Loddon River Environmental Flows update for the EWMP

NORTH CENTRAL CATCHMENT MANAGEMENT AUTHORITY

Updated Environmental Flows for the Loddon River

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Document history and status

Revision	Date	Description	By	Review	Approved
Draft	17/3/2015	Draft for release to Steering Committee and Community Advisory Group	Andrew Sharpe	Simon Treadwell	Simon Treadwell
Final	9/4/2015	Final version addressing comments from PSC and CAG	Andrew Sharpe	Simon Treadwell	Simon Treadwell

Contents

Executive Summary

Environmental flow requirements for the Loddon River were first determined by the Loddon River Environmental Flows Scientific Panel in 2002 and were updated for the Loddon River downstream of Loddon Weir by SKM in 2009. Severe drought and record floods since those studies have changed the condition and status of some environmental values associated with the Loddon River. Moreover, ongoing monitoring in the Loddon River associated with the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) and other environmental flows research has improved our understanding of flow ecology relationships and environmental flow requirements for rivers such as the Loddon. For these reasons, the existing environmental flow recommendations are out of date. The North Central CMA is currently preparing and Environmental Water Management Plan (EWMP) for the Loddon River. Environmental flow recommendations are a critical input to the EWMP and therefore the NCCMA engaged Jacobs to review and where necessary update the environmental flow recommendations for all reaches of the Loddon River. This report describes the approach used to revise the environmental flow objectives and environmental flow recommendations for the Loddon River.

Approach

Jacobs assembled an Environmental Flows Technical Panel (EFTP) (see Table ES 1) to apply the updated FLOWS method to revise the environmental flow requirements for five reaches of the Loddon River. The EFTP conducted seven tasks to inform the environmental flows review:

- Facilitated workshops with Community Advisory Groups (CAGs) for the Upper Loddon River, Middle Loddon River and Lower Loddon River to discuss and document changes to the Loddon River that community members have observed over their lifetime and to understand the environmental values and objectives that the community associate with the river.
- Attended a two day field inspection of the environmental flows reaches and previous environmental flows assessment sites to assess the current condition of the river.
- Facilitated a FLOWS objectives setting workshop with members of the Project Steering Committee to set environmental flow objectives for each reach of the Loddon River.
- Ran a FLOWS technical workshop to update the environmental flow objectives and environmental flow recommendations for all environmental flow reaches of the Loddon River, Tullaroop Creek and Twelve Mile Creek.
- Prepared a draft report to document the updated environmental flow recommendations.
- Facilitated workshops with CAGs to present the draft environmental flow recommendations and seek feedback.
- Used feedback from the CAG and Project Steering Committee to finalise the environmental flow recommendations and produce a final report (i.e. this report).

Table ES 1: Members of the Environmental Flows Technical Panel.

Name (organisation)	Technical discipline
Dr Andrew Sharpe (Jacobs)	Project leader, macroinvertebrates and water quality
Prof Paul Boon (Dodo Environmental)	Instream and riparian vegetation
Justin O'Connor (Arthur Rylah Institute for Environmental Research).	Fish
Dr Melody Serena (Australian Platypus Conservancy)	Platypus
Dr Peter Sandercock (Jacobs)	Geomorphology
Amanda Woodman (Jacobs)	Hydrologist

Overview of the catchment

The Loddon River Environmental Flows Scientific Panel (2002a) divided the Loddon River catchment into five environmental flow reaches. The current review has retained those reaches, but split Reach 4 (between Loddon Weir and Kerang Weir) into four sub-reaches, one of which is Twelve Mile Creek (see Table ES 2). For the purposes of the EWMP, the NCCMA has divided the Loddon River catchment into three systems (Upper Loddon River, Middle Loddon River and Lower Loddon River) that include one or more of the Loddon River environmental flow reaches as well as reaches in Serpentine Creek and Pyramid Creek. The current review describes environmental condition, current issues and broad objectives for the Upper Loddon River, Middle Loddon River and Lower Loddon River and recommends specific environmental flow requirements for all environmental flow reaches and sub-reaches within each system.

Table ES 2: Environmental flow reaches in the Loddon River system and FLOWS assessment sites within each reach.

Environmental flow reach		FLOWS assessment sites and other selected sites inspected for the current project.
Upper Loddon River system		
Reach 1	Loddon River from Cairn Curran Reservoir to Laanecoorie Reservoir	Loddon River at Baringhup Loddon River at Rumbolds Rd
Reach 2	Tullaroop Creek from Tullaroop Reservoir to Laanecoorie Reservoir	Tullaroop Creek at Carisbrook Tullaroop Creek at Baringhup – Havelock Rd
Reach 3a	Loddon River from Laanecoorie Reservoir to Serpentine Weir	Loddon River at Poseidon Rd Loddon River at Penny Lane
Reach 3b	Loddon River between Serpentine Weir and Loddon Weir	Loddon River downstream of Serpentine Weir
Middle Loddon River system (Note this system also includes reaches in Serpentine Creek)		
Reach 4a	Loddon River between Loddon Weir and Twelve Mile Creek	Borung Hurstwood Rd Floodplain breakout point on Geoff Leamon's property* Twelve Mile Creek regulator #
Reach 4b	Twelve Mile Creek	Twelve Mile Creek downstream of Frost Road
Reach 4c	Loddon River west branch between diffluence of Twelve Mile Creek and confluence with Twelve Mile Creek	'The Chute' and Bennets Rd.
Reach 4d	Loddon River between confluence with Twelve Mile Creek and Kerang Weir	Appin South flow gauge
Lower Loddon River system (Note this system also includes reaches in Pyramid Creek)		
Reach 5	Loddon River between Kerang Weir and Little Murray River	Loddon River 1 km downstream of Kerang Weir

* Site not a FLOWS site from previous study, but was visited because it is one of the first parts of the floodplain to receive water as flows increase in Reach 4a, and there is potential landowner interest in allowing inundation of private floodplain land at certain times of the year.

Site not a FLOWs site from previous studies, but was visited to understand potential flow paths to Twelve Mile Creek and the West Branch of the Loddon River under low flow conditions.

Catchment condition and long-term management goals for the Loddon River

The Loddon River has experienced significant environmental change over the last 100-150 years. River regulation has increased the magnitude of summer low flows in the Upper Loddon River, but significantly reduced the magnitude and frequency of high flows and floods throughout all reaches. Extensive land clearing, uncontrolled stock access and mining activities throughout the catchment have caused local bank erosion and delivered large loads of sediment to the river. The combination of high sediment loads and less frequent high flows to re-work and move that sediment have reduced the diversity and quality of instream and riparian habitat.

Deep pools that were once a feature of the Loddon River and provided important refuge habitat for native fish and Platypus during low flow or cease-to-flow periods have completely or partially filled in, and the streambed has become wider and flatter. These conditions have also allowed emergent plants such as *Typha* and *Phragmites* to grow in the middle of the channel and during prolonged periods of very low flow, such as occurred during the Millennium Drought, those plants formed dense stands across the whole width of the channel.

The numerous dams and weirs that control flow in the Loddon River also prevent fish and Platypus from migrating between reaches to breed or to re-colonise areas where populations have declined. This is a particular concern for species such as Golden Perch and Silver Perch that need to migrate to breed and also to species such as Murray Cod that may not be able to recolonize areas if local populations decline. Community members who have families that have lived on the Loddon River for several generations report that the abundance and diversity of native fish populations in all reaches of the Loddon River has declined markedly over the last 40 or more years. The Millennium Drought had a particularly severe effect on aquatic biota. The Middle Loddon River completely dried during the drought and all fish in that system were lost. The Upper Loddon River didn't completely dry, but the quality and quantity of aquatic habitat and food declined and fish and Platypus populations also suffered. The 2011 floods and the construction of the Kerang Weir fishway have helped native fish return to the Middle Loddon River and Lower Loddon River, but the population sizes are still well below levels that are considered self-sustainable. Native fish and Platypus populations in the Upper Loddon River have not recovered to the same extent and increasing their abundance and diversity is a high priority.

The riparian vegetation in all reaches of the Loddon River has been adversely affected by a lack of high flows and uncontrolled stock access. River Red Gums are the dominant tree in the riparian zone, but in most places the trees are restricted to the banks. Land clearing earlier last century probably removed many of the mature trees beyond the top of the bank and the lack of regular floods that are needed for recruitment and uncontrolled grazing by livestock that eat any seedlings have prevented much regeneration in the riparian zone. Regular overbank flows are particularly important in the Middle Loddon River, which would have naturally supported extensive River Red Gum woodlands and floodplain wetlands.

The long-term management goals for the Loddon River focus on promoting widespread and diverse native fish communities, increasing the size of breeding Platypus populations and rehabilitating riparian River Red Gum communities. The EFTP in consultation with the Community Advisory Group and Project Steering Committee developed the following primary flow objectives to help achieve the long-term management goals for the Loddon River:

- Increase the population size (with appropriate age structure) of small-bodied native fish species with opportunistic life history strategies including Flathead Gudgeon, Carp Gudgeon, Australian Smelt and Murray-Darling Rainbowfish (applies to all reaches)
- Increase the population size (with appropriate age structure) and distribution of River Blackfish in Tullaroop Creek and enable River Blackfish to re-colonise the Loddon River between Cairn Curran Reservoir and Laanecoorie Reservoir and become self-sustaining over time (applies to Reaches 1 and 2)
- Enhance natural recruitment of stocked Murray Cod populations in Laanecoorie Reservoir, Serpentine Weirpool, Loddon Weirpool, Bridgewater Weirpool and large natural pools between Laanecoorie Reservoir and Serpentine Creek (applies to Reaches 1, 2 and 3).
- Enhance natural recruitment of stocked Murray Cod population in Kerang Weirpool and allow fish to disperse from those areas to colonise suitable habitats upstream and downstream of Canary Island (applies to Reaches 4 and 5)
- Increase abundance (with appropriate age structure) of Golden Perch, Silver Perch, Bony Herring and Unspecked Hardyhead in reaches upstream and downstream of Canary Island and in the Lower Loddon River and provide opportunities for fish to move through Twelve Mile Creek and the West Branch of the Loddon River at critical times (applies to Reaches 4 and 5)
- Provide conditions that will allow all native fish to move through the Lower Loddon River during key periods to access habitat upstream of Kow Swamp, in the Loddon River upstream of Kerang and further downstream in the Little Murray and Murray River (applies to Reach 5).

- Maintain adult riparian woody vegetation (e.g. River Red Gum, *Callistemon, Leptospermum, Melaleuca* and *Lignum* – species composition will vary between reaches) and facilitate recruitment adjacent to the river channel and in low lying floodplain areas that are watered via floodrunners. (applies to all reaches)
- Maintain floodplain vegetation communities that are connected to the river via floodrunners. These communities are characterized by a River Red Gum overstorey and grassy, sedge or Lignum understorey (applies to Reach 4).
- Increase size of resident breeding populations of Platypus in the Upper Loddon River, Kerang Weirpool and Lower Loddon River to increase their resilience to future drought and floods and to provide surplus juveniles that can colonise other reaches of the Loddon River and connected catchments. Should be achieved by facilitating successful recruitment at least every second year and promoting safe dispersal by juveniles in autumn or early winter (applies to Reaches 1, 2, 3 and 5).
- Maintain a corridor for successful dispersal by juvenile Platypus (applies to all reaches).

Secondary flow objectives were developed to address ecological processes and values that are needed to support the primary objectives.

Environmental flow recommendations

The environmental flows that are required to meet the primary and secondary objectives for each reach of the Loddon River are summarized in Table ES 3 to Table ES 5.

Table ES 3: Summary of environmental flow recommendations for the Upper Loddon River. The flow magnitudes presented for Reach 3a take into account the flow requirements for Reach 3b and Reach 1 of the Serpentine Creek and exceed the minimum flow requirements for Reach 3a. The minimum flow requirements for Reach 3a are shown in brackets.

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency
Cease to flow		NA	NA	NA	NA		
Summer low flow	Wet-average	20-35	10-15	25-35 (20-35)	10-15	Dec-May	
	Dry	10	5	15	5		
Summer fresh	Wet-average	50-80	40	70-100 (50-100)	50-60	1-2 days @ peak 2-3 days @ peak	1 Dec-Feb 2 Mar-May
	Dry	35	30	50-70 (30)	30		
Winter low flow	Wet-average	50-80	30-40	70-100 (50-80)	40-50	Jun-Nov	
	Dry	35	20	50 (30)	30		
Winter fresh	Wet-average	400-700	200-400	900	450-900	1-2 days @ peak 4-5 days @ peak (2-3 week total)	1 Jul-Aug 1 Sep-Oct (2 out of 5 years)
	Dry	NA	NA	NA	NA		
Winter high flow	Any	500-1000	1000	1500-2000	1500-2000	10 days @ peak	2 consecutive events per decade in Sep-Nov
Bankfull	Any	4000	3000	7300	13000	1-2 days @ peak	Natural spills

Table ES 4: Summary of environmental flow recommendations for the Middle Loddon River

Flow component	Wet / Dry	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency
Cease to flow		NA	NA	NA	NA		

Flow component	Wet / Dry	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency
Summer low flow	Wet-average	50	25	25	30	Dec-May	
	Dry	25	20	5	10-15		
Summer fresh	Wet-average	50-100	25-60	25-40	30-75	3-4 days @ peak	1 Dec-Feb 1-2 Mar-May
	Dry	Lower end of range					
Autumn high flow	Wet-average	400	~200	~200	~400	6 days @ peak 3 weeks total	1 Apr-May
	Dry	NA	NA	NA	NA		
Winter low flow	Wet-average	50-100	25-60	25-40	30-75	Jun-Nov	
	Dry	Lower end of range					
Winter high flow	Wet-average	450-750	~200-375	~200-375	~450-750	7-10 days @ peak 2-3 weeks total	1 mid Sep-late Oct
	Dry	NA	NA	NA	NA		

Table ES 5: Summary of environmental flow recommendations for the Lower Loddon River

Flow component	Wet / Dry	Reach 5	Duration	Frequency
Cease to flow		NA		
Summer low flow	Wet-average	60-100	Dec-May	
	Dry	Lower end of range		
Summer fresh	Wet-average	220	2-3 days @ peak 1 week total	1 Dec-Feb 1-2 Mar-May
Autumn high flow	Wet-average	900	10 days @ peak 3 weeks total	1 Mar-Apr Not more than 2 consecutive years without
	Dry	NA		
Winter low flow	All years	200-220	Jun-Nov	
	Operational flows	60	June-Aug	
Winter fresh	Wet-average	900	7-10 days @ peak 2-3 weeks total	1 mid Sep-late Oct Not more than 2 consecutive years without
	Dry	NA		
Bankfull	All	2000	3-4 days @ peak	3-4 per decade

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to review the environmental flow recommendations for the Loddon River in accordance with the scope of services set out in the contract between Jacobs and the North Central CMA. That scope of services, as described in this report, was developed with the North Central CMA.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the North Central CMA and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the North Central CMA and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

Jacobs has relied on existing hydraulic and hydrologic models for the Loddon River. We have improved the calibration of hydraulic models where possible, but some models still have a high degree of error and therefore monitoring during flow releases may be needed to refine some of the environmental flow recommendations. The hydrology of the Loddon River is covered by three separate models. The models that cover the Middle and Lower Loddon River are not reliable for estimating natural low flow conditions, hence there is still uncertainty about the exact nature of the natural flow regime in those reaches. The model used for the Lower Loddon River does not have a natural scenario. Information for the groundwater-surface water interaction assessment was sourced from available reports that analysed data from a particular point in time. Detailed analysis of groundwater bore data was beyond the scope of the current project.

This report has been prepared on behalf of, and for the exclusive use of the North Central CMA and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the North Central CMA. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party

1. Introduction

The North Central Catchment Management Authority is currently preparing an Environmental Water Management Plan (EWMP) for the Loddon River catchment downstream of Cairn Curran Reservoir, and including Tullaroop Creek downstream of Tullaroop Reservoir, Serpentine Creek, Twelve Mile Creek and Pyramid Creek. The EWMP will guide environmental water use in the catchment over the next ten years and has the following specific purposes:

- To identify the long-term environmental flow objectives and water requirements for the river;
- To provide a vehicle for community consultation, including for the long-term objectives and water requirements of the river;
- To inform the development of seasonal watering proposals and seasonal watering plans; and
- To inform long-term watering plans that will be developed by the State as required under Murray-Darling Basin Authorities' Basin Plan.

Environmental flow assessments are a crucial input to EWMPs. The Loddon River Environmental Flows Scientific Panel (2002a), 2002b) used the Flow Events Method to set environmental flow requirements for the Loddon River from Cairn Curran Reservoir to Kerang and Tullaroop Creek from Tullaroop Reservoir to Laanecoorie Reservoir. SKM (2010c), b) used the FLOWS method (DNRE, 2002) to update the environmental flow recommendations for the Loddon River from Loddon Weir to the confluence with the Murray River and develop new recommendations for Twelve Mile Creek. Both of those studies are out of date. The 2002 study used an old assessment method and was conducted at a time when there was relatively little understanding of the specific flow requirements for many environmental values. The 2010 recommendations were significantly influenced by the Millennium Drought, which caused much of the Middle and Lower Loddon River to completely dry and severely restricted the amount of environmental water that could be used in the Loddon River. Record floods in 2010/11 effectively re-set the Loddon River system. The floods removed much of the vegetation that had colonised the bottom of the river channel during the drought, re-established aquatic habitats and provided conditions that allowed fish and other biota to disperse and recolonise all reaches of the Loddon River. The floods also filled all of the storages within the catchment, which means that environmental water allocations for the Loddon River have been at 100% of high reliability entitlements for the last three years.

Quantitative monitoring associated with programs such as the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP), complemented by qualitative observations by community members, NCCMA staff, Goulburn-Murray Water staff and other agency staff over the last decade have significantly improved understanding of how the Loddon River responds to wet and dry conditions and specific environmental flow releases. Other scientific studies throughout the Murray-Darling Basin throughout that period have also increased knowledge of the flow requirements for many of the native fish, vegetation, and other environmental values associated with the Loddon River. The NCCMA needs updated environmental flow recommendations for the Loddon River that incorporate this new knowledge and that are compatible with the environmental flow recommendations for Serpentine Creek and Pyramid Creek that were developed in 2014 (Jacobs, 2014c, b).

The NCCMA engaged Jacobs to assemble an Environmental Flows Technical Panel (EFTP) to use the updated FLOWS method to review and where necessary update the environmental flow recommendations for the Loddon River between Cairn Curran Reservoir and the Murray River, Tullaroop Creek from Tullaroop Reservoir to Laanecoorie Reservoir and Twelve Mile Creek. The EFTP includes specialists in river ecology, geomorphology and hydrology who all have considerable experience in the Loddon River catchment (see Table 1-1).

Table 1-1: Environmental Flows Technical Panel members involved in the 2015 review

Environmental Flows Technical Panel Member	Technical discipline	Relevant experience in the Loddon River
Dr Andrew Sharpe (Jacobs)	Project leader, macroinvertebrates and water quality	• Managed 2009 Lower Loddon River FLOWS study • EFTP member for Serpentine and Pyramid Creek FLOWS studies in 2014. • Designed VEFMAP for the Loddon River • Implemented and analysed VEFMAP fish surveys in the Loddon River • Developed actions to manage blackwater in the Loddon River.
Prof Paul Boon (Dodo Environmental)	Instream and riparian vegetation	• EFTP member for 2009 Lower Loddon River FLOWS study • EFTP member for Serpentine and Pyramid Creek FLOWS studies in 2014.
Justin O'Connor (Arthur Rylah Institute for Environmental Research).	Fish	• EFTP member for Serpentine and Pyramid Creek FLOWS studies in 2014. • Investigated fish movement at Kerang Weir and fish flow requirements for the lower Loddon River.
Dr Melody Serena (Australian Platypus Conservancy)	Platypus	• EFTP member for Serpentine and Pyramid Creek FLOWS studies in 2014. • Produced various reports for the NCCMA documenting the distribution and status of Platypus populations in the North Central CMA region.
Dr Peter Sandercock (Jacobs)	Geomorphology	• EFTP member for 2009 Lower Loddon River FLOWS study • Managed Serpentine and Pyramid Creek FLOWS studies in 2014. • Conducted VEFMAP geomorphology assessments for the Loddon River in 2013.
Amanda Woodman (Jacobs)	Hydrologist	• EFTP member for Serpentine and Pyramid Creek FLOWS studies in 2014. • Conducted VEFMAP geomorphology assessments for the Loddon River in 2013.

1.1 Approach

The EFTP conducted seven tasks to inform the environmental flows review:

- Andrew Sharpe, Louissa Rogers (NCCMA), Phil Slessar (NCCMA) and Brad Drust (NCCMA) facilitated workshops with community advisory groups in the Upper Loddon catchment (Newbridge) and Middle Loddon catchment (Durham Ox)on the 28th January 2015; and Andrew Sharpe and Louissa Rogers facilitated a workshop with the community advisory group for the Lower Loddon catchment (Kerang) on the 29th January 2015 to discuss and document changes to the Loddon River that community members have observed over their lifetime and to understand the environmental values and objectives that the community associate with the river.
- All members of the EFTP (except Amanda Woodman) and Louissa Rogers and Phil Slessar from the NCCMA visited the FLOWS assessment sites that were used during the 2002 and 2009 environmental flow assessments as well as some additional sites identified by the NCCMA to inspect the current condition of the river. The site visits were conducted on 2nd and 3rd February 2015. During the site visits, the EFTP compared site photographs and site descriptions from previous studies against current observations to evaluate physical changes at each site over the last 5-10 years. They also discussed the existing environmental flow objectives for each reach and the information provided by community members at the community workshops.

- All members of the EFTP (except Amanda Woodman and Peter Sandercock) attended a workshop with the Project Steering Committee (comprising NCCMA staff, GMW staff, Victorian Environmental Water Holder (VEWH) Staff and DELWP regional office staff) to set environmental flow objectives for each environmental flow reach. The workshop was held at the NCCMA office in Huntly on 4th and 5th February and was facilitated by Andrew Sharpe. After the workshop Andrew Sharpe prepared three separate reports that described the main environmental flow issues and the agreed environmental flow objectives for the Upper Loddon, Middle Loddon and Lower Loddon River systems. Those reports were distributed to project steering committee members and community members who attended the community workshops, their comments were incorporated into final versions of the objectives reports.
- All members of the EFTP (except Peter Sandercock), Louissa Rogers and Phil Slessar from the NCCMA, Andrew Shields from GMW, Caitlin Davis and Mark Toomey from the VEWH, and Andrea Keleher from DELWP participated in a two day workshop on 26-27th February 2015 to update the environmental flow objectives and environmental flow recommendations for all environmental flow reaches of the Loddon River, Tullaroop Creek and Twelve Mile Creek. Peter Sandercock was unable to attend the workshop, but provided written input in advance. Andrew Sharpe facilitated the workshop and recorded the agreed outcomes.
- All members of the EFTP prepared a draft report to document the outcome of the workshop and present the revised environmental flow recommendations for the Loddon River, Tullaroop Creek and Twelve Mile Creek.
- Andrew Sharpe and Louissa Rogers met with community members in the Upper Loddon, Middle Loddon and Lower Loddon catchment to present the draft revised environmental flow recommendations.
- Andrew Sharpe in consultation with other members of the EFTP, used feedback from the Community Advisory Groups and Project Steering Committee to finalise the environmental flow recommendations for each reach of the Loddon River and produce the final recommendations report (i.e. this report).

A fuller description of the community consultation process implemented through this project and specific input provided by the Community Advisory Group is presented in Appendix A.

1.2 The report

This report presents the updated environmental flow objectives and environmental flow recommendations for the environmental flow reaches of the Loddon River between Cairn Curran Reservoir and the Murray River, Tullaroop Creek between Tullaroop Reservoir and Laanecoorie Reservoir and Twelve Mile Creek. Chapter 2 of this report describes the environmental flow reaches and the sites visited in each reach. Chapter 3 discusses groundwater and surface water interactions throughout the catchment. Chapter 4 describes the current condition, trajectory and threats to environmental values in the catchment. Chapter 5 presents conceptual models that describe the water requirements for each of the environmental values. Chapter 6 presents the environmental flow objectives for each value. Chapter 7 describes the revised environmental flow recommendations for each reach. Chapter 8 describes the threats to meeting the environmental flow objectives and potential complementary actions that may mitigate those threats. Chapter 9 describes monitoring requirements to evaluate the success of future environmental flow releases.

