ephemeral habitats yet rarely in open water. They are typically about 1 mm in length. Some species lay eggs on submerged material or substratum and are also capable of withstanding unfavourable conditions.

**Key community drivers**

Source populations have a major influence on microinvertebrate species composition within rivers. In the lower River Murray, flows from the Darling River system deliver a warm-water rotifer dominated potamoplankton in contrast to the mid–upper River Murray’s cool–temperate microcrustacean dominated limnoplankton (Shiel and Aldridge 2011). Therefore, the community composition downstream is largely dependent upon the relative contributions from these sources; however, in general a mixed assemblage would typically be expected. The key hydrological drivers that then influence these assemblages are water residence time (WRT), water velocity and hydrological connectivity between habitats.

WRT affects the assemblage due to disparity in the period required for individuals to reach adult reproductive stages (i.e. rotifers are capable of reproducing within days, whereas microcrustaceans require weeks). Therefore, higher WRTs tend to favour microcrustacean dominated assemblages whereas lower WRTs favour rotifer dominated assemblages (e.g. Basu and Pick 1996, Sterner et al. 1996). Higher WRTs are also positively related to overall zooplankton abundance and biomass (e.g. Basu and Pick 1996, Sterner et al. 1996). High water velocities may inhibit grazing rates (e.g. above 0.18 m.s⁻¹; Miquelis et al. 1998) as well as reproduction, with suggestions that zooplankton reproduction rarely occurs at water velocities >0.4 m.s⁻¹ (Rzoska 1978). Flooding and hydrological connectivity between habitats can increase diversity in the river main channel as littoral, floodplain and wetland habitats (especially ephemeral) are believed to be primary sources of microbiota diversity within riverine ecosystems. Higher diversity often occurs in floodplain and wetland habitats due to emergence from the egg bank and presence of aquatic and semi-aquatic plant communities which increases the diversity of habitat available (Shiel 1976, 1981, Boulton and Lloyd 1992, Tan and Shiel 1993, Shiel et al. 1998, Ning et al. 2010, Lucena-Moya and Duggan 2011). The community is
likely to be dominated by rotifers within the first one to two weeks of inundation due to the shorter inundation time required to terminate diapause (e.g. Rees 1979) and their ability to rapidly colonise new habitats (Tan and Shiel 1993). The community then typically shifts towards crustacean dominated (e.g. Baranyi et al. 2002, Shiel et al. 2006, Furst 2014).

The magnitude of change in response to these hydrological conditions will be strongly influenced by many factors; however, key factors include seasonality, salinity and flooding history of ephemeral habitats (Shiel 1979, 1981, Boulton and Lloyd 1992, Jeppesen et al. 2005, Adrian et al. 2006). The peak growing season for each of the major microbiota groups is between spring and summer. Therefore, flows delivered during these periods are likely to illicit responses of greatest magnitude from the microbiota community. Salinity in the MDB, as in other systems is inversely related to microbiota species diversity as elevated salinity can affect the dispersal, emergence, reproduction and survival of zooplankton (Shiel 1979, Snell 1986, Nielsen et al. 2003, Brock et al. 2005, Brookes et al. 2009b). As a result of modification of the natural flow regime, salinisation is becoming an increasing threat within habitats of the River Murray and will significantly influence the ability of microbiota to respond to flows. The flooding history of ephemeral habitats (e.g. frequency of inundation and return intervals) can also significantly affect the diversity and abundance of organisms hatching from the egg bank (Boulton and Lloyd 1992). This is because floods replenish zooplankton egg banks while dry periods increase their susceptibility to factors such as senescence, weathering, trampling, predation, disease and dispersal (De Stasio 1989, Caceres and Hairston Jr 1998, Brendonck and De Meester 2003). Significant decreases in the diversity and abundance of microbiota emergence have been demonstrated when the duration between floods exceeds 11 years (Boulton and Lloyd 1992).
4.3 Vegetation

Plant functional groups

A total of 472 plant species have been recorded in the SA River Murray Corridor (main channel, floodplain, associated wetlands, Lower Lakes and Coorong) since 1988 (Appendix 1). They include 156 exotics, 18 of which are declared noxious in SA, eight Weeds of National Significance, nine species listed as rare and one species listed as endangered in SA. Due to the large number of species present it is impractical to take a species based approach to describe the response of plants to different flow bands; therefore, a functional approach based on species water regime preferences will be used for the ‘lower River Murray channel and floodplain’ and the Lower Lakes. The response of *Ruppia tuberosa* will be described for the Coorong because it is the only plant species in the system with a viable population.

Brock and Casanova (1997) developed a functional classification for plants growing in wetlands in the New England Tablelands region of northern NSW that classified plants into three broad categories: terrestrial (intolerant of flooding), amphibious (tolerates or responds to flooding and drying) and submergent (intolerant of desiccation). The terrestrial group was split further into terrestrial dry and terrestrial damp depending on desiccation tolerance (Brock and Casanova 1997). The amphibious group was split into five groups based on anatomy and whether a species changes morphologically to wetting and drying: 1) amphibious fluctuation tolerators – emergent (tolerated flooding and drying but required tissue to remain above the water surface), 2) amphibious fluctuation tolerators – woody (amphibious trees and shrubs), 3) amphibious fluctuation tolerators – low growing (small forbs, sedges and grasses that tolerated inundation and exposure), 4) amphibious fluctuation responders – plastic (changed morphologically to inundation and drying) and 5) amphibious fluctuation responders-floating (entire plants or organs floated on the water surface). Casanova (2011) modified the aforementioned framework by splitting the submergent group into two groups based on Grime’s (1979) competitive (K-selected) and ruderal (r-selected) classification: 1) submergent K-selected (species require permanent water) and 2) submergent r-selected (species are adapted to temporary water bodies and are present as extant plants during the inundated phase and present in the propagule bank during the dry phase). Casanova (2011) also added a new category, submerged emergent, which contains species adapted to permanent shallow water or saturated soil. The two classification frameworks work well at the wet end of the spectrum but do not take into consideration the large number of species that are only found on the floodplains of the lower River Murray in semi-arid to arid climates. These species are not found on the adjacent highlands, intolerant of inundation, and germinate as water levels recede but not in response to rainfall. In wetter climates these species are often classified as terrestrial because they are found in terrestrial ecosystems but in the lower River Murray the only environment with sufficient soil moisture to permit the completion of their life cycles is the floodplain soon after water levels have receded. Therefore, Nicol et al. (2010) proposed an additional group termed ‘floodplain’ species to differentiate species that germinate in response to rainfall (terrestrial species) and those that are restricted to floodplain environments.

Blanch et al. (1999b) devised a plant classification framework for the lower River Murray based on tolerance of species to exposure and inundation. The framework consisted of five groups: 1)
infrequently flooded, 2) widespread common species, generally tolerant of flooding and exposure, 3) common floodplain species, 4) uncommon floodplain species and 5) permanently flooded stable water levels (Blanch et al. 1999b). Whilst this framework was developed from data from the lower River Murray, it is less suitable than the frameworks proposed by Brock and Casanova (1997), Casanova (2011) and Nicol et al. (2010) because it used data collected after several large overbank floods. Terrestrial taxa are not represented because they were uncommon when the data were collected; furthermore, it only applies to river–floodplain systems and is not applicable to the Lower Lakes. Therefore, the frameworks proposed by Brock and Casanova (1997), Casanova (2011) and Nicol et al. (2010) will be used because they can be applied throughout the lower River Murray including the Lower Lakes and Coorong.

The use of a functional group approach to assess the response of the plant community to different flow bands has several advantages compared to a species or community based approach:

- Species with similar water regime preferences are grouped together, which simplifies systems with high species richness (especially where there are large numbers of species with similar water regime preferences);
- Predictions about the response of the plant community are made based on processes and does not require prior biological knowledge of the system;
- Is transferrable between systems; and
- Robust and testable models that predict the response of a system to an intervention or natural event can be constructed, which can in turn be used as hypotheses for monitoring programs.

However, there are limitations of the approach, including:

- Loss of information on species or communities (especially if there are species or communities of conservation significance or there is a pest plant problem);
- Uncertainty regarding which species should be classified into which functional group; and
- Important factors (e.g. salinity) are often not taken into consideration (additional factors can be included; however, this can often complicate the functional classification and in systems where there is low species richness the number of groups may be greater than the number of species).

The functional approach used to assess the response of the plant community to different flow bands is outlined in Table 4-2 and the relationship between depth and duration of inundation is presented in Figure 4-3. Two changes in terminology from the original classifications by Brock and Casanova (1997) and Casanova (2011) are used: the amphibious fluctuation responder-floating group is simply called the ‘floating’ group and the submergent emergent group is now called the ‘emergent’ group (Table 4-2). A list of species recorded in the lower River Murray since 2000 and their functional classification is presented in Appendix 1.
Table 4.2. Functional classification of plant species based on water regime preferences (modified from Brock and Casanova 1997, Casanova 2011).

<table>
<thead>
<tr>
<th>Functional group</th>
<th>Water regime preference</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial dry</td>
<td>• Will not tolerate inundation and tolerates low soil moisture for extended periods.</td>
<td>Atriplex vesicaria, Rhagadia spinescens, Enchylaena tomentosa</td>
</tr>
<tr>
<td>Terrestrial damp</td>
<td>• Will tolerate inundation for short periods (&lt;2 weeks) but require high soil moisture throughout their life cycle.</td>
<td>Centaurea calcitrapa, Chenopodium album, Fumaria bastardii</td>
</tr>
<tr>
<td>Floodplain</td>
<td>• Temporary inundation, plants germinate on newly exposed soil after flooding but not in response to rainfall.</td>
<td>Epaltes australis, Centipedes minima, Glinus lotoides</td>
</tr>
<tr>
<td>Amphibious fluctuation tolerators –</td>
<td>• Fluctuating water levels, plants do not respond morphologically to flooding and drying and will tolerate short-term complete submergence (&lt;2 weeks).</td>
<td>Cyperus gymnocoels, Juncus kraussii, Schoenoplectus pungens</td>
</tr>
<tr>
<td>emergent</td>
<td></td>
<td>Eucalyptus camaldulensis, Melaleuca halmaturorum, Duma florulenta</td>
</tr>
<tr>
<td>Amphibious fluctuation tolerators –</td>
<td>• Fluctuating water levels, plants do not respond morphologically to flooding and drying and are large perennial woody species.</td>
<td>Crassula helmsii, Brachycome basaltica</td>
</tr>
<tr>
<td>woody</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphibious fluctuation tolerators –</td>
<td>• Fluctuating water levels, plants do not respond morphologically to flooding and drying and are generally small herbaceous species.</td>
<td></td>
</tr>
<tr>
<td>low growing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphibious fluctuation responders –</td>
<td>• Fluctuating water levels, plants respond morphologically to flooding and drying (e.g. increasing above to below ground biomass ratios when flooded).</td>
<td>Persicaria lapathifolium, Ludwigia peploides, Myriophyllum verrucosum.</td>
</tr>
<tr>
<td>plastic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floating</td>
<td>• Static or fluctuating water levels, responds to fluctuating water levels by having some or all organs floating on the water surface.</td>
<td>Azolla spp., Lemna spp., Spirodela punctata</td>
</tr>
<tr>
<td>Submergent r-selected</td>
<td>• Temporary wetlands that hold water for &gt; four months.</td>
<td>Ruppia tuberosa, Ruppia polycarpa, Lamprothamnium papulosum</td>
</tr>
<tr>
<td>Emergent</td>
<td>• Static shallow water &lt;1 m or permanently saturated soil.</td>
<td>Typha spp., Phragmites australis, Schoenoplectus validus</td>
</tr>
<tr>
<td>Submergent K-selected</td>
<td>• Permanent water.</td>
<td>Vallisneria australis, Potamogeton crispus, Myriophyllum salsugineum</td>
</tr>
</tbody>
</table>
The ‘terrestrial dry’ functional group is intolerant of flooding and taxa will persist in environments with low soil moisture (Table 4-2) (Brock and Casanova 1997). Taxa from this functional group often invade wetlands that have been drawn down for an extended period or floodplains where there has been a lack of flooding but are often restricted to highlands that never flood (Brock and Casanova 1997).

Taxa in the ‘terrestrial damp’ group will tolerate inundation for short periods and require high soil moisture to complete their life cycle (Table 4-2) (Brock and Casanova 1997). Taxa from this functional group are often winter annuals, perennial species that grow around the edges of permanent water bodies where there is high soil moisture or species that colonise wetlands shortly after they are drawn down and riparian zones and floodplains shortly after flood waters recede (Brock and Casanova 1997).

Taxa in the ‘floodplain’ functional group exhibit most of the traits of terrestrial species; they are generally intolerant of long-term inundation but are restricted to areas that flood periodically (they are absent from the highlands) because they germinate after flood waters recede or wetlands are drawn down, not in response to rainfall (Table 4-2) (Nicol 2004). Taxa from this functional group colonise floodplains and riparian zones after flood waters have receded and when wetlands are drawn down (Nicol 2004). Floodplain species often have flexible life history strategies, they grow whilst soil moisture is high and flower and set seed (after which most species die) in response to low soil moisture (Nicol 2004).

The ‘amphibious fluctuation tolerator – emergent’ group consists mainly of emergent sedges and rushes that prefer high soil moisture or shallow water but require their photosynthetic parts to be
emergent, although many will often tolerate short-term submergence (Table 4-2) (Brock and Casanova 1997). Taxa from this group are often found on the edges of permanent water bodies, in seasonal and temporary wetlands, in riparian zones and areas that frequently wet and dry.

Species in the ‘amphibious fluctuation tolerator – woody’ group have similar water regime preferences to the amphibious fluctuation tolerator – emergent group (Figure 4-3) and consist of woody perennial species (Table 4-2) (Brock and Casanova 1997). Plants generally require high soil moisture in the root zone but there are several species (e.g. lignum) that are tolerant of desiccation for extended periods (Roberts and Marston 2011). Species in this functional group are generally found on the edges of permanent water bodies, in seasonal and temporary wetlands, in riparian zones and areas that frequently wet and dry.

The ‘amphibious fluctuation tolerator – low growing’ group have similar water regime preferences to the amphibious fluctuation tolerator – emergent and amphibious fluctuation tolerator–woody group (Figure 2); however, some species can grow totally submerged except during flowering (when there is a requirement for a dry phase) (Table 4-2) (Brock and Casanova 1997). Species in this functional group are generally found on the edges of permanent water bodies, in seasonal and temporary wetlands, in riparian zones and areas that frequently wet and dry but species are usually less desiccation tolerant than species in the other amphibious tolerator groups (Figure 4-3).

The ‘amphibious fluctuation responder – plastic’ group occupies a similar zone to the amphibious fluctuation tolerator – low growing group; except that they have a physical response to water level changes such as rapid shoot elongation or a change in leaf type (Brock and Casanova 1997). They can persist on damp and drying ground because of their morphological flexibility but can flower even if the site does not dry out. They occupy a slightly deeper/wet for longer area than the amphibious fluctuation tolerator – low growing group (Figure 4-3).

Species in the ‘floating’ functional group float on the top of the water (often unattached to the sediment) with the majority of species requiring the presence of free water of some depth year round; although, some species can survive and complete their life cycle stranded on mud (Table 1) (Brock and Casanova 1997). Taxa in this group are usually found in permanent water bodies, often forming large floating mats upstream of barriers (e.g. weirs), in lentic water bodies and slack waters.

‘Submergent r-selected’ species colonise recently flooded areas (Table 4-2) and show many of the attributes of Grime’s (1979) r-selected (ruderal) species, which are adapted to periodic disturbances. Many require drying to stimulate germination on rewetting; they frequently complete their life cycle quickly and die off naturally. They persist via a dormant, long-lived bank of seeds, spores or asexual propagules (e.g. Ruppia tuberosa and Ruppia polycarpa turions in the soil) (Brock 1982). They prefer habitats that are annually flooded to a depth of >10cm but can persist as dormant propagules for a number of years in temporary and ephemeral wetlands.

The ‘emergent’ group consists of taxa that require permanent shallow water or a permanently saturated root zone, but require emergent leaves or stems (Table 4-2). They are often found on the edges of permanent water bodies and in permanent water up to 2 m deep (depending on species) or in areas where there are very shallow water tables that result in soil saturation at the surface or in the root zone (Roberts and Marston 2011).
‘Submergent K-selected’ species require permanent water >10 cm deep for more than a year to either germinate or reach sufficient biomass to start reproducing (Table 4-2) (Roberts and Marston 2011). Species in this group show many of the attributes of Grime’s (1979) K-selected (competitor) species that are adapted to stable environments and are only found in permanent water bodies. The depth of colonisation of submergent K-selected species is dependent on photosynthetic efficiency and water clarity (sensu Spence 1982).
4.4 Macroinvertebrates

Macroinvertebrate taxa in the lower River Murray

The macroinvertebrate community of the lower River Murray consists largely of taxa which are tolerant of stable flow (Sheldon and Walker 1998). This is especially so within the main channel as a consequence of river regulation and weir pool environments which favour lentic over lotic species. High flows, which produce infilling of wetlands and increased flow velocity, are likely to increase the flow niches available (Sheldon and Thoms 2006). Macroinvertebrates respond rapidly to changes in flow and therefore can be used as short-term indicators of ecological response to changes in flow regimes (Boulton and Lake 1992). Increases in diversity are likely to be a result of increased flow variability and improved water quality, food availability and habitat availability including submerged wood and emergent plants. Previous work in the Chowilla Floodplain revealed the greatest diversity of macroinvertebrate in off-channel habitats, associated with increased flow velocity and increased aquatic plant diversity (Boulton and Lloyd 1991). Changes to food sources such as the increase of filamentous algae have also been reported as a consequence of regulation, and has consequences for macroinvertebrate species, particularly decapods (Burns and Walker 2000a).

Macroinvertebrate traits are increasingly being used in the assessment of macroinvertebrate responses to flow (Beche et al. 2006, Schäfer et al. 2011). Species traits provide the ability to hypothesise and test the mechanisms by which trait groups may respond to flow (Poff 1997). Such approaches group taxa on the basis of similar morphology, habitat preference or other characteristics rather than on the basis of taxonomy (Poff et al. 2006). This approach is somewhat similar to that of guilds of plants or fish but reduces the importance of taxonomic classification considerably. Multiple traits which have various combinations across taxa are used. Traits therefore provide greater potential to develop predictive hypotheses to measure and compare different aspects of community composition such as resilience and functional diversity.

Trait analysis was undertaken to determine preliminary trait groupings for a subset of the macroinvertebrates of the lower River Murray. Trait groups were then used to predict potential responses specific flow bands prescribed for the lower River Murray. Predicted responses to the flow bands based on the trait groups are provided below.

Trait group analysis

Macroinvertebrate family lists from the lower River Murray were sourced from past Sustainable Rivers Audit (SRA) reports (Davies et al. 2010). Given availability of the data at the time of writing only the first SRA was used. Trait groupings were then determined from eight traits adapted from Schäfer et al. (2011), with a total of 32 trait states used in these analyses (Table 4-3). A categorical matrix was created using each trait state (unique value of a trait) coded in a binary fashion (each family against each trait state). A resemblance matrix was created based on the Gower dissimilarity measure, which is suitable
for categorical data. Data were clustered using group averaging trait groups from the cluster. These were statistically confirmed as ‘groups’ using ANalysis Of SIMilarities (ANOSIM). A multi-dimensional scaling (MDS) plot is used to graphically present the grouping of families into trait groups. Traits that substantially contributed to the differences between groups were determined by SIMilarity PERcentages (SIMPER) analysis (Appendix 2 and Appendix 3). All analyses were conducted using PRIMER version 6 (Clarke and Gorley 2006). Each trait group was then conceptualised in terms of its expected response to each flow band. While hypothesised responses to each flow band are provided, it needs to be recognised that macroinvertebrate communities respond not only to individual flow events within a year but to flow regimes over time (Walker and Thoms 1993).

It also should be noted that this analysis is preliminary as it only includes macroinvertebrate families collected as part of the first SRA from the lower River Murray, most key families are included without bias as to the numbers recorded. These data have been used to make general predictions about trait groups. Molluscs and to a lesser extent crustaceans are not adequately covered by these data. Despite these limitations, it provides a useful starting point for conceptualising responses to flow bands based on a mechanistic understanding of response.
### Table 4-3. Macroinvertebrate traits and trait state adapted from (Schäfer et al. 2011).

<table>
<thead>
<tr>
<th>Trait</th>
<th>Trait state</th>
<th>Code</th>
<th>Resistance/resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiol. sensitivity to salinity (mS.cm⁻¹)</td>
<td>Low &lt;7</td>
<td>EC1</td>
<td>Resistance</td>
</tr>
<tr>
<td></td>
<td>Medium 7‒20</td>
<td>EC2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium to high 20‒50</td>
<td>EC3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High &gt;50</td>
<td>EC3</td>
<td></td>
</tr>
<tr>
<td>Time until maturity (years)</td>
<td>&lt;0.5</td>
<td>mat1</td>
<td>Resilience</td>
</tr>
<tr>
<td></td>
<td>0.5‒1</td>
<td>mat2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;1</td>
<td>mat3</td>
<td></td>
</tr>
<tr>
<td>Reproduction type</td>
<td>Aquatic eggs</td>
<td>repro1</td>
<td>Resilience</td>
</tr>
<tr>
<td></td>
<td>Terrestrial eggs</td>
<td>repro2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ovoviviparity</td>
<td>repro3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eggs attached to male adults</td>
<td>repro4</td>
<td></td>
</tr>
<tr>
<td>Food source</td>
<td>Detritus</td>
<td>food1</td>
<td>Resilience</td>
</tr>
<tr>
<td></td>
<td>Plants</td>
<td>food2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>food3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mixture</td>
<td>food4</td>
<td></td>
</tr>
<tr>
<td>Respiration mode</td>
<td>Atmospheric</td>
<td>resp1</td>
<td>Resistance</td>
</tr>
<tr>
<td></td>
<td>Air (plants)</td>
<td>resp2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cutaneous</td>
<td>resp3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gills</td>
<td>resp4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plastron and gills</td>
<td>resp5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pneumostome</td>
<td>resp6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spiracle</td>
<td>resp7</td>
<td></td>
</tr>
<tr>
<td>Generations per year</td>
<td>&lt;1</td>
<td>volt1</td>
<td>Resilience</td>
</tr>
<tr>
<td></td>
<td>1 up to 2</td>
<td>volt2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Up to 5</td>
<td>volt3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Up to 10</td>
<td>volt4</td>
<td></td>
</tr>
<tr>
<td>Duration of life stages out of water</td>
<td>No terrestrial phase, obligate aquatic</td>
<td>dur.terr1</td>
<td>Resilience</td>
</tr>
<tr>
<td></td>
<td>Short-term terrestrial phase (weeks)</td>
<td>dur.terr2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium-term terrestrial phase 1‒3 months</td>
<td>dur.terr3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extended terrestrial phase</td>
<td>dur.terr4</td>
<td></td>
</tr>
<tr>
<td>Dispersal</td>
<td>Low dispersal ability</td>
<td>disp1</td>
<td>Resistance/Resilience</td>
</tr>
<tr>
<td></td>
<td>Drift a strong vector for dispersal</td>
<td>disp2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flight a strong vector for dispersal</td>
<td>disp3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drift and flight both used</td>
<td>disp4</td>
<td></td>
</tr>
</tbody>
</table>
Results

Five trait groups based on the binary coding of 32 trait states were determined by cluster analysis at a cut off of 70% similarity. An MDS based on Gower similarities is presented in Figure 4-4, which displays the grouping of families into trait groups. The individual trait states correlated to these groups and contribution to the differences are overlayed.

![Figure 4-4. MDS plot of Gower similarities of Macroinvertebrate trait groups for the lower River Murray. Trait groups were determined from Cluster analysis.]

**Trait group characteristics**

**Group A**

Representative families: Caenidae, Hydropsychidae, Leptophlebiidae, Orthocladiinae

Trait group A was characterised by aquatic eggs requiring full submersion for development, medium time to mature (0.5–1 year), a medium to low tolerance of increased salinity levels, and a food source of predominantly detritus.

**Group B**

Representative families: Corduliidae, Elmidae, Pyralidae, Tipulidae

Trait group B was characterised by low tolerance to increased salinity, aquatic eggs requiring full submersion for development and, low dispersal ability, (however Corduliidae are an exception here) with a short terrestrial phase up to weeks.
Group C

Representative families: Dytiscidae, Ephydridae, Hebridae, Hydrophilidae, Mesoveliidae, Notonectidae, Staphylinidae, Veliidae and Nemertea

Trait group C was characterised by short maturation time of <6 months, predatory food acquisition, low dispersal ability, with terrestrial eggs which do not require immersion and respiration using a pneumostome. This group consists of primarily aquatic beetles and true bugs.

Group D

Representative families: Atyidae, Corbiculidae, Hymenosomatidae, Perthiidae, Parastacidae, Palaemonidae

Trait group D consisted primarily of decapods and was characterised by ovoviviparity, detrital food source and obligate aquatic life stages. This group has a medium to high salinity tolerance.

Group E

Representative families: Arrenuridae, Aturidae, Chironominae (subfamily), Enchytraeidae, Glossiphoniidae, Halacaridae, Hydraecarina, Hydropsyliidae, Hydryphantidae, Hygrobatidae, Oligochaeta, Oxidae, Pezidae, Pionidae, Psychodidae, Spongillidae, Tubificidae, Unionicolidae

Group E exhibited the largest number of families with diverse taxonomy (several orders). This group was characterised by short maturation time, multivoltinism of up to ten generations per year, with mostly constant requirement for water with no terrestrial phase or very short one as in the case of several families of Diptera (Psychodidae, Chironomidae and Tubificidae). These taxa are likely to have adapted to stable conditions in the Murray requiring no terrestrial phase and have a medium tolerance of salinity.

Given the use of trait information based on published literature the predictions can be classed as moderately certain, although there is no specific information attached to each of the flow bands. Predictions below relate to the delivery of the specific flow band not the successive delivery of a flow regime. In general, a variable flow regime, encompassing all flow bands overtime (Walker and Thoms 1993) is required to maintain and establish a diverse and resilient macroinvertebrate community with a diverse and resilient range of traits.
4.5 Frogs

River regulation and recent drought has had a substantial impact on ecosystem processes and aquatic biota, including frog populations in SA. A reduction in the extent, duration and frequency of flooding in the lower River Murray, and increased incidences of drought, negatively impact on all frog species found within the SA River Murray corridor (Carey and Alexander 2003, Hazell 2003, Piha et al. 2007). Species reliant on seasonal flooding are at risk as a result of reduced flooding frequencies, which is forecast to be exacerbated by climate change (Gonzalez et al. 2011). Species dependent on flooding cues may suffer reduced recruitment opportunities and shortened flooding duration may also result in species being unable to complete breeding cycles. Reduced flooding frequency, duration and extent are likely to result in a decline in vegetation health and reduced available habitat for frogs. Fewer floods may also lead to an increase in salinity due to less available freshwater and drier climate conditions. As a result, those species that exhibit narrow habitat and physiological requirements, such as low salinity tolerances, limited dispersal ability, low reproductive capacity and recruitment rates, are at greater risk of decline due to reductions in flooding (Gonzalez et al. 2011).

Frog species found within the SA River Murray corridor occupy water bodies with a range of hydrological characteristics from permanent to newly inundated ephemeral wetlands and creeks, and highly modified environments such as dams (Gonzalez et al. 2011). The Peron’s tree frog (Litoria peronii), for example, occupies a range of permanent and temporary water bodies (Wassens 2011), but prefers deeper open ponds for breeding. In contrast, the southern bell frog (Litoria raniformis) is typically associated with seasonally flooded wetlands with complex aquatic vegetation communities (Wassens 2011). The southern bell frog is reliant on flooding of temporary wetlands where individuals move seasonally for breeding and then move back to permanent water bodies when temporary habitats dry out (Pyke 2002, Wassens et al. 2008a, Mason and Hillyard 2011). As a result, the southern bell frog is threatened due to reduced flooding frequency and duration in the SA section of the MDB (Gonzalez et al. 2011). Widely distributed across the south-eastern MDB in the past, in recent years the species has undergone major declines (Wassens 2011). This has led to the species being listed as nationally threatened (vulnerable under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999), threatened in SA (National Parks and Wildlife Act 1972), endangered in NSW (Threatened Species Conservation Act 1995), vulnerable in Tasmania (Threatened Species Protection Act 1995) and threatened in Victoria (Flora and Fauna Guarantee Act 1988).

Although most frog species can utilise wetlands with a range of water regimes, they are highly dependent on inundated vegetation and/or physical habitat, such as snags or fallen timber. Emergent vegetation or physical structure (e.g. rocks) is important breeding habitat and required for the anchoring of eggs for the eastern banjo frog (Limnodynastes dumerilii) (Tyler 1977). Most other species prefer to breed in water bodies where abundant, complex and diverse emergent, submerged and fringing vegetation exists (Jansen and Healey 2003, Gonzalez et al. 2011, Wassens 2011, Wassens and Maher 2011). The spotted grass frog (Limnodynastes tasmaniensis) shows a preference for areas where submerged vegetation such as Myriophyllum spp. form dense mats, or water bodies fringed by a range of riparian vegetation such as Cyperus spp. and Paspalum distichum (Gonzalez et
Peron’s tree frog also shows a preference for habitats with emergent vegetation and large trees such as river red gums (Hazell et al. 2004, Wassens 2011).

Frog response to flooding or flow pulses includes three phases: 1) males calling at potential breeding sites to attract females to spawn, 2) tadpole development and 3) metamorphosis (Wassens 2011). The level of frog response to flooding is dependent on many variables such as timing of inundation, vegetation cover, predator abundance and water quality. For example, some species breeding activity is restricted to particular seasons and may not respond to flood events if they occur outside these seasons (Jakob et al. 2003). All species found in the SA MDB are active and known to call and spawn over the spring and summer months, with some species known to breed throughout the year depending on environmental conditions, such as rainfall and temperature (Gonzalez et al. 2011).

**Frog species in the lower River Murray**

Eight frog species are distributed along the SA River Murray floodplain corridor. Five species are known to occur along the length of the River Murray corridor in SA from the fringing Lower Lakes wetlands to the SA border:

- Eastern banjo frog;
- Spotted grass frog;
- Southern bell frog;
- Long-thumbed frog (*Limnodynastes fletcheri*); and
- Peron’s tree frog.

Three species have a limited distribution along the corridor, they are:

- Common froglet (*Crinia signifera*) and brown tree frog (*Litoria ewingii*) found within the lower reaches of the River Murray in SA;
- Eastern sign-bearing froglet (*Crinia parinsignifera*) found within the mid to upper reaches of the River Murray in SA.

Three further species (i.e. the painted burrowing frog, *Neobatrachus pictus*; Sudell’s frog, *Neobatrachus sudelli*, and Bibron’s toadlet, *Pseudophyrne bibronii*) have been intermittently observed within the SA River Murray corridor, but are not commonly found along the river corridor and have been excluded from the conceptual models. The breeding habitat, tadpole and adult requirements of these eight species are described below and were used to develop conceptual models on the response of frogs to varying flows within the River Murray in SA.
Breeding habitat and requirements

Table 4-4. Preferred wetland type and hydrology in relation to breeding habitat and requirements of frogs of the South Australian Murray-Darling Basin.