The report does not include all of the information that would normally be included in an Environmental FLOWS report and should be read as an addendum to the reports produced during the 2002 and 2009 FLOWS studies (Loddon River Environmental Flows Scientific Panel, 2002a, 2002b, SKM, 2010c, b).

2. Description of environmental flow reaches and FLOWS assessment sites

For the purposes of the EWMP, the Loddon River catchment will be divided into three systems, with each system containing several environmental flow reaches (see Table 2-1 and Figure 2-1). This report describes values, environmental flow objectives and presents revised environmental flow recommendations for the reaches in the main stem of the Loddon River between Cairn Curran Reservoir and the Little Murray River, Tullaroop Creek and Twelve Mile Creek. Environmental flow requirements for Serpentine Creek and Pyramid Creek were determined through a separate project in 2014; those recommendations are still current and therefore those reaches were not inspected as part of this project.

The Reach names and numbers presented in Table 2-1 are used throughout the rest of this report.

Table 2-1: Environmental flow reaches in the Loddon River system and FLOWS assessment sites within each reach. Reaches shaded in blue were considered and visited during the current project. Reaches for Serpentine Creek and Pyramid Creek are included in the table for completeness, but the environmental flow recommendations for those reaches were determined through a separate project in 2014.

Environmental flow reach		FLOWS assessment sites and other selected sites inspected for the current project.
Upper Loddon River system		
Loddon River reaches		
Reach 1	Loddon River from Cairn Curran Reservoir to Laanecoorie Reservoir	Loddon River at Baringhup Loddon River at Rumbolds Rd
Reach 2	Tullaroop Creek from Tullaroop Reservoir to Laanecoorie Reservoir	Tullaroop Creek at Carisbrook Tullaroop Creek at Baringhup – Havelock Rd
Reach 3a	Loddon River from Laanecoorie Reservoir to Serpentine Weir	Loddon River at Poseidon Rd Loddon River at Penny Lane
Reach 3b	Loddon River between Serpentine Weir and Loddon Weir	Loddon River downstream of Serpentine Weir
Middle Loddon River system		
Loddon River Reaches		
Reach 4a	Loddon River between Loddon Weir and Twelve Mile Creek	Borung Hurstwood Rd Floodplain breakout point on Geoff Leamon's property* Twelve Mile Creek regulator #
Reach 4b	Twelve Mile Creek	Twelve Mile Creek downstream of Frost Road
Reach 4c	Loddon River west branch between diffluence of Twelve Mile Creek and confluence with Twelve Mile Creek	'The Chute' and Bennets Rd.
Reach 4d	Loddon River between confluence with Twelve Mile Creek and Kerang Weir	Appin South flow gauge
Serpentine Creek reaches		
Serpentine Reach 1	Serpentine Creek between Serpentine Weir and Waranga Western Channel	Assessed in 2014
Serpentine Reach 2	Serpentine Creek between Waranga Western Channel and No. 2 Weir	Assessed in 2014
Serpentine Reach 3	Serpentine Creek between No. 2 Weir and outfall from Irrigation Channel 7/10/1 (i.e. upstream Durham Ox Rd)	Assessed in 2014

Environmental flow reach		FLOWS assessment sites and other selected sites inspected for the current project.
Serpentine Reach 4	Serpentine Creek between Irrigation Channel 7/10/1 and No. 12 Channel	Assessed in 2014
Serpentine Reach 5	Nine Mile Creek (regulator to Red Gum Forest)	Assessed in 2014
Serpentine Reach 6	Pennyroyal Creek (Channel No. 12 outfall to downstream of Hopefield Rd.	Assessed in 2014
Lower Loddon River system		
Loddon River reaches		
Reach 5	Loddon River between Kerang Weir and Little Murray River	Loddon River 1 km downstream of Kerang Weir
Pyramid Creek reaches		
Pyramid Reach 1	Pyramid Creek between Box Creek Regulator and Hird Swamp	Assessed in 2014
Pyramid Reach 2	Pyramid Creek between Hird Swamp and Kerang Weirpool.	Assessed in 2014

* Site not a FLOWS site from previous study, but was visited because it is one of the first parts of the floodplain to receive water as flows increase in Reach 4a, and there is potential landowner interest in allowing inundation of private floodplain land at certain times of the year.

[#] Site not a FLOWs site from previous studies, but was visited to understand potential flow paths to Twelve Mile Creek and the West Branch of the Loddon River under low flow conditions.

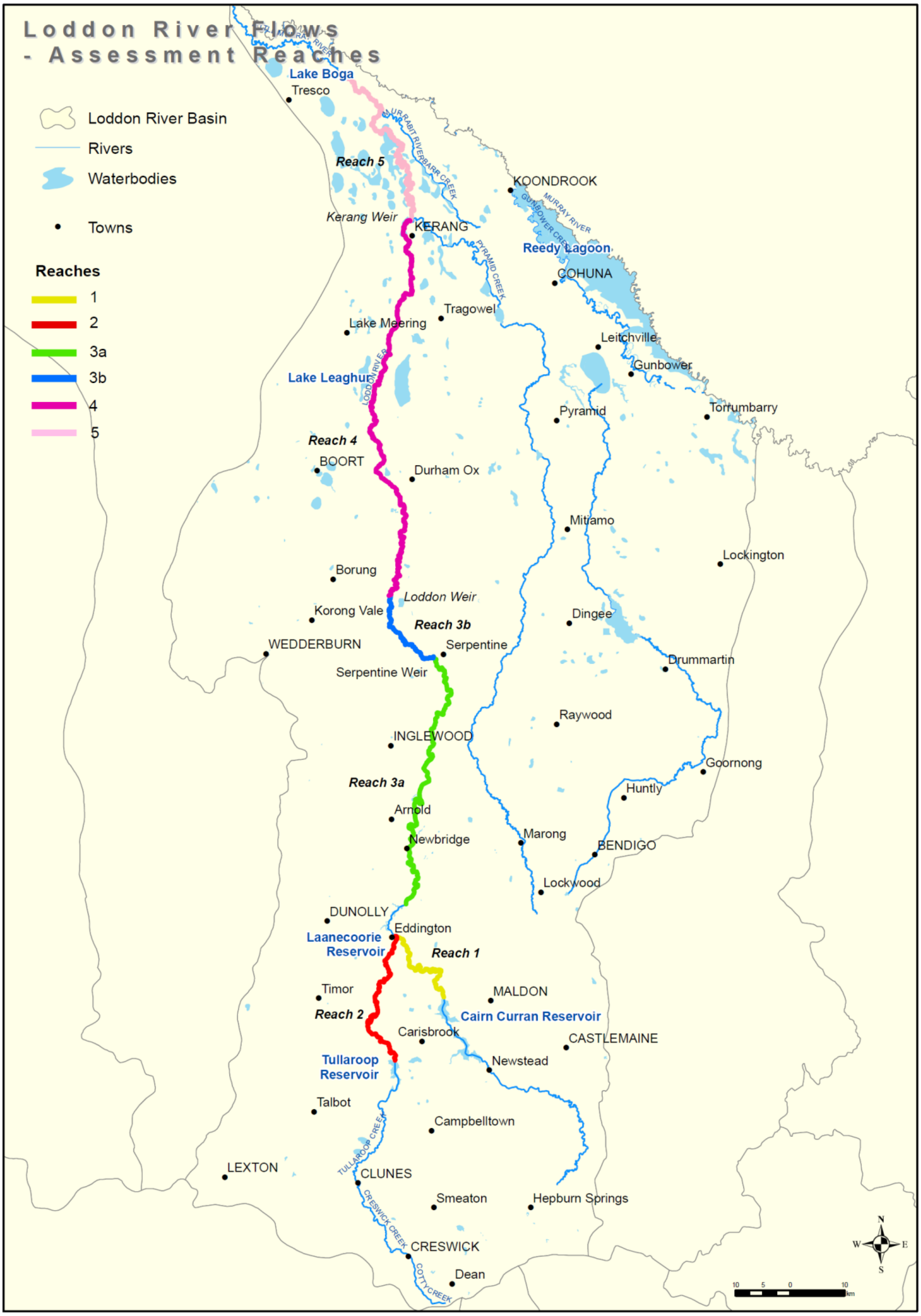

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Figure 2-1: Map of the Loddon River catchment showing environmental flow reaches.

2.1 Catchment overview of the Upper Loddon River

The Upper Loddon River has three reaches (see Figure 2-2). The first reach flows from Cairn Curran Reservoir to Laanecoorie Reservoir, the second reach is the section of Tullaroop Creek that flows from Tullaroop Reservoir to Laanecoorie Reservoir, and the third reach is the section of the Loddon River that flows from Laanecoorie Reservoir to Loddon Weir. The Loddon River Environmental Flows Scientific Panel (2002a) divided Reach 3 into two sub-reaches upstream and downstream of Serpentine Weir and that division has been retained for the current project.

The upstream section of Reach 1 near Baringhup has a gravel bed (see Figure 2-3), which distinguishes it from other parts of the Loddon River, and some distinct riffle and run habitats, and distinct low channel benches. The gravel, rather than sand bed is possibly due to Cairn Curran impeding the downstream supply of finer bed material. Further downstream, near Rumbold’s Road the substrate is predominantly sand and the water is more turbid.

Tullaroop Creek was historically characterised by numerous deep pools that provided habitat for a diverse fish community. Land clearing within the adjacent catchment and mining activities in tributary catchments have delivered large sand slugs to the river, which have filled many of the deep pools, particularly near Carisbrook over the last 20-30 years. Bank erosion over the same period has caused some sections of Tullaroop Creek to become much wider and flatter. Local community members reported that the 2011 floods move some of the sand downstream from Carisbrook and partially scoured some of the pools that had filled during the Millennium Drought. The FLOWS assessment site at Baringhup-Havelock Road has retained much of its natural complexity including large anabranches and flood runners (see Figure 2-3).

The Loddon River between Laanecoorie Reservoir and Serpentine Weir has a deep channel with very high banks in places, multiple levels of bars and benches and a mix of run and pool habitats (see Figure 2-3). Some of the pools are large and deep and support large Murray Cod, other large bodied fish and Platypus. Artificial weirpools at Breidgewater and Newbridge support recreational activities and provide permanent habitat for large-bodied fish, although the structure at Bridgewater is likely to be a barrier to fish movement.

The Upper Loddon River is used to carry irrigation water from Cairn Curran Reservoir and Tullaroop Reservoir to downstream customers. Flow in all three reaches of the Upper Loddon River are higher than natural during the irrigation season (i.e. 15 August to 15 May) and much lower than natural during winter. That seasonal flow reversal combined with cold water releases from Cairn Curran and Tullaroop Reservoir have potentially negative effects on many ecological values in the system. Native fish communities in all three reaches are isolated from each other by large dams, and more importantly are isolated from populations in the Middle and Lower Loddon River and the Murray River.

The main environmental objectives for the Upper Loddon River are to improve native River Blackfish populations in Tullaroop Creek and possibly the Loddon River upstream of Laanecoorie Reservoir, improve the extent and condition of the riparian zone and increase the size of the breeding Platypus population, which declined significantly during the drought.

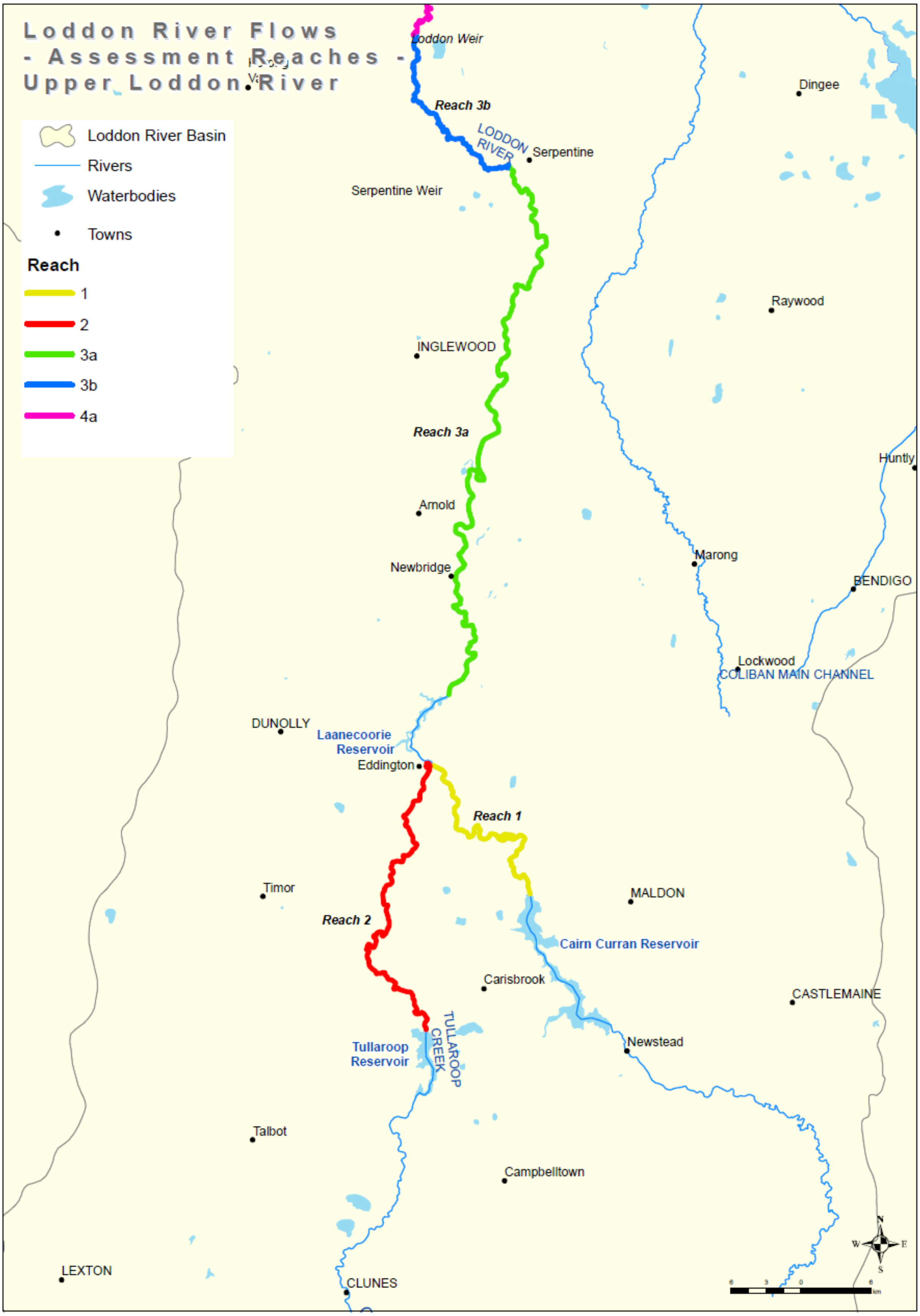

Figure 2-2: Map of Upper Loddon River showing environmental flow reaches.

Figure 2-3: FLOWS assessment sites. Top left – Loddon River at Baringhup (Reach 1). Top Right – Loddon River at Rumbold's Road (Reach 1). Middle left – Tullaroop Creek at Carisbrook (Reach 2). Middle Right – Tullaroop Creek at Baringhup-Havelock Road (Reach 2). Bottom left – Loddon River at Poseidon Rd (Reach 3a). Bottom right – Loddon River at Penny Lane (Reach 3a).

2.2 Catchment overview middle Loddon River

The Middle Loddon River extends from Loddon Weir to Kerang Weir and includes Twelve Mile Creek. For the purposes of this FLOWS assessment we have separated the Middle Loddon River into four sub-reaches (see Figure 2-4). Reach 4a extends from Loddon Weir to the start of Twelve Mile Creek. Reach 4b is Twelve Mile Creek. Reach 4c is the Loddon River that flows along the west side of Canary Island. Reach 4d extends from the point where Twelve Mile Creek re-joins to the Loddon River to Kerang Weir.

The Middle Loddon River flows across the Loddon Plains and has a much lower gradient than the Upper Loddon River. Numerous small and large distributary channels flow from the Loddon River in the section between Loddon Weir and Canary Island and as a result the capacity of the channel and height of the river banks significantly decreases over that distance (see Figure 2-5). Flows that only fill the bottom portion of the channel near Loddon Weir and Serpentine Weir break out of the channel and onto the floodplain near the Twelve Mile Creek offtake and on either side of Canary Island. The largest natural distributary channels are Serpentine Creek, Veniables Creek and Twelve Mile Creek; although Twelve Mile Creek has a lower bed level than the West Branch of the Loddon River and is likely to be the main flow path rather than a distributary channel. The downstream end of Twelve Mile Creek splits further into a series of smaller channels and flood runners. Other channels have been cut to carry flow from the Loddon River to Kinypanial Creek and Wandella Creek. Downstream of Canary Island, Twelve Mile Creek and other channels that drain the floodplain re-join the main Loddon River channel and the channel capacity through that downstream reach increases.

Accounts from community members who have lived in the area for a long time, and journal records from the region's early explorers indicate that the middle Loddon River had moderate floods in most winters and stopped flowing in most summers. Much of the channel manipulation works in the region aimed to divert and store water in off channel wetlands such as Lake Boort during winter so that landowners would have access to water during summer.

During cease-to-flow periods, the middle Loddon River would contract to a series of deep pools that were spaced up to 10 km apart. Those pools held water over summer and would have provided refuge habitats for fish, macroinvertebrates, Water rats, turtles and possibly Platypus. Regular floods would have helped scour and move sediment in the river channel and maintain the dimensions of refuge pools. A combination of river regulation that has reduced the frequency of floods and land clearing that has delivered more sediment to the river has likely caused most of the deep pools in the system to fill in over the last 50-70 years. This is a critical change because it reduces the quality and quantity of refuge habitat for aquatic biota during low flow or cease-to-flow periods, and therefore limits the type of values that can persist in the system. Under very low flow conditions now, the West Branch of the Loddon River and the channel in Twelve Mile Creek will be very shallow and probably have little habitat that can support large-bodied fish, Water rats or some small-bodied fish and some macroinvertebrates. The sections of the Loddon River upstream and downstream of Canary Island that do have a larger capacity are likely to have some deeper pools and therefore those reaches will be the main refuge habitat for aquatic biota during very low flow or cease-to-flow periods.

The main environmental flow objectives for the Middle reaches of the Loddon River therefore aim to maintain permanent populations of a wide range of flora and fauna in the reaches upstream of Canary Island and downstream of Canary Island and maintain habitat that will allow biota to move through Twelve Mile Creek and the West Branch of the Loddon River for most of the year when there is adequate flow. The specific objectives for different values are described in the following section.

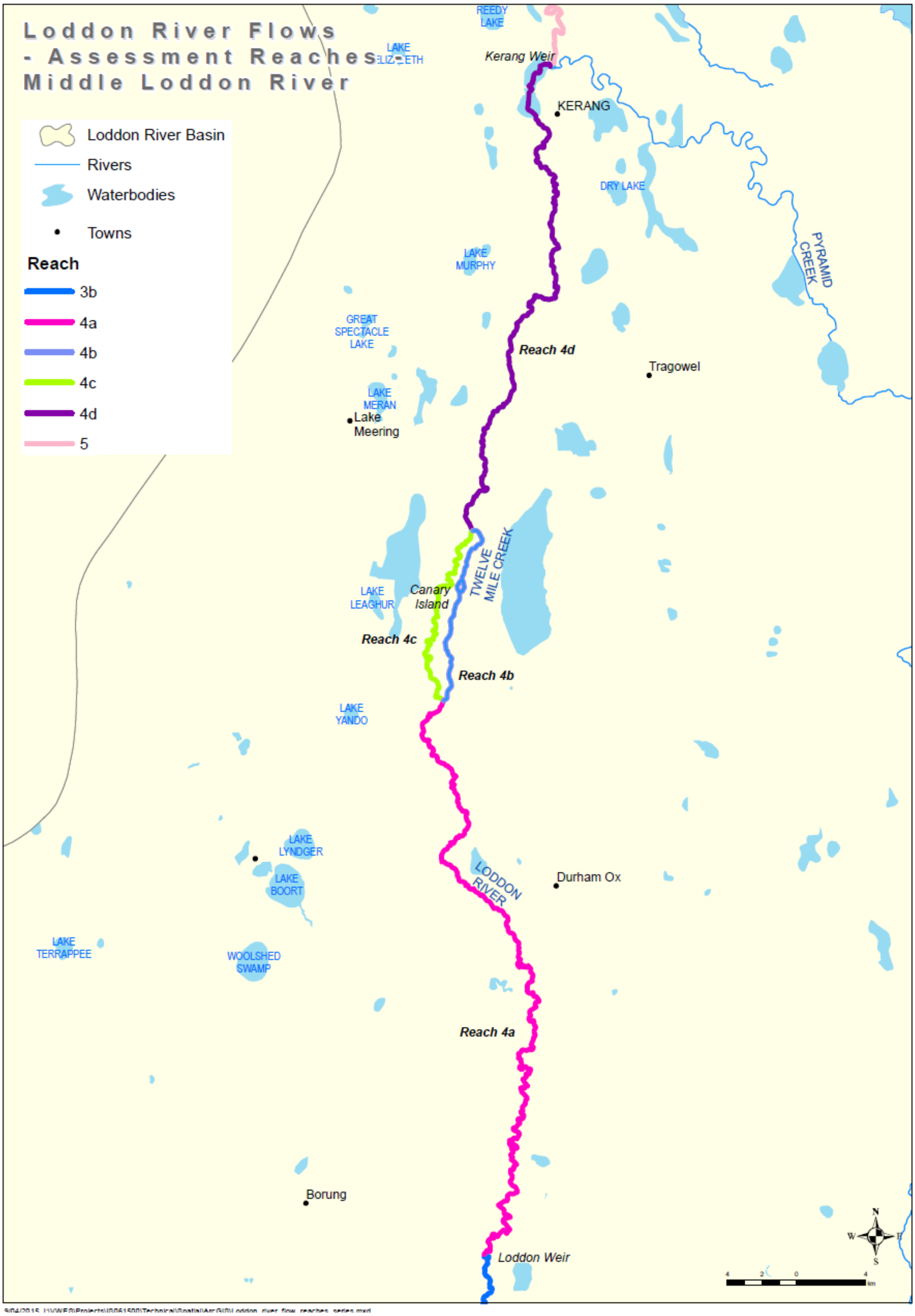

Figure 2-4: Map of the Middle Loddon River showing environmental flow reaches.

Figure 2-5: Photos showing reduction in channel size throughout the Middle Loddon River and then increase downstream of Canary Island. Top left photo at Borung Hurstwood Rd (ds Loddon Weir), top right photo at Twelve Mile Creek, bottom left photo at Loddon West Branch near the 'Chute', bottom right photo at Appin South

2.3 Catchment overview Lower Loddon River

The Lower Loddon River extends from Kerang Weir to the Little Murray River (see Figure 2-6). The Loddon River downstream of Kerang would have probably been an ephemeral chain of ponds system and the main flow path would have been what is now known as Sheepwash Creek. The construction and operation of the Kerang Weirpool combined with the dredging of Pyramid Creek and its use as an irrigation supply channel that flows into the Kerang Weirpool have increased the volume of water in the Lower Loddon River system in summer. That water is directed down what is now known as the Lower Loddon River, which flows from Kerang Weir to Murray River. Flow in the upstream half of the reach (i.e. between Kerang Weir and Benjeroop, downstream of the confluence with Barr Creek) is determined by inflows from the Middle Loddon River and Pyramid Creek. Flow and water levels in the downstream section of the Lower Loddon River are influenced partly by inflows at Kerang and partly by flow in the Murray River, which can back up as far as Benjeroop. Barr Creek used to deliver large salt loads to the lower Loddon River and the Murray River, but the Barr Creek Drainage Disposal Scheme diverts all flow from Barr Creek to Lake Tutchewop during low flow periods to collect salt and prevent it entering the Loddon and Murray Rivers.