<table>
<thead>
<tr>
<th>Species</th>
<th>Preferred breeding habitat and wetland hydrology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern sign-bearing froglet</td>
<td>• Breeds in a broad range of wetland types with a preference for diverse aquatic vegetation or submerged grasses (Wassens 2011).</td>
</tr>
<tr>
<td></td>
<td>• Usually breeds in temporary water bodies but can also use shallow permanent sites with abundant vegetation (Wassens and Maher 2011).</td>
</tr>
<tr>
<td>Common froglet</td>
<td>• Breeds in a broad range of wetland types and is especially noted for frequent use of highly ephemeral sites following wet weather. Has a preference for diverse aquatic vegetation or submerged grasses (Wassens 2011, Hazell et al. 2004).</td>
</tr>
<tr>
<td>Eastern banjo frog</td>
<td>• Breeds in a broad range of habitat and wetland types (Tyler 1977).</td>
</tr>
<tr>
<td></td>
<td>• Responds to flooding to breed in temporary water bodies but will also breed in permanent water bodies (Gonzalez et al. 2011).</td>
</tr>
<tr>
<td>Long-thumbed frog</td>
<td>• Breeds in a broad range of wetland types and can be widespread through permanent reaches, but temporary reaches more likely to support breeding (Wassens and Maher 2011).</td>
</tr>
<tr>
<td></td>
<td>• Prefers sites containing abundant submerged vegetation, with males calling while hidden among clumps of floating grasses and vegetation near the edge of water bodies (Anstis 2002).</td>
</tr>
<tr>
<td>Spotted grass frog</td>
<td>• Prefers temporary shallow breeding sites, containing abundant aquatic vegetation, although shallow, well vegetated permanent sample sites are also used (Wassens and Maher 2011).</td>
</tr>
<tr>
<td></td>
<td>• Readily colonises any wet freshwater area and wetland type (Healey et al. 1997).</td>
</tr>
<tr>
<td>Brown tree frog</td>
<td>• Flexible life history strategies enables the species to colonise a range of breeding sites exhibiting different conditions and is able to exploit highly ephemeral rain fed sites due to short larval phase (Lauck et al. 2005).</td>
</tr>
<tr>
<td></td>
<td>• Habitat generalist recorded in a range of temporary and permanent wetland types (Anstis 2002).</td>
</tr>
<tr>
<td>Peron’s tree frog</td>
<td>• Utilises a wide range of permanent, semi-permanent and temporary wetland types, however temporary reaches more likely to support breeding (Wassens and Maher 2011).</td>
</tr>
<tr>
<td></td>
<td>• Prefers emergent vegetation and larger trees at water margins (Anstis 2013), and rarely breeds in very shallow well vegetated water bodies (Wassens 2011).</td>
</tr>
<tr>
<td>Southern bell frog</td>
<td>• Strong preference for temporary water bodies with large areas of lignum or complex aquatic vegetation communities with an overstorey of river red gums or black box (Wassens 2011).</td>
</tr>
<tr>
<td></td>
<td>• May move to seasonally flooded or temporary wetlands for breeding, and return to permanent water bodies when temporary habitats dry out (Pyke 2002).</td>
</tr>
<tr>
<td></td>
<td>• May favour a low to moderate cover of fringing vegetation rather than no or dense vegetation (Turner et al. 2011).</td>
</tr>
</tbody>
</table>
### Table 4-5. Characteristics of the eggs of frogs of the South Australian Murray–Darling Basin

<table>
<thead>
<tr>
<th>Species</th>
<th>Eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern sign-bearing froglet</td>
<td>• Eggs very small, laid singly, well separated and attached to grass stems or the substrate in shallow, often muddy water (Anstis 2002).</td>
</tr>
</tbody>
</table>
| Common froglet           | • Deposit eggs loosely on the pool bottom and are not as susceptible to fluctuations in water level as other species (Hazell et al. 2003).  
                          | • Females capable of producing three (and as many as four) clutches a year (Lemckert and Shine 1993). |
| Eastern banjo frog       | • Anchor foam nest of eggs to emergent vegetation or stones (Tyler 1977). |
| Long-thumbed frog        | • Require vegetation to attach foam egg masses (Wassens 2011).        |
| Spotted grass frog       | • Produce foam nests on water surface (Wassens 2011), so species is able to use wetlands with fluctuating water levels and can take advantage of flooding after rain that recedes rapidly (Hazell et al. 2003).  
                          | • Females may produce multiple clutches throughout year (Ulkrin 1980). |
| Brown tree frog          | • Eggs laid in fluid, melded globular clutches attached to submerged reeds, vegetation or twigs (Anstis 2013). |
| Peron’s tree frog        | • Eggs laid singly in small groups near sides of ponds among leaf litter or vegetation or attached horizontally along stems or twigs (Anstis 2013). |
| Southern bell frog       | • Eggs are contained within a floating jelly raft that eventually breaks up and sinks.  
                          | • Egg laying occurs within days of flooding and tadpoles hatch 2–4 days later (Schultz 2005). |
Table 4-6. Season and cues in relation to breeding habitat and requirements of frogs of the South Australian Murray-Darling Basin.

<table>
<thead>
<tr>
<th>Species</th>
<th>Seasons and cues</th>
</tr>
</thead>
</table>
| Eastern sign-bearing froglet| • Usually breeds in spring and summer but will also breed successfully in autumn and winter following flooding or heavy rain (Anstis 2013).  
                               | • Described as ‘frequent breeders’ with eggs laid throughout the year (Anstis 2013).                                                         |
| Common froglet              | • Prefers cooler temperatures and generally breeds through winter autumn and spring but will breed at any time of the year depending on the availability of habitat and temperature (Anstis 2002).  
                               | • Described as ‘frequent breeders’ with eggs laid throughout the year (Anstis 2013).                                                         |
| Eastern banjo frog          | • Calling is most intense after heavy rains and mass spawning can occur on the same one of two nights (Anstis 2002).                            
                               | • Breeding is most likely to occur in spring and summer but species can be active at any time of the year (Tyler 1977).                        
                               | • Spawning is typically communal with large numbers of individuals breeding simultaneously at a site, usually on warm, wet nights (Ulkrin 1980). |
| Long-thumbed frog           | • Most likely to breed in spring and summer but can also be active during warmer late winter weather and into autumn (Anstis 2013).            |
| Spotted grass frog          | • Breeding is opportunistic and may occur at any time of year, with males calling through spring, summer, autumn, and mild winter weather, especially after rain (Wassens 2011), but usually peaks in summer and autumn (Anstis 2013). |
| Brown tree frog             | • Does not have a distinct breeding season; calls and breeds at any time of the year (Anstis 2013).                                          |
| Peron’s tree frog           | • Although calling and spawning are restricted to spring and summer, tadpoles may linger within water bodies until April (Wassens 2011).          |
| Southern bell frog          | • Shown to breed over a protracted season, i.e. August–February, in response to flooding (M. Schultz pers.comm.).                             |
Tadpoles

Table 4.7. Habitat requirements of tadpoles of frogs of the South Australian Murray-Darling Basin.

<table>
<thead>
<tr>
<th>Species</th>
<th>Habitat requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern sign-bearing froglet</td>
<td>• Short tadpole phase: wetlands should retain water for six weeks if flooded in spring/summer or three months if flooded in winter (Wassens 2011).&lt;br&gt;• Can respond to declining water by accelerating development, however, the resulting metamorphs are smaller and survival rate in the terrestrial stage significantly lower (Lane and Mahony 2002).&lt;br&gt;• Bottom dwellers and are very well camouflaged (may reduce predation). When disturbed they dart under cover among leaf litter or vegetation (Anstis 2013).&lt;br&gt;• Detritivores and herbivores, feeding on biofilms, algae and detritus (Wassens 2011).&lt;br&gt;• Spikes in recruitment when common carp (Cyprinus carpio) are removed indicate that competition and predation by common carp may limit egg and tadpole survival (Gonzalez et al. 2011).</td>
</tr>
<tr>
<td>Common froglet</td>
<td>• Short tadpole phase: six weeks to three months depending on environmental conditions (Anstis 2013).&lt;br&gt;• Feeds on microscopic plant matter and sediments on the substrate (Anstis 2013).&lt;br&gt;• Other characteristics same as above.</td>
</tr>
<tr>
<td>Eastern banjo frog</td>
<td>• Medium to very long tadpole phase with duration dependent on temperature, e.g. 12–15 months when cool, or as little as 4–5 months when warm (Anstis 2013).&lt;br&gt;• Largely bottom dwellers and are generally rather sedentary unless disturbed, but are capable of swimming fairly fast and using the entire tail for motion (Anstis 2013).&lt;br&gt;• Feed on sediment and vegetation (Anstis 2013).&lt;br&gt;• Predation on tadpoles by introduced fish, e.g. common carp and eastern gambusia (Gambusia holbrooki) is not specifically documented but is expected to be high for most frog species (Gonzalez et al. 2011).</td>
</tr>
<tr>
<td>Long-thumbed frog</td>
<td>• Tadpole phase is 4–5 months when wetlands are flooded through spring and summer (Wassens et al. 2008a).&lt;br&gt;• Largely bottom dwellers, but range throughout most parts of the water body and feed at the surface. They are capable of strong fast swimming when disturbed (Anstis 2013).&lt;br&gt;• Feed on vegetation and sediments as well as any available protein (Anstis 2013).</td>
</tr>
<tr>
<td>Species</td>
<td>Habitat requirements</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Spotted grass frog</strong></td>
<td>• Short tadpole phase, requiring 2.5–4 months to reach metamorphosis, depending on water temperature (Anstis 2013).</td>
</tr>
<tr>
<td></td>
<td>• Most often bottom dwellers when feeding and resting, but also feed in any area of the water body (Anstis 2013).</td>
</tr>
<tr>
<td></td>
<td>• Feed on vegetation and sediments as well as any available protein such as dead insects or tadpoles (Anstis 2013).</td>
</tr>
<tr>
<td></td>
<td>• Generally more abundant in areas with aquatic vegetation (Wassens 2011).</td>
</tr>
<tr>
<td></td>
<td>• Eggs and tadpoles are predated on by common carp and eastern gambusia (Hazell <em>et al.</em> 2004).</td>
</tr>
<tr>
<td><strong>Brown tree frog</strong></td>
<td>• Short tadpole phase of 1.5–2 months (Lauck <em>et al.</em> 2005).</td>
</tr>
<tr>
<td></td>
<td>• Frequent surface of water bodies (may be more detectable to predators) but are fast agile swimmers and will dart to deeper water if disturbed (Anstis 2013).</td>
</tr>
<tr>
<td></td>
<td>• Feed mostly on vegetation or other matter near surface (Anstis 2013).</td>
</tr>
<tr>
<td></td>
<td>• Laboratory study found tadpoles to experience heavy predation from odonates (Peterson <em>et al.</em> 1992).</td>
</tr>
<tr>
<td><strong>Peron’s tree frog</strong></td>
<td>• Medium to long tadpole phase of ~3.5 months (Anstis 2002).</td>
</tr>
<tr>
<td></td>
<td>• Often cruise near the surface and may hide among vegetation in warmer shallow water during the day, are very agile and can rapidly change direction (Anstis 2013).</td>
</tr>
<tr>
<td></td>
<td>• Feed mainly on vegetation but can eat large floating dead insects (Anstis 2013).</td>
</tr>
<tr>
<td><strong>Southern bell frog</strong></td>
<td>• Short to moderate tadpole phase of 2–12 months, with shorter tadpole phases exhibited in temporary wetlands (Clemann and Gillespie 2010).</td>
</tr>
<tr>
<td></td>
<td>• Development times are likely to be driven by water temperature and food availability (Gonzalez <em>et al.</em> 2011).</td>
</tr>
<tr>
<td></td>
<td>• Longer hydroperiods may improve metamorph survivorship due to enhanced foraging opportunities (Wassens 2011).</td>
</tr>
<tr>
<td></td>
<td>• Agile swimmers diving straight to deep water if disturbed (Anstis 2013).</td>
</tr>
<tr>
<td></td>
<td>• Highly sensitive to competition/predation/disturbance by exotic species such as common carp, eastern gambusia and redfin perch (<em>Perca fluviatilis</em>).</td>
</tr>
<tr>
<td></td>
<td>• Recruitment frequently fails at wetlands with high common carp abundances and removal can cause spikes in recruitment (Gonzalez <em>et al.</em> 2011).</td>
</tr>
<tr>
<td></td>
<td>• Likely to have been found at sites that excluded common carp from the wetland, or have denser submerged habitat that limit the impact of common carp on the vegetation habitats (Wassens <em>et al.</em> 2008a).</td>
</tr>
</tbody>
</table>
**Adults**

Table 4-8. Habitat of adult frogs of the South Australian Murray–Darling Basin

<table>
<thead>
<tr>
<th>Species</th>
<th>Habitat requirements</th>
</tr>
</thead>
</table>
| Eastern sign-bearing froglet | - Positive association of adults with vegetation along the River Murray in SA (Healy *et al.* 1997).  
- Occur among dense aquatic vegetation at the water’s edge (Tyler 1994).                                                                                     |
| Common froglet           | - Same as above.                                                                                                                                                                                                       |
| Eastern banjo frog       | - Lives in small holes beneath damp wood or stones; aestivates in a sealed burrow during summer (Tyler 1977).                                                                                                          |
| Long-thumbed frog        | - Aquatic species found in water or sheltering in moist places (Amey and Grigg 1995).  
- Only occurs among dense aquatic vegetation at the water’s edge along the River Murray (Tyler 1994).  
- Shelters during the day under large rocks, logs and other debris and in cracks and in ground crevices including yabby burrows (Barker *et al.* 1995, Cogger 2000). |
| Spotted grass frog       | - Found under stones and debris on the beds of dry creeks, pools and dams during summer (Tyler 1977).  
- Occurs in a range of microhabitat types but frequently in beds of *Cyperus* spp., and *Paspalum distichum* (Healey *et al.* 1997), however other studies have found occupancy of sites by adults to not be related to any of the measured habitat or water quality variables (Wassens and Maher 2011).  
- Has limited capacity to burrow and adults congregate around permanent water during droughts and distribution is restricted to areas with some permanent water (Wassens 2011). |
| Brown tree frog          | - Habitat generalist documented from a range of habitat types such as wet and dry sclerophyll forest, farmland, heathland, semi-arid areas, alpine regions and suburban gardens (Anstis 2002). |
| Peron’s tree frog        | - Able to utilise vertical landscape (e.g. floodplain trees) with distribution closely linked to the availability of standing timber, in particular river red gum forests (Wassens 2011).  
- Greater vegetation diversity a predictor of presence (Lane *et al.* 2007).                                                                                   |
| Southern bell frog       | - Presence of permanent water is important for populations in semiarid landscapes due to lack of water-conserving adaptations such as burrowing, and the low rainfall combined with high evaporation rates limits the availability of moist terrestrial habitats (Pyke 2002).  
- Very limited capacity to survive dry periods and must move to permanent refuge sites (Wassens 2011).  
- Probability of occupancy increased with increasing cover of emergent and submerged vegetation (Wassens *et al.* 2008a). |
Table 4-9. Dispersal and movement of adult frogs of the South Australian Murray–Darling Basin.

<table>
<thead>
<tr>
<th>Species</th>
<th>Dispersal and movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern sign-bearing froglet</td>
<td>Not clear whether they burrow or move into newly flooded wetlands from the associated river systems during flooding (Wassens 2011).</td>
</tr>
<tr>
<td>Common froglet</td>
<td>Same as above.</td>
</tr>
<tr>
<td>Eastern banjo frog</td>
<td>• Sensitive to desiccation and distribution may be restricted by soil type.</td>
</tr>
<tr>
<td></td>
<td>• Possible that dispersal capability and use of refuges might be more important than burrowing ability in terms of recovery following extended dry periods (Gonzalez et al. 2011).</td>
</tr>
<tr>
<td>Long-thumbed frog</td>
<td>No information found.</td>
</tr>
<tr>
<td>Spotted grass frog</td>
<td>• Highly dispersive (Gonzalez et al. 2011).</td>
</tr>
<tr>
<td></td>
<td>• Is often the first frog to colonise new habitats (Mokany 2007).</td>
</tr>
<tr>
<td>Brown tree frog</td>
<td>Likely to be highly mobile and can be found far from water when not breeding.</td>
</tr>
<tr>
<td>Peron’s tree frog</td>
<td>• Good dispersal ability and mobility expected.</td>
</tr>
<tr>
<td></td>
<td>• Documented as able to occur in terrestrial environments a considerable distance from water (Cogger 2000).</td>
</tr>
<tr>
<td>Southern bell frog</td>
<td>• Highly mobile in the landscape (Schultz 2007).</td>
</tr>
<tr>
<td></td>
<td>• Availability of ephemeral habitats and flooding at smaller spatial and temporal scales influences recruitment success, with the larger-scale flooding facilitating dispersal to vacant habitat and gene pool flow (Wassens et al. 2008b).</td>
</tr>
</tbody>
</table>
Fish are important and conspicuous components of aquatic ecosystems. The composition and structure of riverine fish assemblages, and the population dynamics of individual species are influenced by a number of abiotic (e.g. salinity) (Barletta et al. 2005) and biotic factors (e.g. vegetation cover) (Weaver et al. 1997), but most are correlated with the flow regime (Poff and Allan 1995). Flow affects fish population dynamics directly, by influencing critical life history processes including migration, spawning and recruitment (Welcomme 1985, King et al. 2009), and indirectly, by influencing hydraulics and channel morphology, the distribution of aquatic vegetation and structural elements (e.g. in-stream wood), and subsequently habitat availability (Nestler et al. 2012).

Unsurprisingly in the MDB, significant declines in the abundance and distribution of many native fish species have been attributed to river regulation and resulting physical obstruction of movement by regulating structures (e.g. weirs) and alteration to the natural flow regime (e.g. Gehrke et al. 1995).

Groups/guilds of fish species in the SA MDB

From the SA border downstream to the Murray Mouth, over 90 different species of native fish have been recorded (Higham et al. 2002, Lintermans 2007); however, most of these are of marine origin and are irregular visitors to the ‘Lower Lakes and Coorong’. Nevertheless, approximately 36 native species are regularly sampled, representing a diverse range of life history strategies, behaviours, morphologies and perceived values (Table 4-10). Due to the large number of species it is impractical to take a species based approach when describing responses to flow; therefore, a guild based approach is adopted.

Guild approaches are commonly used in fish ecology to classify and simplify complex assemblages into ‘groups’ based upon similarities in chosen ecological/biological parameters including patterns of life history, physiology and behaviour (Winemiller and Rose 1992, Elliott et al. 2007). This approach has been adopted by several authors to classify species of the MDB. Humphries et al. (1999) grouped species into modes based upon life history traits, with particular emphasis upon spawning style, parental care and larval development. Baumgartner et al. (2013) used a different approach, whereby species were grouped based upon similarities in physiology, behaviour and habitat use that could be linked to flow. Both approaches have merit within a lower River Murray context, but require modification to best represent the factors affecting fish distribution and population demographics in the lower River Murray. Furthermore, the target area of the current study includes the Lower Lakes and Coorong, and subsequently, requires the inclusion of estuarine-associated fish ‘groups’. We have integrated information from Humphries et al. (1999), Baumgartner et al. (2013) and Bice (2010b), and derived a total of seven ‘groups’ of fish species across the lower River Murray (including the Lower Lakes and Coorong) based upon similarities in longevity and size, distribution and habitat use, movement and spawning, and recruitment. We hypothesise that given the similarity in these traits between species within these groups, they will respond in a similar fashion to different flow bands in the lower River Murray. The seven groups are defined below, with particular reference to aspects of each group that are influenced by flow; namely, longevity and size, distribution and habitat preference, movement and requirements for spawning and recruitment. These aspects of the ecology of each of these groups will form the basis for developing the hydro-ecological models.
<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Murray cod</td>
<td><em>Maccullochella peeli</em></td>
<td>Circa-annual spawning nester</td>
</tr>
<tr>
<td>Freshwater catfish</td>
<td><em>Tandanus tandanus</em></td>
<td>Circa-annual spawning nester</td>
</tr>
<tr>
<td>River blackfish</td>
<td><em>Gadopsis marmoratus</em></td>
<td>Circa-annual spawning nester</td>
</tr>
<tr>
<td>Golden perch</td>
<td><em>Macquaria ambigua ambigua</em></td>
<td>Flow dependent specialist</td>
</tr>
<tr>
<td>Silver perch</td>
<td><em>Bidyanus bidyanus</em></td>
<td>Flow dependent specialist</td>
</tr>
<tr>
<td>Bony herring</td>
<td><em>Nematalosa erebi</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Australian smelt</td>
<td><em>Retropinna semoni</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Carp gudgeon complex</td>
<td><em>Hypseleotris spp.</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Flat-headed gudgeon</td>
<td><em>Philypnodon grandiceps</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Dwarf flat-headed gudgeon</td>
<td><em>Philypnodon macrostomus</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Murray rainbowfish</td>
<td><em>Melanotaenia fluviatilis</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Unspecked hardyhead</td>
<td><em>Craterocephalus stercusmuscarum fulvus</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Mountain galaxias</td>
<td><em>Galaxias olidus</em></td>
<td>Foraging generalist</td>
</tr>
<tr>
<td>Murray hardyhead</td>
<td><em>Craterocephalus fluviatilis</em></td>
<td>Wetland/floodplain specialist</td>
</tr>
<tr>
<td>Yarra pygmy perch</td>
<td><em>Nannoperca obscura</em></td>
<td>Wetland/floodplain specialist</td>
</tr>
<tr>
<td>Southern pygmy perch</td>
<td><em>Nannoperca australis</em></td>
<td>Wetland/floodplain specialist</td>
</tr>
<tr>
<td>Southern purple-spotted gudgeon</td>
<td><em>Mogurnda adspersa</em></td>
<td>Wetland/floodplain specialist</td>
</tr>
<tr>
<td>Congolli</td>
<td><em>Pseudaphritis urvillii</em></td>
<td>Diadromous</td>
</tr>
<tr>
<td>Common galaxias</td>
<td><em>Galaxias maculatus</em></td>
<td>Diadromous</td>
</tr>
<tr>
<td>Short-finned eel</td>
<td><em>Anguilla australis</em></td>
<td>Diadromous</td>
</tr>
<tr>
<td>Short-headed lamprey</td>
<td><em>Mordacia mordax</em></td>
<td>Diadromous</td>
</tr>
<tr>
<td>Pouched lamprey</td>
<td><em>Geotria australis</em></td>
<td>Diadromous</td>
</tr>
<tr>
<td>Common name</td>
<td>Scientific name</td>
<td>Group</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Black bream</td>
<td><em>Acanthopagrus butcheri</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Greenback flounder</td>
<td><em>Rhombosolea tapirina</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Long-snouted flounder</td>
<td><em>Ammotretis rostratus</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Lagoon goby</td>
<td><em>Tasmanogobius lasti</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Tamar river goby</td>
<td><em>Afurcagobius tamarensis</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Bluespot goby</td>
<td><em>Pseudogobius olorum</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Bridled goby</td>
<td><em>Arenogobius bifrenatus</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Small-mouthed hardyhead</td>
<td><em>Atherinosoma microstoma</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Sandy sprat</td>
<td><em>Hyperlophus vittatus</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Mulloway</td>
<td><em>Argyrosomus japonicus</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Yellow-eyed mullet</td>
<td><em>Aldrichetta forsteri</em></td>
<td>Estuarine dependent</td>
</tr>
<tr>
<td>Australian salmon</td>
<td><em>Arrripis truttaceus</em></td>
<td>Marine species</td>
</tr>
<tr>
<td>Australian anchovy</td>
<td><em>Engraulis australis</em></td>
<td>Marine species</td>
</tr>
<tr>
<td>Smooth toadfish</td>
<td><em>Tetractenos glaber</em></td>
<td>Marine species</td>
</tr>
<tr>
<td>Southern garfish</td>
<td><em>Hyporhamphus melanochir</em></td>
<td>Marine species</td>
</tr>
<tr>
<td>King George whiting</td>
<td><em>Sillaginodes punctatus</em></td>
<td>Marine species</td>
</tr>
</tbody>
</table>

**Group 1. Circa-annual spawning nesting species**

*General description and representative species*

Species that complete their lifecycle within freshwater environments, spawn annually over defined periods irrespective of flow conditions and lay eggs within a nest or similar structure (e.g. hollow logs).

**Longevity and size**

- Medium- (5–10 years) to Long-lived (>10 years).
- Medium (>200 mm) to large adult size (>1,000 mm).
Distribution and habitat

- Murray cod (*Maccullochella peeli*) and freshwater catfish (*Tandanus tandanus*) are found throughout the lower River Murray main channel and potentially Lower Lakes (Ye et al. 2014, Zampatti et al. 2014).
- River blackfish (*Gadopsis marmoratus*) are restricted to select tributaries of the lower River Murray in the eastern Mount Lofty Ranges (i.e. Marne, Angas, Tookayerta and Bremer) (Bice et al. 2011).
- Murray cod and river blackfish prefer main channel habitats of creeks, rivers and anabranches, rather than wetlands or temporarily inundated floodplain habitats (Humphries et al. 1999, King 2004, Koehn 2009, Leigh and Zampatti 2013). Freshwater catfish have similar habitat preferences but regularly utilise permanent off-channel habitats (Koster et al. 2014).
- Murray cod exhibit an association with hydraulically diverse lotic habitats with high levels of physical habitat structure (i.e. coarse woody debris) (Boys and Thoms 2006, Jones and Stuart 2007, Koehn et al. 2009).

Movement

- Movement patterns of adult Murray cod are variable. Most fish exhibit high levels of site fidelity, but may also undertake small- (<2 km) and medium-scale (10s km) ‘ranging’ movements or large-scale (>100 km) upstream movements (Koehn 2009, Saddlier et al. 2009, Leigh and Zampatti 2013). In the lower River Murray increased frequency of movement appears to occur in winter to spring immediately prior to the spawning season. Large-scale upstream movements (including return movements) have been observed during high flows (Leigh and Zampatti 2013).
- Both freshwater catfish (Reynolds 1983, Koster et al. 2014) and river blackfish (Koster and Crook 2008) are considered largely sedentary and occupy restricted home ranges.

Spawning and recruitment

- Eggs are laid in a nest (Murray cod and freshwater catfish) or within hollow logs/rock crevices (river blackfish) which are guarded by the male (McDowall 1996, Humphries 2005, Lintermans 2007).
- After hatching, Murray cod larvae undergo downstream drift for periods of up to seven days (Humphries 2005, Koehn and Harrington 2005). This movement may be reliant on hydraulic conditions that facilitate drift.
- The larvae of river blackfish are negatively buoyant and remain at the spawning site for up to three weeks following hatching (Jackson 1978).
- Broad-scale recruitment of Murray cod (as evidenced by the presence of strong year classes) in the lower River Murray typically occurs following years of elevated flow (e.g. >20,000
ML.day\(^{-1}\) (Ye and Zampatti 2007). Recent evidence from the mid-Murray also suggests enhanced recruitment in association with elevated flows (King et al. 2009).

- Factors influencing the recruitment of freshwater catfish and river blackfish in the lower River Murray are unknown, but increased productivity during and following high flow events may enhance the recruitment of freshwater catfish (Ye et al. 2014).
- Recruitment of Murray cod occurs regularly in the hydraulically diverse Chowilla Anabranch and Lindsay–Mullaroo systems (Zampatti et al. 2011c, Henderson et al. 2012).

### Group 2. Flow dependent specialists

**General description and representative species**

Species that complete their lifecycle within freshwater environments, but require increases in within-channel flow or flooding to stimulate spawning (e.g. golden perch, *Macquaria ambigua ambigua*).

**Longevity and size**

- Long-lived (>10 years).
- Medium adult size (>300 mm).

**Distribution and habitat**

- Throughout the lower River Murray main channel, Lower Lakes and intermittently in the Coorong (Lintermans 2007).
- In the lower River Murray typically found in main channel habitats of the river, creeks and anabranches, and less commonly in connected wetlands. Nonetheless, recent data indicates use of temporary floodplain habitats during flood (SARDI unpublished data).

**Movement**

- Adult golden perch typically exhibit high levels of site fidelity outside of the spawning season (O’Connor et al. 2005). Nonetheless, both adult golden perch and silver perch do undertake large-scale migrations as adults, which may be related to reproduction (Reynolds 1983, O’Connor et al. 2005, Zampatti et al. 2011c). In the lower River Murray, these movements appear to be predominantly in an upstream direction (Zampatti et al. 2011c).
- Eggs and larvae experience an obligate downstream drifting phase (Tonkin et al. 2007), which may carry them in the order of 100s km’s.

**Spawning and recruitment**

- Gonad maturation occurs with increasing water temperature (Lake 1967).
- Elevated flow (likely >15,000 ML.day\(^{-1}\) in the lower River Murray), when water temperature is above thresholds (~20°C), is required to generate a spawning response (Mallen-Cooper and Stuart 2003, King et al. 2009).
- Eggs and larvae undergo downstream drift (Tonkin et al. 2007). Drift may be reliant on hydraulic conditions that facilitate entrainment.
• Recruitment in the lower River Murray is typically observed following both within-channel flow pulses (e.g. 15,000–45,000 ML.day\(^{-1}\)) (Zampatti and Leigh 2013b) and overbank floods (Zampatti and Leigh 2013a).

**Group 3. Foraging generalists**

*General description and representative species*

Species that complete their lifecycle within freshwater environments and typically have generalist/flexible habitat requirements, diets and reproductive strategies (e.g. carp gudgeon complex, *Hypseleotris* spp.).

*Longevity and size*

- Short-lived (<5 years).
- Small to medium adult size (40–300 mm).

*Distribution and habitat*

- Distributed throughout lower River Murray and Lower Lakes and intermittently in the Coorong.
- Found in a range of environments including the river main channel, creeks, anabanches and connected wetlands (Baumgartner *et al.* 2008a, Smith *et al.* 2009). Also temporarily inundated floodplains during flood (SARDI unpublished data).
- Abundance in the main channel appears related to flow and its effect on physical habitat (i.e. aquatic vegetation). Abundance is greatest in the main channel during periods of low flow and high vegetation cover and lowest following high flows and the loss of these habitats (Bice *et al.* 2014).

*Movement*

- Many species in this group were previously thought non-migratory, but have been detected undertaking both longitudinal riverine movements (Stuart *et al.* 2008, Baumgartner *et al.* 2010) and lateral movements between the main channel and off-channel wetlands (Connallin *et al.* 2011, SARDI unpublished data), in the lower River Murray under a range of flows.
- Movement into off-channel habitats may be important under high flows, when the river main channel represents an adverse environment.

*Spawning and recruitment*

- Spawn annually irrespective of flow, typically multiple times, over a protracted season between spring and autumn (Humphries *et al.* 1999).
- Larval abundances are typically greatest during low flow years (Cheshire *et al.* 2012).
- Some species exhibit no parental care (e.g. bony herring), whilst others exhibit male guarding of eggs (e.g. flat-headed gudgeon, *Philypnodon grandiceps*).
- Recruitment may be enhanced during years of low flow (Humphries *et al.* 1999).
Group 4. Wetland/floodplain specialists

General description and representative species

Species that complete their lifecycle within freshwater environments, but have restricted distributions, requiring specific wetland/floodplain habitats (e.g. southern pygmy perch, *Nannoperca australis*).

Longevity and size

- Short-lived (<5 years).
- Small adult size (<100 mm).

Distribution and habitat

- All species are present in the region at a limited number of spatially fragmented sites (Bice et al. 2011), reflected in their conservation status and protection under federal (EPBC Act 1999) and/or state legislation (Fisheries Management Act 2007).
- All species commonly complete their life cycle in off-channel habitats.
- All species are associated with specific physical (e.g. submerged vegetation) and/or physico-chemical (e.g. elevated salinity) habitat conditions.

Movement

- Murray hardyhead (*Craterocephalus fluviatilis*) are likely highly mobile and potentially utilise periods of over-bank floods as a means of expanding distribution (Ellis et al. 2013).

Spawning and recruitment

- Spawn annually, either over a defined season (pygmy perches) or multiple times over a protracted season (Murray hardyhead) (Ellis 2005).
- Some species exhibit no parental care (e.g. Murray hardyhead), whilst others exhibit male guarding of eggs (e.g. southern purple-spotted gudgeon) (Hammer et al. 2009).
- Some evidence suggests enhanced recruitment of pygmy perch species’ in the Lower Lakes during years of elevated lake level in winter/spring (SARDI unpublished data).
- Recent evidence suggests inundation of previously dry stream bed, and resultant zooplankton response, may enhance recruitment of Murray hardyhead through ‘trophic upsurge’ (Wedderburn et al. 2013).

Group 5. Diadromous species

General description and representative species

Species that require movement between freshwater and marine environments in order to complete their lifecycle. Includes both anadromous (i.e. adult marine residence and freshwater spawning; e.g.
short-headed lamprey, *Mordacia mordax* and catadromous species (i.e. adult freshwater residence and marine spawning; e.g. congolli, *Pseudaphritis urvillii*).

**Longevity and size**

- Short- (<5 years, i.e. common galaxias, *Galaxias maculatus*) and long-lived (>10 years, short-finned eel, *Anguilla australis*).
- Small to large adult size (100 – >1,000 mm).

**Distribution and habitat**

- Present in the Lower Lakes and Coorong, lower River Murray and tributaries (Lintermans 2007, Bice et al. 2012).
- Found in a variety of habitats including lake edges, wetlands and streams.

**Movement**

- Catadromous species (i.e. congolli and common galaxias) exhibit freshwater adult residence, downstream spawning migrations, estuarine/marine spawning, marine larval development and corresponding upstream juvenile migrations.
- Anadromous species (i.e. lamprey species) exhibit marine adult residence, upstream spawning migrations, freshwater spawning, freshwater larval/juvenile development and corresponding downstream juvenile migrations.

**Spawning and recruitment**

- Spawning dependent on connectivity and ability to migrate to spawning habitats (Zampatti et al. 2010, 2011b).
- Spawning typically occurs annually, over a defined (congolli) or protracted (common galaxias) season (Bice et al. 2012).
- Recruitment dependent upon connectivity and ability to migrate to adult habitats.

**Group 6. Estuarine dependent species**

**General description and representative species**

Species that either complete their lifecycle within estuarine environments (e.g. black bream, *Acanthopagrus butcheri*) or spend large periods of their lifecycle in the marine environment but are dependent upon estuaries for a particular life stage (e.g. mulloway, *Argyrosomus japonicus*). These two types of species are representative of the ‘estuarine resident’ and ‘marine estuarine dependent’ guilds from Elliott et al. (2007).

**Longevity and size**

- Short- to long-lived.
- Small to large adult size (50 – >1,000 mm).
Distribution and habitat

- Present in the Coorong and intermittently in Lower Lakes.
- Found in varying estuarine habitats.
- Most species complete their lifecycle within the Coorong (e.g. black bream), whilst others are reliant on the Coorong for a specific life stage (i.e. juvenile; e.g. mulloway).

Movement

- Some species move regularly between the Coorong and Lower Lakes (e.g. lagoon goby, *Tasmanogobius lasti*) (Bice et al. 2012).
- Some species require movement between the Coorong and Southern Ocean through the Murray Mouth (e.g. mulloway).
- Some species move extensively throughout the Coorong (e.g. black bream) (SARDI unpublished data).

Spawning and recruitment

- Factors affecting spawning and recruitment may differ between species.
- Several species are likely to spawn and recruit annually (e.g. goby species), whilst others are likely to exhibit temporal variability in spawning and recruitment (e.g. black bream, mulloway).
- Nonetheless, freshwater discharge may be important in promoting recruitment in all species.

Group 7. Marine species

General description and representative species

Species that typically complete their lifecycle and reside in marine environments, but will utilise estuarine habitats when conditions are favourable (e.g. low flow, low salinity) (e.g. Australian salmon, *Arripis truttaceus*).

Longevity and size

- Short- to long-lived.
- Small to large adult size (50–400 mm).

Distribution and habitat

- Present in the Coorong and Southern Ocean.
- Found in varying estuarine habitats of the Coorong, typically during periods of low freshwater discharge (Zampatti et al. 2010).
- Most species complete their lifecycle outside of the Coorong and are not reliant on the Coorong.
**Movement**

- Presence within the Coorong is mediated by movement between the Southern Ocean and Coorong through the Murray Mouth.

**Spawning and recruitment**

- Factors affecting spawning and recruitment may differ between species.
- The Coorong is not an important spawning ground for these species and freshwater discharge is unlikely to be important in promoting recruitment.
4.7 Waterbirds

The issue of scale in the management of aquatic ecosystems for waterbirds

Australian waterbirds are highly mobile (Haig et al. 1998, Kingsford and Norman 2002, Robin et al. 2009, Kingsford et al. 2010), and as such utilise habitat at a variety of scales. For Australian continental nomads (e.g. banded stilt, *Cladorhynchus leucocephalus*, grey teal, *Anas gracilis*, Australian pelican, *Pelecanus conspicillatus*), individual birds respond to hydrological events at continental scales. For these species, different elements of the habitat at this scale are used for fundamentally different components of their life history. Typically, large-scale breeding events are driven by significant flow events on inland catchments, such as the Lake Eyre Basin (and particularly the eastern catchments), and the northern MDB (Maher and Braithwaite 1992, Kingsford and Thomas 1995). These inland breeding opportunities, while large, are both infrequent and do not occur on a regular basis (e.g. seasonally). In the intervening periods, these species typically spend time in more mesic wetlands closer to the Australian coastline (e.g. Coorong wetlands). These periods do not support large-scale breeding events, although smaller-scale breeding still occurs for some species (e.g. Australian pelican). While the productivity of these wetlands for waterbirds is typically lower than inland wetlands during flood, the availability of habitat is more predictable.

For international migratory species, the scales at which individuals and populations operate are larger again, with species spending the Austral summer in the southern hemisphere, during their non-breeding period, and the Austral winter in the northern hemisphere to breed. These migratory patterns are highly energetically demanding, and so international migrants require highly productive wetlands for both the breeding and non-breeding phases of their life cycle. While the scales over which international migrants operate are significantly larger than even the scale over which continental nomads operate, their large scale movements are also more predictable.

A third category of Australian waterbird is the regional residents, that typically move between wetlands within smaller areas. In south-eastern Australia this includes species such as chestnut teal (*Anas castanea*) and Australasian bittern (*Botaurus poiciloptilus*). These species typically spend their entire life within smaller regional areas in comparison to the groups described above, although they do move between wetlands and catchments in response to changing conditions.

The implications of these large-scale movements and population dynamics for managing aquatic ecosystems for waterbirds are significant. Understanding the response of waterbird populations to local (and even Basin-wide) management of water resources is inherently complicated by this scale issue, in particular because waterbird population dynamics are often influenced by environmental change that is occurring well beyond the influence of these management responses (Shorebird Working Group of Wetlands International Asia-Pacific 2001). If we are to make predictions regarding the response of waterbirds to environmental change at local scales, we need to have a much better understanding of the regional, continental and global context within which local change is occurring, and how the waterbirds of interest respond to change at these different interacting scales.

At the regional scale, the response of waterbirds to hydrological conditions is mediated by both population dynamics and individual behavioural decision making. At this scale, the role of wetlands
in the population ecology of each species does not tend to vary (e.g. between breeding and non-breeding), but waterbirds make relative decisions regarding habitat quality to maximise individual opportunities.

In spite of these scale issues as they relate to the response of waterbirds to hydrology, ultimately the ability of an individual wetland to meet the requirements of different waterbird species will be determined at least partly by the hydrology of that wetland, and the ecological responses to this hydrology. For waterbirds, responses to local wetland hydrology are both direct (particularly with regard to variation in water depth in relation to wetland bathymetry) and indirect (through the response of biota on which waterbird species rely on for food and habitat).

**The role of lower River Murray in the ecology of Australian waterbirds**

If we are to assess within-wetland habitat quality for waterbirds, we need to also make an assessment of what role a particular wetland or catchment plays in the population ecology of these different species, and whether it is meeting these requirements. To take an extreme example, the habitat quality of the Coorong for international migratory shorebirds should not be judged on the basis of the number of successful recruits in the Coorong. For Australian continental nomads, the lower River Murray is thought to primarily play a population maintenance role, by providing habitat for the maintenance of adult populations, and provides regular, but relatively small, recruitment opportunities to partially offset adult mortality; this role is thought to be most important during times when inland Australia is under lower-than-average rainfall conditions (Kingsford and Porter 2009). This model is based on the historically regular flows provided to the lower River Murray by the southern basin, in comparison to the larger, but much less frequent (and less regular) northern basin flows. During large flow events driven by northern basin, large wetland and floodplain environments become available for larger breeding events by continental nomads that can often be complemented by large breeding opportunities in the Lake Eyre Basin (and other inland basins). While the lower River Murray receives significant flows during these wet periods, its role in the maintenance of populations of continental nomadic species may be less relevant than during continentally drier periods when the lower River Murray is only receiving flow from the southern basin.

**Wetland-scale habitat requirements of waterbirds**

At the scale of individual wetlands, waterbird habitat can broadly be assessed based on three requirements:

1) Food availability (incorporating abundance of food, and access to food);
2) Roost availability and predator avoidance; and
3) Availability of breeding habitat (where relevant).

However, the availability of these requirements can often interact. For example, access to high quality foraging habitat may be compromised if accessing these habitats increases risk of predation (Pomeroy 2006). Issues related to food availability are further expanded below.
Food availability

Waterbirds are typically higher-order predators, and so wetland-scale habitat quality for waterbirds strongly depends on the availability of other organisms as prey. Availability of prey depends on two factors: 1) the abundance of prey items in a wetland; and 2) the ability of individual waterbirds to access these prey items. Both of these features can be affected by wetland hydrology.

Prey abundance within individual wetlands depends on the complex responses of different biota to flow. While waterbird species tend to specialise on particular prey groups, they are rarely specialised to the level of prey species. For example, obligate piscivores will prey on a range of different fish species, such that individual piscivorous species will select prey more on size and ‘catchability’ rather than species. As a result, juveniles of larger fish species may provide the same food quality for these waterbirds as adult small-bodied fish (Brookes et al. 2009a). Similarly, herbivorous species such as Black Swan depend heavily on submerged aquatic vegetation, but will feed on a diverse range of plant species within this functional group (Brookes et al. 2009a). If an understanding of the response of aquatic biota to flow is to provide information for the management of waterbirds, an understanding of total abundance, biomass and size class distribution would be a useful addition.

The ability of waterbirds to access food (even when it is available) depends primarily on the foraging mode of individual species. While some species are able to use deep water habitats by diving for food (e.g. cormorants, some duck species), foraging habitat for many species is strongly associated with particular depth classes. This is particularly relevant to wading species, for which the depth classes at which food becomes available vary depending on a species’ morphology. Small shorebirds (e.g. red-capped plover, Charadrius ruficapillus, sandpipers) largely forage at (or even above) the shoreline of open mudflat habitats, and so the total inundated wetland area is only relevant where there is a strong relationship between inundated area of mudflat shoreline length. In some cases, where wetlands are fully inundated, these species can, in fact be excluded, as these open shorelines become absent. Larger wading species, such as great egret (Ardea alba) and spoonbills, wade in relatively open water typically to a depth of <15cm. An increase in total area of inundation for these species is only relevant to these species if the area within these depth classes also increases.

Rogers and Paton (2008) classified the waterbirds of the Chowilla Floodplain into three broad categories: 1) ‘grazers’ (ducks, swans and geese); 2) ‘shorebirds’; and 3) ‘piscivores’. These can potentially be split into finer-scale response groups. For example, ‘shorebirds’ can be split into small shorebirds that forage on shorelines and open mudflat habitats (this group includes the majority of global migratory species), larger species that forage in shallow water (e.g. Australasian and little bittern, Ixobrychus minutus, buff-banded rail, Gallirallus philippensis, Australian spotted crake, Porzana fluminea). In addition, some species cross between these functional categories: while cormorants are diving piscivorous species, fish also form a large part of the diet of great egret and white-faced heron (Egretta novaehollandiae), that also depend on shallow wetlands and fringing shoreline habitats (and can thus be classified as Shorebirds). This classification complements, but differs from, the functional classification of Kingsford et al. (2013), who identified five functional groups (ducks, herbivores, large wading birds, shorebirds, and piscivores).
A number of authors have described the requirements of different waterbird species that occur in the lower River Murray. For example, Scott (1997) summarised the responses of waterbirds to flow in the MDB, focussing primarily on breeding requirements. However, these investigations depend heavily on information drawn from breeding events observed in the northern basin that are potentially important drivers of waterbird recruitment (rather than population maintenance). The information drawn from these studies thus needs to be tested in the context of the lower River Murray, whose role in the ecology of these species may differ (see above).

Recent work to support the management of the Lower Lakes and Coorong developed conceptual models for wetland-scale waterbird responses that incorporated the direct and indirect effects of hydrodynamic elements on waterbird habitat (O’Connor et al. 2012). This study developed models for ten waterbird species in the Lower Lakes and Coorong, as representatives of five ecological groups. It combined quantitative and qualitative information to develop conceptual and probabilistic (using Bayesian networks) models that specifically identified the population driver/s for which each species was primarily using the site (e.g. recruitment, survival). In addition these models combined the effects of food availability, predation risk and other habitat features, and their interactions, within a single response model (Figure 4-5). While this study provides a useful template for the lower River Murray, it was based on the responses of waterbirds to the specific hydrological conditions of the Lower Lakes and Coorong, and the individual models would require modification for the different hydrology (and ecology) of the lower River Murray. However the model development approach described in this work provides a template for which to combine multiple lines of evidence into a modelling framework that subsequently allows for model testing and iteration. This approach could potentially be applied to key waterbird species in the lower River Murray, highlighting the twin population drivers of adult survival and low level recruitment.

![Figure 4-5. Conceptual model for the response of fairy tern, Sternula nereis, to environmental change in the Coorong (O’Connor et al. 2012).](image-url)
A conceptual hydrological response model for waterbirds in the lower River Murray

The response of individual species to particular flow events will vary depending on the specific nature of the wetland, the particular requirements of the species (and which ecological requirements are expected to be met), and the antecedent flow regime. However, some conceptual generalisations can be made with regard to local habitat availability in response to generic flow bands.

Much of the information listed regarding the habitat requirements of different waterbird species has been collated in the Handbook of Australian, New Zealand and Antarctic Birds (HANZAAB) (Marchant and Higgins 1990, Higgins 1993, Higgins and Davies 1996). This comprehensive synthesis of the natural history of Australian birds collates information from a range of sources, including peer-reviewed literature, published and unpublished observation, and anecdotal reports. As such the confidence in the information drawn from this source varies. For the purposes of this work we suggest that fundamental natural history of species (e.g. broad habitat requirements) are relatively well understood, although scientific evidence (e.g. peer-reviewed) is often absent.

Scope of this section

The following discussion on the ecology of waterbirds in the SA River Murray focuses primarily on those ecological responses that are directly relevant to the River Murray from Wentworth to Wellington. While important knowledge gaps exist on the ecology of waterbirds in the Lower Lakes and Coorong, there is also an extensive body of work that relates to this ecology (e.g. Paton et al. 2009, Rogers and Paton 2009). While no explicit reference is made to the Lower Lakes and Coorong, the majority of the important research needs identified apply equally to the Lower Lakes and Coorong as to other parts of the river in SA.

Further comments regarding waterbird responses to flow

As suggested above, the specific response of individual species to particular flow events will depend on the geomorphology of a wetland (and, therefore, the distribution and extent of different water depth classes), the spatial relationship between biotic (vegetation) and abiotic habitats, and the spatial relationship between different types of habitat (foraging, nesting, roosting). Furthermore, the response of individual waterbird species depends strongly on trophic responses through the entire ecosystem within a wetland. Understanding waterbird responses to flow therefore requires more comprehensive system response models that incorporate the predicted responses at a range of trophic levels (see example in Figure 4-5).

While these predicted flow band responses by Australian bird species provide some insight into single-flow event responses, riverine and floodplain fauna (and ecosystems more broadly) respond to flow regimes (sequences of flow events) rather than individual flow events. This will be particularly important for the maintenance of long-lived floodplain vegetation, as well as providing maintenance habitat for continental nomadic and regional waterbird species, whose individuals also tend to be long-lived and have slow rates of turnover.
5 Lower base flow (3,000 ML.day\(^{-1}\)) hydro-ecological conceptual models

This section presents data on the hydrology and associated conditions in the lower River Murray in SA under ‘lower base flows’ (3,000 ML.day\(^{-1}\)), and the associated hydro-ecological conceptual models. A general overview of hydraulics (e.g. velocity and water level), floodplain inundation and salinity is provided for the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’. This is followed by the conceptual models for each biotic/abiotic component for each region.

5.1 Hydrology and associated conditions (3,000 ML.day\(^{-1}\))

5.1.1 Lower River Murray channel and floodplain

Hydrology

A flow of 3,000 ML.day\(^{-1}\) is SA entitlement flow at the border from May to June (Figure 3-3). Under pre-development conditions (modelled natural), a discharge of 3,000 ML.day\(^{-1}\) (or above) persisting for 90 days occurred every year (100% of years). Under existing conditions, such a flow still occurs every year (100% of years).

Hydraulics

Water level

Water level for a discharge of 3,000 ML.day\(^{-1}\) is controlled by the weirs, which are usually operated at normal pool level (Table 3-1, Figure 5-1). Maximum depth along the river channel varies from around 3 – 20+ m deep (Figure 5-1).

Velocity

Mean calculated (Gippel 2011) and measured field velocities (Kilsby 2008) are in the vicinity of 0.08–0.2 m.s\(^{-1}\) in the main channel, with some elevation of velocity immediately downstream from weirs compared to immediately upstream (Figure 5-1 and Figure 5-2).

Inundation

Vegetation

The RiMFIM (Overton et al. 2006b) maps the area inundated under different discharges, assuming normal weir operations. Figure 5-3 shows the percent of different vegetation classes on the floodplains (based on locks) inundated by 5,000 ML.day\(^{-1}\). Approximately 34% of the ‘river red gum’ vegetation class is inundated between Wellington and Lock 1, but only 13% between Lock 2 and 3.
Wetlands

The inundated wetland area in hectares and as a percentage of the total wetland area, is shown in Figure 5-4 and Figure 5-5, respectively (data from RiMFIM (Overton et al. 2006b) for 5,000 ML.day⁻¹; note inundation data for 3,000 ML.day⁻¹ are not available). The wetland area inundated varies from 1,576 hectares (Lock 2 floodplain) to 6,360 hectares (between Wellington and Lock 1) (Figure 5-4). In general, over 70% of the wetland area is inundated (Figure 5-5), except for the Lock 6 floodplain, presumably because the wetland area includes creeks and channels on the Chowilla Floodplain that have a higher commence-to-flow discharge.
Figure 5-1  Channel elevation, water level (m AHD) and velocity (m.s$^{-1}$) at ~3,000 ML.day$^{-1}$ in the River Murray channel. Channel depth data from River Murray channel Digital Elevation Model (DEM), water level from normal pool level (below Lock 1) and from backwater curves (~1977) for 5,000 ML.day$^{-1}$. Calculated mean cross-sectional velocity (n=10–27 cross-sections), showing standard deviation of calculated velocity (Gippel 2011), for 5,000 ML.day$^{-1}$. Field velocity measured using an Acoustic Doppler Profiler and shows the median depth-averaged velocity for n= up 500 profiles, with minimum and maximum depth-averaged velocity, at a discharge of ~3,300 ML.day$^{-1}$ (Kilsby 2008).
Figure 5-2 Box plots showing median velocity (horizontal), 25th and 75th percentiles enclosing box, and minimum and maximum values, for each kilometre within the Lock 3–4 reach. Data from MIKE 21 model, for a discharge of 3,000 ML day$^{-1}$ (Wallace et al. 2014).
Figure 5-3 Percent of different vegetation classes on the different lock floodplains, inundated by a discharge of 5,000 ML.day$^{-1}$ (RiMFIM) (Overton et al. 2006b). Note inundation data for 3,000 ML.day$^{-1}$ are not available.

Figure 5-4 Inundated wetland area (ha) on the different lock floodplains, for a discharge of 5,000 ML.day$^{-1}$ (RiMFIM) (Overton et al. 2006b). Note inundation data for 3,000 ML.day$^{-1}$ are not available.

Figure 5-5 Inundated wetland area, as a percent of total wetland area, on the different lock floodplains, for a discharge of 5,000 ML.day$^{-1}$ (RiMFIM) (Overton et al. 2006b). Note inundation data for 3,000 ML.day$^{-1}$ are not available.
5.1.2 Lower Lakes

Salinity

Salinity varies between ~0–2,000 EC units in Lake Alexandrina for barrage discharges 2,500–3,500 ML.day\(^{-1}\) (Figure 5-6). Salinity in Lake Albert (Meningie) exhibits greater variability (up to ~6,500 EC units), but note that most of the measurements presented occurred when Lake Albert was disconnected from Lake Alexandrina from 2007–2011.

Water level

Water level at 2,500–3,500 ML.day\(^{-1}\) is under normal barrage operations and varies from 0.5–1.0 m AHD (Figure 5-7).

5.1.3 Coorong

Salinity

Salinity close to the Murray Mouth varies from ~10–45 g.L\(^{-1}\) for barrage discharges of 2,500–3,500 ML.day\(^{-1}\) (Figure 5-8). Salinity is higher and varies over a greater range (~50–140 g.L\(^{-1}\)) 100 km from the Murray Mouth.

Water level

Water level varies from ~0.4–1 m AHD across the Coorong for barrage discharges of 2,500–3,500 ML.day\(^{-1}\) (Figure 5-9).
Figure 5-6 Salinity measured for barrage discharges of 2,500–3,500 ML.day$^{-1}$ at different locations in the lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Poltalloch Plains (station A4261031), Narrung Jetty (station A4260583) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 5-7 Water level measured for barrage discharges of 2,500–3,500 ML.day$^{-1}$ at different locations in the lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.
Figure 5-8 Salinity at barrage discharges of 2,500–3,500 ML.day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.

Figure 5-9 Water level at barrage discharges of 2,500–3,500 ML.day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.
5.2 Lower River Murray channel and floodplain model (3,000 ML.day\(^{-1}\))

Conceptual models take the form of statements on ecological patterns and processes expected from the defined biotic/abiotic components, based upon the hydrological data provided (see above), for ‘lower base flows’ (3,000 ML.day\(^{-1}\)). Each statement was assigned a measure of certainty (in bold at the end of each statement) to aid in identifying knowledge gaps in conceptual understanding (Section 2.3). The certainty scoring system was adapted from Mallen-Cooper et al. (2011) and is reiterated below in Table 5-1. The conceptual model statements provided by each expert were then synthesised into a simplified conceptual diagram presenting key ecological patterns and processes.

Table 5-1. ‘Certainty’ scoring system used to define confidence in predictive statements of response to flow in the hydro-ecological conceptual models. Adapted from Mallen-Cooper et al. (2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very uncertain</td>
<td>No available data. Diverse views/conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Uncertain</td>
<td>No available data. Expert opinion. Consensus on conceptual understanding</td>
</tr>
<tr>
<td>3</td>
<td>Moderately certain</td>
<td>Supported by indirect, observational or limited scientific data</td>
</tr>
<tr>
<td>4</td>
<td>Very certain</td>
<td>Supported by direct or abundant scientific data. Published peer-reviewed literature</td>
</tr>
</tbody>
</table>

5.2.1 Nutrients, carbon, biofilms and microbes

- Low, within-channel flows are expected to contain clearer water due to particle sedimentation under low velocities and reduced connection with sources of colour and suspended particles, although this depends in part on the source of water (2).
- Higher salinities may further increase particle settling increasing light availability (3).
- The shallower depths within the tail waters at these flows will improve the light availability for phytoplankton which could increase in biomass if nutrient concentrations are supportive of growth (3).
- Stable water levels experienced at entitlement flows are conducive to the establishment of late successional biofilms that are a poor quality food resource for grazers (3).
- Low water velocity (<0.1 m.s\(^{-1}\)) and high solar radiation in summer will mean that the development of thermal stratification is likely although this will also depend upon wind conditions (3).
- System becomes carbon and nutrient limited at low flows as phytoplankton biomass increases (3).
- During warm periods with low wind speed there is a risk of onset of persistent stratification in some reaches that may support the development of phytoplankton blooms that may be dominated by harmful or nuisance cyanobacteria (3).
- At low flows, the river food web relies almost solely on autochthonous organic carbon generated by the phytoplankton and biofilms (3).
5.2.2 Microbiota

- Low water velocities and long WRT such as those that occur at flows of 3,000–7,000 ML.day\(^{-1}\) will likely favour the dominance of crustacean over rotifer biomass and result in high overall zooplankton abundance and biomass (e.g. Shiel 1982, Saunders and Lewis 1988a) (3). Nevertheless, it is important to note that crustaceans have also been found in low numbers during low flows but this was attributed to the presence of high numbers of planktivorous fish (pers. comm. Shiel 2014).
- Differences in microbiota community structure between open water and littoral habitats are likely to be maintained, where the littoral zones may provide protection for larger zooplankton such as cladocerans from fish predation during the day and host a more diverse community (Meerhoff et al. 2003, Estlander et al. 2009) (3).

5.2.3 Vegetation

Terrestrial dry

- Abundant throughout the floodplain (including temporary wetlands), providing flooding has been absent for longer than one year (e.g. Holt et al. 2005, Nicol et al. 2006, Marsland and Nicol 2007, Gehrig et al. 2013) (4).

Terrestrial damp

- Restricted to the upper littoral zone where there is sufficient soil moisture but limited inundation (Zampatti et al. 2011c) (3).

Floodplain

- Restricted to the upper littoral zone where there is sufficient soil moisture but limited inundation (e.g. Blanch and Walker 1997, Blanch et al. 1999b, 2000, Nicol et al. 2006) (3).
- Recruitment limited to the upper littoral zone (3).

Amphibious fluctuation tolerator – emergent

- Present in the littoral zone that regularly wets and dries and in water up to 10 cm deep (e.g. Blanch and Walker 1997, Blanch et al. 1999b, 2000, Holt et al. 2005) (3).
- Recruitment limited to the littoral zone (2).

Amphibious fluctuation tolerator – woody

- Plants growing on the edges of permanent water bodies or in areas where groundwater is being freshened will remain in good condition (e.g. Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4).
• Condition will decline after extended periods without inundation (length of time depends on species) for plants growing farther from permanent water (4).

Amphibious fluctuation tolerator – low growing

• Present in the littoral zone that regularly wets and dries and in water up to 5 cm deep (Blanch and Walker 1997, Blanch et al. 1999b, 2000, Nicol et al. 2006) (2).
• Recruitment limited to the littoral zone (2).

Amphibious fluctuation responder – plastic

• Present in the littoral zone that regularly wets and dries and in water up to 50 cm deep (or deeper for species such as Ludwigia peploides that has stems that will float on water surface) (Blanch and Walker 1997, Blanch et al. 1999b, 2000, Nicol 2004) (3).
• Recruitment limited to the littoral zone (2).

Floating

• Present in river main channel and connected wetlands (e.g. Jessop and Tolken 1986, Cunningham et al. 1992, Blanch and Walker 1997) (4).

Submergent r-selected

• Absent throughout system except in the sediment propagule bank (e.g. Nicol et al. 2006) (4).

Emergent

• Restricted to the edges of permanent water bodies to a depth of 1 m (e.g. Blanch and Walker 1997, Blanch et al. 1999b, 2000, Holt et al. 2005) (4).
• Recruitment will also occur in this zone (3).

Submergent K-selected

• Present in river main channel and connected wetlands, the maximum depth of colonisation will depend on species and water clarity (e.g. Blanch and Walker 1997, Blanch et al. 1999b, 2000, Holt et al. 2005) (4).
5.2.4 Macroinvertebrates

Group A

- Exhibit a decline in abundance and/or diversity due to likely increases in salinity and limited supply of allochthonous food input and low quality biofilms present increase dominance of filamentous algae (Burns and Walker 2000a) (3).

Group B

- Exhibit a decline in abundance and/or diversity due to likely increases in salinity and limited supply of allochthonous food input and low quality biofilms present increase dominance of filamentous algae (Burns and Walker 2000 a) (3).

Group C

- Expected to be maintained at this level of flow due to medium tolerance of increased salinity levels, short generation times and predatory food preference (3).

Group D

- Expected to be maintained at this level of flow due to medium to high tolerance of increased salinity level and use of autochthonous food sources (3).

Group E

- Expected to be maintained at this level of flow due to medium tolerance of increased salinity levels and multiple generations (up to 10) per year (3).

5.2.5 Frogs

Breeding habitat and requirements

- Although most species have a preference for temporary water bodies for breeding, most species are known to breed in permanent water bodies and thus, low levels of reproduction may be expected at this flow band (Gonzalez et al. 2011) (4).
- Low level breeding is most likely to occur in permanent water bodies that have submerged, aquatic, emergent vegetation, as all species have a strong preference for well vegetated water bodies (Gonzalez et al. 2011) (4).
- Limited water level fluctuations associated with these flows means that there is a low risk of water levels dropping rapidly and causing egg desiccation for those species that require vegetation to anchor eggs (2).
Tadpoles

- These flows only affect permanent water bodies, and hence there is no inundation and drying of temporary wetlands. Where species do breed during these flows, the species with mid to long tadpole developmental phases have a low risk of water bodies drying out before metamorphosis is completed (Gonzalez et al. 2011) (2).
- Predation by introduced fish species is expected to be high for most species so good connectivity of permanent water bodies associated with these flows and the presence of fish, in combination with limited inundation of vegetation for shelter, may impact on tadpoles through predation and/or disturbance by fish (Gonzalez et al. 2011) (2).

Adults

- These flows are only associated with permanent wetlands and water bodies which may provide an important refuge in low flow periods for most species (Wassens et al. 2008a, Sheldon et al. 2010) (4).

5.2.6 Fish

Circa-annual spawning nesting species

- Adult Murray cod and freshwater catfish present in river main channel and anabranches (Baumgartner et al. 2008a, Zampatti et al. 2011c, Leigh and Zampatti 2013) (4).
- River blackfish present in specific habitats of certain tributaries (Bice et al. 2011) (4).
- Murray cod may undertake small- to medium-scale (up to 10s km) longitudinal ranging movements, potentially in association with spawning (Koehn et al. 2009, Leigh and Zampatti 2013) (3).
- Freshwater catfish and river blackfish will undertake small-scale movements (<1 km) within restricted home ranges (3).
- Spawning of all species will occur over a defined season (Humphries 2005, Koehn and Harrington 2006, Zampatti et al. 2011c, Cheshire et al. 2012) (4).
- Recruitment of Murray cod is unlikely (Ye and Zampatti 2007) (4).
- Low level recruitment of freshwater catfish is likely (2).
- Recruitment of river blackfish is likely to be dependent upon local habitat and physico-chemical conditions (3).

Flow dependent specialists

- Adults present and common in river main channel and anabranches (e.g. Baumgartner et al. 2008a, Leigh et al. 2012) (4).
- May undertake small- to large-scale (up to 100s km) longitudinal movements (e.g. Zampatti et al. 2011c) (3).
- Spawning and recruitment will not occur (e.g. Humphries et al. 1999, King et al. 2009) (3).
Foraging generalists

- Present and abundant in river main channel, anabranches and connected wetlands (Smith et al. 2009, Bice et al. 2014) (4).
- Depending on antecedent flow conditions, favourable habitat (aquatic vegetation) likely to be abundant in main channel and connected wetlands (Bice et al. 2014) (4).
- May undertake small-scale longitudinal and/or lateral movements (Baumgartner et al. 2008b, Connallin et al. 2011) (2).
- Spawning and recruitment may be enhanced during low flow conditions (Humphries et al. 1999, Cheshire et al. 2012) (3).

Wetland/floodplain specialists

- Present in specific off-channel habitats (Hammer et al. 2013) (4).
- Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (4).

5.2.7 Waterbirds

- At base flow of <10,000 ML.day\(^{-1}\), the extent of inundation in the lower River Murray is limited to permanent wetlands and anabranches (those at or below weir pool operating levels) and the River Murray channel itself. Flow velocity is typically very low, and as such the river channels operate in a comparable way to permanent wetlands. However, the river channels possess a very different morphology to these permanent wetlands; the River Murray channel, for example, is typically U-shaped in cross-section, and thus contains very little low-slope habitat. At these flow rates, both channels and permanent wetlands provide habitat for some waterbird species, although productivity (and therefore the availability of food resources) are low relative to temporarily inundated wetlands and floodplains (4).
- These channels and permanent wetlands do not typically support breeding opportunities for waterbird species (2), although they will provide non-breeding refugia habitat to support maintenance of adults for some waterbird species (2).
- As with other flow bands, the distribution and abundance of waterbirds under entitlement flows will not only be influenced by these local flow and habitat conditions, but by the availability of habitat at other spatial scales (see above for detailed discussion of ‘the issues of scale’) (3).
- U-shaped channel habitats provide foraging habitat for a limited range of waterbird species, notably diving piscivores and omnivores. These include Australasian grebe, *Tachybaptus novaehollandiae*; cormorant species (particularly little pied cormorant, *Microcarbo melanoleucos*; great cormorant, *Phalacrocorax carbo* and little black cormorant, *Phalacrocorax sulcirostris*); Australian pelican and Australasian darter, *Anhinga novaehollandiae* (3).
- The cormorant species and darter also benefit from the proximity of these deep water habitats to large trees that are used for roosting (3).
- Permanent wetlands at this flow band will support small populations of other waterbirds, including teal and other duck species, and larger Australian wading species (e.g. great egret,
yellow-billed spoonbill, *Platalea flavipes*; royal spoonbill; endemic plover species) depending on the nature of shoreline habitat (3).

- Australian pelican and cormorants will also breed during low flow, as long as suitable nesting habitat is available in close proximity to water (e.g. live or dead river red gums for cormorants) (Briggs *et al.* 1997) (4).
5.2.8 Model synthesis

Figure 5-10. Synthesis diagram of hydro-ecological models for flows of 3,000 ML.day⁻¹ in the ‘lower River Murray channel and floodplain’. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
5.3 Lower Lakes and Coorong model (3,000 ML.day⁻¹)

5.3.1 Nutrients, carbon, biofilms and microbes

- Low flow conditions into the lakes result in extended periods of low turbidity, low turbulence, and high light availability resulting in occurrences of cyanobacterial blooms (2).
- At low river flows releases across the barrages are reduced and the Coorong operates as a marine coastal lagoon with phytoplankton dominated by estuarine and marine species of diatoms and flagellates (3).
- If low flow conditions are prolonged a salinity gradient can develop along the Coorong lagoon and halophytic species will appear, often dominated by green algae of the genus *Nannochloris* (3).
- Chlorophyll a levels increased along the Coorong in a north-south direction (low-high salinity) suggesting increased productivity, but this also may be due to the hydrodynamic transport and concentration of cells down the lagoon (3).

5.3.2 Microbiota

- During base flow conditions it is expected that an estuarine microcrustacean zooplankton assemblage will develop within the Coorong including primarily marine copepods (e.g. *Gladioferens* spp. in Geddes and Tanner 2007), some rotifers (e.g. *Synchaeta* spp. in Geddes and Tanner 2007) and no cladocerans (3).
- Lake Albert is likely to contain primarily a halophytic assemblage (1).
- Lake Alexandrina is likely to contain primarily a freshwater limnetic assemblage, similar to River Murray storages (Geddes 1984) (2), however closer to the Coorong and during prolonged drought some saline incursions and subsequently, transport of typically estuarine taxa, may occur (1).

5.3.3 Vegetation

Terrestrial dry

- Plants will colonise lake beds if water levels fall below +0.2 m AHD (Frahn et al. 2013, Nicol et al. 2013) (4).

Terrestrial damp

- Plants will colonise lake beds if water levels fall below +0.2 m AHD (Frahn et al. 2013, Nicol et al. 2013) (3).
Floodplain

- This functional group is generally not present in the Lower Lakes (Frahn et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

- Present at elevations between +0.8 and +0.2 m AHD, will colonise areas to +0.2 m AHD during periods of extremely low water levels (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Amphibious fluctuation tolerator – woody

- Present at elevations above +0.7 m AHD, will colonise lower areas during periods of extremely low water levels but these plants will die once water levels return to normal pool level (Frahn et al. 2013, Nicol et al. 2013) (4).

Amphibious fluctuation tolerator – low growing

- Present at elevations between +0.8 and +0.6 m AHD, will colonise areas to +0.2 m AHD during periods of extremely low water levels (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (3).

Amphibious fluctuation responder – plastic

- Present at elevations between +0.8 and +0.2 m AHD, will colonise areas lower than +0.2 m AHD during periods of extremely low water levels (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Floating

- Present in inundated areas (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent r-selected

- Plants are present in temporary wetlands during winter and spring and present in the propagule bank over summer and autumn (Paton and Bailey 2010, Frahn et al. 2013) (4).