The channel would have naturally been characterised by deep pools that would have provided habitat for fish, Platypus and other biota. Land clearing and uncontrolled stock access in parts of the reach and further upstream, as well as the channelizing and operation of Pyramid Creek as an irrigation channel have delivered large sediment loads to the lower Loddon River. That sediment, combined with a regulated flow regime has filled or partially filled many pools in the channel and also created sediment bars that have been colonised by dense stands of Phragmites and Typha. Local landowners reported that the streambed was covered in a layer of soft sediment during the Millennium Drought. They also reported that the riverbed felt much firmer since the 2011 floods, which suggests that the floods flushed much unconsolidated sediment through the system, but it is unlikely that the water velocities and shear forces generated during the flood were sufficient to scour new deep pools throughout the reach. The floods did drown much of the emergent vegetation that had grown in the middle of the channel during the drought (see Figure 2-7).

Journal records from the first European explorers in the region describe a floodplain and riparian zone that was dominated by Black Box and Lignum, which suggests that the floodplain would not have flooded as often as the Middle Loddon River. Levee banks have been constructed along much of the Lower Loddon River, which isolate the river from its floodplain and a narrow band of River Red Gum grows along the banks of the river. It is likely that those River Red Gum have established and are maintained by the regulated flow regime, which has more permanent flow, but fewer floods than the natural flow regime. Most of the trees are less than 100 years old and are not rapidly replacing the large stands of submerged wood that were actively removed from the lower Loddon River in the 1970s with the aim of reducing flood risk. The river therefore has a limited amount of substrate for biofilm growth and to provide habitat for macroinvertebrates, fish and Platypus.

The Lower Loddon River downstream of Kerang is particularly important for native fish. It would have naturally supported a diverse community of small-bodied and large-bodied native fish and is a critical reach of the Native Fish Recovery Plan that aims to remove barriers and provide flows that will allow native fish to move throughout the Murray River, Lower Loddon River, Pyramid Creek and Gunbower Creek.

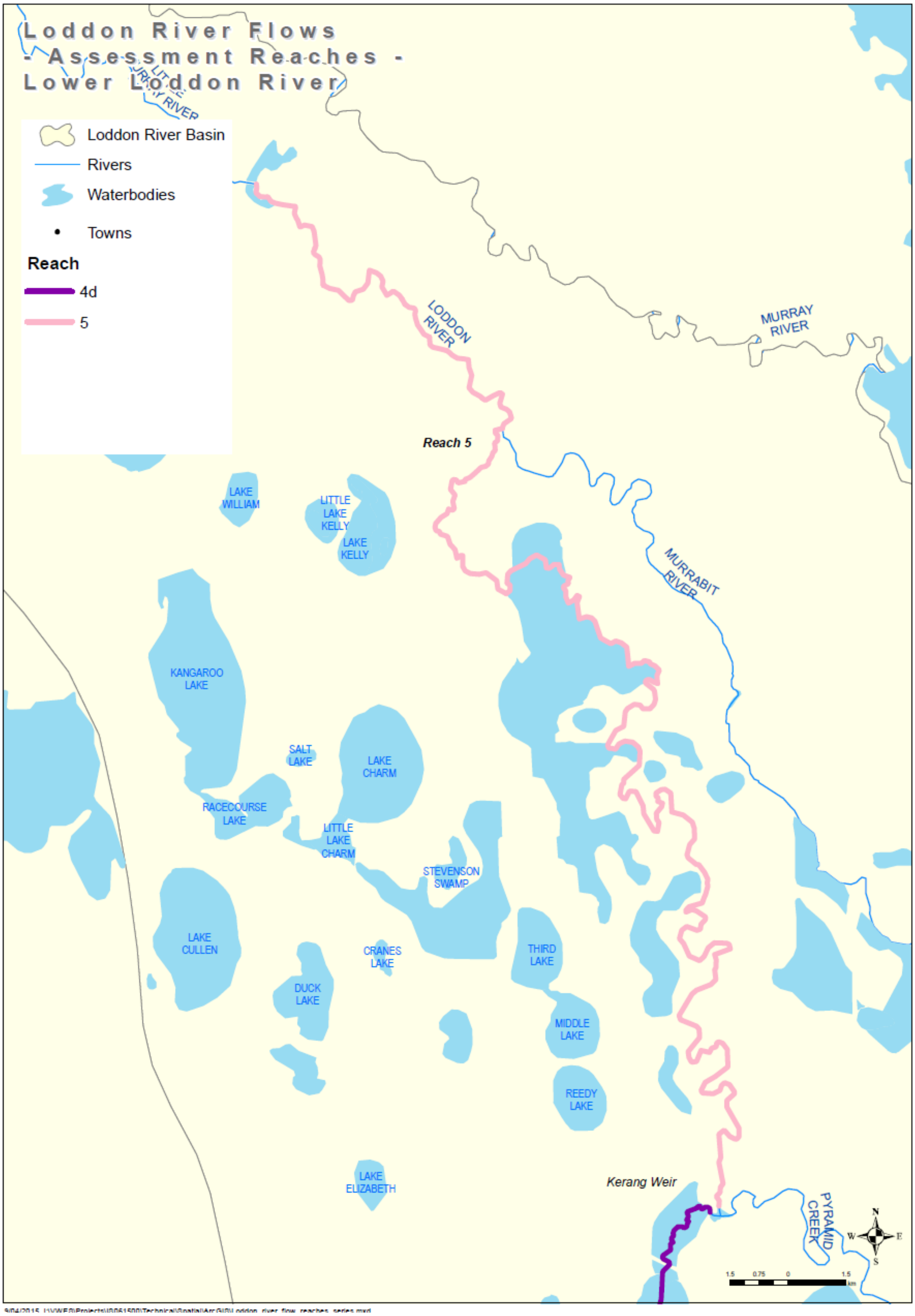

Figure 2-6: Map of the Lower Loddon River showing environmental flow reaches.

Figure 2-7: Loddon River downstream of Kerang Weir (Reach 5).

3. Groundwater – surfacewater interactions

CSIRO (2008) mapped groundwater and surface water interactions throughout the Loddon River catchment as part of the Murray Darling Basin Sustainable Yields Project. That work made the following classifications:

- The reaches upstream of Bridgewater, and a 45 km section of the Loddon River from north of Serpentine to Yando, gain groundwater;
- The section of the Loddon River between Yando and Appin South is hydraulically neutral (i.e. neither gaining nor losing); and
- The section of the Loddon River from Appin South to the Murray River, and the section between Bridgewater and north of Serpentine lose water to groundwater (see Figure 3-1).

CSIRO (2008) suggested that the whole Upper Loddon Catchment (i.e. upstream of Serpentine) would have historically been a gaining section, and that groundwater extraction, which has lowered the water table in the area, is the main reason why the 40 km section between Bridgewater and north of Serpentine now loses water to the water table.

In interpreting these classifications, it needs to be recognised that the mapping was undertaken for a snap-shot in time and the period was a relatively dry one. Groundwater levels throughout the catchment rose after the 2010/11 floods, but did not reach the high levels that were seen during the 1990s as a result of the irrigation practices at that time. The relatively dry period since 2011/12 has caused groundwater levels to decline slightly from the post flood peak. CSIRO (2008) undertook a temporal assessment of groundwater and surface water interaction, in recognition of the potential influence of the dry period on the direction of flux reported in their study. An example of that analysis (shown in Figure 3-2), clearly illustrates how falling groundwater levels affect water levels in the Loddon River.

For a gaining reach the impact of more average (or wetter) climatic conditions relative to the January 2006 dry period, is expected to be a higher rate of groundwater flux to the river (i.e. the river would be more gaining). For a losing reach the impact of more average (or wetter) climatic conditions means that the river reach classified as losing in January 2006, may lose at a lesser rate because of the assumed increase in groundwater elevation or could potentially even switch to gaining conditions.

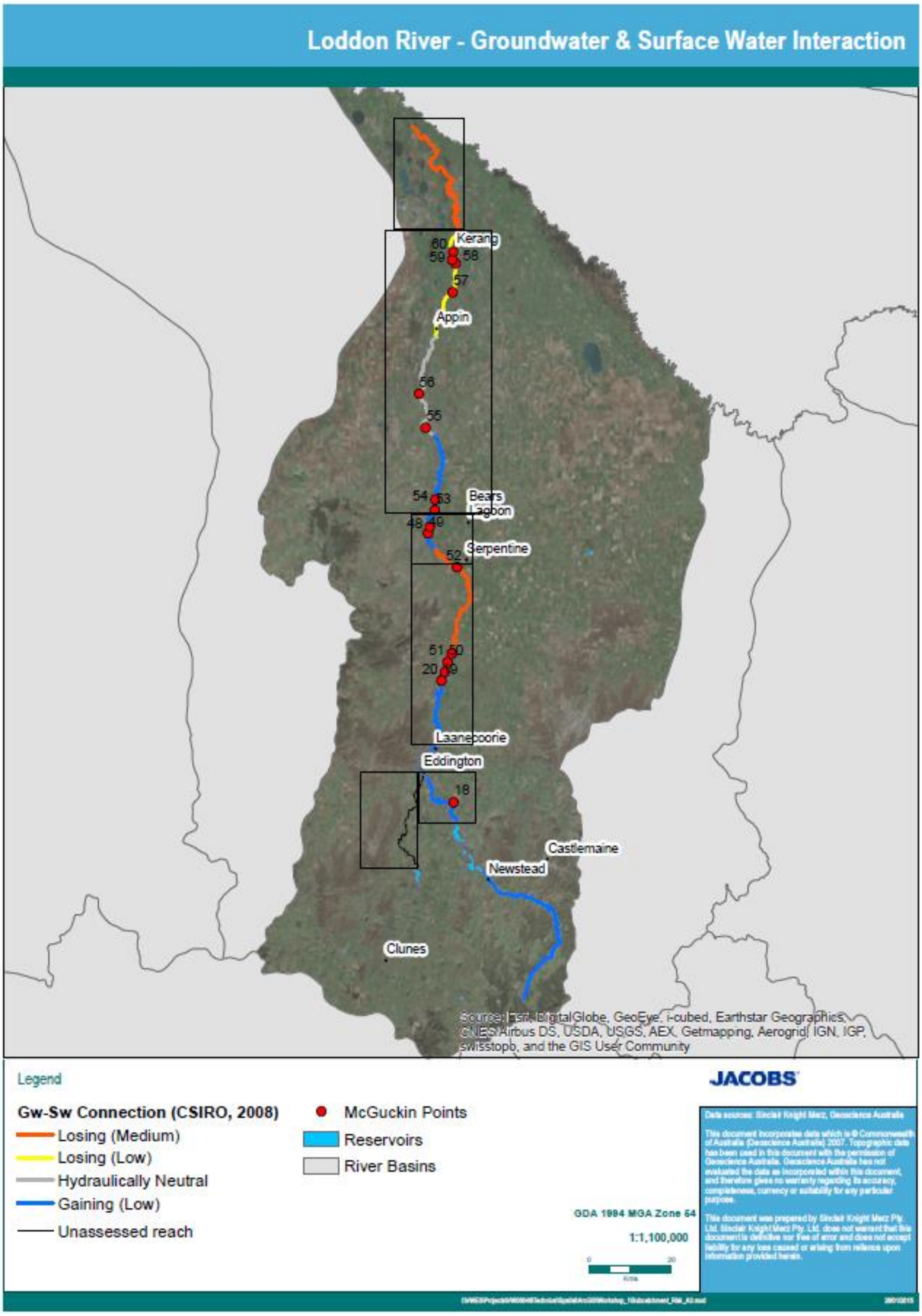

Figure 3-1 : Groundwater-Surface Water Interaction of the Loddon River

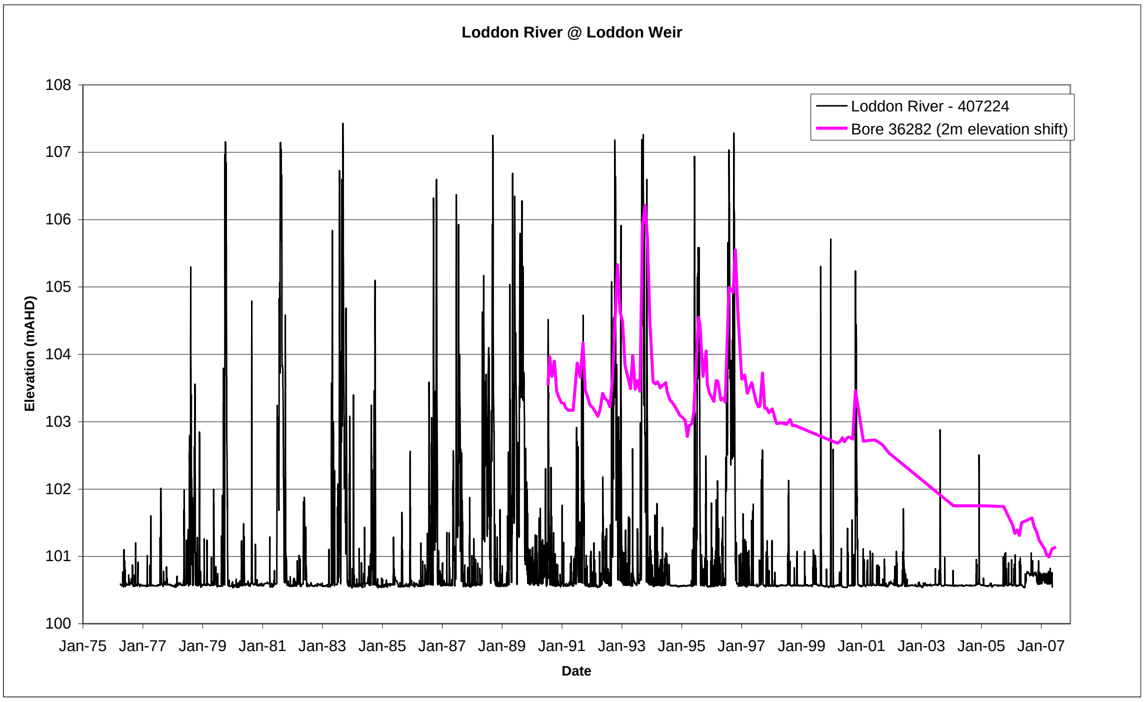

Figure 3-2 Relationship between water level in the Loddon River and nearby groundwater levels between 1975 and 2007 (reproduced from CSIRO, 2008)

3.1 Groundwater – surface water interactions in individual reaches.

Reach 1 - Cairn Curran Reservoir to Laanecoorie Reservoir

Based on data provided by CSIRO (2008), the Loddon River is considered to be gaining at a low rate from approximately Newstead to Bridgewater.

URS (2006) also assessed the river to be gaining along this reach based upon levels from nested bore sites suggesting upward vertical leakage to the water table from the underlying Calivil Formation.

Reach 2 - Tullaroop Reservoir to Laanecoorie Reservoir

There is no available information to confirm the groundwater-surface water interactions in Tullaroop Creek, but based on patterns in nearby areas and observations that the salinity levels in Tullaroop Creek rose significantly during the Millennium Drought, it is likely that this is a gaining reach.

Reach 3a - Laanecoorie Reservoir to Serpentine Weir

The reach from Laanecoorie Reservoir to Serpentine Weir contains both gaining and losing sections. From Laancoorie Reservoir to Point 50 (see Figure 3-1) the Loddon River is gaining at a low rate, and is losing at a medium rate from Point 50 to Serpentine Weir (see Figure 3-1). Groundwater development in this reach (see mapping of licensed bore locations in URS, 2006) would be expected to have some impact on gradients between the river and the aquifer noting that there is considered to be a relatively strong connection between the Calivil Formation and Shepparton Formation in the central parts of the Mid-Loddon WSPA which means that pumping induced drawdown in the Calivil Formation would induce leakage from the Shepparton Formation and hence potentially the river.

In the transition area from gaining to losing reaches identified by CSIRO 2008 (at point 20 in Figure 3-1), monitoring of the river salinity profile within a deep river hole of 6-7 metres depth, indicates no stratification was apparent showing “good mixing is occurring throughout the water column during the irrigation season”. Whilst there are no comparable data available for the non-irrigation season, these results suggest that there is no stratification from saline groundwater entering the river.

URS (2006) considered there was insufficient data upon which to indicate whether the river was losing or gaining between Laanecoorie and Newbridge, however they make the following statement:

"The watertable map prepared using July-August 2004 waterlevels …. indicates groundwater levels at around 127m AHD at Bridgewater, whilst the normal operating water level upstream of the weir at Bridgewater is generally around 137.7m AHD (Dale McGraw and Stephen Arthur, GMW Personal communication), which suggests a head difference in the vicinity of 10 m. This indicates that the river is a losing stream in this area which is also supported by relative fresh river salinities found in a river pool downstream of Newbridge to a depth of approximately 7 metres (McGuckin et al., 1991). These observations and the apparent fresh plume of groundwater to the north east of Bridgewater support the hypothesis contained in URS (2003) that the underlying Newer Volcanics in the area is conduit for leakage from the river to the Calivil Formation system along the Laanecoorie-Newbridge reach".

Reach 3b - Serpentine Weir to Loddon Weir

CSIRO (2008) data shows the upstream half of the reach from Serpentine Weir to Loddon Weir to be losing at a medium rate, while the downstream half of the reach is gaining at a low rate. Plain (2010) suggested that based on regional groundwater levels, the reach has been losing water from 2002 to 2010. Macumber (2007) describes the Bears Lagoon area as a groundwater discharge zone, but groundwater development may have induced watertable level decline.

Further north, the Loddon River deviates to the west away from the Calivil Formation and across a structural bedrock high. URS (2006) concluded that there was little or no interaction with the Loddon deep lead as the river extends further north, which would explain why groundwater pumping has not induced losses in that area.

Reach 4a - Loddon Weir to Kerang Weir

CSIRO (2008) data show the reach from Loddon Weir to south of Point 55 (in Figure 3-1) to be gaining at a low rate, changing to hydraulically neutral heading downstream to south of Appin, then changing to losing at a low rate from south of Appin to Kerang Weir.

McGuckin *et al.* (1991) showed the upper parts of the reach having increasing salinity concentrations consistent with the gaining conditions from a highly saline watertable. McGuckin *et al.* (1991) suggested those higher salinities were not sustained beyond Appin due to outfalls and active releases from the Macorna Channel, which had the indirect benefit of diluting groundwater impacts. Inflows from the Macorna Channel to the Loddon River have declined from nearly 100 ML/day when it was used to supply town water to Kerang, to virtually nothing now. However, improved irrigation practices since the 1990s have helped to lower the water table in the area and therefore even with much lower outfalls from the Macorna Channel, salt concentrations in the river remain at acceptably low levels for aquatic biota. The Millennium Drought also reduced watertable levels as there was less rainfall during that time. Moreover, a lot of water was sold out of the irrigation area adjacent to the river during the drought and the reduced amount of irrigation is likely to have further lowered the watertable.

In parts of the river that receive groundwater, the extent of inflows will be constrained by both the depth of the river and watertable elevations. McGuckin *et al.* (1991) indicates that the river was shallow (< 2 m) during much of the summer/autumn 1990. A shallow river profile will constrain the saturated interface with the groundwater system. SKM (2011) illustrates the substantial fluctuations in the watertable across the northern plains. Watertable elevation will also influence groundwater gradients between the wet and dry years.

Reach 5 - Kerang Weir to Murray River

CSIRO (2008) found the Loddon River to be losing at a low to moderate rate from Kerang Weir to the Murray River.

4. Environmental Values

4.1 Geomorphology

The Loddon River catchment has an unusual morphology. The Upper Loddon River has a moderate gradient and is characterised by a well-defined, incised channel whose capacity increases as a function of distance downstream. The gradient drops markedly downstream of Loddon Weir as the river flows north across the Loddon Plains. The channel capacity also drops as numerous distributary channels carry water from the main channel onto the Loddon River floodplain. The channel capacity begins to increase again downstream of Canary Island as anabranches re-join the main channel and natural drainage lines carry water from the floodplain to the river. Much of the Loddon River downstream of Kerang has levee banks that isolate the floodplain in all but the highest floods. The geomorphological issues and values for the Upper, Middle and Lower Loddon Rivers are described below.

4.1.1 Upper Loddon River

The channel through the upper Loddon River catchment would have naturally been characterised by a gravel or clay substrate with numerous deep pools, vegetated benches, occasional backwater habitats that are inundated during moderate to high flows. Some reaches, particularly Tullaroop Creek have anabranches and flood runners that become engaged at high flows.

The main geomorphological issues in the upper Loddon River are the loss of deep pools (as reported by community members whose families have lived in the area for several generations) due to increased sediment inputs and the creation of silt beds in the middle of the channel that are colonised and consolidated by reeds and other emergent vegetation during prolonged periods of low flow. Deep pools would have naturally provided critical habitat for fish and Platypus throughout the upper Loddon River and community members talk about angling parties taking large numbers of River Blackfish, Golden Perch, Murray Cod and introduced species such as Redfin from deep pools in the 1950s and 1960s. Such pools are particularly important as they provide refuge habitats for biota during low flow or cease-to-flow periods.

Land clearing, uncontrolled stock access and mining activities have caused considerable erosion throughout the catchment. Tributaries of Tullaroop Creek have delivered large sand slugs that have filled many deep pools near Carisbrook over the last 20-30 years. Other sediment has come from local bank and channel erosion, which has caused the river channel to become wider and flatter.

Bankfull and overbank flows generate high shear forces within the channel that create and help maintain deep pools, especially around trees that may have fallen into the river. The 2011 floods did re-establish some pools in Tullaroop Creek downstream of Carisbrook, but the amount of sediment in the system is probably greater than can be competently moved by large flows, especially since flow regulation has greatly reduced the frequency of those events.

Less frequent high flows also mean that flood runners and anabranches are not inundated very often and are likely to become terrestrialised (i.e. colonised by terrestrial vegetation that will also consolidate sediments and make it resistant to future geomorphic processes). Prolonged periods of low flow allow fine silt to accumulate on hard substrates such as submerged wood and emergent macrophytes. If left in place, that silt will smother or reduce the productivity of biofilms and hence their suitability as a food source and habitat for macroinvertebrates, which will have cascading effects on riverine food webs.

4.1.2 Middle Loddon River

The main geomorphological issues in the Middle Loddon River are:

- The loss of deep pools due to increased sediment inputs and less frequent high flows to scour them; and
- Less frequent high flows to engage and maintain distributary channels that connect the river to its floodplain.

Bankfull and overbank flows generate high shear forces within the channel that create and help maintain deep pools, especially around trees that may have fallen into the river. The middle reaches of the Loddon River have a very low gradient (i.e. fall of 25 m over 160 km of river channel between Loddon Weir and Kerang Weir) and therefore bankfull flows in this system will have lower shear forces than bankfull flows in other systems. It is unlikely that floods alone will re-create deep pools that have infilled over the last 100 or more years according to reports from community members whose families have lived in the area for several generations. A more realistic objective is to deliver large flows to help maintain pools that still remain and to scour small pools around trees that have fallen into the river. Large flows that scour material from the streambed will likely deposit it on nearby benches, which will help to maintain their form and therefore assist with other channel maintenance processes.

Given the ecological importance of large pools and the limited ability of flows to create new pools, it may be worth using mechanical means to excavate some new pools at sites where large pools were known to previously exist. Such works may initially be done at a small number of sites on a trial basis to check they do not damage the channel in other ways (e.g. cause excessive erosion or bank failure), will not rapidly fill in and provide habitats that are used by native fish, macroinveratebrates and Platypus.

The diminishing channel capacity downstream of Loddon Weir means that it will not be possible to use environmental water to deliver bankfull flows throughout all reaches of the system or to engage all distributary channels. A flow that only half fills the channel near Loddon Weir will break out of the river and cause widespread flooding further downstream. The NCCMA is however monitoring flow releases to identify certain floodrunners and distributary channels near Canary Island that are inundated at moderate flows and that have some environmental value. The NCCMA is working with landowners in that area to determine acceptable levels of flooding in those areas. The aim will be to agree on a minimum area that can be flooded to produce environmental benefits, without the timing or extent of flooding adversely affecting farming activities on private land.