Emergent

- Present at elevations between +0.9 and 0 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).
- Will persist at these elevations for at least two years during periods of extremely low water levels (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent K-selected

- Present at elevations between +0.5 and -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).
• Extirpated once water levels fall below -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

_Ruppia tuberosa_ (Coorong)

• _Ruppia tuberosa_ will germinate in late autumn when water levels in the South Lagoon rise, but flow over the barrages will be insufficient to maintain water levels in late spring and plants will be exposed and die before flowering and seed set (Paton 2005, Paton and Rogers 2008, Brookes et al. 2009b) (4).
• Three or more consecutive years of low flows will deplete the seed bank (Paton and Rogers 2008, Brookes et al. 2009b) (4).
• Three or more consecutive years of low flows will result in a salinity regime that will be unsuitable for the germination of _Ruppia tuberosa_ in the South Lagoon (Brookes et al. 2009b, Kim 2013, Kim et al. 2013) (4).
• Each consecutive year of low flow results in the distribution of _Ruppia tuberosa_ moving northward and will eventually result in colonisation of the southern end of the North Lagoon (e.g. Geddes 1987, Paton and Rogers 2008) (4).

5.3.4 _Macroinvertebrates_

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 5.2.4).

5.3.5 _Frogs_

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 5.2.5).
• The Coorong does not represent suitable habitat for frogs.

5.3.6 _Fish_

_Circa-annual spawning nesting species_

• All species likely rare or absent from lakes, absent from Coorong (Bice 2010b) (4).
• Spawning of Murray cod may occur in lakes, but recruitment unlikely (2).
• Murray cod and freshwater catfish may undertake small-scale movements within Lower Lakes (1) or large-scale movements between Lower Lakes and lower River Murray channel (1).

_Flow-dependent specialist_

• Adults present and common in Lower Lakes (Ferguson 2008) (4).
- May undertake small-scale movements within Lower Lakes (2) or large-scale movements between Lower Lakes and lower River Murray channel (1).

**Foraging generalist**

- Widespread and abundant in Lower Lakes (Wedderburn et al. 2012) (4).
- Spawning and recruitment may be enhanced during low flow conditions (Humphries et al. 1999) (3).
- Certain species (e.g. bony herring, *Nematalosa erebi*; Australian smelt, *Retropinna semoni*; flat-headed gudgeon) may be present in Coorong in low abundance (Zampatti et al. 2010) (4).
- Likely to attempt return movements from Coorong into freshwater habitats (Zampatti et al. 2010) (4).

**Wetland/floodplain specialist**

- Potentially present in specific off-channel habitats, when water levels >0.3 m AHD (Wedderburn et al. 2012, Hammer et al. 2013) (4).
- Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (Bice and Ye 2007) (3).
- Unlikely present in Coorong (4).

**Diadromous species**

- Present, but abundance reliant on connectivity and recruitment in preceding years (Zampatti et al. 2011a) (3).
- Downstream spawning migrations of catadromous species will occur in winter (Zampatti et al. 2011b) (4).
- Juvenile upstream migrations of catadromous species will occur in spring/summer (Zampatti et al. 2010) (4).
- Abundance of juveniles will be largely dependent upon connectivity during previous spawning season (3).
- Upstream migrations of anadromous species will occur in winter/spring (authors unpublished) (3).

**Estuarine dependent species**

- Small-bodied euryhaline estuarine species (e.g. goby species and small-mouthed hardyhead, *Atherinomorus microstoma*) likely present and abundant in lakes, particularly during times of elevated salinity (Jennings et al. 2008, Wedderburn et al. 2012) (4).
- Small-bodied euryhaline estuarine species (e.g. goby species and small-mouthed hardyhead) likely to spawn and recruit within lakes during times of elevated salinity (Jennings et al. 2008) (3).
• Present in Coorong, particularly within the vicinity of the Murray Mouth, with decreasing diversity with increasing distance from the mouth (Noell et al. 2009) (4).
• May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).
• Spawning and recruitment of circa-annual spawners (e.g. goby species and small-mouthed hardyhead) within Coorong is likely (Ye et al. 2011, 2013) (4).
• Recruitment of other, more flow-dependent species (e.g. mulloway) within the Coorong is unlikely (Ferguson et al. 2008) (2).

Marine species

• Some species (e.g. Australian salmon) may be present in low abundance in the lakes (Bice and Zampatti 2011) (3).
• Spawning and recruitment will not occur within the lakes (4).
• Present in Coorong in varying, but often high abundance, particularly within the vicinity of the Murray Mouth, with decreasing diversity with increasing distance from the mouth (Noell et al. 2009) (4).
• May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (3).
• Spawning and recruitment likely not to occur within the Coorong (2).

5.3.7 Waterbirds

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 5.2.7).
• See waterbird ecology section (Section 4.7).
5.3.8 Model synthesis

Figure 5-11. Synthesis diagram of hydro-ecological models for flows of 3,000 ML/day in the ‘Lower Lakes and Coorong’. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
6 Upper base flow (7,000 ML.day\(^{-1}\)) hydro-ecological conceptual models

This section presents data on the hydrology and associated conditions in the lower River Murray in SA under ‘upper base flows’ (7,000 ML.day\(^{-1}\)), and the associated hydro-ecological conceptual models. A general overview of hydraulics (e.g. velocity and water level), floodplain inundation and salinity is provided for the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’. This is followed by the conceptual models for each biotic/abiotic component for each region.

6.1 Hydrology and associated conditions (7,000 ML.day\(^{-1}\))

6.1.1 Lower River Murray channel and floodplain

Hydrology

A flow of 7,000 ML.day\(^{-1}\) at the SA border is the entitlement flow from December to January (Figure 3-3). Under pre-development conditions (modelled natural), flows 7,000 ML.day\(^{-1}\) (or above) persisting for 90 days occurred 1 in 1.03 years (97% of years). Under existing conditions, such a flow occurs 1 in 1.31 years (76% of years).

Hydraulics

Water level

Water level for a discharge of 7,000 ML.day\(^{-1}\) is controlled by the weirs, which are usually operated at normal pool level (Table 3-1, Figure 6-1). Maximum depth along the river channel varies from around 3 – >20 m deep (Figure 6-1). Water level and depth do not differ significantly from 3,000 ML.day\(^{-1}\).

Velocity

Calculated mean cross-sectional velocity ranges 0.11–0.25 m.s\(^{-1}\) in the main channel, (Gippel 2011, Figure 6-1); a slight increase in velocity from 3,000 ML.day\(^{-1}\). Figure 6-2 demonstrates how the velocity within one weir pool changes with proximity to a weir: immediately upstream of Lock 3 modelled depth-averaged velocity in 15 m x 15 m quadrats is around 0.1 m.s\(^{-1}\), but it increases to almost 0.4 m.s\(^{-1}\) downstream of Lock 4 (data from MIKE 21 model, based on a 15 m x 15 m grid) (Wallace et al. 2014).
Inundation

Vegetation

Figure 6-3 shows the total modelled inundation of different vegetation classes on the Lock floodplains 1–6 for a discharge of 10,000 ML.day\(^{-1}\) (in hectares) (note, inundation data for 7,000 ML.day\(^{-1}\) are not available) while Figure 6-4 shows the data as a percent of that vegetation class on that floodplain (data from DEWNR (2012a, 2012b)). River red gum woodlands have the greatest area inundated of the vegetation classes (a total of 580 ha), compared to 22 hectares for emergent sedgeland). However, a greater percent of the emergent sedgelands on the floodplain are inundated (up to 20%) than for river red gum (mean of around 5% of the river red gum woodland floodplain area). Figure 6-5 highlights the dominance of river red gum woodland vegetation class that is inundated, comprising 54% of the inundated area (on the Lock 1-6 floodplains).

Wetlands

Figure 6-6 shows the total modelled inundation of different wetland classes (permanent, saline and temporary) on the Lock 1-6 floodplains for a discharge of 10,000 ML.day\(^{-1}\) (in hectares) while Figure 6-7 shows the data as a percent of that wetland class on that floodplain (data from DEWNR (2012a, 2012b). In general, over 80% of permanent wetlands are inundated for a discharge of 10,000 ML.day\(^{-1}\), compared to approximately 20% of temporary wetlands Figure 6-7.
Figure 6-1 Channel elevation, water level (m AHD) and velocity (m.s$^{-1}$) at ~7,000 ML.day$^{-1}$ in the River Murray channel. Channel depth data from River Murray channel Digital Elevation Model, water level from normal pool level (below Lock 1) and from modelled backwater curves (MIKE 21 model for 10,000 ML.day$^{-1}$)(DEWNR 2012a). Calculated mean cross-sectional velocity (m.s$^{-1}$, n=10–27 cross-sections), showing standard deviation of calculated velocity (Gippel 2011), for 7,000 ML.day$^{-1}$. 
Figure 6-2 Box plots showing median velocity (horizontal), 25th and 75th percentiles enclosing box, and minimum and maximum values, for each kilometre within the Lock 3-4 reach. Data from MIKE 21 model, for a discharge of 7,000 ML.day⁻¹ (Wallace et al. 2014).
Figure 6-3 Area inundated (ha) of the different vegetation classes on the different lock floodplains. Data for a discharge of 10,000 ML.day\(^{-1}\) (DEWNR 2012a, 2012b).

Figure 6-4 Percent of the vegetation class on the different lock floodplains that is inundated by a discharge of 10,000 ML.day\(^{-1}\). For example, at 10,000 ML.day\(^{-1}\), 23% of emergent sedgelands on the Lock 6 floodplain are inundated. (DEWNR 2012a, 2012b).
Figure 6-5 The composition of the floodplain between Locks 1 and 7 that is inundated at 10,000 ML.day\(^{-1}\). For example, of the area inundated between Locks 1 and 7 by a discharge of 10,000 ML.day\(^{-1}\), 12% is lignum shrubland and 54% is river red gum woodland.

Figure 6-6 The wetland area inundated (ha) at a discharge of 10,000 ML.day\(^{-1}\), for the different wetland classes and lock floodplains (DEWR 2012b).
Figure 6-7  Percent of the wetland category on the different lock floodplains that is inundated by a discharge of 10,000 ML.day\(^{-1}\). For example, at 10,000 ML.day\(^{-1}\), 24% of temporary wetland area on the Lock 2 floodplain is inundated. (DEWNR 2012a, 2012b).

6.1.2 Lower Lakes

Salinity

Salinity varies between ~0–2,000 EC units in Lake Alexandrina for barrage discharges 6,500–7,500 ML.day\(^{-1}\) (Figure 6-8). Salinity in Lake Albert (Meningie) varied more (up to ~6,000 EC units), but note that these measurements occurred in 2011–2012 when Lake Albert was still hydrologically disconnected (or only recently connected) from Lake Alexandrina.

Water level

Water level at 6,500–7,500 ML.day\(^{-1}\) is under normal barrage operations and varies from 0.5–1.0 m AHD (Figure 6-9).

6.1.3 Coorong

Salinity

Salinity close to the Murray Mouth varies from ~10–45 g.L\(^{-1}\) for barrage discharges of 6,500–7,500 ML.day\(^{-1}\) (Figure 6-10). Salinity is higher, and with a greater a range (~50–130 g.L\(^{-1}\)) 100 km from the Murray Mouth.

Water level

Water level varies from ~0.4–1 m AHD across the Coorong for barrage discharges of 6,500-7,500 ML.day\(^{-1}\) (Figure 6-11).
Figure 6-8 Salinity measured for barrage discharges of 6,500–7,500 ML.day⁻¹ at different locations in the lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Poltalloch Plains (station A4261031), Narrung Jetty (station A4260583) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 6-9 Water level measured for barrage discharges of 6,500–7,500 ML.day⁻¹ at different locations in the lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.
Figure 6-10 Salinity at barrage discharges of 6,500–7,500 ML.day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.

Figure 6-11 Water level at barrage discharges of 6,500–7,500 ML.day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.
6.2 Lower River Murray channel and floodplain model (7,000 ML.day\(^{-1}\))

Conceptual models take the form of statements on ecological patterns and processes expected from the defined biotic/abiotic components, based upon the hydrological data provided (see above), for ‘upper base flows’ (7,000 ML.day\(^{-1}\)). Each statement was assigned a measure of certainty (in bold at the end of each statement) to aid in identifying knowledge gaps in conceptual understanding (Section 2.3). The certainty scoring system was adapted from Mallen-Cooper \textit{et al.} (2011) and is reiterated below in Table 6-1. The conceptual model statements provided by each expert were then synthesised into a simplified conceptual diagram presenting key ecological patterns and processes.

Table 6-1. ‘Certainty’ scoring system used to define confidence in predictive statements of response to flow in the hydro-ecological conceptual models. Adapted from Mallen-Cooper \textit{et al.} (2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very uncertain</td>
<td>No available data. Diverse views/conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Uncertain</td>
<td>No available data. Expert opinion. Consensus on conceptual understanding</td>
</tr>
<tr>
<td>3</td>
<td>Moderately certain</td>
<td>Supported by indirect, observational or limited scientific data</td>
</tr>
<tr>
<td>4</td>
<td>Very certain</td>
<td>Supported by direct or abundant scientific data. Published peer-reviewed</td>
</tr>
<tr>
<td></td>
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<td>literature</td>
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</tbody>
</table>

6.2.1 Nutrients, carbon, biofilms and microbes

- Low, within-channel flows are expected to contain clearer water due to particle sedimentation under low velocities and reduced connection with sources of colour and suspended particles, although this depends in part on the source of water (2).
- Higher salinities may further increase particle settling increasing light availability (3).
- The shallower depths within the tail waters at these flows will improve the light availability for phytoplankton which could increase in biomass if nutrient concentrations are supportive of growth (3).
- Stable water levels experienced at entitlement flows are conducive to the establishment of late successional biofilms that are a poor quality food resource for grazers (3).
- Low water velocity (<0.1 m.s\(^{-1}\)) and high solar radiation in summer will mean that the development of thermal stratification is likely although this will also depend upon wind conditions (3).
- System becomes carbon and nutrient limited at low flows as phytoplankton biomass increases (3).
- During warm periods with low wind speed there is a risk of onset of persistent stratification in some reaches that may support the development of phytoplankton blooms that may be dominated by harmful or nuisance cyanobacteria (3).
- At low flows, the river food web relies almost solely on autochthonous organic carbon generated by the phytoplankton and biofilms (3).
6.2.2 Microbiota

- Low water velocities and long WRT such as those that occur at flows of 7,000 ML.day\(^{-1}\) will likely favour the dominance of crustacean over rotifer biomass and result in high overall zooplankton abundance and biomass (e.g. Shiel 1982, Saunders and Lewis 1988a) (3). Nevertheless, it is important to note that crustaceans have also been found in low numbers during low flows yet was attributed to the presence of high numbers of planktivorous fish (pers. comm. Shiel 2014).
- A large increase in the percent of emergent sedgelands inundated on the floodplain during upper base flow, in comparison to lower base flow, will increase the area of habitat for littoral microbiota and possibly result in an increase in overall diversity (e.g. Shiel 1976, Walseng et al. 2006) (2).
- Differences in microbiota community structure between open water and littoral habitats are likely to be maintained, where the littoral zones may provide protection for larger zooplankton such as cladocerans from fish predation during the day and host a more diverse community (Meerhoff et al. 2003, Estlander et al. 2009) (2).

6.2.3 Vegetation

Terrestrial dry

- Abundant throughout the floodplain (including temporary wetlands), providing flooding has been absent for longer than one year (Holt et al. 2005, Nicol et al. 2006, Marsland and Nicol 2007, 2008a, 2009a, 2009b, Marsland 2010, Gehrig et al. 2013) (4).

Terrestrial damp

- Restricted to the upper littoral zone where there is sufficient soil moisture but limited inundation (Zampatti et al. 2011c) (3).

Floodplain

- Restricted to the upper littoral zone where there is sufficient soil moisture but limited inundation (Blanch and Walker 1997, Blanch et al. 1999b, 2000, Nicol et al. 2006) (3).
- Recruitment limited to the upper littoral zone (3).

Amphibious fluctuation tolerator – emergent

- Present in the littoral zone that regularly wets and dries and in water up to 10 cm deep (Blanch and Walker 1997, Blanch et al. 1999b, 2000, Holt et al. 2005) (3).
- Recruitment limited to the littoral zone (2).

Amphibious fluctuation tolerator – woody

• Plants growing on the edges of permanent water bodies or in areas where groundwater is being freshened will remain in good condition (e.g. Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4).
• There will be an improvement in condition of a small area of trees and shrubs (especially in upper weir pools) due to increased water levels and bank recharge (Bacon et al. 1993, Thorburn et al. 1994) (3).
• Condition will decline after extended periods without inundation (length of time depends on species) for plants growing farther from permanent water (4).

Amphibious fluctuation tolerator – low growing

• Present in the littoral zone that regularly wets and dries and in water up to 5 cm deep (e.g. Blanch and Walker 1997, Blanch et al. 1999b, 2000, Nicol et al. 2006) (2).
• Recruitment limited to the littoral zone (2).

Amphibious fluctuation responder – plastic

• Present in the littoral zone that regularly wets and dries and in water up to 50 cm deep (or deeper for species such as Ludwigia peploides that has stems that will float on water surface) (Blanch and Walker 1997, Blanch et al. 1999b, 2000, Nicol 2004) (3).
• Recruitment limited to the littoral zone (2).

Floating

• Present in river main channel and connected wetlands (e.g. Jessop and Tolken 1986, Cunningham et al. 1992, Blanch and Walker 1997) (4).

Submergent r-selected

• Absent throughout system except in the sediment propagule bank (e.g. Nicol et al. 2006) (4).

Emergent

• Restricted to the edges of permanent water bodies to a depth of 1 m (e.g. Blanch and Walker 1997, Blanch et al. 1999b, 2000, Holt et al. 2005) (4).
• Recruitment will also occur in this zone (3).

Submergent K-selected

• Present in river main channel and connected wetlands the maximum depth of colonisation will depend on species and water clarity (Blanch and Walker 1997, Blanch et al. 1999b, 2000, Holt et al. 2005) (4).
6.2.4 Macroinvertebrates

Group A

- Exhibit a decline in abundance and/or diversity due to likely increases in salinity and limited supply of allochthonous food input and low quality biofilms present (increased dominance of filamentous algae) (Burns and Walker 2000a) (3).

Group B

- Exhibit a decline in abundance and/or diversity due to likely increases in salinity and limited supply of allochthonous food input and low quality biofilms present (3).

Group C

- Expected to be maintained at this level of flow due to medium tolerance of increased salinity levels, short generation times and predatory food preference (3).

Group D

- Expected to be maintained at this level of flow due to medium to high tolerance of increased salinity levels and use of autochthonous food sources (3).

Group E

- Expected to be maintained at this level of flow due to medium tolerance of increased salinity levels and multiple generations (up to 10) per year (3).

6.2.5 Frogs

Breeding habitat and requirements

- Although most species have a preference for temporary water bodies for breeding, most species are known to breed in permanent water bodies and thus, low levels of reproduction may be expected at this flow band (Gonzalez et al. 2011) (4).
- Low level breeding is most likely to occur in permanent water bodies that have submerged, aquatic, emergent vegetation, as all species have a strong preference for well vegetated water bodies (Gonzalez et al. 2011) (4).
- Limited water level fluctuations associated with these flows means that there is low risk of egg desiccation when water levels drop rapidly for those species that require vegetation to anchor eggs (2).

Tadpoles

- These flows predominantly affect permanent water bodies, and hence there is limited inundation and drying of temporary wetlands. Where species do breed during these flows,
the species with mid to long tadpole developmental phases have a low risk of water bodies drying out before metamorphosis is completed (Gonzalez et al. 2011) (2).

- Predation by introduced fish species is expected to be high for most species so good connectivity of permanent water bodies associated with these flows and the presence of fish, in combination with limited inundation of vegetation for shelter, may impact on tadpoles through predation and/or disturbance by fish (Gonzalez et al. 2011) (2).

**Adults**

- These flows are mostly associated with permanent wetlands and water bodies which may provide important refuge in low flow periods for most species (Wassens et al. 2008a, Sheldon et al. 2010) (4).

### 6.2.6 Fish

#### Circa-annual spawning nesting species

- Adult Murray cod and freshwater catfish present in river main channel and anabranches (e.g. Baumgartner et al. 2008a, Zampatti et al. 2011c, Leigh and Zampatti 2013) (4).
- River blackfish present in specific habitats of certain tributaries (Bice et al. 2011) (4).
- Murray cod may undertake small- to medium-scale (up to 10s km) longitudinal ranging movements, potentially in association with spawning (Koehn et al. 2009, Leigh and Zampatti 2013) (3).
- Freshwater catfish and river blackfish will undertake small-scale movements (<1 km) within restricted home ranges (3).
- Spawning of all species will occur over a defined season (Humphries 2005, Koehn and Harrington 2006, Zampatti et al. 2011c, Cheshire et al. 2012) (4).
- Recruitment of Murray cod is unlikely (Ye and Zampatti 2007) (4).
- Low level recruitment of freshwater catfish is likely (2).
- Recruitment of river blackfish is likely to be dependent upon local habitat and physico-chemical conditions (3).

#### Flow dependent specialists

- Adults present and common in river main channel and anabranches (Baumgartner et al. 2008a, Leigh et al. 2012) (4).
- May undertake small- to large-scale (up to 100s km) longitudinal movements (e.g. Zampatti et al. 2011c) (3).
- Spawning and recruitment will not occur (Humphries et al. 1999, King et al. 2009) (3).

#### Foraging generalists

- Present and abundant in river main channel, anabranches and connected wetlands (Smith et al. 2009, Bice et al. 2014) (4).
• Depending on antecedent flow conditions, favourable habitat (aquatic vegetation) likely to be abundant in main channel and connected wetlands (Bice et al. 2014) (4).
• May undertake small-scale longitudinal and/or lateral movements (Baumgartner et al. 2008b, Connallin et al. 2011) (2).
• Spawning and recruitment may be enhanced during low flow conditions (Humphries et al. 1999, Cheshire et al. 2012) (3).

Wetland/floodplain specialists

• Present in specific off-channel habitats (Hammer et al. 2013) (4).
• Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (4).

6.2.7 Waterbirds

• At base flow of <10,000 ML.day\(^{-1}\), the extent of inundation in the lower River Murray is limited to permanent wetlands and anabranches (those at or below weir pool operating levels) and the River Murray channel itself. Flow velocity is typically very low, and as such the river channels operate in a comparable way to permanent wetlands. However, the river channels possess a very different morphology to these permanent wetlands; the River Murray channel, for example, is typically U-shaped in cross-section, and thus contains very little low-slope habitat.
• At these flow rates, both channels and permanent wetlands provide habitat for some waterbird species, although productivity (and therefore the availability of food resources) are low relative to temporarily inundated wetlands and floodplains (4). These channels and permanent wetlands do not typically support breeding opportunities for waterbird species (2), although they will provide non-breeding refugia habitat to support maintenance of adults for some waterbird species (2).
• As with other flow bands, the distribution and abundance of waterbirds under entitlement flows will not only be influenced by these local flow and habitat conditions, but by the availability of habitat at other spatial scales (see above for detailed discussion of ‘the issues of scale’) (3).
• U-shaped channel habitats provide foraging habitat for a limited range of waterbird species, notably diving piscivores and omnivores. These include Australasian grebe, cormorant species (particularly little pied cormorant, great cormorant and little black cormorant), Australian pelican and Australasian darter (3).
• The cormorant species and darter also benefit from the proximity of these deep water habitats to large trees that are used for roosting (3).
• Permanent wetlands at this flow band will support small populations of other waterbirds, including teal and other duck species, and larger Australian wading species (e.g. great egret, yellow-billed and royal spoonbill, endemic plover species) depending on the nature of shoreline habitat (3).
Australian pelican and cormorants will also breed during low flow, as long as suitable nesting habitat is available in close proximity to water (e.g. live or dead river red gums for cormorants) (Briggs et al. 1997) (4).
6.2.8 Model synthesis

Figure 6-12. Synthesis diagram of hydro-ecological models for flows of 7,000 ML.day\(^{-1}\) in the ‘lower River Murray channel and floodplain’. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
6.3 Lower Lakes and Coorong model (7,000 ML.day\(^{-1}\))

6.3.1 Nutrients, carbon, biofilms and microbes

- Low flow conditions into the lakes result in extended periods of low turbidity, low turbulence, and high light availability resulting in occurrences of cyanobacterial blooms (2).
- At low river flows releases across the barrages are reduced and the Coorong operates as a marine coastal lagoon with phytoplankton dominated by estuarine and marine species of diatoms and flagellates (3).
- If low flow conditions are prolonged a salinity gradient can develop along the Coorong lagoon and halophytic species appear, often dominated by green algae of the genera *Nannochloris* (3).
- Chlorophyll \(a\) levels increased along the Coorong in a north to south direction (low to high salinity) suggesting increased productivity, but this also may be due to the hydrodynamic transport and concentration of cells down the lagoon (3).

6.3.2 Microbiota

- During base flow conditions it is expected that an estuarine microcrustacean zooplankton assemblage will develop within the Coorong including primarily marine copepods (e.g. *Gladioferens* spp. in Geddes and Tanner 2007), some rotifers (e.g. *Synchaeta* spp. in Geddes and Tanner 2007) and no cladocerans (3).
- Lake Albert is likely to contain primarily a halophytic assemblage (1).
- Lake Alexandrina is likely to contain primarily a freshwater limnetic assemblage, similar to River Murray storages (Geddes 1984) (2); however, closer to the Coorong and during prolonged drought some saline incursions and subsequently, transport of typically estuarine taxa, may occur (1).

6.3.3 Vegetation

**Terrestrial dry**

- Plants will colonise lake beds if water levels fall below +0.2 m AHD (Frahn *et al.* 2013, Nicol *et al.* 2013) (4).

**Terrestrial damp**

- Plants will colonise lake beds if water levels fall below +0.2 m AHD (Frahn *et al.* 2013, Nicol *et al.* 2013) (3).
Floodplain

- This functional group is generally not present in the Lower Lakes (Frahn et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

- Present at elevations between +0.8 and +0.2 m AHD, will colonise areas to +0.2 m AHD during periods of extremely low water levels (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Amphibious fluctuation tolerator – woody

- Present at elevations above +0.7 m AHD, will colonise lower areas during periods of extremely low water levels but these plants will die once water levels return to normal pool level (Frahn et al. 2013, Nicol et al. 2013) (4).

Amphibious fluctuation tolerator – low growing

- Present at elevations between +0.8 and +0.6 m AHD, will colonise areas to +0.2 m AHD during periods of extremely low water levels (Frahn et al. 2013, Nicol et al. 2013) (3).

Amphibious fluctuation responder – plastic

- Present at elevations between +0.8 and +0.2 m AHD, will colonise areas to +0.2 m AHD during periods of extremely low water levels (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Floating

- Present in permanently inundated areas (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent r-selected

- Plants are present in temporary wetlands during winter and spring and present in the propagule bank over summer and autumn (Paton and Bailey 2010, Frahn et al. 2013) (4).

Emergent

- Present at elevations between +0.9 and 0 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).
- Will persist at these elevations for at least two years during periods of extremely low water levels (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent K-selected

- Present at elevations between +0.5 and -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).
• Extirpated once water levels fall below -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

*Ruppia tuberosa* (Coorong)

• *Ruppia tuberosa* will germinate in late autumn when water levels in the South Lagoon rise but flow over the barrages will be insufficient to maintain water levels in late spring and plants will be exposed and die before flowering and seed set (Paton 2005, Paton and Rogers 2008, Brookes et al. 2009b) (4).

• Three or more years of consecutive years of low flows will deplete the seed bank (Paton and Rogers 2008, Brookes et al. 2009b) (4).

• Three or more years of consecutive of low flows will result in a salinity regime that will be unsuitable for the germination of *Ruppia tuberosa* in the South Lagoon (Brookes et al. 2009b, Kim 2013, Kim et al. 2013) (4).

• Each consecutive year of low flow results in the distribution of *Ruppia tuberosa* moving northward and will eventually result in colonisation of the southern end of the North Lagoon (Geddes 1987, Paton and Rogers 2008) (4).

6.3.4 Macroinvertebrates

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 6.2.4).

6.3.5 Frogs

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 6.2.5).

• The Coorong does not represent suitable habitat for frogs.

6.3.6 Fish

Circa-annual spawning nesting species

• All species likely rare or absent from lakes, absent from Coorong (Bice 2010b) (4).

• Spawning of Murray cod may occur in lakes, but recruitment unlikely (2).

• Murray cod and freshwater catfish may undertake small-scale movements within Lower Lakes (1) or large-scale movements between Lower Lakes and lower River Murray channel (1).

Flow-dependent specialist

• Adults present and common in Lower Lakes (Ferguson 2008) (4).
• May undertake small-scale movements within Lower Lakes (2) or large-scale movements between Lower Lakes and lower River Murray channel (1).
• Spawning and recruitment will not occur (Humphries et al. 1999, King et al. 2009, Cheshire et al. 2012) (2).

Foraging generalist

• Widespread and abundant in lakes (Wedderburn et al. 2012) (4).
• Spawning and recruitment may be enhanced during low flow conditions (Humphries et al. 1999) (3).
• Certain species (e.g. bony herring, Australian smelt, flat-headed gudgeon) may be present in Coorong in low abundance (Zampatti et al. 2010) (4).
• Likely to attempt return movements from Coorong into freshwater habitats (Zampatti et al. 2010) (4).

Wetland/floodplain specialist

• Potentially present in specific off-channel habitats, when water levels >0.3 m AHD (Wedderburn et al. 2012, Hammer et al. 2013) (4).
• Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (Bice and Ye 2007) (3).
• Unlikely present in Coorong (4).

Diadromous species

• Present, but abundance reliant on connectivity and recruitment in preceding years (Zampatti et al. 2011a) (3).
• Downstream spawning migrations of catadromous species will occur in winter (Zampatti et al. 2011b) (4).
• Juvenile upstream migrations of catadromous species will occur in spring/summer (Zampatti et al. 2010) (4). Abundance of juveniles will be largely dependent upon connectivity during previous spawning season (3).
• Upstream migrations of anadromous species will occur in winter/spring (authors unpublished) (3).

Estuarine dependent species

• Small-bodied euryhaline estuarine species (e.g. goby species, small-mouthed hardyhead) likely present and abundant in Lower Lakes, particularly during times of elevated salinity (Jennings et al. 2008, Wedderburn et al. 2012) (4).
• Small-bodied euryhaline estuarine species (e.g. goby species, small-mouthed hardyhead) likely to spawn and recruit within Lower Lakes during times of elevated salinity (Jennings et al. 2008) (3).
• Present in Coorong, particularly within the vicinity of the Murray Mouth, with decreasing diversity with increasing distance from the mouth (Noell et al. 2009) (4).
- May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).
- Spawning and recruitment of circa-annual spawners (e.g. goby species, small-mouthed hardyhead) within Coorong is likely (Ye et al. 2011, 2013) (4).
- Recruitment of other, more flow-dependent species (e.g. mulloway) within the Coorong, is unlikely (Ferguson et al. 2008) (2).

**Marine species**

- Some species (e.g. Australian salmon) may be present in low abundance in the Lower Lakes (Bice and Zampatti 2011) (3).
- Spawning and recruitment will not occur within the Lower Lakes (4).
- Present in Coorong in varying, but often high abundance, particularly within the vicinity of the Murray Mouth, with decreasing diversity with increasing distance from the mouth (Noell et al. 2009) (4).
- May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (3).
- Spawning and recruitment likely not to occur within the Coorong (2).

### 6.3.7 Waterbirds

- Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 6.2.7).
- See waterbird ecology section (Section 4.7).
6.3.8 Model synthesis

Figure 6-13. Synthesis diagram of hydro-ecological models for flows of 7,000 ML.day⁻¹ in the 'Lower Lakes and Coorong'. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
7 Freshes (20,000 ML.day\(^{-1}\)) hydro-ecological conceptual models

This section presents data on the hydrology and associated conditions in the lower River Murray in SA under ‘upper base flows’ (20,000 ML.day\(^{-1}\)), and the associated hydro-ecological conceptual models. A general overview of hydraulics (e.g. velocity and water level), floodplain inundation and salinity is provided for the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’. This is followed by the conceptual models for each biotic/abiotic component for each region.

7.1 Hydrology and associated conditions (20,000 ML.day\(^{-1}\))

7.1.1 Lower River Murray channel and floodplain

Hydrology

Under pre-development conditions (modelled natural), flows of 20,000 ML.day\(^{-1}\) (or above) persisted for 120 days at a frequency of 1 in 1.13 years (88.6% of years), for 90 days at 1 in 1.11 years (90.4% of years) and for 60 days at 1 in 1.08 (93% of years). Under existing conditions, such a flow occurs for 120 days at a frequency of 1 in 3.35 years (29.8%), for 90 days at 1 in 2.53 years (39.5%) and for 60 days at 1 in 2.15 years (46.5%).

Hydraulics

Water level

Water level for a discharge of 20,000 ML.day\(^{-1}\) is controlled by the weirs, which are usually operated at normal pool level (Table 3-1, Figure 7-1). The water level differs slightly at the upstream end of the weir pool (immediately downstream of a weir) compared to both lower and upper base flow scenarios, but remains at the same water level as base flow levels the closer to the downstream weir. Maximum depth along the river channel varies from around 3 – >20 m deep (Figure 7-1).

Velocity

Modelled, measured and calculated velocity in the main channel varies from 0.2 – >1 m.s\(^{-1}\) in the main channel (Figure 7-1 and 7-2); greater than the 0.11–0.25 m.s\(^{-1}\) experienced at 7,000 ML.day\(^{-1}\). Velocity varies substantially based on the position within a weir pool; Figure 7-2 presents modelled median velocity increasing from ~0.2 m.s\(^{-1}\) just upstream of Lock 3 to over 1 m.s\(^{-1}\) just downstream of Lock 4 (consistent also with the modelled, measured and calculated velocities shown in Figure 7-1).
Inundation

Vegetation

Figure 7-3 shows the total modelled inundation of different vegetation classes on the floodplains of Locks 1, 2, 4 and 6 for a discharge of 20,000 ML.day$^{-1}$ (DEWNR 2012a, 2012b); data were not available for Locks 3 and 5. Figure 7-4 shows the same data as a percent of that vegetation class on that floodplain (Lock 1, 2, 4 and 6), while Figure 7-5 shows the percent of vegetation classes inundated for Locks 3 and 5, using data from RiMFIM (Overton et al. 2006b; note different vegetation classes between the figures). As water level at 20,000 ML.day$^{-1}$ differs little from base flow (3,000 ML.day$^{-1}$ and 7,000 ML.day$^{-1}$), the vegetation inundation also differs little from base flow. River red gum woodlands have the greatest area inundated of the vegetation classes (a total of 380 hectares for Lock floodplains 1, 2, 4 and 6), compared to 13 hectares for emergent sedgeland (over the same floodplains). However, a greater percent of the emergent sedgelands on the floodplain are inundated (up to 20%) than for river red gum (mean of around 5% of the river red gum woodland floodplain area). Figure 7-6 highlights the dominance of river red gum woodland vegetation class that is inundated, comprising 53% of the inundated area (on Lock floodplains 1, 2, 4 and 6).

Wetlands

Figure 7-7 presents the total modelled inundation of different wetland classes (permanent, saline and temporary) on the floodplains of Locks 1, 2, 4 and 6 for a discharge of 20,000 ML.day$^{-1}$ (DEWNR 2012a, 2012b), and Figure 7-8 shows the total inundated wetland area for Lock floodplains 3 and 5 (data from RiMFIM (Overton et al. 2006b). Figure 7-9 and Figure 7-10 show the same data as Figure 7-7 and Figure 7-8 respectively, but as a percent of the total wetland area on the corresponding floodplain. As for vegetation, as water level at 20,000 ML.day$^{-1}$ differs little from base flow (3,000 ML.day$^{-1}$ and 7,000 ML.day$^{-1}$), the wetland inundation also differs little from base flow; in general, over 80% of permanent wetlands are inundated for a discharge of 20,000 ML.day$^{-1}$, compared to approximately 20% of temporary wetlands.
Figure 7-1 Channel elevation, water level (m AHD) and velocity (m.s\(^{-1}\)) at ~20,000 ML.day\(^{-1}\) in the River Murray channel. Channel depth data from River Murray channel Digital Elevation Model, water level from modelled backwater curves (MIKE 21 model for 20,000 ML.day\(^{-1}\)) (DEWNR 2012a) and from printed backwater charts (~1977) for 20,000 ML.day\(^{-1}\). Calculated mean cross-sectional velocity (n=10–27 cross-sections), showing standard deviation of calculated velocity (Gippel 2011), for 20,000 ML.day\(^{-1}\). Field velocity measured using an Acoustic Doppler Profiler (ADCP) and shows the mean cross-sectional velocity for one transect (Bice et al. 2013) for discharges16,000–25,000 ML.day\(^{-1}\). Modelled velocity using MIKE 21 model for 24,000 ML.day\(^{-1}\) in Bice et al. (2013).
Figure 7.2 Box plots showing median velocity (horizontal), 25th and 75th percentiles enclosing box, and minimum and maximum values, for each kilometre within the Lock 3–4 reach. Data from MIKE 21 model, for a discharge of 20,000 ML.day⁻¹ (Wallace et al. 2014).
Figure 7-3 Area inundated (ha) of the different vegetation classes on the different lock floodplains (data not available for Locks 3 and 5). Data for a discharge of 20,000 ML.day$^{-1}$, from DEWNR (2012a, 2012b). Vegetation classes from DEWNR (2012b).

Figure 7-4 Percent of the vegetation class on the different lock floodplains that is inundated by a discharge of 20,000 ML.day$^{-1}$. For example, at 20,000 ML.day$^{-1}$, 23% of emergent sedgeland on the Lock 6 floodplain are inundated. (DEWNR 2012a, 2012b).
Figure 7.5 Percent of different vegetation classes on the different Lock floodplains 3 and 5, inundated by a discharge of 20,000 ML.day\(^{-1}\) (RiMFIM) (Overton et al. 2006b).

Figure 7.6 The composition of the floodplain between Locks 1, 2, 4 and 6 that is inundated at 20,000 ML.day\(^{-1}\) (DEWNR 2012a, 2012b), and not available for Lock floodplains 3 and 5. For example, of the area inundated by a discharge of 20,000 ML.day\(^{-1}\), 11% is lignum shrubland and 53% is river red gum woodland.
Figure 7-7 The wetland area inundated (ha) at a discharge of 20,000 ML.day\(^{-1}\), for the different wetland classes for Lock floodplains 1, 2, 4 and 6 (DEWNR 2012b). Data not available for Lock floodplains 3 and 5.

Figure 7-8 Inundated wetland area (ha) on the Lock 3 and 5 floodplains, for a discharge of 20,000 ML.day\(^{-1}\) (RiMFIM) (Overton et al. 2006b).

Figure 7-9 Percent of the wetland category on the floodplains of Locks 1, 2, 4 and 6 that is inundated by a discharge of 20,000 ML.day\(^{-1}\). For example, at 20,000 ML.day\(^{-1}\), 33% of the temporary wetland area on the Lock 2 floodplain is inundated. (DEWNR 2012a, 2012b). Data not available for the Lock 3 and 5 floodplains.
7.1.2 Lower Lakes

Salinity

Salinity varies between ~0–3,500 EC units in Lake Alexandrina for discharges 15,000–25,000 ML.day$^{-1}$ (Figure 7-11); higher than those recorded at lower discharges. This may be an artefact of the relatively small number of data points for these flow bands, as higher lake inflows and barrage discharges are often associated with lower salinities (Lester et al. 2011). Salinity in Lake Albert (Meningie) varied more (up to ~10,000 EC units); again higher than those recorded for the lower flow bands. Note that the effects of the long drought and the hydrological disconnection of Lake Albert from Lake Alexandrina (~2007–2011) likely influenced these measurements.

Water level

Water level at 15,000–25,000 ML.day$^{-1}$ is under normal barrage operations and varies from 0.5–1.0 m AHD (Figure 7-12).

7.1.3 Coorong

Salinity

Salinity close to the Murray Mouth varies from ~0–45 g.L$^{-1}$ for barrage discharges of 15,000–25,000 ML.day$^{-1}$ (Figure 7-13). Salinity is higher, and with a greater range (~50–130 g.L$^{-1}$) 100 km from the Murray Mouth.
Water level

Water level varies from ~0.4–1.1 m AHD across the Coorong for barrage discharges of 15,000–25,000 ML.day\(^{-1}\) (Figure 7-14).

Figure 7-11 Salinity measured for barrage discharges of 15,000–25,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Poltalloch Plains (station A4261031), Narrung Jetty (station A4260583) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 7-12 Water level measured for barrage discharges of 15,000–25,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.
Figure 7-13 Salinity at barrage discharges of 15,000–25,000 ML.day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.

Figure 7-14 Water level at barrage discharges of 15,000–25,000 ML.day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Water level data from Webster (1997). Barrage discharge data from the MDBA.
7.2 Lower River Murray channel and floodplain model (20,000 ML.day\(^{-1}\))

Conceptual models take the form of statements on ecological patterns and processes expected from the defined biotic/abiotic components, based upon the hydrological data provided (see above), for ‘freshes’ (20,000 ML.day\(^{-1}\)). Each statement was assigned a measure of certainty (in bold at the end of each statement) to aid in identifying knowledge gaps in conceptual understanding (Section 2.3). The certainty scoring system was adapted from Mallen-Cooper et al. (2011) and is reiterated below in Table 7-1. The conceptual model statements provided by each expert were then synthesised into a simplified conceptual diagram presenting key ecological patterns and processes.

Table 7-1. ‘Certainty’ scoring system used to define confidence in predictive statements of response to flow in the hydro-ecological conceptual models. Adapted from Mallen-Cooper et al. (2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very uncertain</td>
<td>No available data. Diverse views/conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Uncertain</td>
<td>No available data. Expert opinion. Consensus on conceptual understanding</td>
</tr>
<tr>
<td>3</td>
<td>Moderately certain</td>
<td>Supported by indirect, observational or limited scientific data</td>
</tr>
<tr>
<td>4</td>
<td>Very certain</td>
<td>Supported by direct or abundant scientific data. Published peer-reviewed literature</td>
</tr>
</tbody>
</table>

7.2.1 Nutrients, carbon, biofilms and microbes

- Decreases in light penetration may occur associated with the influx of dissolved colour and organic and inorganic suspended particles (3).
- Increasing depths in the tail waters will reduce the river reach mean light available for phytoplankton (3).
- The increase in surface water level in the upper reaches of the weir pools will substantially alter the light environmental experienced by biofilms (3).
- Increases in surface water level and concomitant change in water level will have a similar impact on resetting biofilm communities as a desiccation event (2).
- Changes to biofilm communities induced by changes in water level (deep submergence) and euphotic depth will be short-lived (<30 days) i.e. the biofilm will return to a late successional community upon return to stable water levels (2).
- Very slow rates of water level change eliminate cues and biogeochemical processes associated with flow induced changes in water level in an unregulated system (3).
- The magnitude of biogeochemical response will be mediated by day length and water temperature (3).
- Velocities in some areas approach the threshold at which scouring of existing biofilms may occur, creating surface area available for colonisation by early successional state taxa (3).
- Inundation of low elevation river red gum and early commence to flow wetlands will start to influence the load of carbon and nutrients in the water column (3).
- It is estimated that ~6 and 1,115 kilotonnes of FRP and DOC respectively could be mobilised by a flow of this magnitude (3).
- Diverting (routing) water from upstream unregulated flows via Lake Victoria decreases the load and/or bioavailability of carbon and nutrients in the lower River Murray (2).
- At moderate within-channel flows, phytoplankton communities are likely to be dominated by diatoms (3).
- At moderate within-channel flows, heterotrophic activity will become increasingly important in net ecosystem productivity evidenced by increases in respiration rates, larger bacterial populations and increases in the size and complexity of the heterotrophic microeukaryote communities (2).

### 7.2.2 Microbiota

- During flows of 20,000 ML.day\(^{-1}\), elevated water velocity is likely to begin inhibiting zooplankton reproduction. There will be areas (particularly just below weirs) where no reproduction is likely to occur (water velocity >0.4 m.s\(^{-1}\)) and areas (particularly just above weirs) where reproduction will occur (water velocity <0.4 m.s\(^{-1}\)) (Rzoska 1978). Overall, this may result in lower zooplankton abundance and biomass in comparison to lower and upper base flow bands and a shift from crustacean to a rotifer biomass dominated system (e.g. Saunders and Lewis 1988a, 1988b, 1989) (2). This will possibly occur more prominently in the upper zones than the lower zones also due to flow conditions (Basu and Pick 1996) (2).
- Permanently inundated wetlands are likely to host communities with a higher proportion of crustaceans due to the longer WRTs (e.g. Baranyi et al. 2002) (3).
- Newly inundated temporary wetlands are likely to host considerably more abundant and diverse communities than the river main channel due to community emergence from the egg bank and longer WRTs (e.g. Saunders and Lewis 1988a, 1988b, Boulton and Lloyd 1992, Tan and Shiel 1993) (4). They are likely to be rotifer dominated within the first few weeks and then shift to a crustacean dominated community (Furst 2014) (3).
- Under 20,000 ML.day\(^{-1}\), it is unlikely that flow will be sufficient to flush communities from the wetlands and therefore they are unlikely to reach the river main channel (excluding a small proportion) (2).
- Differences in microbiota community structure between open water and littoral habitats are likely to be maintained, where the littoral zones may provide protection for larger zooplankton such as cladocerans from fish predation during the day and host a more diverse community (Meerhoff et al. 2003, Estlander et al. 2009) (2).

### 7.2.3 Vegetation

**Terrestrial dry**

- Abundant across the floodplain, providing flooding has been absent for longer than one year (Holt et al. 2005, Nicol et al. 2006, Marsland and Nicol 2007, Gehrig et al. 2013) (4).
- Extirpated from temporary wetlands and low lying floodplain inundated by increased flow (Zampatti et al. 2011c) (4).

**Terrestrial damp**

- Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
- Recruitment in temporary wetlands and on low lying floodplain that was inundated by the high flow as water levels recede (Nicol 2004, 2012, Nicol et al. 2010) (3).

**Floodplain**

- Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
- Recruitment in temporary wetlands and on low lying floodplain that was inundated by the high flow as water levels recede (Nicol 2004, 2012, Nicol et al. 2010) (4).

**Amphibious fluctuation tolerator – emergent**

- Plants will recruit in temporary wetlands and on the low lying floodplain that was inundated by the high flow, whether they germinate on submergence or exposure depends on species (Zampatti et al. 2011c) (3).
- Plants growing at or below pool level will be extirpated if inundation is longer than 30 days in upper weir pools but will persist in lower weir pools (1).

**Amphibious fluctuation tolerator – woody**

- Recruitment will occur in temporary wetlands and on the low lying floodplain that was inundated by the high flow as water levels recede (2).
- Plants growing on the edges of permanent water bodies or in areas where groundwater is being freshened will remain in good condition (Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4).
- There will be an improvement in condition of trees and shrubs in temporary wetlands and on the low lying floodplain that was inundated by the high flow (McEwan et al. 2006, Doody et al. 2009, Holland et al. 2009) (4).
- Condition will decline after extended periods without inundation (length of time depends on species) for plants growing farther from permanent water (4).

**Amphibious fluctuation tolerator – low growing**

- Plants will recruit in temporary wetlands and on the low lying floodplain that was inundated by the high flow, whether they germinate on submergence or exposure depends on species (Nicol 2004, 2012, Nicol et al. 2010) (2).
- Plants growing in upper weir pools at or below pool level will persist providing inundation is no longer than 60 days (1).
- Plants growing in lower weir pools at or below pool level will persist (Blanch and Walker 1997, Blanch et al. 1999b, 2000) (2).
Amphibious fluctuation responder – plastic

- Plants will recruit in temporary wetlands and on the low lying floodplain that was inundated by the high flow, whether they germinate on submergence or exposure depends on species (Nicol 2004, 2012, Nicol et al. 2010) (2).
- Plants that recruited during low flows will persist due to their ability to respond morphologically to water level changes (Cooling 1996, Nicol 2004) (2).

Floating


Submergent r-selected

- Plants will recruit in temporary wetlands providing the hydroperiod is sufficient to complete life cycle (Frahn et al. 2013) (2).

Emergent

- Will be most abundant around pool level elevation (Blanch and Walker 1997, Blanch et al. 1999b, 2000) (2).
- Recruitment will occur in temporary wetlands inundated by the higher flows (2).
- Plants growing in deep water in upper weir pools will be temporarily extirpated due to top flooding (1).

Submergent K-selected

- Present in river main channel and permanently connected wetlands the maximum depth of colonisation will depend on species and water clarity (e.g. Blanch and Walker 1997, Blanch et al. 1999b, 2000, Sainty and Jacobs 2003, Holt et al. 2005) (4).  
- Plants growing in deeper water in the upper weir pools will be temporarily extirpated due to lack of light (1).
- Plants growing in lower weir pools will persist (Blanch and Walker 1997, Blanch et al. 1999b, 2000) (3).

7.2.4 Macroinvertebrates

Group A

- Potential to be maintained at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances (3).

Group B

- Potential to be maintained at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances (3).
Group C

- Expected to be maintained at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances (3).

Group D

- Expected to be maintained at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances (3).

Group E

- Expected to be maintained at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances (3).

7.2.5  Frogs

Breeding habitat and requirements

- These flows are mostly associated with permanent water bodies; however, the inundation of low elevation river red gums and riparian vegetation as a result of increasing river levels may provide an increase in preferred breeding habitat when compared to lower flows (Anstis 2013) (3).
- If flow peak rapidly recedes, subsequent receding water levels during spring/summer breeding seasons have the potential to cause desiccation of eggs of those species that anchor eggs to vegetation (2).

Tadpoles

- Inundation of riparian vegetation may provide tadpoles with access to preferred habitats and also provide a decreased risk of predation and disturbance from fish (Anstis 2013) (3).
- Where these flows have inundated low lying wetlands, if flows are of a short duration and the temporary wetlands are shallow, there is the potential that if breeding occurs, tadpoles of species with medium to long tadpole developmental phases will be at risk of desiccation (4).

Adults

- These flows are also mostly associated with permanent wetlands and water bodies which may provide important refuge in low flow periods for most species (Wassens et al. 2008a, Sheldon et al. 2010) (4).
7.2.6  Fish

Circa-annual spawning nesting species

- Adult Murray cod and freshwater catfish present in river main channel and anabranches (Baumgartner et al. 2008a, Zampatti et al. 2011c, Zampatti et al. 2014) (4).
- River blackfish present in specific habitats of certain tributaries (Bice et al. 2011) (4).
- Increased water velocities and accompanying hydraulic diversity will result in increased area of favourable adult and juvenile Murray cod habitat in the main channel (Koehn 2009) (2).
- Murray cod may undertake small- to medium-scale (up to 10s km) longitudinal ranging movements, potentially in association with spawning (Koehn et al. 2009, Leigh and Zampatti 2013) (3).
- Freshwater catfish and river blackfish will undertake small-scale movements (<1 km) within restricted home ranges (3).
- Spawning of all species will occur over a defined season (Humphries 2005, Koehn and Harrington 2006, Zampatti et al. 2011c) (4).
- Recruitment of Murray cod to young-of-year may occur at flows of this magnitude (Ye and Zampatti 2007) (2).
- Recruitment of freshwater catfish is likely (2).
- Recruitment of river blackfish is likely to be dependent upon local habitat and physico-chemical conditions (3).

Flow dependent specialists

- Adults present and common in river main channel and anabranches (Baumgartner et al. 2008a, Leigh et al. 2012) (4).
- May undertake small- to large-scale (up to 100s km) longitudinal movements in association with flow and potentially spawning (e.g. Zampatti et al. 2011c) (3).
- Spawning will likely occur should flow coincide with temperature thresholds (Mallen-Cooper and Stuart 2003, King et al. 2009, Cheshire et al. 2012) (3).
- Downstream drift of larvae from upstream areas (e.g. the Darling and mid-Murray Rivers) will occur (SARDI unpublished data) (3).
- Recruitment to young-of-year likely (Ye et al. 2008, Zampatti and Leigh 2013b) (3).
- Recruits may be derived from upstream and/or local spawning (SARDI unpublished data) (2).

Foraging generalists

- Present and common in river main channel and connected wetlands, but cover of favourable habitat (aquatic vegetation) may be reduced (Bice et al. 2014), particularly in weir tailwaters (4).
- May undertake longitudinal and/or lateral movements between river channel and connected wetlands (Baumgartner et al. 2008b, Connallin et al. 2011) (3).
- Spawning will occur over protracted season and recruitment is likely (Humphries et al. 1999) (3).
Wetland/floodplain specialists

- Present in specific off-channel habitats (Hammer et al. 2013) (4).
- Off-channel habitats that support these species may experience hydrological connection with the main channel and variability in water levels (3), and may involve associated movement of fish (2).
- Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (Ellis 2005) (4), and may be enhanced due to increased productivity associated with water level variability (Wedderburn et al. 2013) (2).

7.2.7 Waterbirds

- At flows of 20,000 ML.day$^{-1}$, low elevation river red gum woodlands become inundated, as well as early commence-to-flow wetlands. From the perspective of waterbirds, this will increase the area of habitat available to waders and shorebirds, and potentially increase the density of food resources for these species (1).
- Depending on the congruence between nest site availability and early commence-to-flow wetlands, small-scale breeding events may occur in response to these flows (1).
- An increase in the area of fringing vegetation that becomes inundated will provide habitat for some reed-dependent waterbirds, by providing spatial overlap between structural habitat (reed beds) and aquatic food resources (2). This will be important for the nationally threatened Australasian bittern, which has particularly specialised habitat requirements (shallow water under extensive reeds) (2).
7.2.8 Model synthesis

Figure 7.15. Synthesis diagram of hydro-ecological models for flows of 20,000 ML day\(^{-1}\) in the 'lower River Murray channel and floodplain'. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
7.3 Lower Lakes and Coorong model (20,000 ML.day⁻¹)

7.3.1 Nutrients, carbon, biofilms and microbes

- During periods of elevated flows there are increases in turbidity causing reduced light availability (2).
- Barrage releases into the Coorong result in the transfer of freshwater phytoplankton into the North Lagoon with mixing of conditions along the South Lagoon increasing with flow (2).
- The freshwater species in the Coorong will decline with distance from the out flow in response to increasing salinity. This will depend on the balance of flows across the barrage and in through the Murray Mouth (3).
- Freshwater species suitable to the lagoon conditions appear along with those transported by barrage flows (2).
- The phytoplankton in Lake Alexandrina is dominated by green algae and diatoms, commonly the filamentous green alga, *Planctonema lauterbornii* (2).

7.3.2 Microbiota

- During freshes, it is expected that an estuarine microcrustacean zooplankton assemblage will remain within the Coorong including primarily marine copepods (e.g. *Gladioferens* spp. in Geddes and Tanner 2007), some rotifers (e.g. *Synchaeta* spp. in Geddes and Tanner 2007) and no cladocerans (3).
- Lake Albert is likely to contain primarily a halophytic assemblage (1).
- Lake Alexandrina is likely to contain primarily a freshwater limnetic assemblage, similar to River Murray storages (Geddes 1984) (2), however closer to the Coorong and during prolonged drought some saline incursions and subsequently, transport of typically estuarine taxa, may occur (1).

7.3.3 Vegetation

Terrestrial dry

- Restricted to above +0.9 m AHD (Frahn *et al.* 2013) (4).

Terrestrial damp

- Restricted to above +0.9 m AHD (Frahn *et al.* 2013) (4).

Floodplain

- This functional group is generally not present in the Lower Lakes (Frahn *et al.* 2013) (4).
Amphibious fluctuation tolerator – emergent

- Present and recruiting at elevations between +0.8 and +0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Amphibious fluctuation tolerator – woody

- Present at elevations above +0.7 m AHD (Frahn et al. 2013, Nicol et al. 2013) (4).
- Recruitment will occur on water level recession if water levels rise above +0.8 m AHD (1).

Amphibious fluctuation tolerator – low growing

- Present at elevations between +0.8 and +0.6 m AHD (Frahn et al. 2013, Nicol et al. 2013) (3).

Amphibious fluctuation responder – plastic

- Present at elevations between +0.8 and +0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Floating

- Present in inundated areas (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent r-selected

- Plants are present in temporary wetlands during winter and spring and present in the propagule bank over summer and autumn (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Emergent

- Present at elevations between +0.9 and 0 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent K-selected

- Present at elevations between +0.5 and -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

*Ruppia tuberosa* (Coorong)

- *Ruppia tuberosa* will germinate in late autumn when water levels in the South Lagoon rise (Brock 1982, Brookes et al. 2009b) (4).
- If flow over the barrages persists until late spring or early summer water levels in the South Lagoon will be sufficient for *Ruppia tuberosa* to complete its life cycle and replenish the propagule bank (2).
### 7.3.4 Macroinvertebrates

- Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 7.2.4).

### 7.3.5 Frogs

- Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 7.2.5).
- The Coorong does not represent suitable habitat for frogs.

### 7.3.6 Fish

**Circa-annual spawning nesting species**

- All species likely rare or absent from the Lower Lakes and absent from Coorong (Bice 2010b) (4).
- Adult and juvenile Murray cod and freshwater catfish may undertake small-scale movements within Lower Lakes (1) or large-scale movements between Lower Lakes and lower River Murray channel (1).
- Local spawning of Murray cod and freshwater catfish may occur within the Lower Lakes (2).
- Larvae and juveniles may be transported from upstream (Koehn and Harrington 2005) (2).

**Flow-dependent specialist**

- Adults present and common in Lower Lakes (Ferguson 2008) (4).
- May undertake small-scale movements within Lower Lakes (2) or large-scale movements between Lower Lakes and ‘lower River Murray channel and floodplain’ (1).
- Local spawning may occur within the Lower Lakes should flow coincide with temperature thresholds (2).
- Downstream drift of larvae and juveniles into the Lower Lakes from upstream areas (e.g. the lower River Murray) will occur (SARDI unpublished data) (2).
- Recruitment may occur within Lower Lakes (Mayrhofer 2007, Bice 2010a) (2).
- Likely present in low abundance in Coorong (Bice et al. 2012) (3).
- Likely to attempt return movements from the Coorong into freshwater habitats (Zampatti et al. 2010) (4).

**Foraging generalist**

- Widespread and abundant (Wedderburn et al. 2012) (4).
- Spawning will occur over a protracted season and recruitment will occur (Humphries et al. 1999) (3).
- Certain species (e.g. bony herring, Australian smelt, flat-headed gudgeon) likely present in Coorong in moderate abundance (Zampatti et al. 2010, Ye et al. 2012b, Livore et al. 2013) (4).
- Likely to attempt return movements from the Coorong into freshwater habitats (Zampatti et al. 2010) (4).

**Wetland/floodplain specialist**

- Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (Ellis 2005, Bice and Ye 2007) (4), and may be enhanced due to increased productivity associated with water level variability (Wedderburn et al. 2013) (2).
- Unlikely present in Coorong (3).

**Diadromous species**

- Present in Lower Lakes but abundance reliant on connectivity and recruitment in preceding years (Zampatti et al. 2011a) (3).
- Present in Coorong, particularly within the vicinity of the Murray Mouth (Noell et al. 2009, Ye et al. 2012b, Livore et al. 2013) (4).
- Downstream spawning migrations of catadromous species will occur in winter (Zampatti et al. 2011b) (4).
- Juvenile upstream migrations of catadromous species will occur in spring/summer (Zampatti et al. 2010) (4).
- Abundance of juveniles will be largely dependent upon connectivity during previous spawning season (3).
- Upstream migrations of anadromous species will occur in winter/spring (authors unpublished) (3).

**Estuarine dependent species**

- Small-bodied euryhaline estuarine species (e.g. goby species, small-mouthed hardyhead) likely present in low-moderate numbers in Lower Lakes (Jennings et al. 2008, Wedderburn et al. 2012) (4).
- Select small-bodied euryhaline estuarine species (e.g. lagoon goby and small-mouthed hardyhead) may spawn and recruit within Lower Lakes (Jennings et al. 2008) (1).
- Present in Coorong, particularly within the vicinity of the Murray Mouth, with decreasing diversity with increasing distance from the mouth (Ye et al. 2012b, Livore et al. 2013) (4).
- May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (3).
- Spawning and recruitment of circa-annual spawners (e.g. goby species, small-mouthed hardyhead) is likely (Ye et al. 2012b, Livore et al. 2013) (4).
- Recruitment of other, more flow-dependent species (e.g. mulloway and black bream), may occur (Ferguson et al. 2008, Ye et al. 2012a) (2).
• Increased abundance of small-bodied pelagic species (e.g. sandy sprat, *Hyperlophus vittatus*) is likely (Bice *et al.* 2012, Bice and Zampatti 2014) (3) potentially as a result of the transport of freshwater zooplankton to the Coorong or increased estuarine productivity with elevated freshwater flow (1).

**Marine species**

• Unlikely to be present in Lower Lakes (3).
• Present in Coorong in varying, but moderate to high abundance, particularly within the vicinity of the Murray Mouth, with decreasing diversity with increasing distance from the mouth (Ye *et al.* 2012b, Livore *et al.* 2013) (4).
• May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).
• Spawning and recruitment likely not to occur within the Coorong (2).

**7.3.7 Waterbirds**

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 7.2.7).
• See waterbird ecology section (Section 4.7).
7.3.8 Model synthesis

Figure 7.16. Synthesis diagram of hydro-ecological models for flows of 20,000 ML\(\text{day}^{-1}\) in the 'Lower Lakes and Coorong'. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
8 Bank-full (40,000 ML.day$^{-1}$) hydro-ecological conceptual models

This section presents data on the hydrology and associated conditions in the lower River Murray in SA under ‘upper base flows’ (40,000 ML.day$^{-1}$), and the associated hydro-ecological conceptual models. A general overview of hydraulics (e.g. velocity and water level), floodplain inundation and salinity is provided for the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’. This is followed by the conceptual models for each biotic/abiotic component for each region.

8.1 Hydrology and associated conditions (40,000 ML.day$^{-1}$)

8.1.1 Lower River Murray channel and floodplain

Hydrology

Under pre-development conditions (modelled natural), flows of 40,000 ML.day$^{-1}$ (or above) persisted for 120 days at a frequency of 1 in 2.03 years (49% of years), for 90 days at 1 in 1.75 years (57% of years) and for 60 days at 1 in 1.43 (70% of years). Under existing conditions, such a flow occurs for 120 days at a frequency of 1 in 9.5 years (11%), for 90 days at 1 in 4.9 years (20%) and for 60 days at 1 in 3.8 years (26%).

Hydraulics

Water level

Water level for a discharge of 40,000 ML.day$^{-1}$ is still influenced by the weirs. In most cases immediately upstream of the weir normal pool level (Table 3-1) is established, but soon after the water level (in m AHD) increases heading upstream (Figure 8-1) (as opposed to having a flat water level for the lower discharges – see Figure 6-1 as a comparison).

Velocity

Calculated and modelled velocity in the main channel varies from 0.5 – >1 m.s$^{-1}$ (Figure 8-1 and Figure 8-2) at 40,000 ML.day$^{-1}$; an increase in the speed on the minimum velocity at 20,000 ML.day$^{-1}$ (0.2 m.s$^{-1}$). There is still an increase in velocity heading upstream from the weir (Figure 8-1 and Figure 8-2), but the difference is not as great as for 20,000 ML.day$^{-1}$ (compare Figure 8-2 and Figure 7-2).
Inundation

Vegetation

Figure 8-3 shows the percent of vegetation classes inundated for the different lock floodplains, using data from RiMFIM (Overton et al. 2006b). The area of inundation of floodplain vegetation has increased from a discharge of 3,000 ML.day\(^{-1}\) (Figure 5-3), but not significantly; for example, the percent of river red gum inundated on the Lock 4 floodplain has increased from 20% (at 3,000 ML.day\(^{-1}\)) to 27% (40,000 ML.day\(^{-1}\)). This is consistent with a discharge of 40,000 ML.day\(^{-1}\) reaching the top of the main channel, but still mostly confined to the main channel – ‘bank-full’. Note that for the reach between Wellington and Lock 1, a discharge of 40,000 ML.day\(^{-1}\) is starting to inundate the floodplain: river red gum and black box have increased in inundated area from 34% to 53% and 26% to 38% respectively.

Wetlands

The inundated wetland area in hectares, and as a percentage of the total wetland area, is shown in Figure 8-4 and Figure 8-5 respectively (data from RiMFIM (Overton et al. 2006b) for 40,000 ML.day\(^{-1}\)). Inundated wetland area remains high (over 80%), except for the Lock 6 floodplain, where many channels are wetland areas have not received water yet.
Figure 8.1 Channel elevation, water level and velocity at ~40,000 ML day\(^{-1}\) in the River Murray channel. Channel depth data from River Murray channel Digital Elevation Model, water level from modelled backwater curves (MIKE 21 model for 40,000 ML day\(^{-1}\)) (DEWNR 2012a) and from printed backwater charts (~1977) for 40,000 ML day\(^{-1}\). Calculated mean cross-sectional velocity (\(n=10\sim27\) cross-sections), showing standard deviation of calculated velocity (Gippel 2011), for 20,000 ML day\(^{-1}\). Modelled velocity using MIKE 21 for 40,000 ML day\(^{-1}\) (Bice et al. 2013).
Figure 8-2 Box plots showing median velocity (horizontal), 25\textsuperscript{th} and 75\textsuperscript{th} percentiles enclosing box, and minimum and maximum values, for each kilometre within the Lock 3-4 reach. Data from MIKE 21 model, for a discharge of 40,000 ML.day\textsuperscript{-1}.
Figure 8.3 Percent of different vegetation classes on the different lock floodplains, inundated by a discharge of 40,000 ML day⁻¹ (RiMFIM) (Overton et al. 2006b).

Figure 8.4 Inundated wetland area (ha) on the different lock floodplains, for a discharge of 40,000 ML day⁻¹ (RiMFIM) (Overton et al. 2006b).

Figure 8.5 Inundated wetland area, as a percent of total wetland area, on the different lock floodplains, for a discharge of 40,000 ML day⁻¹ (RiMFIM) (Overton et al. 2006b).
### 8.1.2 Lower Lakes

**Salinity**

Salinity varies between ~0–2,000 EC units in Lake Alexandrina for discharges 35,000–45,000 ML.day\(^{-1}\) (Figure 8-6). Salinity in Lake Albert (Meningie) was much greater (~4,000–8,000 EC units), but note that these measurements were recorded when Lake Albert was still hydrologically disconnected from (or just recently reconnected to) Lake Alexandrina.