4.1.3 Lower Loddon River

The main geomorphological issue in the lower Loddon River is the loss of deep pools and loss of habitat heterogeneity due to increased sediment inputs and less frequent high flows to scour them. The bed of the channel is generally flatter and more uniform than it would have naturally been. As with the Middle Loddon River, the low gradient of the Lower Loddon River means that bankfull flows are unlikely to re-create large deep pools and therefore the main objective will be to use bankfull flows to maintain existing pools and increase small-scale habitat heterogeneity.

Overbank flows are normally important in maintaining floodplain features such as wetlands, watering floodplain vegetation communities and moving carbon between the floodplain and the river. Most of the lower Loddon River has levee banks that prevent floods from inundating private land. Those levee banks isolate the floodplain from the river channel and therefore overbank floods (except those that are large enough to breach the levee banks) have relatively little ecological benefit.

4.2 Vegetation

Aquatic and riparian vegetation associated with the Loddon River can be grouped into four broad types:

- In-stream plants with submerged or floating leaves. An example of a submerged-leaf aquatic plant common across south-eastern Australia is Ribbonweed or Eelweed (*Vallisneria australis*); an example of a species with floating leaves is Water Ribbons (*Triglochin procerum*). Many pondweeds (*Potamogeton* spp.) also have floating leaves. Although a variety of native submerged plants occur in streams of south-eastern Australia, a large number of introduced species may be present too, usually in impoundments.
- Emergent non-woody vegetation in the shallow margins of the stream or on the lower banks. This is often a floristically diverse group and may include plants in the Family Juncaceae such as rushes (*Juncus* spp.), as well as many genera in the Family Cyperaceae, including twigrushes (*Baumea* spp.), clubrushes or clubsedges (*Bolboschoenus* and *Schoenoplectus* spp.), sedges (*Carex* and *Cyperus* spp.), spikerushes (*Eleocharis* spp.), and sawsedges (*Gahnia* spp.). Grasses (in the Family Poacea) may also be present: a widespread native example is the Common Reed (*Phragmites australis*), but there may be also a large

number of exotics and weeds, usually potentially invasive pasture species. Cumbungi (*Typha* spp., in the Family Typhaceae) may also be found in this ecotone, especially when shallow, nutrient-rich water is allowed to remain over summer.

- Fringing woody vegetation in the riparian zone. The most widely distributed example in this group is the River Red Gum (*Eucalyptus camaldulensis*) near the river and Black Box (*Eucalyptus largiflorens*) further away on the floodplain. Lignum (*Duma florulenta*) is a woody perennial shrub common as an understorey species in the lower sections of the Loddon River. The riparian zone of rivers in the Murray-Darling Basin is highly susceptible to invasion by woody weeds (e.g. willows, **Salix* spp.) and by non-woody herbs, forbs and grasses (Smith & Smith 1990).
- Periphyton and biofilms that grow on submerged wood, rocks and the streambed. This group is characterised by rapidly growing species that provide an important component of riverine foodwebs. The main objective for this group is to provide conditions that will allow biofilms and periphyton to be regularly refreshed to ensure enough productivity to support abundant communities of macroinvertebrates and other consumers.

4.2.1 Current condition of vegetation in the Loddon River

The extent and quality of the riparian and instream vegetation throughout the Loddon River is largely influenced by land management. Areas that have been fenced, and that have effective grazing control, have a wider riparian zone with more diverse understorey species; although the lack of frequent high flows appears to have limited the recruitment of large trees. Areas that have unrestricted stock access to the channel have less emergent fringing vegetation and less instream or fringing vegetation and little or no recruitment of riparian vegetation, especially of River Red Gum. A brief overview of the condition of riparian and in-stream vegetation in the Upper, Middle and Lower Loddon River is provided in the following sections.

4.2.1.1 Upper Loddon River

Parts of the Upper Loddon River that are not heavily grazed or severely affected by large sediment inputs have a diverse mix of in-stream plants such as *Triglochin* and *Potamogeton spp.* and non-woody emergent vegetation such as *Phragmites, Carex, Bulboschoenus* and *Juncus spp*. The riparian zone is dominated by mature River Red Gums of varying condition (i.e. trees at some sites in Reach 3a had very sparse canopies, indicating poor health), with some *Calistemon* shrubs and a mix of native and exotic grasses. In some locations exotic emergent taxa such as Spiny Rush *Juncus acuta* were present. The most notable features of the riparian zone are its narrow width (it only extends 1-2 tree widths beyond the top of the bank throughout much of the system) and the lack of widespread recruitment of juveniles into the population. A series of photos showing the composition and condition of vegetation throughout the Upper Loddon River is shown in Figure 4-1.

A combination of high sediment loads that have filled pools and flattened the bed of the channel, especially in the Loddon River between Cairn Curran Reservoir and in Tullaroop Creek, and low flows have allowed emergent vegetation such as *Phragmites australis* to become established in the channel. Vegetation monitoring for the Victorian Environmental Flows Monitoring Assessment Program (VEFMAP) showed that emergent vegetation encroached far into the channel during the Millennium Drought, where it often formed extensive and dense beds (SKM, 2013b). Encroaching vegetation formed a potential barrier to fish movement at some sites and excluded other emergent species, which effectively reduced the diversity of the vegetation community and reduced the quality and diversity of habitat for fish, macroinvertebrates and Platypus. The 2011 floods removed virtually all of the emergent vegetation that had grown in the middle of the channel during the preceding drought (SKM, 2013b). Emergent vegetation has since recolonised the margins of the channel, but so far has not encroached too far into the middle of the channel. It remains to be seen whether robust emergent taxa such as *Phragmites australis* will continue to colonise across the stream and into deeper water, or whether they will be limited by water depth or other hydrological variables.

The Loddon River immediately downstream of Cairn Curran Reservoir has a coarse gravel substrate, which can support biofilms, but submerged wood is the main surface for biofilms throughout all reaches of the river. The quality and productivity of biofilm communities is therefore influenced by the abundance of woody debris and the extent to which flows can clean and periodically wet and dry those surfaces.

Figure 4-1: Photos of the upper Loddon River. Top row – Loddon River between Cairn Curran Reservoir and Laanecoorie Reservoir showing diverse riparian shrubs and backwater habitat at Baringhup (top left) and cattle in the stream near Rumbolds Road (top right). Middle row – Tullaroop Creek between Tullaroop Reservoir and Laanecoorie Reservoir showing an anabranch that should be inundated at moderate to high flows (middle left) and Bulboschoenus growing at the margin of the channel and Triglochin growing in the middle of the channel at Carisbrook (middle right). Bottom row – Loddon River between Laanecoorie Reservoir and Serpentine Weir showing narrow riparian zone at top of bank, little understorey or emergent fringing vegetation and a moderate load of submerged wood.

4.2.1.2 Middle Loddon River

The Middle Loddon River has an extensive floodplain that supports important River Red Gum woodlands and wetlands (see Figure 4-2) that are watered by bankfull and overbank flows. Such flows occur much more frequently than in upstream reaches because the channel capacity throughout the Middle Loddon River is much smaller. The Middle Loddon River has noticeably less emergent fringing vegetation and less instream vegetation than the upper Loddon River (see Figure 4-2). It is also likely to be less floristically diverse with, for example, *Callistemon spp.* being relatively uncommon in the Middle Loddon River. Lignum, however, is much more widespread throughout the Middle Loddon River and may reflect the slightly drier climate in this part of the catchment. The lack of fringing emergent vegetation may be a recent change because during the Millennium Drought some sections of channel were completely choked with *Phragmites, Typha* and juvenile River Red Gum (SKM, 2013b). Virtually all of those plants were removed by the 2011 floods and subsequent recruitment has been slow. Some of the floodrunners at the downstream end of Twelve Mile Creek that have been inundated multiple times in the last four years are beginning to support diverse communities of wetland type plants (see Figure 4-2). The 2011 floods also triggered significant recruitment of woody vegetation, especially of River Red Gum, on the floodplain adjacent to Twelve Mile Creek in areas where livestock have been excluded. That recruitment is particularly important as it replaces adult trees that died during or before the drought (see Figure 4-2).

The low abundance and diversity of instream vegetation may be explained by the high turbidity in these reaches of the Loddon River (see Figure 4-2). Rooted submerged plants cannot grow in very turbid water because the light cannot penetrate close enough to the streambed to allow plants to get established, and for established plants there may be insufficient light to allow photosynthesis. The only instream vegetation likely to occur in the Middle Loddon River now are floating-leafed species such as *Triglochin, Myriophyllum* and *Potamogeton*, and the objective should be to increase the distribution of both species. Control over stock access is also likely to be required for these taxa to become established, as many are highly palatable to stock.

Given the relatively low abundance of instream vegetation and the high proportion of submerged wood (see Figure 4-2), biofilms are likely to be very important in the Middle Loddon River as a source of food for aquatic invertebrates and thus for aquatic foodwebs. Specific objectives should aim to vary the water depth on submerged wood to periodically wet and dry the biofilms and provide freshes that will prevent them being smothered by fine sediment. Both flow components provide a periodic disturbance that maintains palatable and productive biofilms on hard surfaces in the river.

Figure 4-2: Photos of the Middle Loddon River. Top row – Loddon River between Loddon Weir and Twelve Mile Creek showing River Red Gum woodland habitat (top left) and lack of instream and fringing vegetation (top right). Middle row – Twelve Mile Creek showing vegetation growth in flood runner (middle left) and regeneration on adjacent floodplain (middle right). Bottom row – Loddon River between Canary Island and Kerang showing turbid water and adjacent floodplain.

4.2.1.3 Lower Loddon River

The Lower Loddon River floodplain is dominated by Black Box and Lignum. A narrow band of River Red Gum grows in a thin band along the bank of the river; they are not found higher on the floodplain. Most of these River Red Gum are thought to be less than 100 years old and anecdotal evidence suggest they have established after the Loddon River and Pyramid Creek were modified for use as irrigation supply channels. Levee banks that have been built to prevent flooding on private land have isolated the Lower Loddon River floodplain from the river and land management practices are now the main factor that influences the composition and condition of floodplain vegetation. As in the upstream reaches, areas where livestock have been excluded have well established vegetation on the river banks and floodplain, while areas with unrestricted stock access have bare banks, lacking a shrub layer and juvenile eucalypts (see Figure 4-3). Although the beneficial effects of stock exclusion on riparian vegetation are well established, some community members consulted for the project were concerned that the complete removal of grazing would allow Lignum and weeds to become too dense and thereby create a flood risk, fire risk and habitat for pest species such as foxes and cats. They favoured a management strategy that allowed controlled grazing and asked for more information and guidance on appropriate target conditions for riparian vegetation and advice on how to achieve that condition. Providing such advice is beyond the scope of the current FLOWS study.

The Lower Loddon River had extensive stands of emergent fringing vegetation that grew into the middle of the channel during the Millennium Drought. Such encroachment can reduce fish passage and trap sediment, promoting further encroachment and progressively reducing the diversity and quality of aquatic and fringing habitat. Much of the vegetation that grew in the middle of the channel during the drought was either physically removed or drowned by the 2011 floods; the mechanism for its loss has not been established. The current objective for fringing riparian vegetation should be to promote a mosaic of native plants along the margin of the channel while limiting its encroachment into the channel.

The Lower Loddon River currently has a very low abundance and diversity of instream vegetation, which may be best explained by the high turbidity of water throughout the system (see Figure 4-3). As noted earlier, rooted submerged plants cannot grow in very turbid water because the light cannot penetrate close enough to the streambed to allow plants to get established, or for established plants to photosynthesise. The only instream vegetation likely to occur in the Lower Loddon River now are species with floating leaves such as *Triglochin, Myriophyllum*, and *Potamogeton*, and the objective should be to increase the distribution of both species. As for the Middle Loddon River, control over stock access is also likely to be required for these taxa to become established, as many are highly palatable to stock.

Biofilms are usually an important primary producer in systems with high turbidity because they can grow on hard surfaces (such as submerged wood) in the top few centimetres of the water column through which light can penetrate. They are especially important in the lower reaches of rivers, as wood from long-lived trees often falls into the river and provides a long-term and stable substratum on which microbes can grow. Biofilms can grow rapidly and colonise different substrates as the position of the photic zone changes with changing water levels. Moreover, biofilm productivity benefits from wetting and drying associated with changing water levels. The main problem for biofilms in the Lower Loddon River is the scarcity of submerged wood in the river and therefore the lack of suitable surfaces on which biofilms can grow. The main objectives for biofilms should therefore be to increase the amount of submerged wood in the channel (doing so will also increase the quantity of habitat for fish and Platypus) and provide a flow regime that, by creating periodic disturbances, flushes fine sediment from biofilms and provides varying water levels to regularly wet and dry the substrates on which biofilms grow.

Figure 4-3: Loddon River downstream of Kerang showing the effect of uncontrolled stock access on the riparian zone.

4.2.2 Changes in water-dependent vegetation of the Loddon River

4.2.2.1 Sources of information

Information of variable detail on water-dependent vegetation associated with the Loddon River is available in a number of reports:

- Remnant vegetation survey and botanical inventory of the Shire of Gordon (Foreman and Westerway, 1994)
- Loddon catchment riparian vegetation investigation (Thexton, 2000)
- The original environmental flows study of 2002 (Loddon River Environmental Flows Scientific Panel, 2002a, 2002b)
- Review of environmental flow requirements for the lower Loddon River system undertaken in 2009 (SKM, 2010c, b)
- Cross section and Vegetation surveys of the Loddon River and Tullaroop Creek (SKM, 2013b).

For the purposes of the current investigation in terms of identifying current status and likely trajectories, the most critical comparisons are between the vegetation characteristics in the original environmental flows study of 2002 and the review of environmental flow requirements for the lower Loddon River system of 2009 − both prepared when south-eastern Australia was in drought − versus the observations made during the field inspections of early February 2015. Of the two older sources of information for the drought period, the SKM (2010a, b) reports are the more useful as they contain detailed descriptions of in-stream and fringing woody and non-woody vegetation. The 2009/2010 FLOWS study, only focussed on the Loddon River downstream of Loddon Weir, therefore contrasts between current conditions and Millennium Drought conditions are based on the less detailed descriptions provided in the 2002 environmental flows assessment.

Comparisons between the drought and 2015 conditions were broadly similar for all reaches and rather than describe vegetation condition trends for each reach we describe changes for the four broad vegetation types across the whole system. The following text highlights the main changes in condition for each vegetation group since the drought and likely trajectories if environmental watering is not provided.

4.2.2.2 Changes in in-stream vegetation

The most obvious change in aquatic vegetation between the earlier studies and the current investigation has taken place with in-stream and fringing plants. In 2009 the channel of the Loddon River downstream of Loddon Weir to the 12 Mile regulator, for example, was heavily terrestrialised with Common Reed and, in some places, young River Red Gum had established in the thalweg. Most, if not all of that in-stream and fringing vegetation was removed during the flood (either by drowning or scour) (see Figure 4-4). Patches of in-stream vegetation have re-established at some sites, where the water is sufficiently clear and the substrate is suitable (see Figure 4-5), but there is little in-stream vegetation at sites that have very turbid water and there is no sign of terrestrial plants encroaching into the middle of the channel at any of the sites visited during the current project. The comparison holds for all reaches the river upstream of Kerang weir.

Figure 4-4: Loddon River downstream of Loddon Weir showing dense stands of *Phragmites* in 2009 (left photo) and clear channel in 2015 (right photo).

Figure 4-5: Examples of in-stream vegetation that has recolonised since the 2011 floods. *Triglochin* in Tullaroop Creek (left photo) and *Potamogeton* in Loddon River downstream of Serpentine Weir (right photo). Photos taken February 2015.

4.2.2.3 Changes in emergent non-woody vegetation

Most of the Loddon River catchment had extensive stands of emergent vegetation such as *Juncus* and *Cyperus* spp. growing at the margin and in the bottom of the channel in 2009. The wet conditions and floods in 2010/2011 removed much of that vegetation and subsequent recolonisation has been variable. Mosaics of emergent non-woody vegetation have recolonised shallow sections of the channel in the Upper Loddon River (see Figure 4-6). In contrast the low banks and floor of the channel in the middle and lower Loddon River remain relatively bare (see Figure 4-7 and Figure 4-8). These emergent plants generally colonised shallow silt beds during the drought; wetter conditions since 2011 have potentially flushed some of those silt beds, especially in the lower Loddon River, which has reduced the likelihood that emergent plants will re-colonise the bottom of the channel.

Figure 4-6: Tullaroop Creek at Carisbrook (left photo) and Loddon River at Baringhup (right photo) showing recovering stands of emergent fringing vegetation in 2015.

Figure 4-7: Loddon River downstream of Serpentine Weir (left photo) and upstream of Twelve Mile Creek (right photo) showing bare banks in 2015.

Figure 4-8: Loddon River downstream of Kerang Weir showing dense stands of emergent macrophytes including *Juncus* and *Cyperus* spp. in 2009 (left photo) and a wider and clearer channel in 2015 (right photo).

4.2.2.4 Changes in woody riparian vegetation

Two comparisons reveal the scale of changes in woody vegetation in the river between the Millennium Drought and 2015. The first example comes from the Loddon River at the 12 Mile Creek regulator. In 2009 the river was dry (see left photo in Figure 4-9). The right side photo in Figure 4-9 shows the river channel fully wet and the same mature River Red Gum in much better condition in 2015.

Figure 4-9: Loddon River at Twelve Mile Creek regulator showing a dry river bed in 2009 (left photo) and the fully wetted river channel in 2015 (right photo). Note the tree behind the regulator in the left photo is the same as the tree in the right photo.

The second example comes from 12 Mile Creek. In 2009 the channel of Twelve Mile Creek was dry and showed strong terrestrialisation. There were abundant juvenile River Red Gum in the channel (see Figure 4-10), but little evidence of recruitment on the banks. In some places where small flood runners penetrated into the floodplain, River Red Gum had recruited strongly but the surrounding floodplain generally showed few or no young River Red Gum. Many dying or unhealthy adult River Red Gum were evident on the floodplain. Extensive swards of Spiny Mud-grass (*Pseudoraphis spinescens*) were present in the channel in some places (see background of Figure 4-10). A small number of scattered emergent macrophytes, including *Juncus* spp. and *Eleocharis* spp, also grew along the edges of the channel. In 2015 there was shallow water in the channel of 12 Mile Creek and the River Red Gum saplings that were evident in 2009 were drowned (see Figure 4-10). There were also extensive swards of *Bolboschoenus* and *Juncus* spp. lining the stream, and juvenile River Red Gum and Lignum had regenerated vigorously on the floodplain among dead adult trees (see Figure 4-10).

Figure 4-10: Twelve Mile Creek showing a dry channel with juvenile River Red Gum growing in the channel in 2009 (top left), the same site with water and drowned River Red Gum in 2015 (top right) and juvenile River Red Gum and other riparian species growing among dead mature trees on the adjacent floodplain in 2015 (bottom photo).

4.2.2.5 Changes in periphyton and biofilms

The distribution and condition of periphyton and biofilms has not been described for any part of the Loddon River and therefore it is not possible to quantify changes to its condition or extent. The presence of more permanent water and more variable flow regimes that wet and dry submerged wood and other substrates that biofilms grow on, mean that the periphyton and biofilm community in all reaches of the Loddon River is likely to be more productive now compared to during the Millennium Drought. Periphyton and biofilms are particularly important in reaches where the water is too turbid to allow in-stream plants to become established. Biofilms are able to grow in turbid water because they can colonise wood that is just beneath the water surface and therefore within the shallow photic zone (i.e. portion of the water column that sunlight can penetrate) (see Figure 4-11).

Figure 4-11: Loddon River showing turbid water and submerged wood that provide ideal substrates for periphyton and biofilms (Left photo – Loddon River upstream of Twelve Mile Creek). (Right photo – Loddon River at Penny Lane upstream of Serpentine Weir).

4.2.3 Likely trajectory of water-dependent vegetation of the Loddon River

The comparison of changes in the four broad groups of water-dependent vegetation of the Loddon River over drought and normal/wet climatic periods gives an indication to likely trajectories should environmental water not be provided. Extended dry periods − either enforced by severe climate events or by an inability to provide sufficient environmental water − will likely result in:

- Loss of in-stream vegetation that is obligately aquatic, until wetter conditions return. Examples of species that may be lost (temporarily or long-term) include *Triglochin*, *Vallisneria*, *Myriophyllum*, and *Potamogeton spp.*
- Retraction of the extent, and possibly also floristic diversity, of emergent non-woody macrophytes such as rushes and reeds, twigrushes, clubrushes and clubsedges, sedges, and spikerushes.
- Terrestrialisation of the stream channel by emergent non-woody taxa (e.g. *Phragmites australis*) and by eucalypts, especially juvenile River Red Gum.
- Poor recruitment of River Red Gum in the riparian zone nearest the stream (it is assumed that overbank flooding will not occur, because of the risk of inundation of private land).
- Decreases in condition of adult River Red Gum.
- Lower biofilm and periphyton productivity.

The question as to whether or not such changes are desirable hinges on whether or not river managers seek to maintain a quasi-steady state approach to water-dependent vegetation or decide to let the vegetation change markedly in response to climatic variations. Erskine and Warner (1998) proposed that rivers in south-eastern Australia undergo alternating flood- and drought-dominated regimes, driven by long-term changes in rainfall over decadal time periods. Flood-dominated regimes are characterized by episodic catastrophic floods and persistent flood activity; drought-dominated regimes by long periods of low flood activity. The periodicity of each regime could vary from ~5−20 years.

Fundamental geomorphological changes are also proposed to take place in the each regime: deposition and channel contraction during drought periods; and bank erosion, channel widening and chute cutting during flood-dominated periods. The cross-sectional surveys reported in SKM (2013a) showed little change in channel morphology between drought and normal/wet periods for the Loddon River, which suggests that the vegetation changes outlined above and described more quantitatively in SKM (2013b) are more sensitive to flood and drought dominated flow regimes.

4.2.4 Threats to water-dependent vegetation in the Lower Loddon River system

The most detailed analysis of threats to ecological condition of aquatic and riparian vegetation in the Loddon River is that undertaken by Thexton (2000). Additional information is available in Loddon Shire Council (1995) and Loddon River Environmental Flows Scientific Panel (2002a), 2002b). Thexton (2000) concluded that the following changes had occurred to vegetation since European colonisation:

- Narrowing and fragmentation of riparian zones.
- Loss of indigenous species through persistent grazing by domestic stock, exacerbated by grazing impacts from rabbits.
- Introduction of weed species through agricultural activities.
- Simplification of vegetation structure, mostly through the retention of only the upper tree layer and loss of shrub and ground layers.
- Loss of plant-animal interactions, with possible impacts on processes such as pollination.
- Extensive alterations to wetting and drying cycles through the creation and operation of water storages, irrigation infrastructure, dispersal drainage and levees.

Thexton (2000) identified six main threats to existing riparian vegetation in the Loddon River catchment:

- Salinisation
- Grazing by stock and vermin (i.e. rabbits)
- Weed invasions
- Regulated streamflow
- Soil disturbance
- Erosion and silting of waterways.

Specific information on threats – and their manifestation as altered ecological condition – are available for parts of the Loddon River system in Loddon River Environmental Flows Scientific Panel (2002b) and results of Index of Stream Condition assessments (summarised in SKM, 2010c). The Loddon River Environmental Flows Scientific Panel (2002b, page 62) concluded that land-use practices (particularly grazing) were a dominant impact on riparian communities in the Loddon River downstream of the Loddon Weir, but noted some evidence of terrestrialisation of bank communities 'due to less frequent bank inundation'.

SKM (2010c), b) concluded that the major threat to the extent and condition of in-stream, riparian and floodplain vegetation in the Loddon River system was altered hydrology − but it is critical to note that this investigation was undertaken at the end of one of the most severe droughts in the European history of south-eastern Australia. The terrestrialisation of the stream channel observed in that study was undoubtedly a result of very low river discharge over the previous decade. Lack of bank-full and over-bank flows had almost certainly contributed to the poor recruitment of River Red Gum (and perhaps Black Box in the most downstream reaches) and to the structural simplification of the existing riparian vegetation; an issue noted also by Riparian Australian (2000) and Loddon River Environmental Flows Scientific Panel (2002b).