**Water level**

Water level at 35,000–45,000 ML.day\(^{-1}\) is under normal barrage operations and varies from 0.5–1.0 m AHD (Figure 8-7).

### 8.1.3 Coorong

**Salinity**

Salinity close to the Murray Mouth varies from ~0–35 g.L\(^{-1}\) for barrage discharges of 35,000–45,000 ML.day\(^{-1}\) (Figure 8-8). Salinity is higher, and with a greater a range (~50–110 g.L\(^{-1}\)) 100 km from the Murray Mouth. These salinities are a slightly lower range than recorded for the lower flow bands.

**Water level**

Water level varies from ~0.1–1.2 m AHD across the Coorong for barrage discharges of 35,000–45,000 ML.day\(^{-1}\) (Figure 8-9); a slightly higher range than the lower flow bands.
Figure 8-6 Salinity measured for barrage discharges of 35,000–45,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Poltalloch Plains (station A4261031), Narrung Jetty (station A4260583) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 8-7 Water level measured for barrage discharges of 35,000–45,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.
Figure 8.8 Salinity at barrage discharges of 35,000–45,000 ML day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.

Figure 8.9 Water level at barrage discharges of 35,000–45,000 ML day$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Water level data from Webster (1997). Barrage discharge data from the MDBA.
8.2 Lower River Murray channel and floodplain model (40,000 ML.day⁻¹)

Conceptual models take the form of statements on ecological patterns and processes expected from the defined biotic/abiotic components, based upon the hydrological data provided (see above), for ‘bank-full flows’ (40,000 ML.day⁻¹). Each statement was assigned a measure of certainty (in bold at the end of each statement) to aid in identifying knowledge gaps in conceptual understanding (Section 2.3). The certainty scoring system was adapted from Mallen-Cooper et al. (2011) and is reiterated below in Table 8-1. The conceptual model statements provided by each expert were then synthesised into a simplified conceptual diagram presenting key ecological patterns and processes.

Table 8-1. ‘Certainty’ scoring system used to define confidence in predictive statements of response to flow in the hydro-ecological conceptual models. Adapted from Mallen-Cooper et al. (2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very uncertain</td>
<td>No available data. Diverse views/conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Uncertain</td>
<td>No available data. Expert opinion. Consensus on conceptual understanding</td>
</tr>
<tr>
<td>3</td>
<td>Moderately certain</td>
<td>Supported by indirect, observational or limited scientific data</td>
</tr>
<tr>
<td>4</td>
<td>Very certain</td>
<td>Supported by direct or abundant scientific data. Published peer-reviewed literature</td>
</tr>
</tbody>
</table>

8.2.1 Nutrients, carbon, biofilms and microbes

- There is reduced autotrophic production due to light limitation resulting from increased depths as well as turbidity and colour (2).
- Increases in surface water level and concomitant change in water level will have a similar impact on resetting biofilm communities as a desiccation event (2).
- Changes to biofilm communities induced by changes in water level (deep submergence) and euphotic depth will be short-lived (<30 days) i.e. the biofilm will return to a late successional community upon return to stable water levels (3).
- The increase in surface water level in the mid and upper reaches of the weir pools will substantially alter the light environmental experienced by biofilms (3).
- Very slow rates of water level change eliminate cues and biogeochemical processes associated with flow induced changes in water level in an unregulated system (3).
- The magnitude of biogeochemical response will be mediated by day length and water temperature (3).
- Velocities are likely to be sufficient to generate some scouring of existing biofilms, creating surface area available for colonisation by early successional state taxa (3).
- There may be a marked increase in resources (carbon, nutrients and zooplankton) upon recession of the high flows as inundated areas drain back to the river channel (2).
- It is estimated that ~8.8 and 1,808 kilotonnes of FRP and DOC respectively could be mobilised by a flow of this magnitude (3).
Diverting (routing) water from upstream unregulated flows via Lake Victoria decreases the load and/or bioavailability of carbon and nutrients in the lower River Murray (2).

As flood waters move on and off the floodplain phytoplankton composition changes with increases in chlorophytes and cyanobacteria influenced by growth conditions in the flood waters (2).

Heterotrophic activity will increase markedly, as evidenced by large increases in respiration rates, larger bacterial populations and increases in the size and complexity of the heterotrophic microeukaryote communities (2).

Heterotrophic activity will increasingly dominate net ecosystem productivity in the river channel while autotrophic production is reduced due to light limitation (2).

The increase in organic material will increase the activity of the microbial pathway for energy transfer to the aquatic food web (2).

Following the initial inundation and release of soluble material, and an associated surge in heterotrophic activity on the floodplain, autotrophic processes may become dominant in the floodplain and wetland areas (2).

The removal of weirs between flows of 40,000 and 60,000 ML.day\(^{-1}\) will facilitate the downstream (longitudinal) transport of resources (2).

The rapid re-instatement of weirs as flows decline will interrupt the downstream (longitudinal) transport of resources (2).

### 8.2.2 Microbiota

During flows of 40,000 ML.day\(^{-1}\), elevated water velocity is likely to begin inhibiting zooplankton reproduction. There will be areas (particularly just below weirs) where no reproduction is likely to occur (water velocity >0.4 m.s\(^{-1}\)) and areas (particularly just above weirs) where reproduction will occur (water velocity <0.4 m.s\(^{-1}\)) (Rzoska 1978). Overall, this may result in lower zooplankton abundance and biomass in comparison to 3,000, 7,000 and 20,000 ML.day\(^{-1}\) and a shift further to a rotifer biomass dominated system (Saunders and Lewis 1988a, 1988b, 1989) (2). This will possibly occur more prominently in the upper zones than the lower zones also due to flow conditions (Basu and Pick 1996) (2).

Permanently inundated wetlands are likely to host communities with a higher proportion of crustaceans due to the longer WRTs (Baranyi et al. 2002, Obertegger et al. 2007) (3).

Newly inundated temporary wetlands are likely to host considerably more abundant and diverse communities than the river main channel due to community emergence from the egg bank and longer WRTs (e.g. Saunders and Lewis 1988a, 1988b, Tan and Shiel 1993) (4). They are likely to be rotifer dominated within the first few weeks and then shift to a crustacean dominated community (Furst 2014) (3).

Under 40,000 ML.day\(^{-1}\), it is unlikely that flow will be sufficient to flush communities from the wetlands and therefore they are unlikely to reach the river main channel (excluding a small proportion) (2).

Differences in microbiota community structure between open water and littoral habitats are likely to be maintained, where the littoral zones may provide protection for larger zooplankton such as cladocerans from fish predation during the day and host a more diverse community (Meerhoff et al. 2003, Estlander et al. 2009) (2).
8.2.3 Vegetation

Terrestrial dry

- Abundant across the floodplain, providing flooding has been absent for longer than 1 year (Holt et al. 2005, Nicol et al. 2006, Marsland and Nicol 2007, Gehrig et al. 2013) (4).
- Extirpated from temporary wetlands and floodplain inundated by increased flow (Gehrig et al. 2013, Holland et al. 2013) (4).

Terrestrial damp

- Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
- Recruitment in temporary wetlands and on floodplain inundated by the high flow as water levels recede (Nicol 2004, 2012, Nicol et al. 2010) (3).

Floodplain

- Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
- Recruitment in temporary wetlands and on floodplain that was inundated by the high flow as water levels recede (Gehrig et al. 2013, Holland et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

- Plants will recruit in temporary wetlands and floodplain that was inundated by the high flow, whether they germinate on submergence or exposure depends on species (Gehrig et al. 2013) (3).
- Plants growing at or below pool level will be extirpated if inundation is longer than 30 days in upper weir pools but will persist in lower weir pools (1).

Amphibious fluctuation tolerator – woody

- Recruitment will occur in temporary wetlands and floodplain that was inundated by the high flow as water levels recede (2).
- Plants growing on the edges of permanent water bodies or in areas where groundwater is being freshened will remain in good condition (e.g. Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4).
- There will be an improvement in condition of trees and shrubs in temporary wetlands and on the floodplain inundated by the high flow (McEwan et al. 2006, Doody et al. 2009, Holland et al. 2009) (4).
- Condition will decline after extended periods without inundation (length of time depends on species) for plants growing in other areas (Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4).
Amphibious fluctuation tolerator – low growing

- Plants will recruit in temporary wetlands and on floodplain inundated by the high flow, whether they germinate on submergence or exposure depends on species (2).
- Plants growing in upper weir pools at or below pool level will persist providing inundation is no longer than 60 days (1).
- Plants growing in lower weir pools at or below pool level will persist (Blanch and Walker 1997, Blanch et al. 1999b, 2000) (2).

Amphibious fluctuation responder – plastic

- Plants will recruit in temporary wetlands and on floodplain that was inundated by the high flow, whether they germinate on submergence or exposure depends on species (2).
- Plants that recruited during low flows will persist due to their ability to respond morphologically to water level changes in lower weir pools (Cooling 1996, Nicol 2004) (2).
- Plants that recruited during low flows will be temporarily extirpated at low elevations in upper weir pools due to the water level increase being greater than the maximum plant response (1).

Floating


Submergent r-selected

- Plants will recruit in temporary wetlands providing the hydroperiod is sufficient to complete its life cycle (Frahn et al. 2013) (2).

Emergent

- Will be most abundant around pool level elevation in lower weir pools (Blanch and Walker 1997, Blanch et al. 1999b, 2000) (2).
- Recruitment will occur in temporary wetlands inundated by higher flows (2).
- Plants growing in deep water in upper weir pools will be temporarily extirpated due to top flooding (1).

Submergent K-selected

- Present in river main channel and permanently connected wetlands the maximum depth of colonisation will depend on water clarity (Blanch and Walker 1997, Blanch et al. 1999b, 2000, Holt et al. 2005) (4).
- Plants growing in deeper water in upper weir pools will be temporarily extirpated due to lack of light (Blanch and Walker 1997, Blanch et al. 1999a, 1999b, Bice et al. 2014) (1).
- Plants growing in lower weir pools will persist (Blanch and Walker 1997, Blanch et al. 1999a, 1999b) (3).
**8.2.4 Macroinvertebrates**

**Group A**

- Expected to be maintained at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances, greater provision of habitat and food resources (3).

**Group B**

- Expected to be maintained at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances, greater provision of habitat and food resources (3).

**Group C**

- Expected increase in abundance at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances, greater provision of habitat (3).

**Group D**

- Expected increase in abundance at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances, greater provision of habitat and food resources, and improved quality of autochthonous food resources (3).

**Group E**

- Expected to increase in abundance at this level of flow due to within-channel increases in flow maintaining salinity levels above tolerances greater provision of habitat and food resources, and improved quality of autochthonous food resources (3).

**8.2.5 Frogs**

**Breeding habitat and requirements**

- Flows of magnitudes up to 40,000 ML.day\(^{-1}\) will provide an increase in the area of inundation of low elevation wetlands and vegetation habitats (river red gum, black box, and in particular lignum), which will provide an increase in preferred breeding habitat (Gonzalez et al. 2011) (4).

- Species that anchor eggs to vegetation (eastern sign-bearing froglet, brown tree frog, Peron’s tree frog, eastern banjo frog and long-thumbed frog) have the potential for egg desiccation if water levels decrease rapidly immediately after breeding has occurred (2).

**Tadpoles**

- Increased inundation in area, depth and duration of temporary wetlands associated with these flows are likely to provide most species with sufficient hydroperiods for
metamorphosis to be completed, in particular those species with mid to long tadpole phases (e.g. southern bell frog) except in cases where these flows are short-lived, and wetlands are shallow (Wassens 2011) (4).

- Increased area of inundation of vegetation with harder structural integrity (e.g. lignum) as a result of these flows will provide increased protection of tadpoles from predation and disturbance from fish and potentially increase survival and recruitment (Anstis 2013) (3).
- Increased wetland hydroperiods that may occur during these flows lead to an increase in food resources for tadpoles and subsequent increases in survival and recruitment (Wassens 2011) (2).

**Adults**

- Increased inundation of temporary areas will lead to an increase in the numbers of adults utilising inundated habitat for breeding (4).

### 8.2.6 Fish

**Circa-annual spawning nesting species**

- River blackfish present in specific habitats of certain tributaries (Bice et al. 2011)
- Increased water velocities and accompanying hydraulic diversity will result in increased area of favourable adult and juvenile Murray cod habitat in the main channel (Koehn 2009) (2).
- A proportion of the Murray cod population will undertake small- to large-scale (up to 100s km) longitudinal movements in association with flow and potentially spawning (Koehn et al. 2009, Leigh and Zampatti 2013) (3).
- Freshwater catfish and river blackfish will undertake small-scale movements (<1 km) within restricted home ranges (3).
- Spawning of all species will occur over a defined season (Humphries 2005, Koehn and Harrington 2006, Zampatti et al. 2011c) (4).
- Enhanced recruitment of Murray cod to young-of-year is likely to occur at flows of this magnitude if delivered during spawning season (Ye and Zampatti 2007) (2)
- Recruitment of freshwater catfish is likely (2).
- Recruitment of river blackfish is likely to be dependent upon local habitat and physico-chemical conditions (3).

**Flow dependent specialists**

- May become a dominant species in riverine fish assemblage (Bice et al. 2014) (3).
- May undertake small- to large-scale (up to 100s km) longitudinal movements in association with flow and potentially spawning (3).
- Spawning will likely occur should flow coincide with temperature thresholds (Mallen-Cooper and Stuart 2003, King et al. 2009, Cheshire et al. 2012) (3).
• Downstream drift of larvae from upstream areas (e.g. the Darling and mid-Murray Rivers) will occur (SARDI unpublished data) (3).
• Enhanced recruitment to young-of-year likely (Zampatti and Leigh 2013a, Zampatti and Leigh 2013b) (3).
• Recruits may be derived from upstream and local spawning (SARDI unpublished data) (2).

Foraging generalists

• Absent or present in river main channel in low abundance due to reductions in favourable habitat (aquatic vegetation) (Bice et al. 2014), particularly in weir tailwaters (4).
• Present in connected wetland and floodplain habitats (Thwaites and Fredberg 2014) (4).
• Partial inundation of floodplain habitats and raised water levels in connected permanent wetlands may increase off-channel habitat area and promote lateral movement in these species (Lyon et al. 2010, Connallin et al. 2011, SARDI unpublished data) (2).
• Spawning will occur over protracted season and some level of recruitment is likely in off-channel habitats (Humphries et al. 1999, Cheshire et al. 2012) (3).

Wetland/floodplain specialists

• Present in specific off-channel habitats (Bice et al. 2011) (3).
• Off-channel habitats that support these species may experience hydrological connection with the main channel and variability in water levels (3) and may involve associated movement of fish (Lyon et al. 2010) (2).
• Spawning and recruitment likely to occur dependent upon local habitat and physicochemical conditions (Ellis 2005) (3), and may be enhanced due to increased productivity associated with water level variability (Wedderburn et al. 2013) (2).

8.2.7 Waterbirds

• Flows of 40,000 ML.day\(^{-1}\) will increase the area of inundated floodplain vegetation and higher elevation wetlands. As more temporary wetlands and floodplain are inundated, the area of higher productivity also increases, potentially increasing breeding opportunities for Australian nomadic waterbirds and regional waterbirds (1).
• Furthermore, increasing the inundated area of particular vegetation types (e.g. lignum shrubland) increases the spatial congruence of nesting habitat and foraging habitat (1).
• Increased flows further increase habitat availability for reed-dependent waterbirds (2).
8.2.8 Model synthesis

Figure 8-10: Synthesis diagram of hydro-ecological models for flows of 40,000 ML day\(^{-1}\) in the 'lower River Murray channel and floodplain'. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
8.3 Lower Lakes and Coorong model (40,000 ML.day⁻¹)

8.3.1 Nutrients, carbon, biofilms and microbes

- During periods of elevated flows there are increases in turbidity causing reduced light availability (2).
- The salinity gradient along the Coorong is weakened (2).
- Barrage releases into the Coorong result in the transfer of freshwater phytoplankton into the North Lagoon with mixing of conditions along the South Lagoon increasing with flow (2).
- The freshwater species in the Coorong will decline with distance from the outflow in response to increasing salinity. This will depend on the balance of flows across the barrage and in through the Murray Mouth (3).
- Freshwater species suitable to the lagoon conditions appear along with those transported by barrage flows (2).
- The phytoplankton in Lake Alexandrina is dominated by green algae and diatoms, commonly the filamentous green alga, Planctonema lauterbornii (2).

8.3.2 Microbiota

- During bank-full flows, it is expected that an estuarine microcrustacean zooplankton assemblage will remain within the Coorong including primarily marine copepods (e.g. Gladioferens spp. in Geddes and Tanner 2007), some rotifers (e.g. Synchaeta spp. in Geddes and Tanner 2007) and no cladocerans (3).
- Lake Albert is likely to contain primarily a halophytic assemblage (1).
- Lake Alexandrina is likely to contain primarily a freshwater limnetic assemblage, similar to River Murray storages (Geddes 1984) (2), however closer to the Coorong and during prolonged drought some saline incursions and subsequently, transport of typically estuarine taxa, may occur (1).

8.3.3 Vegetation

Terrestrial dry

- Restricted to above +0.9 m AHD (4) (Frahn et al. 2013).

Terrestrial damp

- Restricted to above +0.9 m AHD (4) (Frahn et al. 2013).
Floodplain

- This functional group is generally not present in the Lower Lakes (Frahn et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

- Present and recruiting at elevations between +0.8 and +0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Amphibious fluctuation tolerator – woody

- Present at elevations above +0.7 m AHD (Frahn et al. 2013, Nicol et al. 2013) (4).
- Recruitment will occur on water level recession if water levels rise above +0.8 m AHD (1).

Amphibious fluctuation tolerator – low growing

- Present at elevations between +0.8 and +0.6 m AHD (Frahn et al. 2013, Nicol et al. 2013) (3).

Amphibious fluctuation responder – plastic

- Present at elevations between +0.8 and +0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Floating

- Present in inundated areas (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent r-selected

- Plants are present in temporary wetlands during winter and spring and present in the propagule bank over summer and autumn (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Emergent

- Present at elevations between +0.9 and 0 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent K-selected

- Present at elevations between +0.5 and -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Ruppia tuberosa (Coorong)

- Ruppia tuberosa will germinate in late autumn when water levels in the South Lagoon rise (Brock 1982, Brookes et al. 2009b) (4).
- If flow over the barrages persists until late spring or early summer water levels in the South Lagoon will be sufficient for *Ruppia tuberosa* to complete its life cycle and replenish the propague bank (Frahn et al. 2012) (2).

### 8.3.4 Macroinvertebrates

- Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 8.2.4).

### 8.3.5 Frogs

- Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 8.2.5).
- The Coorong does not represent suitable habitat for frogs.

### 8.3.6 Fish

**Circa-annual spawning nesting species**

- Murray cod and freshwater catfish likely rare, and river blackfish likely absent (Bice 2010b) (4).
- Adult and juvenile Murray cod and freshwater catfish may undertake small-scale movements within Lower Lakes (1) or large-scale movements between Lower Lakes and lower River Murray channel (1).
- Local spawning of Murray cod and freshwater catfish may occur (2).
- Larvae and juveniles may be transported from upstream (Koehn and Harrington 2005) (2).
- Recruitment may occur within Lower Lakes (2).
- All species likely absent from Coorong (2).

**Flow-dependent specialist**

- Adults present and common in Lower Lakes (Ferguson 2008) (4).
- May undertake small-scale movements within Lower Lakes (2) or large-scale movements between Lower Lakes and ‘lower River Murray channel and floodplain’ (1).
- Local spawning may occur should flow coincide with temperature thresholds (2).
- Downstream drift of larvae and juveniles from upstream areas (e.g. the lower River Murray) will occur (SARDI unpublished data) (3).
- Recruitment will occur within Lower Lakes (Ye 2005, Mayrhofer 2007, Bice 2010a) (2).
- Likely present in Coorong in low to moderate abundance (Bice et al. 2012, Ye et al. 2012b) (3).
Foraging generalist

- Widespread and abundant in Lower Lakes (Wedderburn et al. 2012) (4).
- Spawning will occur over a protracted season and recruitment will occur (Humphries et al. 1999) (3).
- Certain species (e.g. bony herring, Australian smelt, flat-headed gudgeon) likely abundant in Coorong (Bice et al. 2012, Zampatti et al. 2012, Livore et al. 2013) (4).

Wetland/floodplain specialist

- Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (Ellis 2005, Bice and Ye 2007) (4), and may be enhanced due to increased productivity associated with water level variability (Wedderburn et al. 2013) (2).
- May be present in Coorong in low abundance (2).

Diadromous species

- Present in Lower Lakes but abundance reliant on connectivity and recruitment in preceding years (Zampatti et al. 2011a) (3).
- Present in Coorong, particularly within the vicinity of the Murray Mouth and into the North Lagoon (Bice et al. 2012, Ye et al. 2012b) (4).
- Downstream spawning migrations of catadromous species will occur in winter (Zampatti et al. 2011b) (4).
- Juvenile upstream migrations of catadromous species will occur in spring/summer (Zampatti et al. 2010) (4). Abundance of juveniles will be largely dependent upon connectivity during previous spawning season (3).
- Upstream migrations of anadromous species will occur in winter/spring (authors unpublished) (3).

Estuarine dependent species

- Small-bodied euryhaline estuarine species (e.g. goby species, small-mouthed hardyhead) likely present in the Lower Lakes in low to moderate numbers (Jennings et al. 2008, Wedderburn et al. 2012) (4).
- Select small-bodied euryhaline estuarine species (e.g. lagoon goby and small-mouthed hardyhead) may spawn and recruit within Lower Lakes (Jennings et al. 2008) (1).
- Present in Coorong, within the vicinity of the Murray Mouth and more broadly in the North Lagoon (Ye et al. 2012b, Livore et al. 2013) (3) with decreasing diversity with increasing distance from the mouth (Ye et al. 2012b, Livore et al. 2013) (4).
- May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).
- Spawning and recruitment of circa-annual spawners (e.g. goby species, small-mouthed hardyhead) is likely (Ye et al. 2013) (3).
- Recruitment of flow-dependent species (e.g. mulloway and black bream), may occur (Ferguson et al. 2008, Ye et al. 2012a) (2).
- Increased abundance of small-bodied pelagic species (e.g. sandy sprat) is likely (Bice et al. 2012, Bice and Zampatti 2014) (3) potentially as a result of the transport of freshwater zooplankton to the Coorong or increased estuarine productivity with elevated freshwater flow (1).

**Marine species**

- Unlikely to be present in Lower Lakes (3).
- Present in Coorong in varying, but often low abundance, largely restricted to the vicinity of the Murray Mouth (Ye et al. 2012b) (4).
- May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).
- Spawning and recruitment likely not to occur within the Coorong (2).

**8.3.7 Waterbirds**

- Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 8.2.7).
- See waterbird ecology section (Section 4.7).
8.3.8 Model synthesis

Figure 8-11. Synthesis diagram of hydro-ecological models for flows of 40,000 ML.day\(^{-1}\) in the 'Lower Lakes and Coorong'. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
9 Small overbank (60,000 ML.day\(^{-1}\)) hydro-ecological conceptual models

This section presents data on the hydrology and associated conditions in the lower River Murray in SA under ‘upper base flows’ (60,000 ML.day\(^{-1}\)), and the associated hydro-ecological conceptual models. A general overview of hydraulics (e.g. velocity and water level), floodplain inundation and salinity is provided for the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’. This is followed by the conceptual models for each biotic/abiotic component for each region.

9.1 Hydrology and associated conditions (60,000 ML.day\(^{-1}\))

9.1.1 Lower River Murray channel and floodplain

Hydrology

A discharge of 60,000 ML.day\(^{-1}\) to SA has an annual exceedance probability (AEP) of ~55% pre-development, but now has an AEP of ~15% (Maheshwari et al. 1995).

Hydraulics

Water level

Water level for a discharge of 60,000 ML.day\(^{-1}\) is still strongly influenced by the weirs (Figure 9-1), although the navigable pass for many weirs is removed at this discharge.

Velocity

Calculated mean cross-sectional velocity has increased to 0.7–1.1 m.s\(^{-1}\) (Figure 9-1).

Inundation

Vegetation

Figure 9-2 presents the percent of vegetation classes inundated for the different lock floodplains, using data from RiMFIM for 60,000 ML.day\(^{-1}\) (Overton et al. 2006b). The figure shows that this discharge is inundating the floodplain; 30–60% of river red gums are inundated. In general, river red gum and lignum have a greater percentage inundated than saline shrubland and black box.

Wetlands

The inundated wetland area in hectares, and as a percentage of the total wetland area, is shown in Figure 9-3 and Figure 9-4 respectively (data from RiMFIM (Overton et al. 2006b) for 60,000 ML.day\(^{-1}\).
The wetland area is mostly inundated (at a mean of 90%; except for Lock 6). On the Lock 6 floodplain many wetland areas have been reached, increasing the inundated area to 49%, from 35% for a discharge of 40,000 ML.day$^{-1}$ (Figure 8-5).
Figure 9-1 Channel elevation, water level (m AHD) and velocity (m.s\(^{-1}\)) at ~60,000 ML.day\(^{-1}\) in the River Murray channel. Channel depth data from River Murray channel Digital Elevation Model, water level from printed backwater charts (~1977) for 60,000 ML.day\(^{-1}\). Calculated mean cross-sectional velocity (n=9–21 cross-sections), showing standard deviation of calculated velocity (Gippel 2011), for 60,000 ML.day\(^{-1}\).
Figure 9-2 Percent of different vegetation classes on the different lock floodplains, inundated by a discharge of 60,000 ML day⁻¹ (RiMFIM) (Overton et al. 2006b).

Figure 9-3 Inundated wetland area (ha) on the different lock floodplains, for a discharge of 60,000 ML day⁻¹ (RiMFIM) (Overton et al. 2006b).

Figure 9-4 Inundated wetland area, as a percent of total wetland area, on the different lock floodplains, for a discharge of 60,000 ML day⁻¹ (RiMFIM) (Overton et al. 2006b).
9.1.2 Lower Lakes

Salinity

Salinity is primarily between ~0–1,000 EC units in Lake Alexandrina for discharges 55,000–65,000 ML.day\(^{-1}\) (Figure 9-5). Salinity in Lake Albert (Meningie) was much greater (~4,000–8,000 EC units), but note that these measurements were recorded when Lake Albert was still hydrologically disconnected from (or just recently reconnected to) Lake Alexandrina.

Water level

Water level at 55,000–65,000 ML.day\(^{-1}\) is under normal barrage operations and varies from 0.5–1.0 m AHD (Figure 9-6).

9.1.3 Coorong

Salinity

Salinity close to the Murray Mouth varies from ~0–25 g.L\(^{-1}\) for barrage discharges 55,000–65,000 ML.day\(^{-1}\) (Figure 9-7). Salinity is higher, and with a greater a range (~50–110 g.L\(^{-1}\)) 100 km from the Murray Mouth. The salinity range has lowered and reduced from the lower flow bands (e.g. upper base flow (7,000 ML.day\(^{-1}\)) ranged from 10–45 g.L\(^{-1}\) and ~50–130 g.L\(^{-1}\) for near Murray Mouth and 100 km along the Coorong respectively).

Water level

Water level stays above sea level (varying from ~0–1.2 m AHD) across the Coorong for barrage discharges of 55,000–65,000 ML.day\(^{-1}\) (Figure 9-8); higher than those recorded for the lower flow bands (e.g. upper base flow (7,000 ML.day\(^{-1}\)) ranged from ~0.4–1 m AHD).
Figure 9-5 Salinity measured for barrage discharges of 55,000–65,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Poltaloch Plains (station A4261031), Narrung Jetty (station A4260583) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 9-6 Water level measured for barrage discharges of 55,000–65,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltaloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.
Figure 9-7 Salinity at barrage discharges of 55,000–65,000 ML.day\(^{-1}\) in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km away from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.

Figure 9-8 Water level at barrage discharges of 55,000–65,000 ML.day\(^{-1}\) in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km away from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Water level data from Webster (1997). Barrage discharge data from the MDBA.
9.2 Lower River Murray channel and floodplain model (60,000 ML.day\(^{-1}\))

Conceptual models take the form of statements on ecological patterns and processes expected from the defined biotic/abiotic components, based upon the hydrological data provided (see above), for ‘small overbank flows’ (60,000 ML.day\(^{-1}\)). Each statement was assigned a measure of certainty (in bold at the end of each statement) to aid in identifying knowledge gaps in conceptual understanding (Section 2.3). The certainty scoring system was adapted from Mallen-Cooper et al. (2011) and is reiterated below in Table 9-1. The conceptual model statements provided by each expert were then synthesised into a simplified conceptual diagram presenting key ecological patterns and processes.

Table 9-1. ‘Certainty’ scoring system used to define confidence in predictive statements of response to flow in the hydro-ecological conceptual models. Adapted from Mallen-Cooper et al. (2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very uncertain</td>
<td>No available data. Diverse views/conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Uncertain</td>
<td>No available data. Expert opinion. Consensus on conceptual understanding</td>
</tr>
<tr>
<td>3</td>
<td>Moderately certain</td>
<td>Supported by indirect, observational or limited scientific data</td>
</tr>
<tr>
<td>4</td>
<td>Very certain</td>
<td>Supported by direct or abundant scientific data. Published peer-reviewed literature</td>
</tr>
</tbody>
</table>

9.2.1 Nutrients, carbon, biofilms and microbes

- There is reduced autotrophic production due to light limitation resulting from increased depths as well as turbidity and colour (2).
- Increases in surface water level and concomitant change in water level will have a similar impact on resetting biofilm communities as a desiccation event (2).
- Changes to biofilm communities induced by changes in water level (deep submergence) and euphotic depth will be short-lived (<30 days) i.e. the biofilm will return to a late successional community upon return to stable water levels (3).
- The increase in surface water level throughout the weir pools will substantially alter the light environmental experienced by biofilms (3).
- Very slow rates of water level change eliminate cues and biogeochemical processes associated with flow induced changes in water level in an unregulated system (3).
- The magnitude of biogeochemical response will be mediated by day length and water temperature (3).
- Velocities are likely to be sufficient to generate some scouring of existing biofilms, creating surface area available for colonisation by early successional state taxa (3).
- The area of black box inundated and the area of river red gum inundated more than doubles from that inundated at 40,000 ML.day\(^{-1}\), dramatically increasing the amount of NOM that will be mobilised (3).
- It is estimated that ~14.5 and 3,803 kilotonnes of FRP and DOC respectively could be mobilised by a flow of this magnitude (3).
• Diverting (routing) water from upstream unregulated flows via Lake Victoria decreases the load and/or bioavailability of carbon and nutrients in the lower River Murray (2).
• Much of the organic material (dissolved and particulate) flushed into the river is likely to be transported downstream and may be lost from the end of the system, providing a supply to the Lower Lakes, Coorong and coastal waters (3).
• As flood waters move on and off the floodplain, phytoplankton composition changes with increases in chlorophytes and cyanobacteria influenced by growth conditions in the flood waters (2).
• Heterotrophic activity will increase markedly, as evidenced by large increases in respiration rates, larger bacterial populations and increases in the size and complexity of the heterotrophic microeukaryote communities (2).
• Heterotrophic activity will increasingly dominate net ecosystem productivity in the river channel while autotrophic production is reduced due to light limitation (2).
• The increase in organic material will increase the activity of the microbial pathway for energy transfer to the aquatic food web (2).
• Following the initial inundation and release of soluble material, and an associated surge in heterotrophic activity on the floodplain, autotrophic processes may become dominant in the floodplain and wetland areas (2).
• There will be a marked increase in resources (carbon, nutrients, zooplankton, phytoplankton) upon recession of the high flows as inundated areas drain back to the river channel (3).
• Stores of organic material may remain in the channel following a flood and continue to support heterotrophic production (3).
• The removal of weirs between flows of 40,000 and 60,000 ML.day\(^{-1}\) will facilitate the downstream (longitudinal) transport of resources (2).
• The rapid re-instatement of weirs as flows decline will interrupt the downstream (longitudinal) transport of resources (2).

9.2.2 Microbiota

• Flows of 60,000 ML.day\(^{-1}\) that occur during spring to early summer are likely to result in an increase in overall abundance, diversity and biomass, despite the high water velocities still inhibiting reproduction within the river main channel (Ning et al. 2012, Furst 2014) (3).
• Flows will be sufficient to flush some of the established communities within previously inundated wetlands back into the river main channel (Furst 2014) (3). This may result in an initial increase in cladoceran and copepod abundance within the river main channel; however, they are likely to diminish rapidly (1).
• The area of temporary wetland inundated is approximately 1,000 hectares higher than during bank-full flows (Gibbs et al. 2012). These newly inundated temporary wetlands are likely to host considerably more abundant and diverse communities than the river main channel due to community emergence from the egg bank and longer WRTs (e.g. Saunders and Lewis 1988a, 1988b, Boulton and Lloyd 1992, Tan and Shiel 1993) (4).
• Rotifers are also likely to be transferred from the newly inundated and permanent wetlands (Furst 2014) (3).
The percentage of lignum inundated significantly increases, which increases habitat availability and complexity for littoral microfauna, and may result in an increase in abundance and diversity of these communities community (e.g. Lucena-Moya and Duggan 2011, Meerhoff et al. 2003) (2).

Species richness is likely to increase in the river main channel due to the increasing extent and variability of habitats and exchange amongst them (e.g. Havel et al. 2000, Shiel et al. 2006) (3).