Lack of flow was inferred as a fundamental issue to the paucity of aquatic in-stream, riparian and wetland vegetation observed during the 2009 field investigations reported in SKM (2010c). With the exception of some emergent macrophytes (e.g. scattered *Cyperus* spp, *Eleocharis* spp and *Juncus* spp) and a large sward of Spiny Mud-grass in Twelve Mile Creek, little emergent aquatic vegetation was reported during that study. The lack of aquatic or in-stream vegetation in 2009 contrasted strongly with the findings of the Loddon River Environmental Flows Scientific Panel (2002b), who observed some aquatic vegetation (e.g. a dense patch of senescing Nardoo *Marsilea drummondii*) and inferred the likely existence a wide range of aquatic vegetation (e.g. Nardoo, Water Primrose *Ludwigia peploides*, Pondweeds *Potamogeton* spp., Swamp Buttercup *Ranunculus inundatus* and Milfoils *Myriophyllum* spp) in the study area during earlier wetter times. The 2015 field investigation also noted few examples of in-stream vegetation, particularly obligate aquatic submerged taxa. Poor water clarity may be a causal factor, which in turn may be related to stock access and uncontrolled grazing of the river banks.

Grazing was not seen as a critical problem in the 2009 investigation, perhaps because the absence of water in the stream channel meant that stock were not attracted to the stream in the first instance. Little or none of the streams were fenced in 2002 and the Loddon River Environmental Flows Scientific Panel (2002b, page 60) noted that there was ‘general uncontrolled stock access’ to the Loddon River below Kerang Weir. Approximately 54% of the main stem of the Loddon River has subsequently been fenced as part of a broader package of works funded through the Loddon Stressed Rivers Project (NCCMA, 2015), but fencing is not continuous and some fenced areas still have uncontrolled stock access to the river channel (see Figure 4-12). Such grazing will prevent many of the intended benefits of environmental watering on all vegetation groups.

Figure 4-12: Loddon River between Cairn Curran Reservoir and Laanecoorie Reservoir showing cattle access to the river channel.

4.3 Fish

4.3.1 Upper Loddon River

The upper Loddon River would have naturally supported diverse native fish communities comprising:

- Resident populations of small-bodied native fish species such as Flathead Gudgeon, Carp Gudgeon, Australian Smelt and Mountain Galaxias complex that are short-lived and have variable breeding from year to year depending on flow conditions and food availability.
- Resident populations of longer lived species such as Murray Cod and Freshwater Catfish that would live and recruit in large pools and River Blackfish that would breed in cool streams with low turbidity and an abundant supply of submerged hollow logs.
- Migratory species such as Golden Perch and Silver Perch that would have moved upstream from the Murray River, but would not necessarily breed in the upper Loddon River.

Community members report that pools in Tullaroop Creek and the Loddon River between Cairn Curran Reservoir and Serpentine Weir were reliable fishing areas in the 1950s – 1970s, with anglers regularly catching large numbers of River Blackfish, Murray Cod, Golden Perch and the introduced species Redfin. Changes to flow, the loss of deep in-channel pools, the effect of artificial migration barriers (e.g. Loddon Weir and Laanecoorie Reservoir) and pressures from exotic species such as Carp have significantly reduced the abundance and diversity of fish communities in the upper Loddon River. The Millennium Drought further reduced the abundance of remaining species, although recent surveys suggest that populations of some native fish species have recovered slightly (Jacobs, 2014a).

All reaches of the Loddon River upstream of Serpentine Weir are likely to support breeding populations of short-lived, small-bodied native fish. The main objective for these species will be to provide appropriate flows and habitat to increase the size of those populations and make them more resilient to future stresses.

River Blackfish used to be very abundant in Tullaroop Creek and the Loddon River upstream of Laanecoorie Reservoir. Some River Blackfish are still present at a small number of sites in Tullaroop Creek (Jacobs, 2014a), but they do not migrate far and the population is likely to be small and isolated. River Blackfish has high regional significance and the main objective for this species will be to increase the size and distribution of the population in Tullaroop Creek and then help it re-colonise sections of the Loddon River between Cairn Curran Reservoir and Laanecoorie Reservoir. That reach of the Loddon River has habitat that could potentially support River Blackfish, but it may be necessary to translocate some individuals to facilitate recolonisation.

Murray Cod is stocked in Cairn Curran Reservoir, Laanecoorie Reservoir, Serpentine Weir and several large pools near Newbridge and Bridgewater. Large individuals are occasionally caught by anglers and during fish surveys (Jacobs, 2014a). The main objective for Murray Cod will be to provide flows that facilitate recruitment within stocked populations in Laanecoorie Reservoir and the large pools between Laanecoorie Reservoir and Serpentine Weir. It is expected that some fish will move from Laanecoorie Reservoir into Reach 1 of the Loddon River and Tullaroop Creek, and move throughout the entire length of Reach 3a when flow allows.

Golden Perch is also stocked in the upper Loddon River system, but downstream weirs and dams prevent individuals from migrating to the Murray River and therefore it is not expected to breed in these reaches. The main objective for Golden Perch will be to provide flow and habitat that will sustain stocked individuals in weirpools and large natural pools and allow individual fish to disperse within each reach.

4.3.2 Middle Loddon River

The Middle Loddon River would have naturally supported diverse native fish communities comprising:

- Resident populations of small-bodied native fish species such as Flathead Gudgeon, Carp Gudgeon, Australian Smelt and Murray-Darling Rainbowfish that are short-lived and have variable breeding from year to year depending on flow conditions and food availability.
- Resident populations of longer lived species such as Murray Cod and Freshwater Catfish that would live and recruit in large pools. River Blackfish may have also lived in some sections of the Loddon River that held permanent water and had an abundant supply of submerged wood and hollow logs. River Blackfish have not been recorded in the main channel of the Middle Loddon River for many years, but are still present in Serpentine Creek (SKM, 2010a).
- Migratory species such as Golden Perch and Silver Perch that would have moved upstream from the Murray River, but would not necessarily breed in the middle Loddon River.

Community members report that large pools throughout the middle Loddon River used to produce reliable catches of Murray Cod and Golden Perch. Anglers also used to catch River Blackfish, but community members suggest that River Blackfish was probably displaced from the reach in the 1970s by exotic species such as Carp and Redfin.

The middle Loddon River completely dried up during the Millennium Drought and all fish in the system were lost. The 2011 floods reconnected the middle Loddon River to downstream fish habitats and fish surveys conducted since the floods have recorded small-bodied native fish including Flathead Gudgeon, Australian Smelt, Carp Gudgeon and Murray-Darling Rainbowfish; large-bodied species including Golden Perch, Silver Perch and Bony Bream and many exotic fish species (Jacobs, 2014a). Recent fish surveys recorded Murray Cod in the reach between Serpentine Weir and Loddon Weir (Jacobs, 2014a); it is likely those fish persisted in the Loddon Weirpool throughout the drought, rather than recolonised the river after the floods.

The loss of large pools throughout the Middle Loddon River due to increased sediment loads in the river and less frequent bankfull flows is a major threat to native fish, because those pools would provide refuge habitats during low flow or cease-to-flow periods. The deeper channels in the reach immediately downstream of Loddon Weir (Reach 4a) and in the reach downstream of Canary Island (Reach 4d) still have some pools. Those two sub-reaches are likely to provide the best habitat for small and large-bodied native fish and are expected to support permanent fish populations as long as there is sufficient flow to maintain the quality and quantity of pool habitats. Small-bodied fish should persist in Twelve Mile Creek (Reach 4b) and the West Branch of the Loddon River (Reach 4c) as long as there is at least near-permanent shallow connecting flow. Fish of all size classes should be able to move through Reaches 4b and 4c during high flows, but those two reaches are not likely to support permanent populations of large-bodied fish.

The main fish objective for the middle Loddon River is to increase the abundance and richness of native fish populations. Specific objectives include increasing the size of permanent resident populations of large and small-bodied native fish in the reaches upstream of Canary Island in the in the Reach downstream of Canary Island, and providing opportunities and habitat for fish to move through Twelve Mile Creek and the West Branch of the Loddon River during winter and spring. Ideally, populations of small-bodied native fish will also be maintained in parts of Twelve Mile Creek and the West Branch of the Loddon River. Associated works to improve connections between this reach of the Loddon River and the Murray River mean these objectives are achievable. Moreover, they are a very high priority for the North Central CMA and Loddon River community.

Regularly connecting the fish populations upstream and downstream of Canary Island and providing connection to communities in the lower Loddon River and Murray River will be crucial in maintaining the sustainability of native fish communities in the middle Loddon River. Such connections are critical for species such as Golden Perch and Silver Perch that most likely migrate to the Murray River to spawn. Juvenile or young adult Golden Perch and Silver Perch move from the Murray River into major tributaries such as the Loddon River. Providing flows that will enable fish to move between the middle Loddon River and lower Loddon River is more important now than ten years ago, because the construction of a fishway at Kerang Weir and the planned construction of a fishway at Box Creek Regulator on Pyramid Creek should significantly increase the abundance and diversity of native fish that will be able to access the middle Loddon River from the Murray River and other nearby systems. Proposed works to improve fish passage at smaller artificial barriers within the middle Loddon River such as at ‘The Chute’ will also help achieve this objective. If fish populations recover in Reach 4a, a case may be made to provide fish passage at Loddon Weir and Serpentine Weir to connect fish populations throughout the whole Loddon River system.

4.3.3 Lower Loddon River

The Lower Loddon River would have naturally supported diverse native fish communities comprising:

- Resident populations of small-bodied native fish species such as Flathead Gudgeon, Carp Gudgeon, Australian Smelt, Murray-Darling Rainbowfish and Unspecked Hardyhead that are short-lived and have variable breeding from year to year depending on flow conditions and food availability.
- Resident populations of longer lived species such as Murray Cod and Freshwater Catfish that would live and recruit in large pools.
- Migratory species such as Golden Perch, Silver Perch and Bony Herring that would have moved upstream from the Murray River.

Community members reported catching large numbers of Murray Cod, Golden Perch and Freshwater Catfish prior to the 1980s, and noted that the decline in the abundance of native fish coincided with an increase in the number of Carp. Extensive dredging in Pyramid Creek in the 1960s altered the flow regime in the Lower Loddon River and also delivered large sediment loads, which is likely to have reduced habitat for native fish. The section of the Lower Loddon River between Kerang Weir and Benjeroop dried up during the Millennium Drought, but fish moved back into the system from the Murray River once flows resumed. Recent fish survey results suggest that most of the fish species that would have naturally lived in the Lower Loddon River have returned although the abundance of those populations is still low (Jacobs, 2014a).

The Kerang Weir fishway, which was built in 2008 and modified several times since to improve its operation, allows fish to move upstream from the Lower Loddon River into the Middle Loddon River and Pyramid Creek. Another fishway will be built at Box Creek regulator in the coming year as part of the GMW Connections Project, which when complete will allow fish to move between the Murray River, Loddon River, Pyramid Creek and Gunbower Creek systems. These fishways will be an integral part of the Native Fish Recovery Plan, which aims to increase breeding and recruitment opportunities for many native fish including iconic species such as Murray Cod, Golden Perch and Silver Perch. Allowing fish to move throughout these connected systems should increase the overall abundance of native fish and increase the resilience of native fish populations to droughts and other disturbances. A key fish objective for the Lower Loddon River is to provide suitable flows to operate the Kerang Weir Fishway, to provide flows that will attract fish from the Murray River into the Lower Loddon River and to provide habitat that will support permanent fish populations in the river and that other fish can use as they move through the system.

4.4 Platypus

4.4.1 Distribution, status and limiting conditions

Platypus live-trapping surveys have not to date been conducted along the Loddon River or its tributaries downstream of Cairn Curran and Tullaroop Reservoirs. However, some information relating to the species' distribution and status is available based on sightings, mainly reported by Goulburn-Murray Water field officers or long-time landholders owning substantial river frontage and recorded in the course of interviews using methods outlined in Serena and Williams (2011). In addition, some live-trapping records have been obtained of Platypus recorded as bycatch in the course of fish surveys carried out by consultants.

4.4.1.1 Platypus in the Upper Loddon River

Loddon River from Cairn Curran Reservoir to Laanecoorie Reservoir. Platypus have been seen at many sites along the Loddon between Cairn Curran and Laanecoorie Reservoirs since 2000, with most persons interviewed from 2000-2004 indicating that animals were seen regularly or occasionally, i.e. consistent with the occurrence of an established breeding population. Few sightings have been reported since about 2005, presumably as an outcome of the very dry conditions that prevailed from 2005-2009. Parts of both Laanecoorie Reservoir and Cairn Curran Reservoir are expected to provide opportunities for foraging and to serve as important drought refuges; an illegal gill net that was recovered by Goulburn-Murray Water staff in the mid-1990s, after being abandoned on the banks of Cairn Curran Reservoir near Welshmans Reef Caravan Park, held the carcasses of 6-10 Platypus (confirmed through photographic evidence).

Tullaroop Creek from Tullaroop Reservoir to Laanecoorie Reservoir. Local residents have reported regularly seeing Platypus at a number of locations between Tullaroop and Laanecoorie Reservoirs up until about 2005, after which sightings declined or ceased. More recently, the species has been recorded as by-catch in fish survey nets set a short distance downstream of Tullaroop Reservoir (in 2008 and 2009), in and near Carisbrook (in 2011 and 2012), approximately midway between Carisbrook and Laanecoorie Reservoir (in 2011 and 2012) and about 2 km upstream of Eddington (in 2010) (D. Iervasi, in litt.). Elsewhere in the Tullaroop Creek catchment, Platypus have been seen since 2000 at sites along upper Tullaroop, Birch's, Creswick and McCallum's Creeks as well as Dean Reservoir, Newlyn Reservoir, Hepburn Lagoon and St Georges Lake.

Loddon River from Laanecoorie Reservoir to Serpentine Weir. Platypus have been seen since 2000 at a number of sites distributed from Newbridge to Serpentine Weir, with the most recent records (near Bridgewater) dating from 2013 and 2014. About half of informants reported seeing platypus on a regular or occasional basis.

4.4.1.2 Platypus in the Middle Loddon River

Loddon River from Serpentine Weir to Loddon Weir. Platypus appear to use this area, though the low number of sightings recorded since 2000 suggests that population density is not high. One animal was seen at Loddon Weir by a Goulburn-Murray Water worker in 2004, and a kayaker made another single sighting at Loddon Weir in 2009. The stretch of water impounded upstream of Loddon Weir is potentially large enough to support at least one breeding female during drought periods.

Loddon River from Loddon Weir to Kerang Weir. The only regular Platypus sightings in this area (i.e. consistent with the presence of resident animals) have been reported for the Kerang Weir pool near the shire caravan park in Kerang, where a Goulburn-Murray Water officer reported that up to two animals could often be seen feeding at dusk from the 1960s up until at least 2001 or 2002. The only other record since 2000 involves an animal seen on 2-3 occasions in the Loddon River west of Durham Ox in late 2003-early 2004. In addition, a Platypus was found dead in an irrigation water wheel located approximately 1 km west of the point where the Macorna Channel intersects the Loddon in the mid-1980s, and a live animal was reportedly seen on one occasion in the Loddon River at its confluence with Wandela Creek ("the Chute") in the early 1980s. The sporadic and short-term nature of these sightings suggests that animals were seen while travelling through the area as dispersing juveniles or possibly males searching for mates during the breeding season. Six landholders occupying long-established family properties with extensive river frontage at Appin South or Canary Island reported that they had never seen a Platypus on their land or heard of one being seen there by their fathers or grandfathers. Factors contributing to widely unsuitable habitat conditions for Platypus in this part of the Loddon River include a predominantly silt bed, channel depth that regularly drops below 1 m, seasonally poor water quality (e.g. low dissolved oxygen) insofar as this limits the availability of preferred Platypus food items such as caddis-fly and mayfly larvae, and lack of substantial pools to provide preferred feeding habitat and serve as refuges when discharge is low (McGuckin and Doeg, 2000, SKM, 2007).

Twelve Mile Creek. No reliable Platypus sightings or other records have been reported to date for Twelve Mile Creek, but the channel habitat is not likely to support resident breeding animals.

4.4.1.3 Platypus in the Lower Loddon River

Loddon River from Kerang Weir to Murray River. No reliable Platypus sightings or other records have been reported to date for the Loddon River downstream of Kerang Weir. Platypus habitat quality presumably has been adversely affected by siltation arising from the dredging of Pyramid Creek in the 1960s as well as subsequent de-snagging programs (McGuckin and Doeg, 2000, SKM, 2007). However, given that Platypus apparently occupied both the Kerang Weir pool and the Little Murray anabranch system into at least the early 2000s, it would be surprising if there was no associated use of the intervening stretch of the Loddon River.

4.4.2 Management objectives

Upstream of Loddon Weir.

Platypus management along the Loddon River between Cairn Curran Reservoir and Loddon Weir and Tullaroop Creek downstream of Tullaroop Reservoir should in the next decade primarily focus on providing suitable conditions (including adequate access to reliable refuge habitats during long drought periods) to support a viable breeding population across this area into the future. Apart from producing enough juveniles to be reliably self-sustaining, this population should also be viewed as an important source of surplus juveniles that are needed to help support the demographic and genetic integrity of adjoining Platypus populations located farther upstream in the Loddon River and Tullaroop Creek catchments and in Serpentine Creek. Over the longer term, it should also contribute suitable migrants to promote recolonisation of the Murray River and its anabranches downstream of Echuca, and thereby support development of a regional Platypus metapopulation occupying the Murray River and its tributaries from Echuca downstream to at least Swan Hill.

Middle and lower Loddon River downstream of Loddon Weir.

Platypus management along Twelve Mile Creek and the Loddon River downstream of Loddon Weir should in the next decade focus primarily on providing the flows and habitat conditions needed to support successful dispersal by juvenile Platypus between Loddon Weir and the Little Murray River, including animals that may enter this area via Pyramid Creek. The critical period for Platypus dispersal is believed to extend from (roughly) late April to June. Given the relatively lengthy distances involved, dispersal is most likely to succeed if the lower Loddon channel reliably holds water throughout its length during the predicted dispersal period (both to reduce predation risk and facilitate efficient travel) and adequate foraging opportunities are available to juveniles while en route. This second requirement may potentially be addressed most effectively by encouraging growth and recruitment of native riparian trees and shrubs (to help stabilise the banks and generate instream woody habitat) and also working to establish a series of sizable pools or backwaters along the channel over the longer term, e.g. by mechanically deepening proximal segments of selected floodrunners.

In addition, the Kerang Weir pool and the Loddon River channel downstream of Kerang Weir are appropriately viewed as habitats that could potentially support small breeding populations in their own right within the next 10 years if they don’t currently do so. Flow requirements on behalf of Platypus will generally align with those recently identified as benefiting other environmental assets along the Loddon downstream of Kerang Weir and Barr Creek (SKM, 2010b), with provision of occasional high winter flow events to increase the complexity of channel form and desilt pools likely to be a particularly high priority to improve the quality of Platypus foraging habitats.

4.5 Water rats

4.5.1 Distribution, status and limiting factors

The Australian water-rat (or Rakali) is very widely distributed across Australia (Watts and Aslin, 1981) but often appears to be relatively uncommon at a local scale (Smales, 1984, Smart *et al.*, 2011, Speldewinde *et al.*, 2013). Water-rat surveys have not been carried out to date in the Loddon River catchment downstream of Cairn Curran and Tullaroop Reservoirs. However, at least four animals were seen during site inspections carried out on 2-3 February 2015 by persons involved in developing this review document, including one fairly small (presumed juvenile) water-rat observed in the Loddon River at Rumbolds Road between Cairn Curran and Laanecoorie Reservoirs, and three individuals (including one very small juvenile) seen between Loddon Weir and the Kerang Weir pool. According to local residents, water-rats also continue to be sighted quite frequently in the section of the Loddon River located downstream of Kerang Weir (L. Rogers, pers. comm.).

4.5.2 Management objectives

The main objective of water-rat management in the Loddon River catchment downstream of Cairn Curran Reservoir and lower Tullaroop Creek should be to provide suitable conditions (including adequate access to reliable refuge habitats during long drought periods) to maintain a viable and widespread breeding population. Based on available (albeit very limited) evidence, the highest priority area for water-rats should be along Twelve Mile Creek and the Loddon River between Loddon Weir and the Murray River, i.e. the part of the catchment where recent sightings have been most numerous. Water-rats have plausibly both benefited from the large numbers of introduced fish species found in these water bodies and may ultimately help to control their proliferation through predation.

4.6 Macroinvertebrates

The macroinvertebrate community in the Loddon River downstream of Laanecoorie Reservoir is dominated by species that can tolerate relatively poor water quality and is typical of many lowland rivers in Northern Victoria (EPA, 2000, McGuckin and Doeg, 2000, EPA, 2008). The Loddon River between Cairn Curran Reservoir and Laanecoorie Reservoir and Tullaroop Creek between Tullaroop Reservoir and Laanecoorie Reservoir has a higher gradient, and more riffle type habitats than the reaches downstream of Laanecoorie Reservoir. As such the two most upstream reaches considered in this environmental flows study are likely to support macroinvertebrate communities that are more suited to faster flowing streams (McGuckin and Doeg, 2000). However, the macroinvertebrate communities in all reaches of the Loddon River have been affected by land-use changes. The most significant impacts have probably been mining activities in the upper catchment, clearing of the riparian zone and unrestricted stock access that have collectively delivered high sediment loads to the river, which have filled pools and smothered other potential macroinvertebrate habitats (Loddon River Environmental Flows Scientific Panel, 2002b).

Macroinvertebrate productivity and diversity is likely to decline during very low flow conditions as habitat becomes less available, but their short life cycles and an ability to disperse widely (many macroinvertebrates have flying adult life stages) means that most groups can quickly recover when conditions improve. The Middle Loddon River completely dried during the Millennium Drought and therefore did not support any macroinvertebrates for several years. No recent macroinvertebrate surveys have been conducted in the Loddon River and therefore the post-drought recovery has not been quantified. It is likely that most insect groups have re-colonised all reaches of the catchment, but several community members have provided anecdotal accounts that there are fewer shrimps and other crustaceans in the Upper and Middle Loddon River compared to the 1990's. The relatively low abundance of crustaceans is possibly due to a combination of their limited dispersal ability (i.e. they cannot disperse or recolonise via land or air) and the much lower abundance of *Phragmites* and other emergent macrophytes that provide important habitat for shrimp in particular.

4.6.1 Management objectives

The macroinvertebrate community in the Loddon River does not have high intrinsic value in its own right, but macroinvertebrates are an integral part of riverine foodwebs. They are an important food source for fish, Platypus and other aquatic biota and play a significant role in breaking down coarse particulate organic material, nutrient spiralling and other ecological processes (Wallace and Webster, 1996). Rather than setting a target condition for macroinvertebrate communities (e.g. to increase the abundance and diversity of families that are sensitive to low water quality), the aim in the Loddon River should be to maintain a diverse range of macroinvertebrate functional feeding groups to drive ecological processes and maintain or increase overall macroinvertebrate biomass to ensure it is sufficient to support higher order predators such as fish and Platypus.

4.7 Water quality

Environmental water is not intended to be used to ameliorate water quality problems associated with poor land management such as high nutrient concentrations due to livestock and the application of fertiliser, or other forms of pollution such as urban stormwater run-off. It will only be used to control natural water quality impacts that have been exacerbated by current flow regulation.

The main flow related water quality issues in the Loddon River are:

- High salinity, high water temperature and low dissolved oxygen concentrations during prolonged periods of very low flow; and
- The risk of hypoxic blackwater events following high flow events in summer.

4.7.1 High salinity levels during low flow periods

Most aquatic biota in lowland rivers can tolerate electrical conductivity levels up to 2,000 EC and many can tolerate up to 3,000 EC (Koehn and O'Connor, 1990). Based on those thresholds, it is apparent that high salinity during low flow periods is only an issue in those parts of the Loddon River that gain groundwater (i.e. the Loddon River and Tullaroop Creek upstream of Bridgewater, and the Loddon River immediately downstream of Loddon Weir – see Chapter 3). Groundwater often has moderate to high salt concentrations, but land clearing in the Bet Bet and McCallum Creek catchments has caused the groundwater in that part of the Loddon River catchment to become more saline over time. High salinity was a problem in the Loddon River downstream of Canary Island through the 1990s, but improved agricultural practices have lowered the water table through that reach and therefore the risk of high salinity in the future has reduced. Salt interception schemes in Pyramid Creek and Barr Creek have also reduced the salt contributions to the Lower Loddon River

The current area of greatest concern is Tullaroop Creek, where electrical conductivity rose to over 6,000 EC when flows fell below 10 ML/day during the Millennium Drought (see Figure 4-13). High electrical conductivity levels were also recorded at Laaneoorie and Turners Crossing in Reach 3a when flows were less than 20 ML/day (see Figure 4-13). Those results support observations by landowners in the Upper Loddon River who reported that water taken from the river during the Millennium Drought was very salty and scalded their crops. The high salinity levels in Tullaroop Creek represent the greatest risk because that reach supports River Blackfish, which are less tolerant of high salinity than native fish species found in other parts of the catchment. The salinity water quality objective will be to ensure that gaining reaches of the Loddon River have sufficient low flow to dilute saline groundwater and prevent electrical conductivity in the river from exceeding 3500 EC.

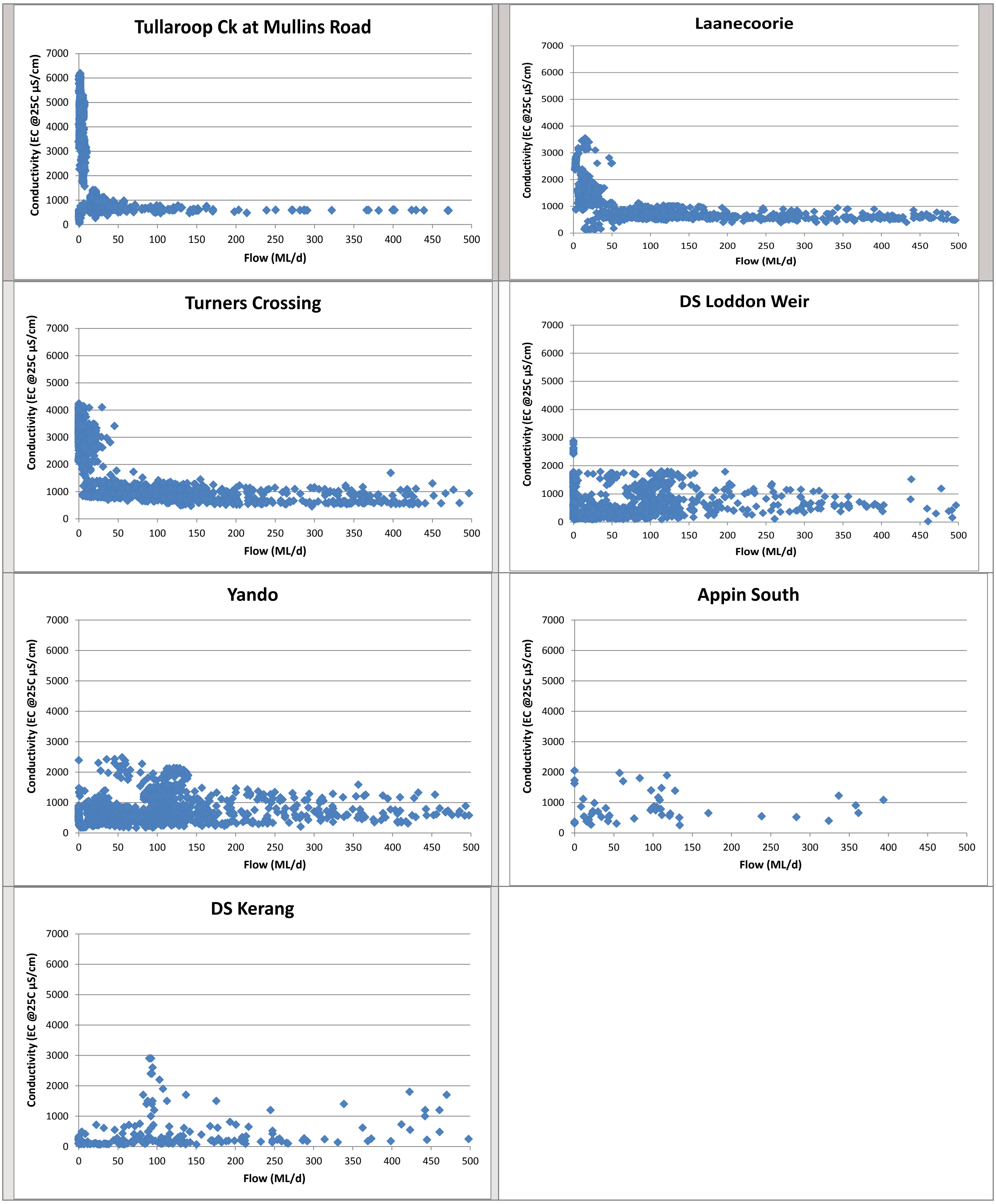

Figure 4-13: Plot of Electrical conductivity vs flow at selected sites in the Loddon River catchment. Plots show available data from 2005-2014. Flows greater than 500 ML/day have been excluded for graphing purposes.

4.7.2 Low dissolved oxygen and high water temperature during low flow periods

The main water quality issue at low flow is the potential for pools to become too hot and de-oxygenated. Pools throughout most reaches of the Loddon River are much smaller than they would have naturally been. Small pools are more susceptible to poor water quality simply as a function of their volume. They can heat up and cool down quicker than large pools and small amounts of decaying organic matter can deplete oxygen levels. Clearing of the riparian zone has exacerbated these risks, especially temperature fluctuations, because without an adequate canopy of riparian trees the river channel is subject to hours of direct sunlight. Poor water quality is mainly an issue under very low flow or cease-to-flow conditions and therefore these risks can be ameliorated by providing adequate flow throughout the reach for as long as possible each year.

Dissolved oxygen concentrations naturally drop under low flow conditions, because the lower rate of water movement means that the water column is not mixed as thoroughly and less of the water has direct contact with the air. Lower dissolved oxygen concentrations are also expected in summer, because warm water cannot hold as much oxygen as cool water. Aquatic biota in lowland rivers are adapted to cope with seasonal variations in oxygen concentration, but few aquatic animals can cope with very low dissolved oxygen concentrations. Many aquatic biota become stressed when dissolved oxygen concentrations fall below 4 mg/L and some die when concentration drops below 2 mg/L (Koehn and O'Connor, 1990).

Dissolved oxygen concentrations fall to potentially dangerous levels for aquatic biota in Tullaroop Creek and immediately downstream of Loddon Weir when flow drops below approximately 5 ML/day (see Figure 4-14). There are no known reports of widespread fish kills associated with low dissolved oxygen under very low flow conditions in these reaches though.

Very low dissolved oxygen concentrations have been recorded at higher flows in the reach between Loddon Weir and Twelve Mile Creek (see plots for DS Loddon Weir and Yando in Figure 4-14), but those records may be associated with anoxic blackwater events which are discussed in Section 4.7.3.

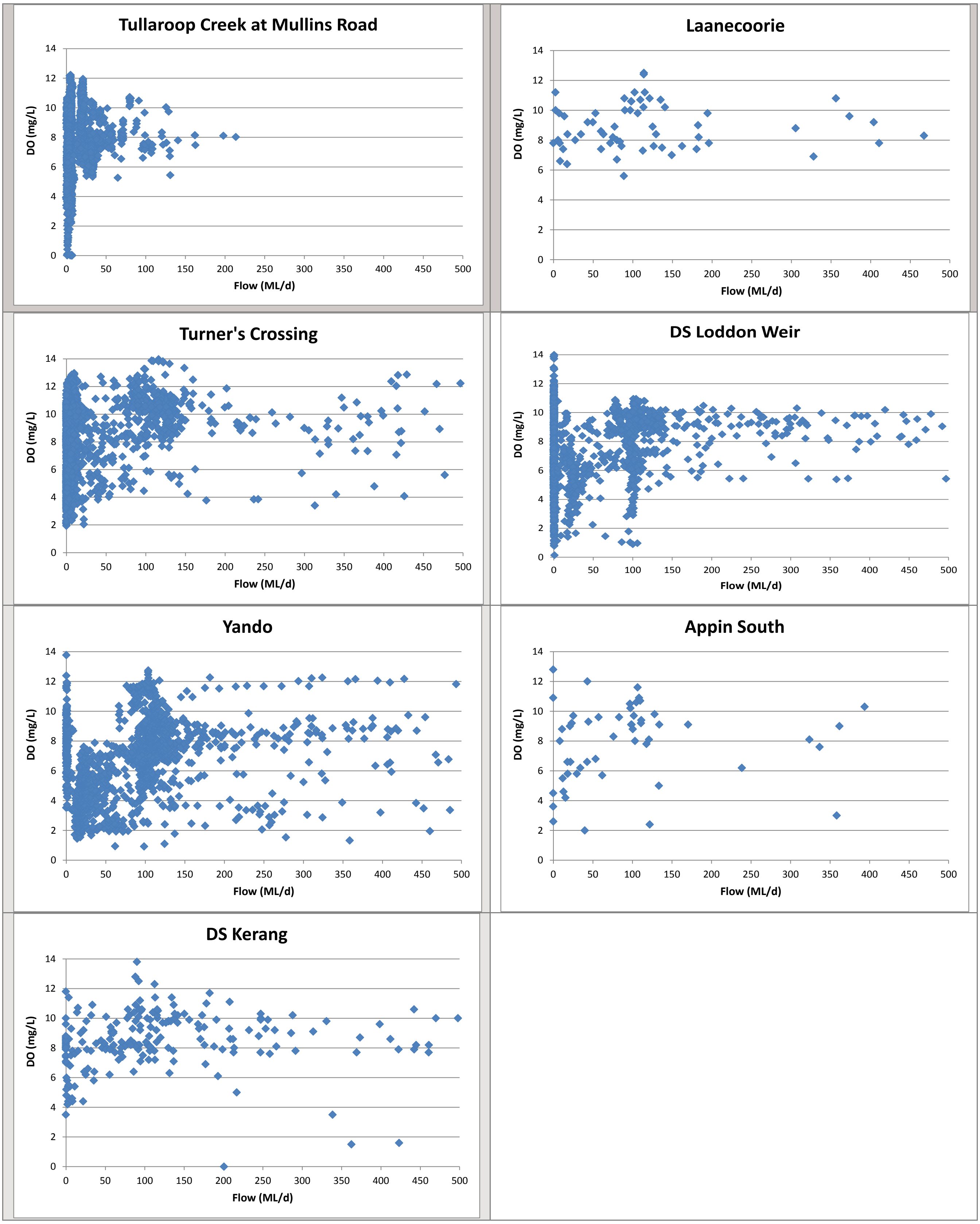

Figure 4-14: Plot of dissolved oxygen concentration vs flow at selected sites in the Loddon River catchment. Plots show available data from 2005-2014. Flows greater than 500 ML/day have been excluded for graphing purposes.

4.7.3 Hypoxic blackwater events

Hypoxic blackwater events are characterised by high levels of dissolved organic carbon (DOC), which lead to low dissolved oxygen (DO) in the water column and potentially widespread fish and crustacean death (Hladyz *et al.*, 2011). **Blackwater events are a natural feature of floodplain systems and events that discolour the water without severely depleting oxygen concentrations are of no consequence. Moreover, high flows that regularly wash leaf litter and other organic matter into the river system are needed to provide a carbon source (i.e. food and energy) for riverine foodwebs. Without a regular supply of leaf litter, the abundance of macroinvertebrates, fish, Platypus and other consumers in the Loddon River will decline.** The only blackwater events of concern are those that create hypoxic conditions and kill fish and other aquatic biota.

Hypoxic blackwater events usually occur when ephemeral streams with high loads of leaf litter and other organic matter are inundated or when high flows in permanent streams wash large amounts of accumulated leaf litter from the banks and floodplain into the main channel. Microbes rapidly consume the carbon and their respiration depletes the oxygen concentrations in the water column. The most severe blackwater events occur when large amounts of carbon are washed into the river during summer, because warm water temperatures increase the rate of microbial activity and therefore respiration. Hypoxic blackwater events occurred in the Loddon River downstream of Loddon Weir in February 2004, February 2006 and December 2006. Two of those events were associated with an accidental spill or unscheduled release of between 75 ML/day and 120 ML/day from the Loddon Weir, and the third event was associated with a scheduled environmental flow release of 50 ML/day for 14 days from Loddon Weir following another very dry period (SKM, 2008a). In all cases, the flow magnitude was not very large, but followed a prolonged period of very low or no flow. Managing the risk of hypoxic blackwater events in the future is a high priority.

4.7.4 Other water quality issues

During the Millennium Drought, potential Acid Sulfate Soils (ASS) were identified in the Loddon River downstream of Loddon Weir, and the 2009 environmental flow study discussed actions that may need to be taken to manage that risk (SKM, 2010c). The 2011 floods eliminated the risk at that time and given that improved agricultural practices have lowered groundwater levels in the Middle Loddon River, the risk of ASS forming in the foreseeable future is low. For that reason, this document does not include specific objectives to manage risks associated with ASS.

Some community members noted that stormwater run-off from Kerang reduced water quality in the Kerang Weirpool and was likely to affect water quality downstream of Kerang Weir. We acknowledge that urban stormwater impacts are a real threat to the health of the Lower Loddon River, but the risk should be managed by better control of stormwater rather than environmental flows.

5. Conceptual understanding of the water requirements of environmental values

5.1 Geomorphology

Flow regime and the size of particles moved by different magnitude flow events have a fundamental effect on river geomorphology. The most important flow components for geomorphological processes are bankfull flows and very low flows:

- Bankfull flows generate the highest shear stress and energy within the river channel and depending on the gradient of the stream can move substrate elements ranging from gravels to large stones and rocks. Bankfull flows scour pools in the bottom of the channel and deposit sediment on benches. River regulation has reduced the frequency of bankfull flows in the Loddon River, which means that pools are not scoured as often as they would have naturally been and benches are not replenished. That reduction in frequency, combined with increased sediment inputs from local bank erosion and other land clearing activities in the broader catchment, have caused pools in the Loddon River to gradually fill with sediment. As a result, the river channel is more homogenous than it would have naturally been and there are much fewer high quality refuge habitats for fish, Platypus and other biota during low flow periods.
- Very low flows have the least amount of energy and therefore fine silt often accumulates on the streambed, submerged wood and emergent macrophytes during prolonged periods of low flow. Relatively regular increases in flow magnitude are needed to flush that fine silt from submerged surfaces, and therefore maintain their ability to support a variety of biological processes (see discussions in subsequent sections of this chapter).

5.1.1 Geomorphological flow requirements for the Loddon River

The geomorphological changes that have occurred in the Loddon River since river regulation are probably too great to repair through environmental flows. The low gradient of the Middle and Lower Loddon River means that even under bankfull flows, the shear stress in the channel will not be sufficient to re-create the deep pools that have filled with sediment. Despite that limitation, bankfull flows will be important in limiting further infilling of pools, replenishing benches and bars in the channel and creating localized scour around submerged logs and other structures. High flows will also be needed several times per decade to inundate secondary flow paths (e.g. flood-runners and anabranches) to maintain their dimensions and to prevent them being dominated by terrestrial plants. Regular summer freshes and similar sized winter flows will also help to clean fine silt from substrates to support ecological processes.

5.2 Vegetation

Figure 5-1 and Figure 5-2 shows conceptual models of the way in-stream submerged or floating vegetation, emergent non-woody fringing vegetation and woody riparian vegetation respond to variations in flow in the Loddon River. The first model (Figure 5-1) shows a holistic view of the river and its floodplain: the second model (Figure 5-2) focuses on in-stream aquatic vegetation.

The model shows that in-stream vegetation may be limited by a number of factors:

- Water clarity: water that is too turbid or coloured limits the depth to which plants with submerged leaves can grow. In contrast, species with floating leaves may not be excluded from even highly turbid waters, as their photosynthetic organs are exposed to sufficient light at all times of the day to maintain a positive carbon balance.
- Water depth: water that is too deep, especially if it is turbid or coloured, will not support submerged taxa. Conversely, prolonged dry periods will see the extent of in-stream vegetation retract, notwithstanding the likely ability of plants to recolonise areas once wetter conditions return.
- Water velocity: fast-flowing water may physically uproot submerged plants, many of which have only a poorly developed root system (since they obtain their nutrients from the water column).

- Substratum: dense clay sediments may be largely impenetrable to plant roots; conversely, sandy sediment may be too unstable to allow plants to establish.
- Source of propagules: for plants to establish in a given area there must be a source of propagules, either as seed (which can be brought in via water, wind, or on animals) or as plant fragments (usually brought from upstream, via flow).
- Grazing pressure: the consumption of plants, by aquatic animals (e.g. carp), birds (e.g. swans), stock (e.g. cattle) or pest species (e.g. rabbits) may limit the biomass of in-stream submerged and fringing vegetation that accrues over time.

Fringing and riparian woody and non-woody vegetation may be affected by a similarly broad suite of environmental factors. Because they have aerial photosynthetic organs, these vegetation groups are not strongly affected by water clarity. They are, however, very susceptible to herbivory, especially by domestic stock. Aquatic taxa are often softer and more palatable to stock than are terrestrial plant species; and the seedlings and young plants of even woody riparian taxa are often eagerly consumed by herbivores. Successful recruitment of young plants into the population is therefore almost always contingent upon the control of grazing pressures (either by native animals, such as kangaroos and wallabies; feral species, such as rabbits; or domestic stock such as cattle).

There is now a robust literature on the way that different water-dependent groups of plants, and in some cases even specific taxa, respond to different water regimes (e.g. Ganf *et al.*, 2010, Roberts and Marston, 2011, Rogers and Ralph, 2011). Existing information is limited to a relatively small number of well-studied species, and it is often necessary to infer optimal water regimes for broad plant groups (Brock and Casanova, 2000, Rogers *et al.*, 2012). The pattern of fringing woody and non-woody vegetation is controlled not only by water regime, but by the interaction among water regime, elevation (e.g. up a bank) and small-scale variations in topography (Raulings *et al.*, 2010). The interaction between flow and landscape topography creates a mosaic of wetting and drying regimes at a wide range of spatial scales in the riparian zones that fringe a stream, and different types of fringing vegetation are variously advantaged or selected against by this subtle suite of hydrological conditions.

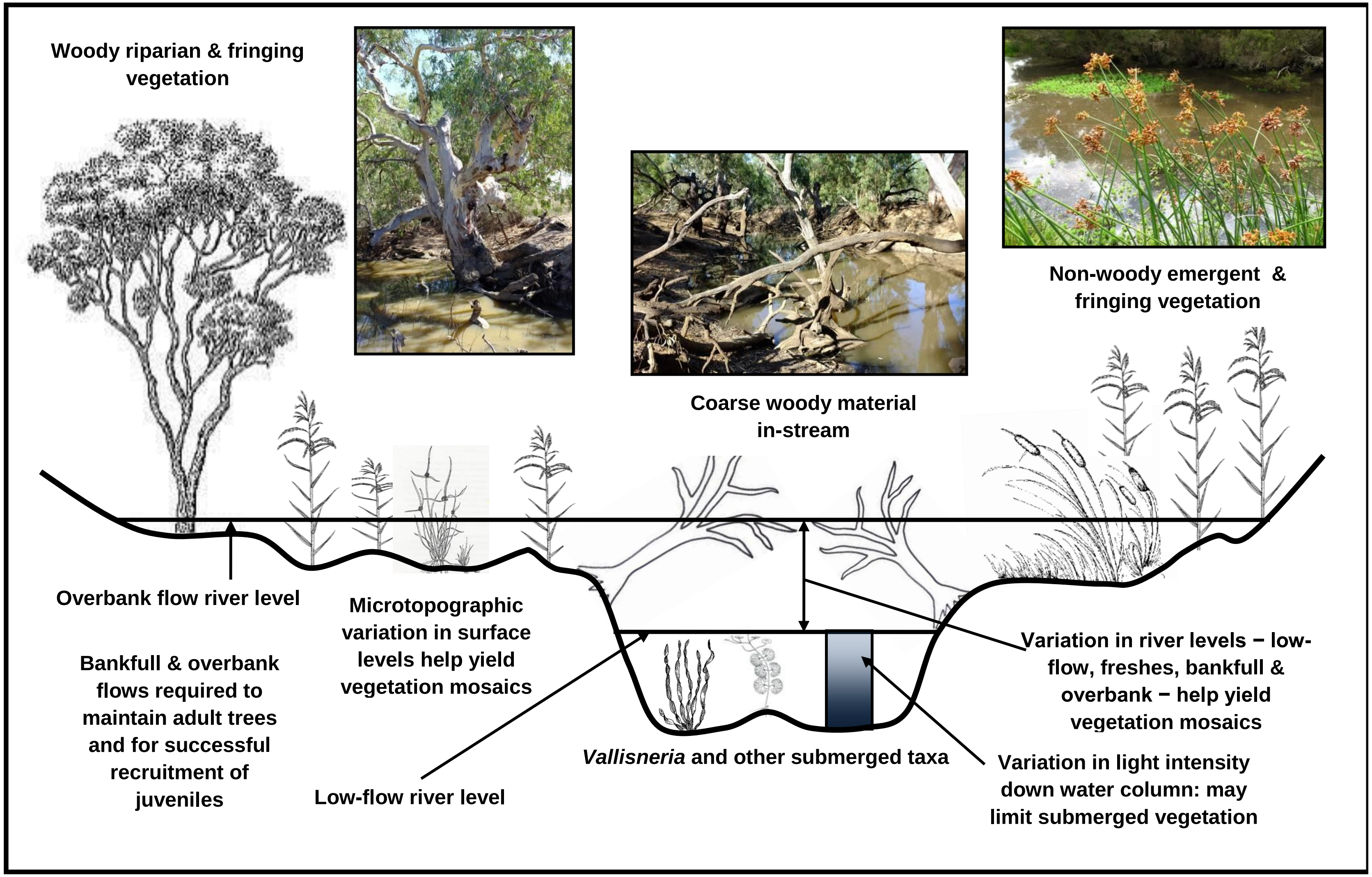

Figure 5-1: Conceptual model of the relationship among water dependent vegetation, flows, and land-use practices in the Loddon River.

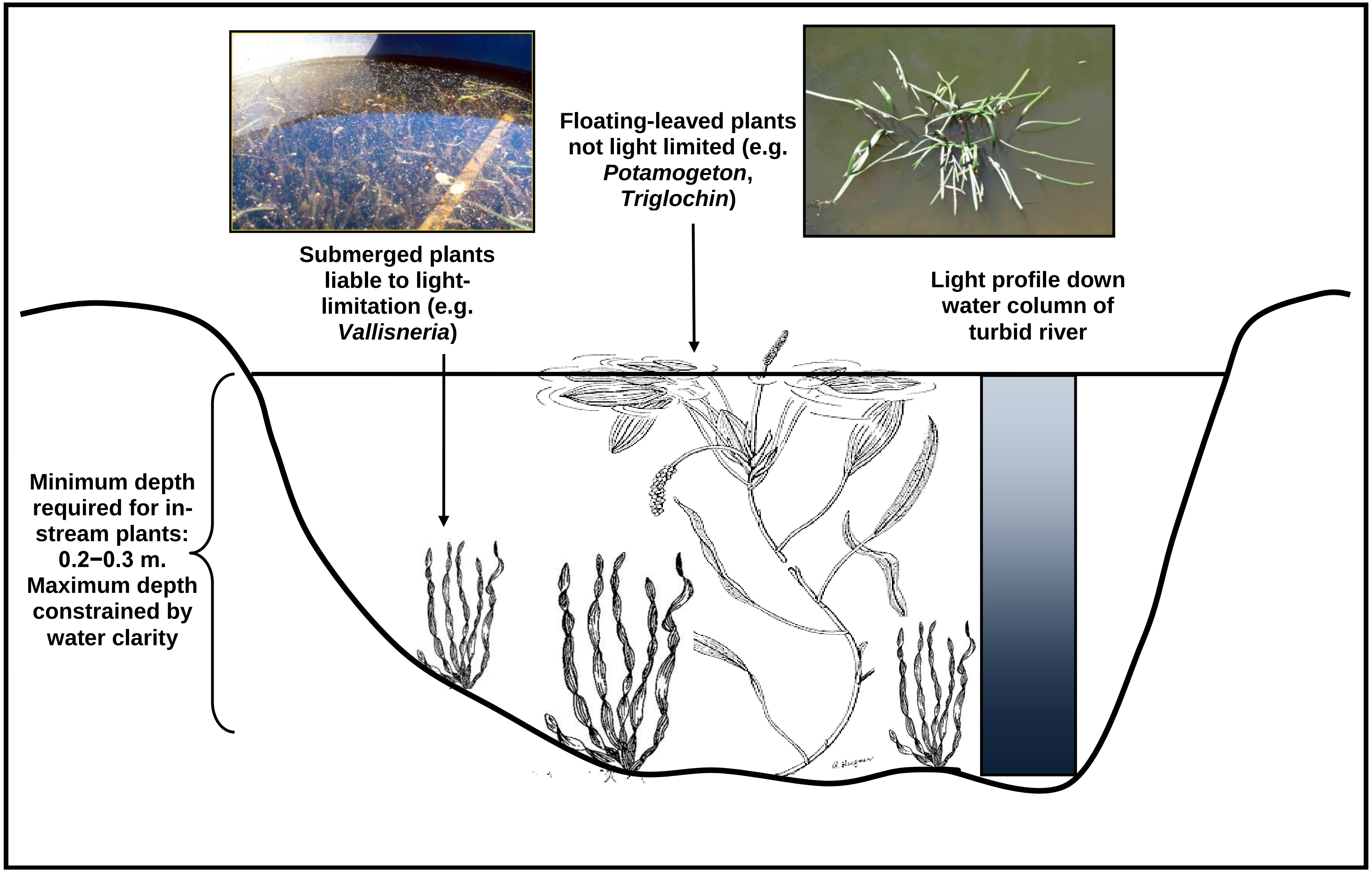

Figure 5-2: Conceptual model of the relationship among in-stream aquatic vegetation, flows, and water quality in the Loddon River.