The response to flows of 60,000 ML.day$^{-1}$ during autumn and winter months is unknown. It is possible that a similar response may occur but to a much lesser extent (1).

9.2.3 Vegetation

Terrestrial dry

- Extirpated from temporary wetlands and floodplain inundated by increased flow (Gehrig et al. 2013, Holland et al. 2013) (4).
- Only present on high elevation floodplain (Gehrig et al. 2013, Holland et al. 2013) (4).

Terrestrial damp

- Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
- Recruitment in temporary wetlands and floodplain inundated by the high flow as water levels recede (Nicol 2004, 2012, Nicol et al. 2010) (3).

Floodplain

- Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
- Widespread recruitment in temporary wetlands and on floodplain inundated by the high flow as water levels recede (e.g. Siebentritt et al. 2004, Gehrig et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

- Plants will recruit in temporary wetlands and low elevation floodplain that was inundated by the high flow, whether they germinate on submergence or exposure depends on species (Gehrig et al. 2013, Holland et al. 2013) (3).
- Plants growing at or below pool level will be extirpated if inundation is longer than 30 days (1).
- Plants will not recruit on high elevation floodplain (1).

Amphibious fluctuation tolerator – woody

- Widespread recruitment will occur in temporary wetlands and floodplain inundated by the high flow as water levels recede (Gehrig et al. 2013, Holland et al. 2013) (3).
- Plants growing on the edges of permanent water bodies or in areas where groundwater is being freshened will remain in good condition (Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4).
- There will be a widespread improvement in condition of trees and shrubs in temporary wetlands and on the floodplain inundated by the high flow (McEwan et al. 2006, Doody et al. 2009, Holland et al. 2009) (3).
- Condition of plants growing on high elevation floodplain will continue to decline after extended periods without inundation (length of time depends on species) (Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4).

**Amphibious fluctuation tolerator – low growing**
- Plants will recruit in temporary wetlands and on floodplain inundated by the high flow, whether they germinate on submergence or exposure depends on species (2).
- Plants growing at or below pool level will persist providing inundation is no longer than 60 days (1).
- Plants growing at or below pool level will be temporarily extirpated if inundation exceeds 60 days (1).
- Plants will not recruit on high elevation floodplain (1).

**Amphibious fluctuation responder – plastic**
- Plants will recruit in temporary wetlands and on low elevation floodplain inundated by the high flow, whether they germinate on submergence or exposure depends on species (2).
- Plants that recruited during low flows will be temporarily extirpated due to the water level increase being greater than the maximum plant response (1).
- Plants will not recruit on high elevation floodplain (1).

**Floating**

**Submergent r-selected**
- Plants will recruit in temporary wetlands providing the hydroperiod is sufficient to complete its life cycle (Frahn et al. 2013) (2).

**Emergent**
- Recruitment will occur in temporary wetlands inundated by higher flows (2).
- Plants growing around pool level will be temporarily extirpated due to top flooding (1).

**Submergent K-selected**
- Widespread temporary extirpation of plants except in areas immediately upstream of weirs (Blanch and Walker 1997, Blanch et al. 1999a, 1999b, Bice et al. 2014) (3).
9.2.4 Macroinvertebrates

Group A

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat (including off-channel habitats with faster flow velocity) and higher abundance of allochthonous food resources and better quality autochthonous food sources (3).

Group B

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat (including off-channel habitats with faster flow velocity) and allochthonous food resources and better quality autochthonous food sources (3).

Group C

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat. However, may decline due to intolerance of physical scouring of higher flows within the channel (3).

Group D

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat and allochthonous food resources (3).

Group E

- Expected to decline in abundance in main channel due to intolerance of physical scouring of higher flows (3).

9.2.5 Frogs

Breeding habitat and requirements

- Increased areas of inundation associated with these flows occur in all lock reaches for all vegetation communities, in particular river red gum, black box and lignum. This will provide an increase in preferred breeding habitat for all species, e.g. southern bell frog (Gonzalez et al. 2011) (4).
- Increased inundation of temporary wetlands/floodplain areas and vegetation could lead to more than one breeding events for species that can lay multiple clutches in a year (Anstis 2013) (2).
- Species that anchor eggs to vegetation (eastern sign-bearing froglet, brown tree frog, Peron’s tree frog, eastern banjo frog and long-thumbed frog) have the potential for egg desiccation if water levels decrease rapidly immediately after breeding has occurred (2).
Tadpoles

- Increased inundation in area, depth and duration of temporary wetlands will provide most species with sufficient hydroperiods for metamorphosis to be completed (Wassens 2011) (4).
- Where these flows lead to an increased area of inundation of vegetation with harder structural integrity (e.g. river red gum, black box, saline shrublands, lignum) better protection for tadpoles from predation and disturbance from fish will be provided (Anstis 2013) (3).
- Increased wetland hydroperiods that may occur during these flows lead to an increase in food resources for tadpoles and subsequent increases in survival and recruitment (Wassens 2011) (2).

Adults

- Increased inundation of temporary wetland and floodplain areas will lead to dispersal of mobile species and an increase in the numbers of adults utilising inundated habitat (4).

9.2.6 Fish

Circa-annual spawning nesting species

- Adult Murray cod and freshwater catfish present in river main channel and anabranches (Leigh and Zampatti 2013, Zampatti et al. 2014) (4).
- River blackfish present in specific habitats of certain tributaries (Bice et al. 2011) (4).
- Increased water velocities and accompanying hydraulic diversity will result in increased area of favourable adult and juvenile Murray cod habitat in the main channel (Koehn 2009) (2).
- A proportion of the Murray cod population will undertake small- to large-scale (up to 100s km) longitudinal movements in association with flow and potentially spawning (Koehn et al. 2009, Leigh and Zampatti 2013) (3).
- Freshwater catfish and river blackfish will undertake small-scale movements (<1 km) within restricted home ranges (3).
- Spawning of all species will occur over a defined season (Humphries 2005, Koehn and Harrington 2006, Zampatti et al. 2011c) (4).
- Enhanced recruitment of Murray cod to young-of-year is likely to occur at flows of this magnitude if delivered during spawning season (Ye and Zampatti 2007) (2).
- Recruitment of freshwater catfish is likely (2).
- Recruitment of river blackfish is likely to be dependent upon local habitat and physico-chemical conditions (3).

Flow dependent specialists

- Present and common in river main channel (e.g. Wilson et al. 2012) (4) and also potentially in wetland and floodplain habitats (SARDI unpublished data) (3). May become dominant species in riverine fish assemblage (Bice et al. 2014) (3).
• May undertake small- to large-scale (up to 100s km) longitudinal movements in association with flow and potentially spawning (3).

• Spawning will likely occur should flow coincide with temperature thresholds (King et al. 2009, Cheshire et al. 2012) (3).

• Downstream drift of larvae from upstream areas (e.g. the Darling and mid-Murray Rivers) will occur (SARDI unpublished data) (3).

• Recruitment to young-of-year likely (Zampatti and Leigh 2013a, Zampatti and Leigh 2013b) (3).

• Recruits may be derived from upstream and local spawning (SARDI unpublished data) (2).

• Young-of-year will use a broad range of habitats including the floodplain (SARDI unpublished data) (2).

**Foraging generalists**

• Absent or present in river main channel in low abundance due to reductions in favourable habitat (aquatic vegetation) (Bice et al. 2014) (4).

• Present in connected wetland and floodplain habitats (SARDI unpublished data) (3).

• Widespread inundation of floodplain habitats and raised water levels in connected permanent wetlands may increase off-channel habitat area and promote lateral movement in these species (Lyon et al. 2010, Connallin et al. 2011) (2).

• Spawning will occur over protracted season and some level of recruitment is likely in off-channel habitats (3).

**Floodplain specialists**

• Present in specific off-channel habitats (3).

• Off-channel habitats that support these species will experience inundation and hydrological connection with the main channel (4), which may also involve associated movement of fish (particularly Murray hardyhead) (Lyon et al. 2010, Connallin et al. 2011) (2).

• Spawning and recruitment may occur and may be dependent upon local habitat and physico-chemical conditions (2).

9.2.7 **Waterbirds**

• Inundation of upper elevation wetlands and floodplains will further increase habitat availability and wetland-scale breeding opportunities for continental nomadic and regional waterbird species. In addition, the inundation of higher elevation woodlands (particularly spatially-extensive black box woodlands) will provide important long-term habitat for terrestrial bird species that otherwise use semi-arid, mallee woodland in the landscapes that surround the lower River Murray (1).

• These floodplain woodlands are thought to provide important complementary habitats for these terrestrial woodland birds, as they are thought to maintain productivity over longer periods (being relatively mesic) and are potentially important during dry periods within the landscape (2).
9.2.8 Model synthesis

Figure 9-9. Synthesis diagram of hydro-ecological models for flows of 60,000 ML.day\(^{-1}\) in the 'lower River Murray channel and floodplain'. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
9.3 Lower Lakes and Coorong model (60,000 ML.day⁻¹)

9.3.1 Nutrients, carbon, biofilms and microbes

- During periods of elevated flows there are increases in turbidity causing reduced light availability (2).
- The salinity gradient in the Coorong is reduced to a minimum (2).
- Much of the organic material (dissolved and particulate) flushed into the river is likely to be transported downstream and may be lost from the end of the system, providing a supply to the Lower Lakes, Coorong and coastal waters (3).
- Barrage releases into the Coorong result in the transfer of freshwater phytoplankton into the North Lagoon with mixing of conditions along the South Lagoon increasing with flow (2).
- The freshwater species in the Coorong will decline with distance from the outflow in response to increasing salinity. This will depend on the balance of flows across the barrage and in through the Murray Mouth (3).
- Freshwater species suitable to the lagoon conditions appear along with those transported by barrage flows (2).
- The phytoplankton in Lake Alexandrina is dominated by river species, with low cell concentrations due to turbidity, mixing and flushing (2).

9.3.2 Microbiota

- High flows are likely to flush a large proportion of the estuarine zooplankton assemblages from the Coorong and Lake Albert, and replace it with a freshwater rotifer dominated community (Shiel and Aldridge 2011) (3).
- Species diversity is also likely to increase within the Lower Lakes however more so within Lake Alexandrina due to the diversity of source populations (i.e. what is coming in via the river main channel) as well as some local emergence from propagule egg banks in flooded riparian margins (Shiel and Aldridge 2011) (3).

9.3.3 Vegetation

Terrestrial dry

- Restricted to above +0.9 m AHD (Frahn et al. 2013) (4).

Terrestrial damp

- Restricted to above +0.9 m AHD (Frahn et al. 2013) (4).
Floodplain

- This functional group is generally not present in the Lower Lakes (Frahn et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

- Present and recruiting at elevations between +0.8 and +0.2 m AHD (Frahn et al. 2013) (4).

Amphibious fluctuation tolerator – woody

- Present at elevations above +0.7 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).
- Recruitment will occur on water level recession if water levels rise above +0.8 m AHD (1).

Amphibious fluctuation tolerator – low growing

- Present at elevations between +0.8 and +0.6 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (3).

Amphibious fluctuation responder – plastic

- Present at elevations between +0.8 and +0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Floating

- Present in inundated areas (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent r-selected

- Plants are present in temporary wetlands during winter and spring and present in the propagule bank over summer and autumn (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Emergent

- Present at elevations between +0.9 and 0 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent K-selected

- Present at elevations between +0.5 and -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Ruppia tuberosa (Coorong)

- Ruppia tuberosa will germinate in late autumn when water levels in the South Lagoon rise (Brock 1982, Brookes et al. 2009b) (4).
• If flow over the barrages persists until late spring or early summer water levels in the South Lagoon will be sufficient for *Ruppia tuberosa* to complete its life cycle and replenish the propagule bank (Frahn et al. 2012) (2).

• If flows over the barrages cease before the end of spring, reproductive failure of *Ruppia tuberosa* will result due to rapid water level recession in the South Lagoon due to widening of the Murray Mouth (2).

• Reduced salinity in the North Lagoon will result in smothering of *Ruppia tuberosa* by filamentous algae and distribution will be restricted to the South Lagoon (3).

**9.3.4 Macroinvertebrates**

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 9.2.4).

**9.3.5 Frogs**

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 9.2.5).

• The Coorong does not represent suitable habitat for frogs.

**9.3.6 Fish**

**Circa-annual spawning nesting species**

• Murray cod and freshwater catfish likely rare, and river blackfish likely absent (Bice 2010b) (4).

• Adult and juvenile Murray cod and freshwater catfish may undertake small-scale movements within Lower Lakes (1) or large-scale movements between Lower Lakes and lower River Murray channel (1).

• Local spawning of Murray cod and freshwater catfish may occur (2).

• Larvae and juveniles may be transported from upstream (Koehn and Harrington 2005) (2).

• Recruitment may occur within Lower Lakes (2).

• All species likely absent from Coorong (2).

**Flow-dependent specialist**

• Adults present and common in Lower Lakes (Ferguson 2008) (4).

• May undertake small-scale movements within Lower Lakes (2) or large-scale movements between Lower Lakes and lower River Murray (1).

• Local spawning may occur should flow coincide with temperature thresholds (2).

• Downstream drift of larvae and juveniles from upstream areas (e.g. the lower River Murray) will occur (SARDI unpublished data) (3).
• Recruitment will occur within Lower Lakes (Ye 2005, Mayrhofer 2007, Bice 2010a) (2).
• Likely present in Coorong in low to moderate abundance (Bice et al. 2012, Ye et al. 2012b) (3).
• Likely to attempt return movements into freshwater habitats during times of elevated salinity (Bice et al. 2012, Zampatti et al. 2012) (4).

Foraging generalist

• Widespread and abundant (Wedderburn et al. 2014) (4).
• Spawning will occur over a protracted season and recruitment will occur (Humphries et al. 1999) (3).
• Certain species (e.g. bony herring, Australian smelt, flat-headed gudgeon) likely abundant in Coorong (Bice et al. 2012, Zampatti et al. 2012, Ye et al. 2012b) (4).
• Likely to attempt return movements from the Coorong into freshwater habitats during times of elevated salinity (Bice et al. 2012, Zampatti et al. 2012) (4).

Wetland/floodplain specialist

• Potentially present in specific off-channel habitats (Wedderburn et al. 2012, Hammer et al. 2013) (4).
• Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (Ellis 2005, Bice and Ye 2007) (4), and may be enhanced due to increased productivity associated with water level variability (Wedderburn et al. 2013) (2).
• May be present in Coorong in low abundance (2).

Diadromous species

• Present in Lower Lakes, but abundance reliant on connectivity and recruitment in preceding years (Zampatti et al. 2011a) (3).
• Present in Coorong, particularly within the vicinity of the Murray Mouth and into the North Lagoon (Bice et al. 2012, Ye et al. 2012b) (4).
• Downstream spawning migrations of catadromous species will occur in winter (Zampatti et al. 2011b) (4).
• Juvenile upstream migrations of catadromous species will occur in spring/summer (Zampatti et al. 2010) (4).
• Abundance of juveniles will be largely dependent upon connectivity during previous spawning season (3).
• Upstream migrations of anadromous species will occur in winter/spring (authors unpublished) (3).

Estuarine dependent species

• Small-bodied euryhaline estuarine species (e.g. goby spp., small-mouthed hardyhead) likely present in the Lower Lakes in low to moderate numbers (Jennings et al. 2008, Wedderburn et al. 2012) (4).
Select small-bodied euryhaline estuarine species (e.g. lagoon goby and small-mouthed hardyhead) may spawn and recruit within Lower Lakes (Jennings et al. 2008) (1).

Present in Coorong, within the vicinity of the Murray Mouth and more broadly in the North Lagoon (Ye et al. 2012b) (3) with decreasing diversity with increasing distance from the mouth (Noell et al. 2009, Ye et al. 2012b) (4).

May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).

Spawning and recruitment of circa-annual spawners (e.g. goby species, small-mouthed hardyhead) is likely (Ye et al. 2011, 2012a) (2).

Recruitment of flow-dependent species (e.g. mulloway and black bream), may occur (Ferguson et al. 2008, Ye et al. 2012a) (2).

Increased abundance of small-bodied pelagic species (e.g. sandy sprat) is likely (Bice et al. 2012, Ye et al. 2012b) (3) potentially as a result of the transport of freshwater zooplankton to the Coorong or increased estuarine productivity with elevated freshwater flow (1).

**Marine species**

Unlikely to be present in Lower Lakes (3).

Present in Coorong in varying, but often low abundance, largely restricted to the vicinity of the Murray Mouth (Ye et al. 2012b) (4).

May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).

Spawning and recruitment likely not to occur within the Coorong (2).

**9.3.7 Waterbirds**

Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 9.2.7).

See waterbird ecology section (Section 4.7).
Figure 9-10. Synthesis diagram of hydro-ecological models for flows of 60,000 ML.day\(^{-1}\) in the ‘Lower Lakes and Coorong’. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
10 Large overbank (80,000 ML.day\(^{-1}\)) hydro-ecological conceptual models

This section presents data on the hydrology and associated conditions in the lower River Murray in SA under ‘upper base flows’ (80,000 ML.day\(^{-1}\)), and the associated hydro-ecological conceptual models. A general overview of hydraulics (e.g. velocity and water level), floodplain inundation and salinity is provided for the ‘lower River Murray channel and floodplain’, and the ‘Lower Lakes and Coorong’. This is followed by the conceptual models for each biotic/abiotic component for each region.

10.1 Hydrology and associated conditions (80,000 ML.day\(^{-1}\))

10.1.1 Lower River Murray channel and floodplain

Hydrology

A discharge of 80,000 ML.day\(^{-1}\) to SA has an AEP of \(~25\%\) pre-development, but now has an AEP of \(~7\%\) (Maheshwari et al. 1995).

Hydraulics

Water level

Water level for a discharge of 80,000 ML.day\(^{-1}\) overtops the weirs (Figure 10-1), which have, in most cases been ‘removed’ (i.e. all stop logs removed) (Table 3-1).

Velocity

Calculated velocity is >0.8 m.s\(^{-1}\) for all calculated points and the influence on the weir has reduced. For example, velocities are similar immediately upstream and downstream of Lock 2 (Figure 10-1).

Inundation

Vegetation

Figure 10-2 shows the percent of vegetation classes inundated for the different lock floodplains, using data from RiMFIM (Overton et al. 2006b). The figure shows that this discharge is inundating the floodplain; in many cases over 75% of the vegetation class is inundated. In general, river red gum and lignum have a greater percentage inundated than saline shrubland and black box.

Wetlands

The inundated wetland area in hectares, and as a percentage of the total wetland area, is shown in Figure 10-3 and Figure 10-4 respectively (data from RiMFIM (Overton et al. 2006b) for
80,000 ML.day$^{-1}$. The wetland area is almost completely inundated (at a mean of 97%; except for Lock 6). On the Lock 6 floodplain many wetland areas have been reached, increasing the inundated area to 91%, from 49% for a discharge of 60,000 ML.day$^{-1}$. 
Figure 10-1 Channel elevation, water level (m AHD) and velocity (m.s\(^{-1}\)) at ~80,000 ML.day\(^{-1}\) in the River Murray channel. Channel depth data from River Murray channel Digital Elevation Model, water level from printed backwater charts (~1977) for approximately 90,000 ML.day\(^{-1}\). Calculated mean cross-sectional velocity (n=9–21 cross-sections), showing standard deviation of calculated velocity (Gippel 2011), for 80,000 ML.day\(^{-1}\).
Figure 10-2 Percent of different vegetation classes on the different lock floodplains, inundated by a discharge of 80,000 ML.day\(^{-1}\) (RiMFIM) (Overton et al. 2006b).

Figure 10-3 Inundated wetland area (ha) on the different lock floodplains, for a discharge of 80,000 ML.day\(^{-1}\) (RiMFIM) (Overton et al. 2006b).

Figure 10-4 Inundated wetland area, as a percent of total wetland area, on the different lock floodplains, for a discharge of 80,000 ML.day\(^{-1}\) (RiMFIM) (Overton et al. 2006b).
10.1.2 Lower Lakes

Salinity

Salinity is primarily between ~0–1,000 EC units in Lake Alexandrina for discharges 75,000–85,000 ML.day\(^{-1}\) (Figure 10-5). Salinity in Lake Albert (Meningie) was much greater (~5,000–7,000 EC units), but note that these measurements were recorded when Lake Albert was still hydrologically disconnected from (or just recently reconnected to) Lake Alexandrina.

Water level

Water level at 75,000–85,000 ML.day\(^{-1}\) is under normal barrage operations and varies from 0.5–1.0 m AHD (Figure 10-6).

10.1.3 Coorong

Salinity

Salinity close to the Murray Mouth is 0–10 g.L\(^{-1}\) for barrage discharges 75,000–85,000 ML.day\(^{-1}\) (Figure 10-7). Salinity is higher, and with a greater range (~50–100 g.L\(^{-1}\)) 100 km from the Murray Mouth. The salinity range has lowered and reduced from the lower flow bands (e.g. upper base flow (7,000 ML.day\(^{-1}\)) ranged from 10–45 g.L\(^{-1}\) and ~50–130 g.L\(^{-1}\) for near Murray Mouth and 100 km along the Coorong respectively).

Water level

Water level stays above sea level (varying from ~0–1 m AHD) across the Coorong for barrage discharges of 75,000–85,000 ML.day\(^{-1}\) (Figure 10-8); higher than those recorded for the lower flow bands (e.g. upper base flow (7,000 ML.day\(^{-1}\)) ranged from ~0.4–1 m AHD).
Figure 10-5 Salinity measured for barrage discharges of 75,000–85,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Salinity data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.

Figure 10-6 Water level measured for barrage discharges of 75,000–85,000 ML.day\(^{-1}\) at different locations in the Lower Lakes during the period 2002–2012 (see Figure 3-12 for locations). Note that there was a drought (and consequently no barrage discharge) from ~2007–2010, and that Lake Albert was hydraulically disconnected from Lake Alexandrina ~2007–2011. Water level data from Water Connect (2013) for Milang Jetty (station A4260524), Tauwitchere Barrage US (station A4260527), Poltalloch Plains (station A4261031) and Meningie Sailing Club Jetty (station A4260630). Barrage discharge data from MDBA.
Figure 10-7 Salinity at barrage discharges of 75,000–85,000 ML.d$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km away from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Salinity data from Webster (1997). Barrage discharge data from the MDBA.

Figure 10-8 Water level at barrage discharges of 75,000–85,000 ML.d$^{-1}$ in the Coorong near the Murray Mouth (Coorong – 0 km) and in the Coorong at a point 100 km away from the mouth (Coorong – 100 km) from 1984–2012 (see Figure 3-12 for locations). Water level data from Webster (1997). Barrage discharge data from the MDBA.
10.2 Lower River Murray channel and floodplain model (80,000 ML.day⁻¹)

Conceptual models take the form of statements on ecological patterns and processes expected from the defined biotic/abiotic components, based upon the hydrological data provided (see above), for ‘large overbank flows’ (80,000 ML.day⁻¹). Each statement was assigned a measure of certainty (in bold at the end of each statement) to aid in identifying knowledge gaps in conceptual understanding (Section 2.3). The certainty scoring system was adapted from Mallen-Cooper et al. (2011) and is reiterated below in Table 10-1. The conceptual model statements provided by each expert were then synthesised into a simplified conceptual diagram presenting key ecological patterns and processes.

Table 10-1. ‘Certainty’ scoring system used to define confidence in predictive statements of response to flow in the hydro-ecological conceptual models. Adapted from Mallen-Cooper et al. (2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very uncertain</td>
<td>No available data. Diverse views/conceptual understanding</td>
</tr>
<tr>
<td>2</td>
<td>Uncertain</td>
<td>No available data. Expert opinion. Consensus on conceptual understanding</td>
</tr>
<tr>
<td>3</td>
<td>Moderately certain</td>
<td>Supported by indirect, observational or limited scientific data</td>
</tr>
<tr>
<td>4</td>
<td>Very certain</td>
<td>Supported by direct or abundant scientific data. Published peer-reviewed</td>
</tr>
<tr>
<td></td>
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<td>literature</td>
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</tbody>
</table>

10.2.1 Nutrients, carbon, biofilms and microbes

- There is reduced autotrophic production due to light limitation resulting from increased depths as well as turbidity and colour (2).
- Increases in surface water level and concomitant change in water level will have a similar impact on resetting biofilm communities as a desiccation event (2).
- Changes to biofilm communities induced by changes in water level (deep submergence) and euphotic depth will be short-lived (<30 days) i.e. the biofilm will return to a late successional community upon return to stable water levels (3).
- The increase in surface water level throughout the weir pools will substantially alter the light environmental experienced by biofilms (3).
- Very slow rates of water level change eliminate cues and biogeochemical processes associated with flow induced changes in water level in an unregulated system (3).
- The magnitude of biogeochemical response will be mediated by day length and water temperature (3).
- Velocities are likely to be sufficient to generate some scouring of existing biofilms, creating surface area available for colonisation by early successional state taxa (3).
- The area of black box inundated increases by almost five-fold, and the area of river red gum inundated more than doubles from that inundated at 60,000 ML.day⁻¹, dramatically increasing the amount of NOM that will be mobilised (3).
• Diverting (routing) water from upstream unregulated flows via Lake Victoria decreases the load and/or bioavailability of carbon and nutrients in the lower River Murray (2).
• Much of the organic material (dissolved and particulate) flushed into the river is likely to be transported downstream and may be lost from the end of the system, providing a supply to the Lower Lakes, Coorong and coastal waters (3).
• As flood waters move on and off the floodplain phytoplankton composition changes with increases in chlorophytes and cyanobacteria influenced by growth conditions in the flood waters (2).
• Heterotrophic activity will increase markedly, as evidenced by large increases in respiration rates, larger bacterial populations and increases in the size and complexity of the heterotrophic microeukaryote communities (2).
• Heterotrophic activity will increasingly dominate net ecosystem productivity in the river channel while autotrophic production is reduced due to light limitation (2).
• The increase in organic material will increase the activity of the microbial pathway for energy transfer to the aquatic food web (2).
• Following the initial inundation and release of soluble material, and an associated surge in heterotrophic activity on the floodplain, autotrophic processes may become dominant in the floodplain and wetland areas (2).
• There will be a marked increase in resources (carbon, nutrients, zooplankton, phytoplankton) upon recession of the high flows as inundated areas drain back to the river channel (3).
• Stores of organic material may remain in the channel following a flood and continue to support heterotrophic production (3).
• The removal of weirs between flows of 40,000 and 60,000 ML.day\(^{-1}\) will facilitate the downstream (longitudinal) transport of resources (2).

10.2.2 Microbiota

• Flows of 80,000 ML.day\(^{-1}\) that occur during spring to early summer will result in similar response to flows of 60,000 ML.day\(^{-1}\) with an increase in overall abundance, diversity and biomass (Furst 2014) (3).
• Flows will flush established communities from previously inundated wetlands back into the river main channel (Furst 2014) (3).
• Cladocerans and copepods are likely to be virtually absent, even within floodplain areas, as high flow velocities will limit population establishment (Richardson 1992) (3).
• The area of temporary wetland inundated increases by approximately 1400 hectares in comparison to small overbank flows (Gibbs et al. 2012). These newly inundated temporary wetlands are likely to host considerably more abundant and diverse communities than the river main channel due to community emergence from the egg bank and longer WRTs (e.g. Saunders and Lewis 1988a, 1988b, Boulton and Lloyd 1992, Tan and Shiel 1993) (4).
• During the first few weeks these habitats will be rotifer dominated and a proportion of these communities are likely to be transferred to the river main channel (Shiel et al. 2006, Ning et al. 2012, Furst 2014) (3).
• The percentage of lignum inundated significantly increases resulting in increased habitat availability and complexity for littoral microfauna, possibly resulting in an increase in the abundance and diversity of the community (e.g. Lucena-Moya and Duggan 2011, Meerhoff et al. 2003) (2).
• Species richness is likely to increase in the river main channel due to the increasing extent and variability of habitats and exchange amongst them (for example between littoral and pelagic or wetland and main channel habitats) (e.g. Shiel 1976, Havel et al. 2000) (3).
• The response to flows of 80,000 ML.day⁻¹ during autumn and winter months is unknown. It is possible that a similar response may occur but to a much lesser extent (1).

10.2.3 Vegetation

Terrestrial dry

• Extirpated from temporary wetlands and floodplain inundated by increased flow (Gehrig et al. 2013, Holland et al. 2013) (4).
• Only present on very high elevation floodplain (Gehrig et al. 2013, Holland et al. 2013) (4).
• Will be completely extirpated from floodplain at flows >130,000 ML.day⁻¹ (Overton et al. 2004) (3).

Terrestrial damp

• Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
• Recruitment in temporary wetlands and floodplain inundated by the high flow as water levels recede (Nicol 2004, 2012, Nicol et al. 2010) (3).

Floodplain

• Extirpated from the upper pool level littoral zone (Zampatti et al. 2011c) (3).
• Widespread recruitment in temporary wetlands and on floodplain inundated by the high flow as water levels recede (Siebentritt et al. 2004, Gehrig et al. 2013, Holland et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

• Plants will recruit in temporary wetlands and low elevation floodplain that was inundated by the high flow, whether they germinate on submergence or exposure depends on species (Gehrig et al. 2013, Holland et al. 2013) (3).
• Plants growing at or below pool level will be extirpated if inundation is longer than 30 days (1).
• Plants will not recruit on high elevation floodplain (1).

Amphibious fluctuation tolerator – woody

• Adults present across the floodplain and in temporary wetlands (Jessop and Tolken 1986, Brooker and Kleinig 1999, Sainty and Jacobs 2003) (4).
- Widespread recruitment will occur in temporary wetlands and floodplain inundated by the high flow as water levels recede (Gehrig et al. 2013, Holland et al. 2013) (3).
- Plants growing on the edges of permanent water bodies or in areas where groundwater is being freshened will remain in good condition providing inundation does not exceed 180 days (e.g. Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (2).
- There will be a widespread improvement in condition of trees and shrubs in temporary wetlands and on the floodplain inundated by the high flow (McEwan et al. 2006, Doody et al. 2009, Holland et al. 2009) (3).
- Condition of plants growing on very high elevation floodplain will continue to decline after extended periods without inundation (length of time depends on species) (Bacon et al. 1993, Thorburn et al. 1994, Overton et al. 2006a, Berens et al. 2009) (4). This zone will not be present for flows >130,000 ML.day⁻¹ (Overton et al. 2004).

Amphibious fluctuation tolerator – low growing

- Plants will recruit in temporary wetlands and on floodplain inundated by the high flow, whether they germinate on submergence or exposure depends on species (2).
- Plants growing at or below pool level will persist providing inundation is no longer than 60 days (1).
- Plants growing at or below pool level will be temporarily extirpated if inundation exceeds 60 days (1).
- Plants will not recruit on high elevation floodplain (1).

Amphibious fluctuation responder – plastic

- Plants will recruit in temporary wetlands and on low elevation floodplain inundated by the high flow, whether they germinate on submergence or exposure depends on species (2).
- Plants that recruited during low flows will be temporarily extirpated due to the water level increase being greater than the maximum plant response (1).
- Plants will not recruit on high elevation floodplain (1).

Floating


Submergent r-selected

- Plants will recruit in temporary wetlands providing the hydroperiod is sufficient to complete its life cycle (Frahn et al. 2013) (2).

Emergent

- Recruitment will occur in temporary wetlands inundated by higher flows (2).
- Plants growing around pool level will be temporarily extirpated due to top flooding (Bice et al. 2014) (1).
Submergent K-selected

- Widespread temporary extirpation of plants (Bice et al. 2014) (3).

### 10.2.4 Macroinvertebrates

**Group A**

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat (including off-channel habitats with faster flow velocity) and allochthonous food resources (3).

**Group B**

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat (including increased flow velocity) and allochthonous food resources (3).

**Group C**

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat (including increased flow velocity) and allochthonous food resources (3).

**Group D**

- Abundance and diversity of this group expected to increase due to increased area of inundation providing more diverse habitat and allochthonous food resources (3).

**Group E**

- Expected to decline in abundance due to intolerance of physical scouring of higher flows (3).

### 10.2.5 Frogs

**Breeding habitat and requirements**

- Significant inundation of preferred breeding habitats (river red gum woodlands, lignum shrublands, other dry floodplain vegetation) will lead to significant breeding activity for all species (Gonzalez et al. 2011) (4).
- Species that anchor eggs to vegetation (eastern sign-bearing froglet, brown tree frog, Peron’s tree frog, eastern banjo frog and long-thumbed frog) have the potential for egg desiccation if water levels decrease rapidly immediately after breeding has occurred (Anstis 2013) (2).
- Increased inundation of temporary wetlands/floodplain areas and vegetation could lead to more than one breeding events for species that can lay multiple clutches in a year (Anstis 2013) (2).

**Tadpoles**

- Increased inundation in area, depth and duration of temporary wetlands will provide all species with sufficient hydroperiods for metamorphosis to be completed (Wassens 2011) (4).
- Large areas of inundation of vegetation with harder structural integrity (e.g. river red gum, black box, saline shrublands, lignum) will provide better protection for tadpoles from predation and disturbance from fish (Anstis 2013) (3).
- Increased wetland hydroperiods that may occur during these flows lead to an increase in food resources for tadpoles and subsequent increases in survival and recruitment (Wassens 2011) (2).

**Adults**

- Increased inundation of temporary wetland and floodplain areas will lead to dispersal of mobile species and an increase in the numbers of adults utilising inundated habitat (4).

**10.2.6 Fish**

**Circa-annual spawning nesting species**

- Adult Murray cod and freshwater catfish present in river main channel and anabranches (Leigh and Zampatti 2013, Zampati et al. 2014) (4).
- River blackfish present in specific habitats of certain tributaries (Bice et al. 2011) (4).
- Increased water velocities and accompanying hydraulic diversity will result in increased area of favourable adult and juvenile Murray cod habitat in the main channel (Koehn 2009) (2).
- A proportion of the Murray cod population will undertake small- to large-scale (up to 100s km) longitudinal movements in association with flow and potentially spawning (Koehn et al. 2009, Leigh and Zampatti 2013) (3).
- Freshwater catfish and river blackfish will undertake small-scale movements (<1 km) within restricted home ranges (3).
- Spawning of all species will occur over a defined season (Humphries 2005, Koehn and Harrington 2006, Zampatti et al. 2011c, Cheshire et al. 2012) (4).
- Enhanced recruitment of Murray cod to young-of-year is likely to occur at flows of this magnitude if delivered during spawning season (Ye and Zampatti 2007) (2).
- Recruitment of freshwater catfish is likely (2).
- Recruitment of river blackfish is likely to be dependent upon local habitat and physico-chemical conditions (3).
Flow dependent specialists

- Present and common in river main channel (Wilson et al. 2012, SARDI unpublished data) (4) and also potentially in wetland and floodplain habitats (SARDI unpublished data) (3). May become dominant species in riverine fish assemblage (Bice et al. 2014) (3).
- May undertake small- to large-scale (up to 100s km) longitudinal movements in association with flow and potentially spawning (3).
- Spawning will likely occur should flow coincide with temperature thresholds (King et al. 2009, Cheshire et al. 2012) (3).
- Downstream drift of larvae from upstream areas (e.g. the Darling and mid-Murray Rivers) will occur (SARDI unpublished data) (3).
- Recruitment to young-of-year likely (Zampatti and Leigh 2013a, Zampatti and Leigh 2013b) (3).
- Recruits may be derived from upstream and local spawning (SARDI unpublished data) (2).
- Young-of-year will use a broad range of habitats including the floodplain (SARDI unpublished data) (2).

Foraging generalists

- Absent or present in river main channel in low abundance due to reductions in favourable habitat (aquatic vegetation) (Bice et al. 2014) (4).
- Present in connected wetland and floodplain habitats (Thwaites and Fredberg 2014) (3).
- Widespread inundation of floodplain habitats and raised water levels in connected permanent wetlands may increase off-channel habitat area and promote lateral movement in these species (Lyon et al. 2010, Connallin et al. 2011) (2).
- Spawning will occur over protracted season and some level of recruitment is likely in off-channel habitats (3).

Floodplain specialists

- Present in specific off-channel habitats (3).
- Off-channel habitats that support these species will experience inundation and hydrological connection with the main channel (4), which may also involve associated movement of fish (particularly Murray hardyhead) (Lyon et al. 2010, Connallin et al. 2011) (2).
- Spawning and recruitment may occur and may be dependent upon local habitat and physico-chemical conditions (2).

10.2.7 Waterbirds

- Inundation of upper elevation wetlands and floodplains will further increase habitat availability and wetland-scale breeding opportunities for continental nomadic and regional waterbird species. In addition, the inundation of higher elevation woodlands (particularly spatially-extensive black box woodlands) will provide important long-term habitat for terrestrial bird species that otherwise use semi-arid mallee woodland in the landscapes that surround the lower River Murray (1).
These floodplain woodlands are thought to provide important complementary habitats for these terrestrial woodland birds, as they are thought to maintain productivity over longer periods (being relatively mesic) and are potentially important during dry periods within the landscape (2).
10.2.8 Model synthesis

Figure 10.9. Synthesis diagram of hydro-ecological models for flows of 80,000 ML/day in the 'lower River Murray channel and floodplain'. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
10.3 Lower Lakes and Coorong model (80,000 ML.day⁻¹)

10.3.1 Nutrients, carbon, biofilms and microbes

- During periods of elevated flows there are increases in turbidity causing reduced light availability (2).
- The salinity gradient in the Coorong is reduced to a minimum (2).
- Much of the organic material (dissolved and particulate) flushed into the river is likely to be transported downstream and may be lost from the end of the system, providing a supply to the Lower Lakes, Coorong and coastal waters (3).
- Barrage releases into the Coorong result in the transfer of freshwater phytoplankton into the North Lagoon with mixing of conditions along the South Lagoon increasing with flow (2).
- The freshwater species in the Coorong will decline with distance from the outflow in response to increasing salinity. This will depend on the balance of flows across the barrage and in through the Murray Mouth (3).
- Freshwater species suitable to the lagoon conditions appear along with those transported by barrage flows (2).
- The phytoplankton in Lake Alexandrina is dominated by river species, with low cell concentrations due to turbidity, mixing and flushing (2).

10.3.2 Microbiota

- The higher flows are likely to flush most of the estuarine zooplankton assemblages from the North Lagoon of the Coorong (Shiel and Aldridge 2011) (3) and Lake Albert and replace it with a freshwater rotifer dominated community (1).
- Species diversity is also likely to increase within the Lower Lakes, especially within Lake Alexandrina, due to the diversity of source populations (i.e. what is coming in via the river main channel) as well as some local emergence from propagule egg banks in flooded riparian margins (Shiel and Aldridge 2011) (3).

10.3.3 Vegetation

Terrestrial dry

- Restricted to above +0.9 m AHD (Frahn et al. 2013) (4).

Terrestrial damp

- Restricted to above +0.9 m AHD (Frahn et al. 2013) (4).
Floodplain

- This functional group is generally not present in the Lower Lakes (Frahn et al. 2013) (4).

Amphibious fluctuation tolerator – emergent

- Present and recruiting at elevations between +0.8 and +0.2 m AHD (Frahn et al. 2013) (4).

Amphibious fluctuation tolerator – woody

- Present at elevations above +0.7 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).
- Recruitment will occur on water level recession if water levels rise above +0.8 m AHD (1).

Amphibious fluctuation tolerator – low growing

- Present at elevations between +0.8 and +0.6 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (3).

Amphibious fluctuation responder – plastic

- Present at elevations between +0.8 and +0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Floating

- Present in inundated areas (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent r-selected

- Plants are present in temporary wetlands during winter and spring and present in the propagule bank over summer and autumn (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Emergent

- Present at elevations between +0.9 and 0 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Submergent K-selected

- Present at elevations between +0.5 and -0.2 m AHD (Gehrig et al. 2011, Frahn et al. 2013, Nicol et al. 2013) (4).

Ruppia tuberosa (Coorong)

- *Ruppia tuberosa* will germinate in late autumn when water levels in the South Lagoon rise (Brock 1982, Brookes et al. 2009b) (4).
• If flow over the barrages persists until late spring or early summer, water levels in the South Lagoon will be sufficient for *Ruppia tuberosa* to complete its life cycle and replenish the propagule bank (Frahn et al. 2012) (2).
• If flows over the barrages cease before the end of spring, reproductive failure of *Ruppia tuberosa* will result due to rapid water level recession in the South Lagoon due to widening of the Murray Mouth (2).
• Salinity in the North Lagoon will result in smothering of *Ruppia tuberosa* by filamentous algae and distribution will be restricted to the South Lagoon (4).

10.3.4 Macroinvertebrates

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 10.2.4).

10.3.5 Frogs

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 10.2.5).
• The Coorong does not represent suitable habitat for frogs.

10.3.6 Fish

Circa-annual spawning nesting species

• Murray cod and freshwater catfish likely rare, and river blackfish likely absent (Bice 2010b) (4).
• Adult and juvenile Murray cod and freshwater catfish may undertake small-scale movements within Lower Lakes (1) or large-scale movements between Lower Lakes and lower River Murray channel (1).
• Local spawning of Murray cod and freshwater catfish may occur (2).
• Larvae and juveniles may be transported from upstream (Koehn and Harrington 2005) (2).
• Recruitment may occur within Lower Lakes (2).
• All species likely absent from Coorong (2).

Flow-dependent specialist

• Adults present and common in Lower Lakes (Ferguson 2008) (4).
• May undertake small-scale movements within Lower Lakes (2) or large-scale movements between Lower Lakes and ‘lower River Murray channel and floodplain’ (1).
• Local spawning may occur in Lower Lakes should flow coincide with temperature thresholds (2).
- Downstream drift of larvae and juveniles from upstream areas (e.g. the lower River Murray) will occur (SARDI unpublished data) (3).
- Recruitment will occur within Lower Lakes (Ye 2005, Mayrhofer 2007, Bice 2010a) (3).
- Likely present in Coorong in low to moderate abundance (Bice et al. 2012) (3).

**Foraging generalist**

- Widespread and abundant (Wedderburn et al. 2014) (4).
- Spawning will occur over a protracted season and recruitment will occur (Humphries et al. 1999) (3).
- Certain species (e.g. bony herring, Australian smelt, flat-headed gudgeon) likely abundant in Coorong (Bice et al. 2012, Zampatti et al. 2012, Ye et al. 2012b) (4).

**Wetland/floodplain specialist**

- Spawning and recruitment likely to occur dependent upon local habitat and physico-chemical conditions (Ellis 2005, Bice and Ye 2007) (4), and may be enhanced due to increased productivity associated with water level variability (Wedderburn et al. 2013) (2).
- May be present in Coorong in low abundance (2).

**Diadromous species**

- Present, but abundance reliant on connectivity and recruitment in preceding years (Zampatti et al. 2011a) (3).
- Present in Coorong; broadly distributed within the vicinity of the Murray Mouth and the North Lagoon, and potentially some residence in the South Lagoon (Ye et al. 2012b) (4).
- Downstream spawning migrations of catadromous species will occur in winter (Zampatti et al. 2011b) (4).
- Juvenile upstream migrations of catadromous species will occur in spring/summer (Zampatti et al. 2010) (4). Abundance of juveniles will be largely dependent upon connectivity during previous spawning season (3).
- Upstream migrations of anadromous species will occur in winter/spring (authors unpublished) (3).

**Estuarine dependent species**

- Small-bodied euryhaline estuarine species (e.g. goby species, small-mouthed hardyhead) likely present in the Lower Lakes in low to moderate numbers (Jennings et al. 2008, Wedderburn et al. 2012) (4).
• Select small-bodied euryhaline estuarine species (e.g. lagoon goby and small-mouthed hardyhead) may spawn and recruit within Lower Lakes (Jennings et al. 2008) (1).

• Present in Coorong; broadly distributed within the vicinity of the Murray Mouth and the North Lagoon, and potentially some residence in the South Lagoon with decreasing diversity with increasing distance from the mouth in the South Lagoon (Ye et al. 2012b) (3).

• May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).

• Spawning and recruitment of circa-annual spawners (e.g. goby species, small-mouthed hardyhead) is likely (Ye et al. 2011, Livore et al. 2013) (3).

• Recruitment of flow-dependent species (e.g. mulloway and black bream), may occur (Ferguson et al. 2008, Ye et al. 2012a) (2).

• Increased abundance of small-bodied pelagic species (e.g. sandy sprat) is likely (Bice et al. 2012, Ye et al. 2012b) (3) potentially as a result of the transport of freshwater zooplankton to the Coorong or increased estuarine productivity with elevated freshwater flow (1).

Marine species

• Unlikely to be present in Lower Lakes (3).

• Present in Coorong in varying, but low abundance, largely restricted to the vicinity of the Murray Mouth (Ye et al. 2012b) (4).

• May undertake small- and large-scale movements both within the Coorong and between the Coorong and Southern Ocean (authors unpublished) (3).

• Spawning and recruitment likely not to occur within Coorong (2).

10.3.7 Waterbirds

• Patterns and processes in the Lower Lakes as per ‘lower River Murray channel and floodplain’ model (Section 10.2.7).

• See waterbird ecology section (Section 4.7).
10.3.8 Model synthesis

Figure 10.10. Synthesis diagram of hydro-ecological models for flows of 80,000 ML day\(^{-1}\) in the ‘Lower Lakes and Coorong’. Select vegetation symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols).
11 Knowledge gaps

A primary aim of the current project was to identify key knowledge gaps in current understanding of flow-related ecology in the lower River Murray, including the Lower Lakes and Coorong, through the development of hydro-ecological conceptual models. These knowledge gaps should inform the prioritisation of future research to better support decisions regarding flow restoration in the lower River Murray. Experts were asked to compile all predictive statements from their hydro-ecological models that received ‘uncertain’ (i.e. 2) or ‘very uncertain’ (i.e. 1) scores (Table 2-2). This list was then synthesised into coherent knowledge gaps for each biotic/abiotic ecosystem component. Key knowledge gaps for each biotic/abiotic component are presented within the following ecological/biological ‘themes’: 1) trophic dynamics, 2) population dynamics and community structure, 3) distribution, 4) condition, 5) movement and 6) habitat use. Furthermore, some experts have presented a consolidated list of knowledge gaps for the whole lower River Murray, whilst others have presented knowledge gaps grouped by regions (i.e. ‘lower River Murray channel and floodplain’ or ‘Lower Lakes and Coorong’). The themes were adopted to present the knowledge gaps in a coherent manner and highlight general areas of system ecology which require further research attention.

In total 71 knowledge gaps were identified for the seven biotic/abiotic components across the six ecological/biological themes (Table 11-1). The greatest numbers of knowledge gaps were identified under the themes of trophic dynamics (40 knowledge gaps) and population dynamics and community structure (23 knowledge gaps). Whilst the theme of trophic dynamics is broad, this result highlights a substantial lack of understanding of diets, trophic pathways and food web structure in relation to flow in the lower River Murray. Furthermore, there appears a need for greater understanding of the life history of native biota in relation to flow. Whilst all knowledge gaps identified represent priorities for future research, these two general ecological/biological themes are perhaps most pertinent.
Table 11.1. Summary of the number of knowledge gaps identified as priorities for future research in relation to each ecosystem component and ecological/biological theme.

<table>
<thead>
<tr>
<th>Ecological/biological theme</th>
<th>Trophic dynamics</th>
<th>Population dynamics and community structure</th>
<th>Distribution</th>
<th>Condition</th>
<th>Movement</th>
<th>Habitat use</th>
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<td>71</td>
</tr>
</tbody>
</table>

11.1 Nutrients, carbon, biofilms and microbes

A total of 33 knowledge gaps were identified for nutrients, carbon, biofilms and microbes. These knowledge gaps are grouped within the theme of ‘trophic dynamics’ but are presented under the themes of 1) ‘food resources’, 2) ‘trophic group responses’ and 3) ‘food web structure and function’. The knowledge gaps are also presented by region.

11.1.1 General (i.e. applies to both lower River Murray channel and floodplain, and Lower Lakes and Coorong)

Food resources

- The basal forms of organic carbon supplies (internal or external organic carbon) that predominate and how they change with flow, salinity, and connectivity.
- The extent to which external (allochthonous) organic material supports higher trophic levels and larger organisms.
- The influence of light availability and euphotic depth on system autotrophic productivity and the relative importance of heterotrophic and autotrophic pathways.

Trophic group responses

- How the community composition of heterotrophic aquatic microorganisms responds under all flow bands.
- How the community composition of autotrophic aquatic microorganisms responds under all flow bands.
- Whether heterotrophic and autotrophic productivity are predictable with respect to flows.
• Whether there are critical periods of supply of organic carbon needed to meet life cycle requirements of organisms, for example short, intense supply periods for larval fish or prolonged supply periods for small bodied fish.
• Whether there are specific requirements of larvae and juveniles of native fish for particular basal supplies of organic materials that, although not directly consumed, support the development of suitable food items.

Food web structure and function

• How the conditions of flow, salinity, and connectivity influence the relative importance of the classical and microbial food chains in transferring basal forms of organic carbon to higher trophic levels and larger organisms.
• The efficiency of transfer of organic materials to larger organisms under different flow conditions and when different food chains are operating.
• The supply of organic materials that structures the food webs to optimise delivery of food resources for higher trophic levels and larger organisms.

11.1.2 Lower River Murray channel and floodplain

Food resources

• The influence of diverting (routing) water from upstream unregulated flows via Lake Victoria on the load and/or bioavailability of carbon and nutrients in the lower River Murray.
• The benefits of microorganisms, including phytoplankton and zooplankton, that grow within the shallow floodwaters on the floodplain to food resources in the river channel supporting higher trophic levels and larger aquatic organisms.
• Whether within-reach storages of allochthonous organic material prolong the productivity response post-recession of high flows.
• The persistence of increased organic material supplies whether from internal or external sources.
• The spatial influence of site based management actions on supplies of organic material and trophic structures i.e. kilometres, weir pool, river reach.

Trophic group responses

• Whether the increased diversity of microeukaryotes in response to flows that enhance connectivity with the floodplain is a response to the increased quantity and complexity of allochthonous organic material transferred from the floodplain.
• The critical flow relationships that influence light limitation and nutrient limitation of photoautotrophs in the Lower River Murray and the nutrients that are likely to limit production.
• The influence of temperature/flow on river metabolism (photosynthesis and respiration) and whether there is a minimum temperature/flow threshold for sustaining positive net production.
• Whether weir pool manipulations and/or flow changes reset biofilms, and if so, 1) how long-lived, and 2) what are the benefits (e.g. does a +0.5 m weir pool raising at 20,000 ML.day\(^{-1}\) significantly alter within-stream productivity relative to the same flow at routine weir pool heights)?

• Whether the changes in phytoplankton community dominance from cyanobacteria to chlorophytes to diatoms that occurs with increasing flows leads to improved food quality and enhanced secondary production.

**Food web structure and function**

• Whether there is a critical flow velocity at which the role of the classical and microbial pathways are altered.

• The efficiency of transfer of organic materials to higher trophic levels and larger organisms under different flow conditions and when different food chains are operating.

• The supply of organic materials that structures the food webs to optimise delivery of food resources for higher trophic levels and larger organisms.

**11.1.3 Lower Lakes and Coorong**

**Food resources**

• What loads of nutrients, carbon and other materials are transported downstream to the Lower Lakes and Coorong and what is retained under different flow conditions?

• The relative contribution of internal nutrients, organic carbon and other resources in the Lower Lakes and Coorong including due to resuspension.

• Whether increased resources from higher flow events result in increased productivity in the Lower Lakes and Coorong.

**Trophic group responses**

• Changes in the diversity and functionality of microeukaryotes in response to inflows and resuspension of organic material, and links with the quantity and complexity of the organic material.

• The changes in phytoplankton communities that occur in response to changing river inflows and whether they lead to improved food quality and enhanced secondary production.

• The critical inflow and lake conditions that influence light limitation and nutrient limitation of photoautotrophs in the Lower Lakes and Coorong, and the nutrients that are likely to limit production.

• The relative roles of production and hydrodynamic transport of organisms that result in the longitudinal changes in concentration and community composition along the Coorong.

**Food web structure and function**

• Whether the substantive trophic links are autotrophic or heterotrophic, and how they change in response to flow, salinity, and connectivity.
• The influence of Lake and Coorong characteristics (e.g. inflow, outflow, depth, water quality) on food web structures and the supply of food resources to higher trophic levels and larger organisms.

11.2 Microbiota

A total of seven knowledge gaps were identified for microbiota, which are presented concurrently for each region. All knowledge gaps are grouped under the theme of ‘population dynamics and community structure’.

• Regional differences (i.e. ‘lower River Murray main channel and floodplain’, ‘Lower Lakes and Coorong’) in microbiota community structure (diversity and abundance) under all flow bands.
• Changes in diversity of littoral microbiota with water level variability (i.e. changes in habitat availability) at low flow bands (i.e. ≤7,000 ML.day⁻¹) and during floodplain inundation (≥60,000 ML.day⁻¹).
• Spatial variation in microbiota community structure (diversity and abundance) between littoral and openwater habitats at a range of flow bands.
• Microbiota community structure (diversity and abundance) in Lake Albert under all flow conditions.
• Changes in microbiota community structure (diversity and abundance) in the lower River Murray main channel under high within-channel flows (i.e. 20,000 and 40,000 ML.day⁻¹) as a result of the inhibition of reproduction due to elevated water velocities.
• Microbiota community structure (diversity and abundance) dynamics as a result of wetland and floodplain ‘flushing’ under flows ≥20,000 ML.day⁻¹.
• Microbiota community structure (diversity and abundance) dynamics in relation to floodplain inundation during winter.

11.3 Vegetation

A total of six knowledge gaps were identified for vegetation. These are presented concurrently for each region and are grouped under the themes of 1) ‘population dynamics and community structure’, 2) ‘distribution’ and 3) ‘condition’.

Population dynamics and community structure

• Recruitment dynamics of ‘amphibious fluctuation tolerator – woody’ group at temporary wetland and floodplain habitats in the ‘lower River Murray channel and floodplain’ and Lower Lakes under high within-channel and overbank flows.
- Recruitment dynamics of ‘amphibious fluctuation tolerator – low growing’, ‘amphibious fluctuation responder – plastic’, ‘emergent’ and ‘submergent r-selected’ groups in temporary wetlands and floodplain habitats following inundation at flows >20,000 ML.day\(^{-1}\).
- Recruitment dynamics of *Ruppia tuberosa* in the Coorong at flows ≥20,000 ML.day\(^{-1}\), in relation to the timing of barrage discharge, mouth openness and Coorong water levels.

**Distribution**


**Condition**

- Condition of ‘amphibious fluctuation tolerator – woody’ trees under large overbank flows (>80,000 ML.day\(^{-1}\)) in the lower River Murray.

### 11.4 Macroinvertebrates

There are many knowledge gaps regarding the response of macroinvertebrates to flow in the River Murray. Although trait groups provide a mechanism for determining specific hypotheses about the mechanisms of change, it is difficult to determine actual responses without empirical data. Nonetheless, two broad knowledge gaps were specifically identified under the theme of ‘trophic dynamics’.

- Food resources that are required by the different macroinvertebrate groups of the lower River Murray.
- How macroinvertebrate populations are influenced by changes in the distribution, abundance and quality of lower trophic levels (e.g. microcrustaceans, macrophytes, biofilms, etc.).

There is little known about the macroinvertebrate food webs which exist within the lower River Murray (Davies *et al.* 2010). This is especially important given it has been established that changes to biofilms, associated with the conversion of the lower River Murray from a lotic environment to a predominantly lentic environment, has favoured introduced snails over native ones and likely reduced macroinvertebrate diversity as a whole (Sheldon and Walker 1997).

A key gap in the trait analysis was the lack of a trait indicating rheophilix for these taxa. Given the response of macroinvertebrate diversity to water velocity observed by Boulton and Lloyd (1991) in floodplain anabranch habitats, it is likely a key to maximising macroinvertebrates. The trait analysis is also limited by taxonomic level of resolution of trait information. Many genera within families are known to exhibit different traits. However, those that exist within the lower River Murray are likely to have fairly similar traits although this remains a knowledge gap to be investigated. Analysis of existing macroinvertebrate data sets in relation to flow may provide more insight into these knowledge gaps.
11.5 Frogs

A total of five key knowledge gaps were identified for frogs of the lower River Murray. These are presented concurrently for each region and are grouped under the theme of ‘population dynamics and community structure’.

- Spawning and recruitment dynamics of all species under low flow conditions (e.g. 3,000–7,000 ML.day\(^{-1}\)).
- Impact of predation on tadpoles of the lower River Murray, particular under low flow conditions (e.g. 3,000–7,000 ML.day\(^{-1}\)).
- Following high flows, the influence of rapid changes in water level and desiccation on egg survival and subsequent recruitment of frogs that anchor eggs to vegetation.
- The influence of increased wetland hydroperiod and floodplain inundation under high flows, on tadpole food resources and subsequent survival and recruitment.
- Influence of flooding on the seasonal breeding frequency (e.g. single vs multiple clutches) of frog species of the lower River Murray.

11.6 Fish

A total of 12 key knowledge gaps were identified for fish of the lower River Murray. These are presented concurrently for each region and are grouped under the themes of 1) population ‘dynamics and community structure’, 2) ‘movement’, 3) ‘habitat use’ and 4) ‘trophic dynamics’.

Population dynamics and community structure

- Recruitment dynamics of ‘Murray cod’ in the ‘lower River Murray channel and floodplain’ and Lower Lakes under flow bands ≥20,000 ML.day\(^{-1}\).
- Recruitment dynamics of ‘freshwater catfish’ in the ‘lower River Murray channel and floodplain’ and Lower Lakes under all flows.
- Spawning and recruitment dynamics of ‘flow-dependent specialists’ in the Lower Lakes under all flow bands.
- Source of newly recruited ‘flow-dependent specialists’ (i.e. local spawning or drift from upstream areas) in the ‘lower River Murray channel and floodplain’ and Lower Lakes, in relation to flow (i.e. magnitude, source, etc.), under flow bands ≥20,000 ML.day\(^{-1}\).
- Spawning and recruitment dynamics of ‘floodplain specialists’ in association with water level variability and floodplain inundation in the ‘lower River Murray channel and floodplain’ and Lower Lakes.
- Flow-related spawning and recruitment dynamics of ‘estuarine dependent’ and ‘marine species’ in the Coorong.
Movement

- The movement of ‘circa-annual spawning nesting species’ (i.e. Murray cod and freshwater catfish) within the Lower Lakes, and between the Lower Lakes and River Murray main channel under all flow bands.
- The movement of ‘flow-dependent specialists’ within the Lower Lakes, and between the Lower Lakes and River Murray main channel under all flow bands.
- The movement (longitudinal and lateral) of ‘foraging generalists’ and ‘floodplain specialists’ under all flow bands within and between the ‘lower River Murray channel and floodplain’, and the Lower Lakes.

Habitat use

- Changes in main channel habitat availability and use by ‘Murray cod’ under flows ≥20,000 ML.day⁻¹.
- Habitat use of young-of-year ‘flow-dependent specialists’ in the ‘lower River Murray channel and floodplain’, during floodplain inundation (>50,000 ML.day⁻¹).

Trophic dynamics

- Variability in the abundance of ‘estuarine dependent’ species in the Coorong as mediated by the influence of freshwater flows on estuarine productivity and trophic dynamics

11.7 Waterbirds

A total of six key knowledge gaps were identified for waterbirds of the lower River Murray. Waterbirds are much more mobile than all other biotic groups investigated in the current project and thus, utilise habitats at an equally large variety of scales. As such patterns and processes may occur over scales far greater than the lower River Murray. Knowledge gaps are thus presented as those relating to the landscape scale (i.e. beyond the lower River Murray) and the site scale (i.e. within the lower River Murray), and are grouped by the themes of 1) ‘population dynamics and community structure’, 2) ‘habitat use’ and 3) ‘trophic dynamics’.

The following knowledge gaps in understanding of the ecology of waterbirds primarily relate to ecological responses that are directly relevant to the River Murray from Wentworth to Wellington. While important knowledge gaps exist in the ecology of waterbirds in the Lower Lakes and Coorong, there is also an extensive body of work that relates to this ecology (e.g. Paton et al. 2009, Rogers and Paton 2009). While no explicit reference is made to the Lower Lakes and Coorong, the majority of important research needs identified apply equally to the Lower Lakes and Coorong as to other parts of the river in SA.
11.7.1 Landscape scale

Population dynamics and community structure

- Understanding population responses of continental nomads to local changes in hydrology requires an understanding of the Australian hydrological context within which these local changes are occurring, and the continental response of these species. Information to support this knowledge gap is being developed for some species (e.g. banded stilt), but needs to be interpreted for lower River Murray management, and developed for other continental nomadic species (e.g. grey teal, Australian pelican).

- Understanding the contribution that lower River Murray recruitment events make to the demography of continental nomads (e.g. in comparison to larger recruitment events in northern catchments). A hypothesis that requires testing is that the key role of the lower River Murray in continental waterbird demography is that it provides maintenance habitats, allowing for the maintenance of adult populations and small-scale recruitment events. However this hypothesis is based primarily on flow and wetland inundation behaviour in the lower River Murray, and not on demographic information of the bird species themselves.

Habitat use

- Improving understanding of site choice (for foraging and/or recruitment) by individual waterbirds, in the context of alternative choices within the regional aquatic landscape. This will provide better predictions of ‘habitat quality’ and the expected response of waterbirds to change at the site scale (as responses to site-scale change are being made in the context of habitat availability at larger scales).

11.7.2 Site scale

Population dynamics

- Site-scale response models, similar to those developed by O’Connor et al. (2012) for the CLLMM, should be developed for key species in the lower River Murray, populated with existing information and identifying levels of uncertainty. This would provide a framework for describing explicit research priorities at this scale for different species.

- Another specific site-scale knowledge gap that has been identified is a better understanding of the low flow breeding requirements of waterbirds in the lower River Murray, and under what flow conditions these requirements are met. This would need to be complemented by an improved understanding of the importance of breeding events in the lower River Murray for continental waterbirds, as outlined above.

Trophic dynamics

- Among general site-scale knowledge gaps, an improvement in the knowledge of prey species for a range of species is required, and how prey choice reflects prey availability (i.e. whether selectivity is being expressed).
12 Conclusion

This report provides a comprehensive summary of contemporary knowledge on the flow-related ecology of the lower River Murray, specifically in regards to nutrients, carbon, biofilms and microbes, microbiota, vegetation, macroinvertebrates, frogs, fish and waterbirds. As such it represents a readily accessible repository of knowledge to support decisions regarding environmental water provision and ultimately, hydrological and ecological restoration in the SA MDB.

We applied a flow band approach, in line with hydrological templates being utilised by agencies charged with the management of environmental water (i.e. the MDBA, CEWO), to describe ecologically important facets of riverine hydrology in the SA MDB. Through the process of developing hydro-ecological conceptual models, we have quantified the rigour of our knowledge and identified key deficiencies in contemporary ecological understanding. These deficiencies form priority hydro-ecological research questions in the SA MDB. In particular there were a large number of knowledge gaps identified under the ecological themes of ‘trophic dynamics’ and ‘population dynamics and community structure’; these general themes require particular attention in relation to environmental water provisions.

In the southern MDB, engineered floodplain inundation by means of floodplain regulators has become a contemporary substitute for hydrological restoration. Nevertheless, ecosystem response to this novel intervention and how this compares to natural flooding remain significant knowledge gaps (Bond et al. 2014, Koehn et al. 2014). The conceptualisation of ecosystem response to engineered floodplain inundation was beyond the scope of this project but should be considered a high priority for future investigation.

The conceptual models and knowledge gaps developed in this project should not be viewed as exhaustive. Indeed as new research becomes available, conceptual models and knowledge gaps will need to be updated. Due to resource constraints, factors not explicitly considered in the development of conceptual models were antecedent conditions (e.g. sequences of flows), interactions between biotic groups or response and impacts of non-native species. These factors may have a large bearing on ecological response to flow and it would be prudent to include these in any future update of the conceptual models.
13 References


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14 Appendix


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</tr>
<tr>
<td>Trachymene cyanopetula</td>
<td>Apiaceae</td>
<td>Floodplain</td>
</tr>
<tr>
<td>Trifolium arvense var. arvense*</td>
<td>Fabaceae</td>
<td>Terrestrial dry</td>
</tr>
<tr>
<td>Trifolium repens*</td>
<td>Fabaceae</td>
<td>Terrestrial dry</td>
</tr>
<tr>
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</tr>
<tr>
<td>Triglochin procerum</td>
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<td>Emergent</td>
</tr>
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<td>Triglochin striatum</td>
<td>Juncaginaceae</td>
<td>Amphibious fluctuation tolerator – emergent</td>
</tr>
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<tr>
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<td>Typhaceae</td>
<td>Emergent</td>
</tr>
<tr>
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<td>Hydrocharitaceae</td>
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<td>Scrophulariaceae</td>
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<td>Vicia sativa*</td>
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<tr>
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<tr>
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<tr>
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<tr>
<td>Vulpia muralis*</td>
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<tr>
<td>Xanthium strumarium agg. **</td>
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<tr>
<td>Zannichellia palustris#</td>
<td>Zannichelliaceae</td>
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Appendix 2: SIMPER analysis of trait states associated with each trait group.

Group A (average similarity = 55.1%)

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<th>Species</th>
<th>Av. Abund</th>
<th>Av. Sim</th>
<th>Sim/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>repro1</td>
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<td>25.1</td>
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Group B (average similarity = 53.6%)

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<th>Sim/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
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</thead>
<tbody>
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Group C (average similarity = 54.5%)

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<th>Sim/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
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<tbody>
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<td>1.8</td>
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<td>7.9</td>
<td>1.2</td>
<td>1.2</td>
<td>52.1</td>
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Group D (average similarity = 69.2%)

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<th>Sim/SD</th>
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<th>Cum.%</th>
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Group E (average similarity = 73.8%)

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<th>Sim/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
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<td>17.1</td>
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Appendix 3: SIMPER analysis of the differences between trait states associate with each macroinvertebrate trait group.

Groups A&B (average dissimilarity = 66.5%)

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<th>Group A Av. Abund</th>
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<th>Av. Diss</th>
<th>Diss/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
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<td>18.3</td>
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<td>40.2</td>
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Groups D&B (average dissimilarity = 76.8%)

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<th>Diss/SD</th>
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Groups D&A (average dissimilarity = 79.8%)

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<th>Diss/SD</th>
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<th>Cum.%</th>
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Appendix 3 continued.

Groups A&C (average dissimilarity = 83.3%)

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Groups E&D (average dissimilarity = 64.5%)

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Groups e&a (average dissimilarity = 66.4%)

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<th>Diss/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
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Groups E&B (average dissimilarity = 71.3%)

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<th>Av. Diss</th>
<th>Diss/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
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The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.