5.2.1 Summary of flow requirements for aquatic and riparian vegetation

The hydrological requirements for in-stream plants, emergent non-woody plants and riparian woody plants are reasonably well known (see reviews in Roberts and Marston, 2011, Rogers, 2011). The specific requirements for some representative groups that occur in the Loddon River are described below:

- Submerged angiosperms require annual flooding, typically of 50−100 cm, for prolonged periods. Many can withstand temporary drying, either because they possess desiccation-resistant organs (e.g. the turions of *Triglochin procerum*) or the surface layer of masses of drying leaves protects the still-living plants near the sediments (e.g. *Vallisneria australis*).
- Reeds, *Phragmites australis*, are a focus because they are common in the steam-side zone and provide valuable habitat. *Phragmites australis* has one of the widest hydrological niches of all riparian plants, and typically grows best under fluctuating water levels, in water up to 2 m deep. Adults can withstand prolonged inundation (if some vegetative material remains aerial), but also prolonged dry periods.
- Rushes and sedges are a floristically diverse group but typically require annual inundation for 2−4 months over spring to summer in water up to ~ 30 cm deep. Some taxa are advantaged by inundation in late winter or early spring (e.g. *Bolboschoenus fluviatilis*) whereas others (e.g. *Eleocharis spacelata*) will mainly benefit from flooding in late spring or early summer when temperatures are warmer. Other taxa require near-permanent inundation (e.g. *Typha* spp.) and some more terrestrial conditions (e.g. *Poa* spp.). The ecological consequence of these various hydrological requirements in the rushes and sedges is that mosaics of vegetation can be expected, in time and in space, according to wetting and drying regimes.
- In the Loddon River system, River Red Gum is the riparian tree species of most interest, although a number of other genera in the family Myrtaceae also occur along the stream sides (e.g. *Callistemon* spp.). Lignum is also an important component of the riparian zone in the Middle and Lower reaches of the Loddon River. The water requirements of River Red Gum are well known, with variations in flooding intensity and duration prompting a shift between forest and woodland plant assemblages. Unlike many taxa of aquatic and riparian plants (Hatton *et al.*, 2008), River Red Gum is not clonal and recruitment requires floods in spring or summer, with plant establishment thought to be maximized if floods occur in consecutive years. Roberts and Marston (2011) and Rogers (2011) detail the hydrological requirements of River Red Gum in terms of i) the maintenance of adult specimens, and ii) successful sexual recruitment.

The instream and riparian vegetation communities of the Loddon River have the following general water regime requirements:

- Permanent of near permanent low flows to maintain pool habitats for aquatic floating or submerged plants and to prevent terrestrial plants from encroaching far into the main channel. Most aquatic plants that naturally occur in the Loddon River can tolerate short dry periods as long as their root zones are protected. Cease-to-flow events would not be deliberately applied for any purpose, but the aquatic plant community is likely to cope with natural cease-to-flow events as long as they do not last too long and as long as permanent refuge pools hold water during those periods.
- Variable water levels during low flow periods are needed to wet and dry substrates (e.g. wood, emergent macrophyte stems and patches of the streambed) that are likely to support biofilms and periphyton. Regular wetting and drying patterns will increase biofilm and periphyton productivity and increase the amount of habitat within the photic zone that biofilms can colonise.
- Seasonal variation in water levels (i.e. spring flows that are higher than summer flows, and short duration freshes in summer and spring) to promote a mosaic of woody and non-woody vegetation in a wide zone on the lower banks of the channel and on low benches and bars. High flow events will also water the roots of plants growing higher up the bank. High flows in winter will have little effect on vegetation because they will be outside the main growing period.
- High flows or floods in spring to water and maintain established riparian trees (such as River Red Gum) and facilitate new recruitment of those species high on the bank and in flood-runners. Such floods are only needed 2-4 times per decade to maintain existing riparian vegetation, but events may be needed in successive years to ensure successful recruitment because juvenile River Red Gums may die if they are not watered in their second and third year

5.3 Fish

Baumgartner *et al.* (2014) divided the freshwater fish of the Murray Darling Basin into four broad groups based on physiological and behavioural similarities that can be linked to flow:

- **Long lived apex species (e.g. Murray Cod and Trout Cod).**

  These species do not require a large flow event to trigger spawning, but high flows during the spring spawning season can increase spawning and recruitment success by inundating more spawning habitat than would be available at low flows, promoting dispersal, allowing recolonisation of main channel habitats where fish may have been lost and providing temporary connections between the main channel and off channel habitats. Apex species may temporarily move into off channel habitats during floods, but more importantly, flows that connect the main channel with off channel habitats will flush carbon and nutrients from the floodplain into the river channel, which will in turn drive foodwebs and increase available food for larval and juvenile fish (King *et al.*, 2009).

  The main environmental flow recommendations for these species include adequate low flows throughout the year to maintain the quality and quantity of in-channel habitats (i.e. maintain deep pools and inundate woody debris) and high flows in spring to inundate potential spawning habitats, allow movement and increase food for developing fish. An appropriate flow regime is likely to facilitate some natural breeding and recruitment in the stocked Murray Cod populations in the Upper Loddon River. An appropriate flow regime downstream of Loddon Weir should also increase breeding of resident populations of Murray Cod and provide opportunities for sub-adult fish to move into the Loddon River from the Murray River system.

- **Flow dependant species (e.g. Golden Perch and Silver Perch).**

  Pulses of high flow are needed to generate a spawning response in flow dependent species. Golden Perch and Silver Perch are not expected to have high rates of spawning in the Loddon River, but adults in the Middle and Lower Loddon River may move downstream in response to high spring flows to spawn in the Murray River. The larvae of Golden Perch and Silver Perch are considered obligate 'drifters' that have some control over how and where they drift (Humphries and King, 2004). Larvae and juveniles from Loddon River populations are likely to settle in the Murray River, where they develop. Sub-adults then undertake large-scale upstream migration back into the Loddon River and other tributaries in response to high autumn flows.

  Flow dependent species are not expected to spawn and naturally recruit in the Loddon River upstream of Loddon Weir because they cannot negotiate the artificial barrier, and therefore no specific flows are recommended for Golden Perch and Silver Perch in the Upper Loddon River. Populations in all reaches downstream of the Loddon Weir are potentially connected to the Murray River and therefore flows that facilitate spawning and migration of flow dependent species is a high priority for the Middle and Lower Loddon River. Flow dependent fish species in those reaches will require minimum flows throughout the year to maintain pool habitats and inundate woody debris in the channel to provide permanent habitat and high flows in spring and autumn. The spring high flow needs to significantly increase water depth and water velocity. Its main function will be to trigger pre-spawning movement by adult fish and spawning. The autumn high flow is needed to trigger 1+ year old fish to move from the Murray River into the Loddon River and to facilitate passage across natural and small artificial barriers.

- **Foraging (opportunistic) species (e.g. Australian Smelt, Bony Herring, Murray-Darling Rainbowfish, Unspecked Hardyhead, Carp Gudgeon, Flathead Gudgeon and River Blackfish).**

  Opportunistic foraging species have more flexible spawning and recruitment strategies than flow dependent or apex species. Many of these species rely on shallow slackwater habitats at the margin of the river channel for their developing larvae and juveniles and therefore spawn mostly during predictable summer low flow periods (Humphries *et al.*, 1999). The slackwater habitats support zooplankton and macroinvertebrates that developing larvae feed on and also provide a refuge from fast flows and predators. Other than River Blackfish, these species do not have a rigidly defined breeding season and will generally spawn when conditions are suitable. Moreover, some opportunistic species may spawn multiple times in a year. The critical flows for these species are low flows that maintain suitable pool habitats and adequate food supplies (usually macroinvertebrates) at all times for adult fish and that maintain slackwater habitats for long enough to allow larvae and juveniles to develop into competent swimmers. Winter low flows and summer freshes that increase connectivity within and between river reaches are also likely to be important in helping fish disperse and replenish populations throughout the river system. These higher flows are particularly important following droughts or other disturbances because they will help opportunistic species disperse from refuge habitats and re-colonise areas where populations may have declined.

River Blackfish are particularly susceptible to habitat degradation, especially the loss of snag habitat and sedimentation of pool habitats. They do not require specific flows to trigger migration or spawning, but moderate to high flows in spring may help flush fine sediment from hollow logs that River Blackfish use as nesting sites, and relatively stable flows through summer may reduce the likelihood that developing larvae will be swept out of those nests. The species is considered relatively sedentary (Koehn, 1986), although Koster and Crook (2008) found that several fish used inundated riparian areas during a flood and two fish made rapid, large movements coinciding with the elevated flows. River Blackfish also move into riffle areas at night to forage and therefore adequate flows are required to allow access to these habitats.

- **Floodplain specialist species (e.g. Southern Pygmy Perch, Murray Hardyhead and Flat-headed Galaxias).**

  Floodplain specialists typically inhabit backwaters and floodplain wetlands and are susceptible to any changes to the flow regime that reduces the frequency of high flow events that wet those habitats and allow them to dry out. There are very few floodplain wetlands that are connected to the Loddon River frequently enough to support many floodplain specialist fish species and therefore they are not considered a high priority for this environmental flows study.

5.3.1 Summary of fish flow requirements

The relative size and timing of flow events required to support each of the four groups of native fish that are likely to occur in the Loddon River are summarised in Figure 5-4. Long lived apex species and flow dependant species have been pooled under the same hydrograph as both of these guilds are likely to benefit from high flows that last for up to three weeks (minimum of 5-10 days at peak) in spring and autumn (Baumgartner *et al.*, 2014), even though each guild may have slightly different responses or different levels of need for each flow. Opportunistic foraging species require relatively stable flows during the late spring to early autumn breeding season, with occasional small to moderate flow increases that will improve water quality and provide temporary access to new habitats and food, without flushing juveniles or larvae from slackwater habitats. It is difficult to accommodate the flow requirements of floodplain specialists in rivers such as the Loddon River because there is often not enough environmental water or suitable infrastructure to create overbank floods and the unintended consequences of flooding private land are too great.

The recommended flow requirements do not need to be delivered for all fish guilds in all years. Long-lived apex and flow dependent species probably need high spring and autumn flows approximately five out of every 10 years, as long as there is no more than three consecutive years (Baumgartner *et al.*, 2014). Foraging generalist species will have varying levels of recruitment each year and need approximately three very good recruitment years per decade to maintain populations.

Species with different strategies can exist in the same reaches of rivers, since different conditions, both spatial and temporal, provide advantages for one strategy over another. Thus, Murray Cod, a long-lived apex species , Golden Perch, a flow-dependent species, and Australian Smelt, an opportunistic species, can all persist in relative abundance in the same reach of a river. Larger apex and flow-dependent species are able to move to more favourable habitats if conditions are not optimal. Opportunistic species are smaller and less able to move large distances, but, over time, can recolonise new areas. For fishes in highly variable, unpredictable inland rivers, mobility is a necessity for continued persistence (Puckridge *et al.*, 1998).

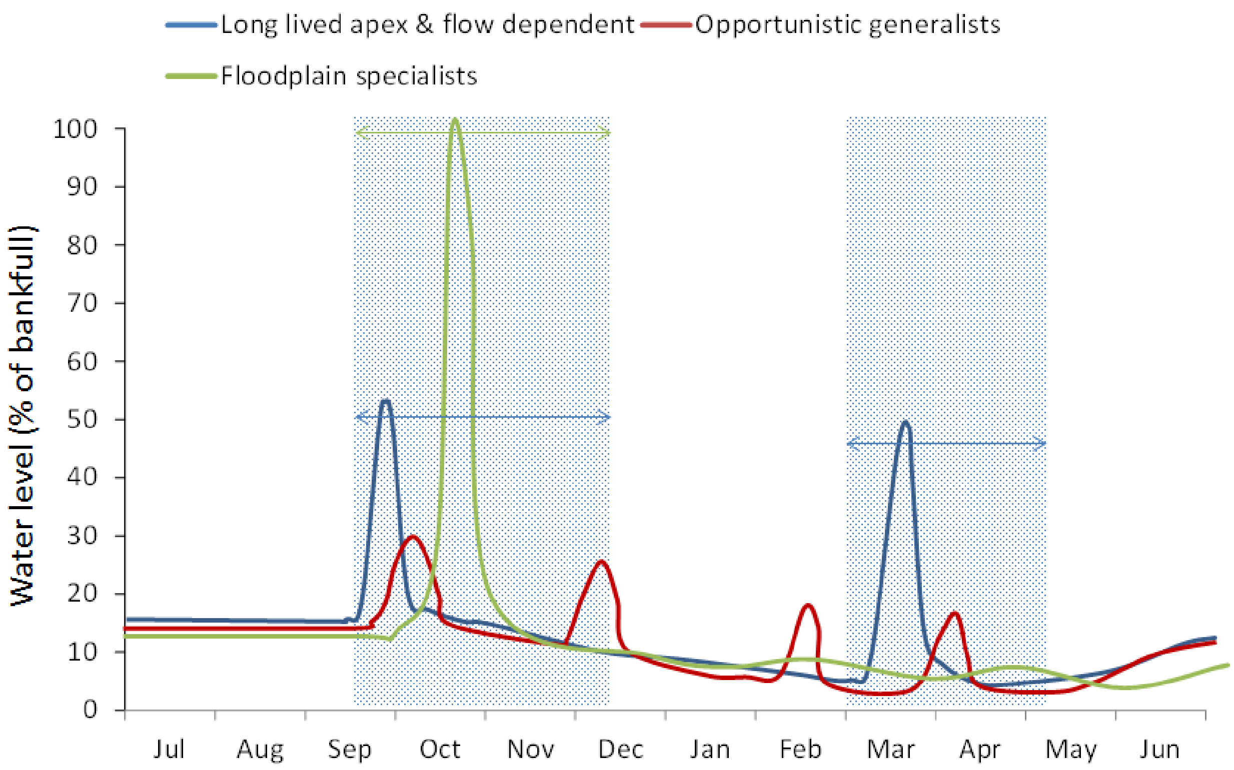

Figure 5-4: Schematic hydrograph showing the flow requirements for the main groups of native freshwater fish that are likely to be found in the Loddon River. Shaded areas indicate the suitable windows of time for the spring and autumn high flows and overbank flows. Note that long-lived apex and flow dependent species have been pooled under the same hydrograph.

5.4 Platypus

The Platypus feeds exclusively in the water on a broad range of benthic macro-invertebrates, though caddis-fly larvae characteristically comprise a large proportion of its diet (Faragher *et al.*, 1979, McLachlan-Troup *et al.*, 2010). To remain in good condition, non-breeding adults must ingest the equivalent of about 15-30% of their body mass in food each day, rising to as much as 80% of body mass when females are lactating (Holland and Jackson, 2002, Krueger *et al.*, 1992). Breeding is therefore limited to reliably perennial aquatic habitats supporting productive macro-invertebrate populations. The Platypus's very substantial food requirements also means that animals typically need to travel long distances each day while feeding, with adult female and male home ranges respectively encompassing up to 4.5 and 15.1 km of channel (Gardner and Serena, 1995b, Serena *et al.*, 1998). At a finer scale, in-stream habitat features that are positively associated with foraging activity include relatively coarse inorganic substrates, relatively slow-flowing pools, stably undercut (or notched) banks, and submerged woody debris and leaf packs (Grant *et al.*, 2004, McLachlan-Troup *et al.*, 2010, Serena *et al.*, 2001). Foraging mainly occurs at a depth of 1 to 3 metres, though occasionally down to nearly 9 metres (Bethge *et al.*, 2003, Grant *et al.*, 2004). The animals are believed to limit their use of shallow water mainly to reduce the risk of being attacked by predators such as foxes and the larger birds of prey (Serena and Williams, 2010). Platypus are particularly likely to be preyed on when forced to leave the water, e.g. to access disjunct feeding areas along intermittent water bodies (Grant and Temple-Smith, 1998). Similarly, lactating females and their offspring become vulnerable to predators if a substantial gap develops between the water's edge and nursery burrow entrances in the period from spring through about the end of February (Grant *et al.*, 2004).

Although adult Platypus generally survive flooding, flood-related mortalities can occur (Connolly *et al.*, 1998, Serena and Williams, 2010). More importantly, major flooding can severely reduce Platypus reproductive success. Platypus preferentially build nursery burrows in high banks adjacent to reliably deep pools. The burrow entrance is typically just below the low flow water level, with the height of the nesting chamber ultimately constrained by bank height. Females will try to place the nesting chamber containing their offspring high enough to withstand most high flow events, but there is an energy cost associated with excavating large and long burrows and therefore it is possible that animals will use recent flow history to determine how high their burrows need to be.

A lactating female blocks the entry tunnel of her nursery burrow with a series of consolidated soil ‘pugs’ when it houses young juveniles, presumably to help protect them from drowning if water levels rise (Burrell, 1974). This practice is predicted to work best in the case of floods that have a relatively short peak of 12-24 hours, because females need to breach pugs when they exit to feed themselves and when they return to feed their young. Females stop making pugs when juveniles become old enough to leave the burrow and begin foraging. Juveniles are initially not very competent swimmers so bankfull or near-bankfull flows that occur from late December to at least mid-February can cause high mortality (Serena and Williams, 2010, Serena *et al.*, 2014). For example, following a major flood event in early February 2005, the mean juvenile capture rate recorded in Melbourne streams was less than 10% of the corresponding mean capture rate from 2001-2004 (Serena and Williams, 2010). In addition, fast and/or turbulent flows can reduce Platypus foraging efficiency by making it more difficult for animals to detect and capture prey (Grant and Bishop, 1998). Platypus living along the Goulburn River increased their use of backwaters when irrigation water was being released from Lake Eildon in high-flow periods (Gust and Handasyde, 1995). Figure 5-5 presents a series of schematic diagrams showing how the size and timing of high flow events may threaten juvenile Platypus.

Platypus population size is predicted to drop through the course of severe droughts as an outcome of multiple adverse effects. Firstly, as sections of a river dry up, animals occupying those areas will either starve as surface water disappears or shift their home range to use alternative foraging habitats remaining in the vicinity, thereby reducing food resources for individuals previously occupying those habitats. Mortality due to predation is also expected to rise as animals are increasingly forced to search for food in shallow water and/or regularly move across dry land, e.g. to travel between remnant pools or from these pools to burrow sites in the banks. As an outcome of these and related changes, juvenile recruitment – either as an outcome of local reproduction or via dispersal from more perennial habitats that may remain elsewhere in the catchment – will also inevitably decline. In the absence of adequate recruitment, population size will also be progressively reduced as senescing individuals fail to be replaced, with the median and maximum ages of Platypus living near Melbourne respectively estimated to be 6 and 14+ years (Serena *et al.*, 2014). In practice, the very severe impact of the Millenium Drought on the Loddon catchment – compounded by presumed widespread reproductive failure in 2010 and 2011 as an outcome of major summer flood events – means that the number of Platypus occupying the Loddon catchment in 2012 is conservatively estimated to have dropped to $\leq$15% of the number of animals present in the late 1990s, i.e. in the order of perhaps 200-250 individuals. Assuming that females typically breed for the first time at the age of 2-4 years (Grant *et al.*, 2004), that litters normally comprise 1-2 juveniles (Burrell, 1974) and that less than half of breeding age females reproduce successfully on average in any given year (Grant *et al.*, 2004), the Platypus population in the Loddon catchment may well require a decade or even longer to recover completely.

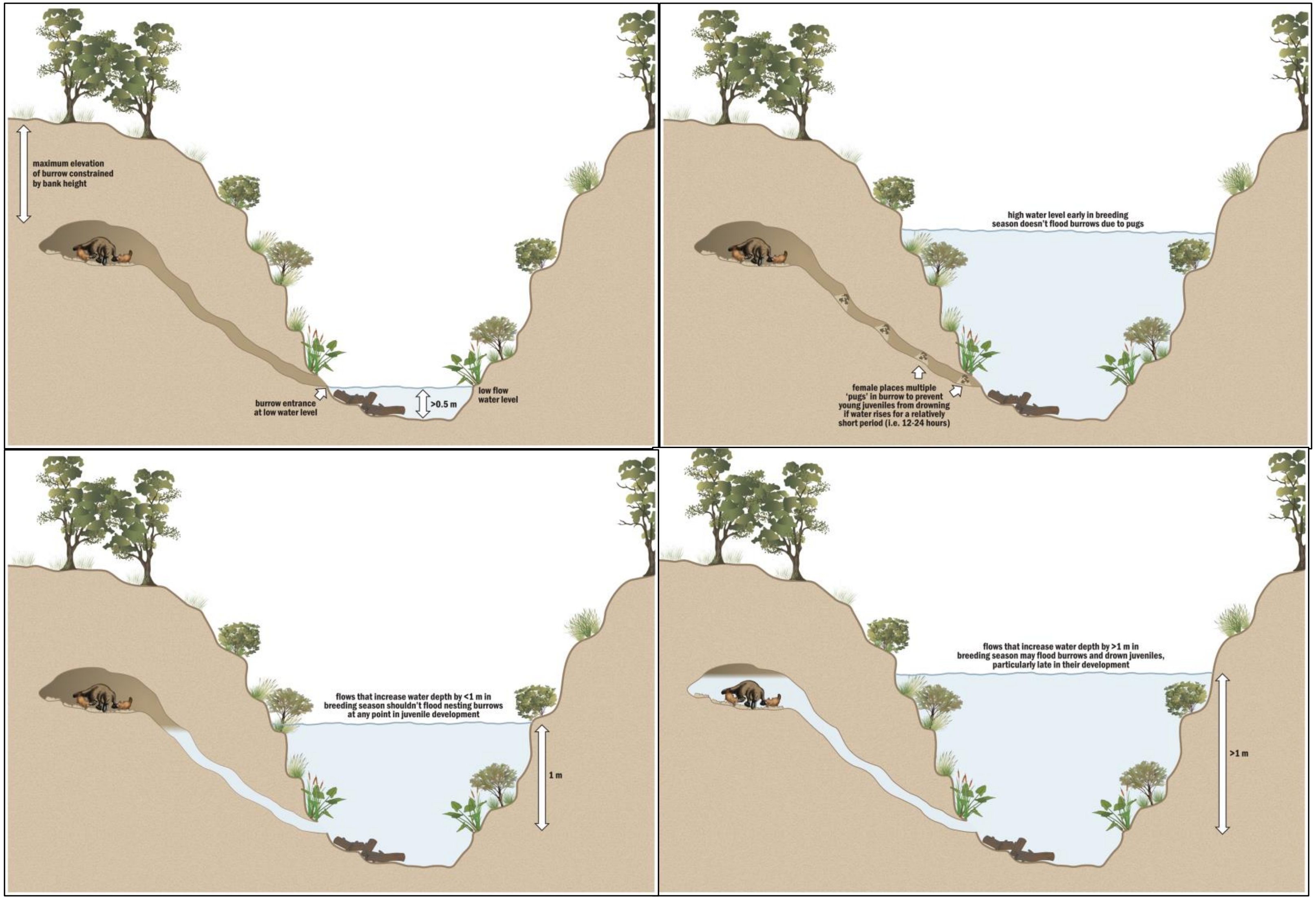

Figure 5-5: Schematic diagram showing the position of Platypus breeding burrows in the river bank and how the size and timing of high flows and floods can affect survival of young.

5.4.1 Flow requirements for Platypus

Platypus flow requirements are expected to align closely with those for macro-invertebrates (given that successful breeding by this species requires access to an ample food supply through most of the year), geomorphological processes that help to create and maintain diverse channel habitat features (particularly pools), and vegetation (to provide protective cover from predators and a source of in-stream woody habitat). In addition:

- Flows should be high enough throughout the year to minimise the likelihood that resident Platypus are killed by predators (particularly foxes), and to provide a corridor for safe passage by dispersing juveniles in late autumn and early winter.
- Freshes scheduled in spring or summer should be coupled to a preceding event of similar or greater magnitude in August (i.e. around the time that breeding females select nursery burrow sites), to encourage females to locate nesting chambers above the point where they are likely to be inundated.
- The duration of substantial freshes scheduled in spring or summer (i.e. when juveniles are restricted to burrows) should be limited to the minimum length of time needed to carry out their designated environmental function.
- Bankfull or near-bankfull flows should be scheduled whenever possible outside the Platypus reproductive period from September through February. If it is deemed necessary to carry out such an event in this period, it should be scheduled as early as possible to reduce the amount of energy wastefully invested in failed reproduction.

Reaches that provide important dispersal corridors for juvenile Platypus, but do not support resident breeding females, only need sufficient flow and water depth from late autumn to early winter in years when nearby breeding populations are likely to produce surplus juveniles. Dispersal is most likely to succeed if river channels reliably hold water throughout their length during the predicted dispersal period (both to reduce predation risk and facilitate efficient travel) and adequate foraging opportunities are available to juveniles while en route. This second requirement may potentially be addressed most effectively by encouraging growth and recruitment of native riparian trees and shrubs (to help stabilise the banks and generate instream woody habitat) and also working to establish a series of sizable pools or backwaters along the channel over the longer term, e.g. by mechanically deepening proximal segments of selected floodrunners.

5.5 Water rat

The water-rat is considered to be a classic “boom-or-bust” species with the capacity to repopulate vacant habitat relatively quickly after severe disturbance events such as major droughts and floods. It is believed that the animals’ high mobility is an important contributing factor, e.g. movements have been recorded of 3.1 km in less than 6 hours (Gardner and Serena, 1995a), and at least 3 and probably 4.5 km overnight (Vernes, 1998). Although water-rats are associated with diverse aquatic environments, their preferred habitat appears to consist of relatively slow-flowing water in small creeks, irrigation channels, swamps and wetlands, or pools and backwaters in larger rivers (Smart *et al.*, 2011, Speldewinde *et al.*, 2013, Watts and Aslin, 1981). Population density has also been found to be positively associated with bank stability, emergent in-stream vegetation and low-growing vegetation on the banks (Smart *et al.*, 2011, Speldewinde *et al.*, 2013). Water-rats are highly opportunistic predators and scavengers, though their diet is typically dominated by fish and large macro-invertebrates (Watts and Aslin, 1981). Introduced fish species (especially goldfish, redfin perch and mosquitofish) were consumed in preference to native fish at a study site near Griffith, New South Wales (Woollard *et al.*, 1978).

Female water-rats typically raise a single litter annually in the wild (McNally, 1960), with both males and females becoming reproductively senescent by the age of 3-4 years (Olsen, 1982). In irrigation districts near Rochester and Echuca, pregnancies were recorded from early September to January, though most females (92%) were either pregnant or had already given birth by the end of October (McNally, 1960). Gestation and lactation collectively require around 9 weeks to complete (Olsen, 1982), implying that the most juveniles are weaned by early January in northern Victoria. Juveniles continue to grow through summer and mainly disperse in autumn (McNally, 1960).

Water-rats will make use of brackish coastal lagoons and even ocean beaches, and so are unlikely to be directly limited by the amount of salinity in surface waters elsewhere (Watts and Aslin, 1981). However, their body temperature drops when water temperatures are <25 ºC, declining very rapidly at temperatures <15 ºC (Fanning and Dawson, 1980). To avoid becoming extremely hypothermic in cold water, water-rats return to burrows periodically to dry their fur and warm up (Gardner and Serena, 1995a). It is reasonably inferred that the release of cold water from deep dams will entail a cost to water-rats, especially in terms of increased energy expenditure to maintain core body temperature while foraging.

5.5.1 Flow requirements for water rats

Water-rat flow requirements are expected to align particularly closely with those for fish and macro-invertebrates (i.e. preferred food resources), geomorphological processes that help to create and maintain diverse habitat features to support a wide range of fish and macro-invertebrates, and emergent/fringing vegetation (to provide protective cover from predators). The species' relatively short reproductive life span also implies that conditions conducive to successful reproduction should ideally be provided at least one year in two to ensure that populations reliably persist over time.

5.6 Macroinvertebrates

Few studies have demonstrated a clear link between flow regime and typical measures of macroinvertebrate community composition and condition (e.g. Ausrivas and SIGNAL scores) in lowland rivers. The only exceptions appear to be cases where a lack of flow has caused massive deterioration in water quality such as very high salinity (e.g. Lind *et al.*, 2006, 2007), or where a lack of flow causes streams, or certain habitats within streams to completely dry (see Figure 5-6 and Boulton, 2003, Stubbington *et al.*, 2009).

The main macroinvertebrate objective for all environmental flow reaches in the Loddon River is to maintain a diverse range of macroinvertebrate functional feeding groups to drive ecological processes and maintain or increase overall macroinvertebrate biomass to ensure it is sufficient to support higher order predators such as fish and Platypus. The River Continuum Concept (RCC) (Vannote *et al.*, 1980) predicts that the relative proportion of functional feeding groups will change from headwater streams to lowland reaches. The Loddon River downstream of Laanecoorie Reservoir is probably typical of the middle part of the catchment if we consider it in the context of its position in the Murray River catchment. Therefore according to the RCC the macroinvertebrate community in these reaches should be made up of about 50 % collectors, 35 % grazers, 10 % predators and 5 % shredders, with the relative proportion of grazers and shredders declining further downstream (Vannote *et al.*, 1980). The RCC does not necessarily translate well to Australian temperate rivers and therefore these predictions need to be considered with care. According to the MDFRC (2006) rivers in the Murray and Western Plains Bioregion (which includes the Loddon River downstream of Laanecoorie Reservoir) should commonly support shredders (7 families), filtering collectors (4 families), gathering collectors (5 families), scrapers (9 families), predators (21 families) and macrophytes piercers (1 family), but the relative biomass of each group is not predicted.

Invertebrate species within different functional groups use a variety of instream habitats, but as demonstrated in other low gradient rivers (see Benke *et al.*, 1985, Benke and Wallace, 2014) the most significant habitats in the Loddon River catchment downstream of Cairn Curran Reservoir (including Tullaroop Creek and Twelve Mile Creek) are likely to be submerged wood, submerged and emergent macrophytes, and slackwater habitats where leaf litter and other organic matter settles. The relative abundance and distribution of these habitats and the amount of carbon inputs from falling leaf litter and primary production are likely to influence the relative abundance and biomass of different functional feeding groups and therefore the total biomass of macroinvertebrates in each reach. Different functional groups are likely to use different habitats and therefore we may expect that changes to the quality or quantity of particular habitats (due to flow or other factors) will have a marked effect on some functional feeding groups and no effect on other functional feeding groups. We assume that providing a range of important habitats and carbon sources will maximise the biomass of macroinvertebrates and therefore maximise the carrying capacity of the system for fish, platypus and other target aquatic values.

Many reaches of the Loddon River currently have a large load of wood within the river channel that can provide a substrate for biofilm growth and food and habitat for macroinvertebrates, although snag removal programs in the 1950's -1970's reduced woody debris in some reaches. It also has many slackwater habitats across a range of low flow magnitudes. Prior to the floods, the Loddon River supported very dense stands of emergent vegetation such as *Typha* and *Phragmites* and patches of submerged plants such as *Myriophyllum*, *Valisneria* and *Triglochin*. The floods scoured virtually all of these emergent and submerged plants from the channel and they are yet to return in most reaches, which potentially means an important macroinvertebrate habitat and food source is missing or in very low abundance. It is not clear what role flow and other factors will play in determining the relative abundance and quality of instream and submerged vegetation and even if there is likely to be a static level of such vegetation in the Loddon River. It may be that these plants would be naturally scoured by high flows and then gradually increase in abundance and distribution during periods of prolonged low flow, thereby creating a dynamic rather than static distribution.

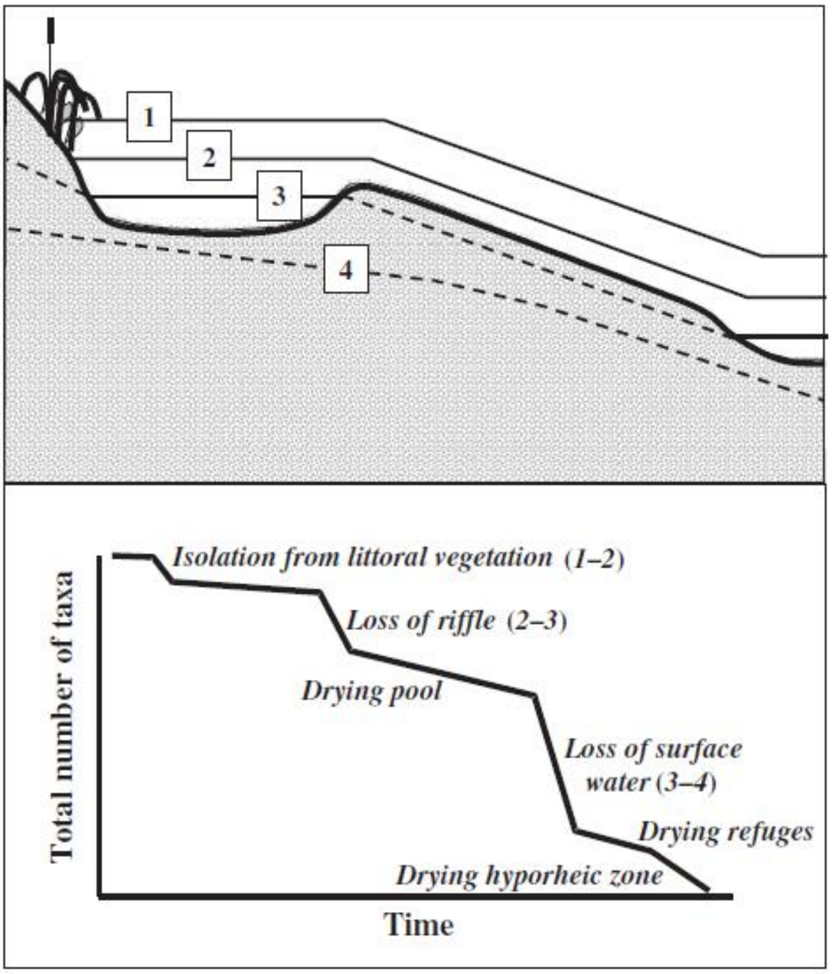

Figure 5-6: Changes in macroinvertebrate assemblage composition in a 'stepped' fashion during transitions across threshold discharges or water levels. During drying, total numbers of taxa are posited to decline sharply when submerged or trailing littoral vegetation is isolated from the free water (1 to 2), then as flow ceases in the riffle (2 to 3), and when surface water disappears (3 to 4). (Figure reproduced from Boulton, 2003).

5.6.1 Flow requirements for macroinvertebrates

The main flow requirements for macroinvertebrates have been developed to maintain or provide a range of in-stream habitats as described below:

- Flows should permanently inundate some wood and periodically inundate other wood as wetting and drying will be important to drive biofilm production. Water levels should not fluctuate so rapidly that they strand macroinvertebrates or force them below the photic zone. Moreover, turbidity should not be too high to allow primary producers to grow on snags.

- Flows should be high enough to connect all channel habitats, but not too high such that they limit the quality and quantity of slackwater habitats.
- Low flows should be provided to allow submerged and emergent macrophytes to become established, but high flows may also be needed to periodically scour vegetation.
- There should be sufficient flow to flush fine sediment or prevent fine sediment from smothering hard substrates that macroinvertebrates use for food or habitat.

5.7 Water quality

The two main flow related water quality objectives for the Loddon River are maintaining adequate water quality for aquatic biota during low flow periods (i.e. prevent high salinity and low dissolved oxygen) and preventing hypoxic blackwater events. Managed flow releases from Cairn Curran Reservoir, Laanecoorie Reservoir and Tullaroop Reservoir have the potential to lower water temperatures in downstream reaches (SKM, 2008b), but that is an operational issue rather than an issue that needs to be addressed by delivering environmental flows. High nutrient concentrations due to local land use and agricultural practices should also be addressed through land management actions rather than environmental flows.

5.7.1 Poor water quality during low flow conditions

Under very low flow conditions, the sections of the Loddon River that gain groundwater (i.e. the Loddon River upstream of Bridgewater including Tullaroop Creek, and the section of the Loddon River between Loddon Weir and Twelve Mile Creek) are likely to become more saline. This is because the groundwater is more saline than the surface water and under very low or cease-to-flow conditions the groundwater accounts for a larger proportion of the water in the river. The lack of water movement under very low flow conditions also means that pools are not mixed and therefore only a small proportion of the water in the river directly contacts the air. As a result, dissolved oxygen concentrations in pools can drop.

The exact flow magnitude required to mix pools, maintain dissolved oxygen concentrations at a level that is needed to sustain aquatic biota and prevent highly saline conditions varies between rivers and between sites within rivers depending on a range of factors such as channel shape, channel volume, the rate of groundwater inflow and the salinity of that groundwater. An analysis of water quality data from various sites in the Loddon River catchment suggests that low dissolved oxygen concentrations and high electrical conductivity are most likely to occur when flow drops below 5-10 ML/day (see Section 4.7). Conditions may be more or less severe at other sites and are likely to be worse at the downstream end of reaches due to losses associated with seepage and evaporation and the potential for other contamination en route. As a minimum environmental flows should provide visible surface flow throughout all reaches at all times, with occasional summer freshes that will mix pools and ensure they do not become stagnant.

5.7.2 Hypoxic blackwater events

Hypoxic blackwater events are characterised by high levels of dissolved organic carbon (DOC), which lead to low dissolved oxygen (DO) in the water column and potentially widespread fish and crustacean death (Hladyz *et al.*, 2011). **Blackwater events are a natural feature of floodplain systems and events that discolour the water without severely depleting oxygen concentrations are of no consequence**. The only events of concern are those that create hypoxic conditions and kill fish and other aquatic biota.

Hypoxic blackwater events generally occur when ephemeral streams with high loads of accumulated leaf litter are inundated or when high flow events wash large amounts of leaf litter into the river from the adjacent bank, benches and floodplain (see Figure 5-7). Microbes rapidly consume the available carbon and it is their respiration that severely depletes oxygen levels in the water column. Microbial activity is higher in warm temperatures and is also governed by the amount of available organic material. The three factors that determine the likelihood and severity of a hypoxic blackwater event are therefore the magnitude of the high flow or re-wetting event, the timing of that event and the amount of accumulated organic material. Hypoxic blackwater events are more likely to occur following high flow events in summer (Howitt *et al.*, 2007). Hypoxic blackwater events occurred in the Loddon River downstream of Loddon Weir in February 2004, February 2006 and December 2006. Two of those events were associated with an accidental spill or unscheduled release of between 75 ML/day and 120 ML/day from the Loddon Weir, and the third event was associated with a scheduled environmental flow release of 50 ML/day for 14 days from Loddon Weir following another very dry period (SKM, 2008a). In all cases, the flow magnitude was not very large, but followed a prolonged period of very low or no flow.

Hypoxic blackwater events occur naturally in lowland rivers and wetlands in south-eastern Australia. The main concern from an environmental flow perspective is to reduce the likelihood that managed flow releases will trigger a blackwater event. The best way to reduce that risk is to deliver one or more flow events in winter or spring that are at least as large as the biggest managed flows that will be delivered in summer or autumn. Delivering high flows in the cool months will flush accumulated leaf litter from banks and benches and therefore reduce the amount of organic material that is likely to be washed into the river by summer environmental flow releases.

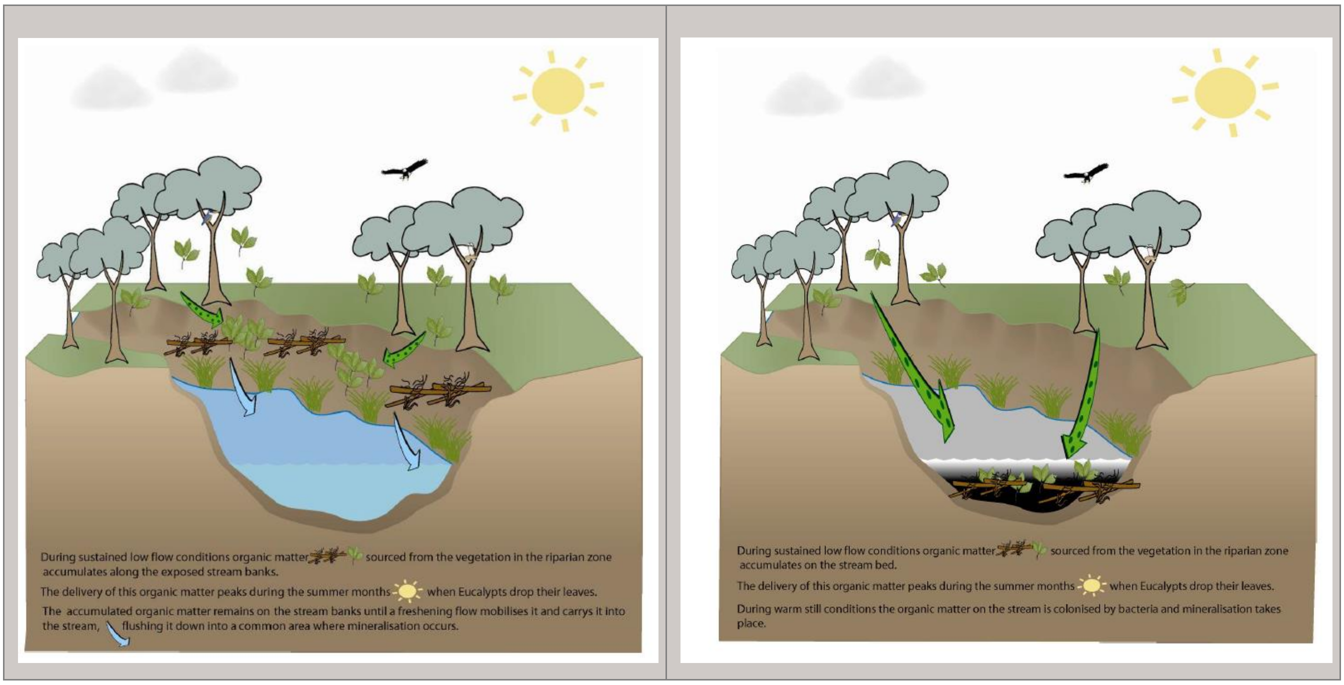

Figure 5-7: Conceptual models showing the processes that contribute to hypoxic blackwater events. Either high flows in summer wash accumulated leaf litter into the stream (left picture) or leaf litter falls into remnant pools under very low flow conditions (right picture). In both cases, the increase in organic matter during summer leads to rapid microbial activity and then oxygen depletion. (Figures reproduced from SKM, 2008a).

5.7.3 Water requirements for water quality

The main environmental flow requirements for water quality in the Loddon River are:

- Minimum summer low flows that maintain constant visible flow through all reaches to control salinity and keep water oxygenated.
- Two or three freshes during summer to partially mix pools and periodically increase dissolved oxygen concentrations.
- Winter low flows and freshes that equal or exceed the magnitude of any expected summer flows to entrain leaf litter at a time when it can be consumed by micro-organisms and incorporated into the riverine food web without causing a hypoxic blackwater event.

6. Long term management goals

The EFTP and Project Steering Committee used input from the Community Advisory Groups and the background reviews that contributed to the FLOWS objectives reports for the current project, to set long-term management goals for the Upper Loddon River, Middle Loddon River and Lower Loddon River. The management goals are described below:

Upper Loddon River

Promote a widespread and diverse aquatic fauna community, particularly platypus and native fish including River Blackfish, by providing high quality breeding and feeding habitat; and rehabilitate riparian River Red Gum vegetation communities.

Middle Loddon River

Promote a widespread and diverse native fish community by providing high quality breeding and feeding habitat and facilitating connection to the Mid-Murray Floodplain System; provide a safe dispersal corridor for Platypus and rehabilitate riparian River Red Gum vegetation communities along the river and where possible in connected floodplain habitats.

Lower Loddon River

Promote a widespread and diverse aquatic fauna community, particularly platypus and native fish, by providing high quality breeding and feeding habitat and facilitating movement throughout the Mid-Murray Floodplain System; and rehabilitate riparian River Red Gum vegetation communities along the river.

7. Ecological objectives

The ecological objectives described in the following sections have been developed to achieve the long-term management goals for the Loddon River system. Objectives for each value are classified as either primary objectives or secondary objectives. Primary objectives (shaded yellow in the relevant tables) relate specifically to the highest priority environmental values described in the long-term management goals and identified by the EFTP and/or the Community Advisory Groups for the Upper, Middle and Lower Loddon River systems. Secondary objectives relate to the values and processes that support the primary objectives. For example, the primary objectives of increasing the abundance and diversity of native fish and increasing the abundance of breeding Platypus populations can only be met if the secondary objective of maintaining a productive macroinvertebrate community with a diverse range of functional groups is also met.

More detailed descriptions and discussion of the objectives is provided in the Environmental Flows Objectives reports that were prepared for the Upper Loddon River, Middle Loddon River and Lower Loddon River as part of the current project (see Jacobs, 2015c, b, a).

7.1 Geomorphology objectives

The geomorphological objectives for the Loddon River, and the specific reaches they relate to are summarised in Table 7-1.

Table 7-1: Environmental flow objectives for geomorphology in the Loddon River.

No.	Objective	Justification	Relevant reaches
G1	Re-establish deep pools in areas that have been affected by sand slugs, maintain existing pools in other areas and replenish benches within the channel.	Channel form and habitat heterogeneity are critical to providing habitat and food for aquatic and riparian flora and fauna. In particular deep pools provide a critical drought (and potentially flood) refuge for aquatic fauna and flora. Many pools in Tullaroop Creek, and the Middle and Lower Loddon River have filled or partially filled with sediment. Large flows in the Upper Loddon River may generate enough shear stress to scour pools, but lower gradients in the Middle and Lower Loddon River mean large flows are more likely to maintain existing pools rather than create new large pools.	All reaches, but especially in Tullaroop Creek (Reach 2) where sand slugs have filled a large proportion of channel pools.
G2	Flush accumulated silt and sediment from substrates including rocks, submerged wood and macrophytes	Regular flows that flush silt and fine sediment from hard surfaces will increase their suitability for macroinvertebrates and biofilm production and lead to an overall increase in biological productivity and diversity.	All reaches
G3	Engage distributary channels, backwaters, anabranches and floodrunners	Floodrunners and distributary channels are an important feature of the Middle Loddon River and Tullaroop Creek. These channels and backwaters need to be regularly inundated to maintain their capacity, to flush organic matter from them into the main river channel and to maintain vegetation communities that grow in the channels or that are watered via the channels.	All reaches, but especially Tullaroop Creek, and the Middle Loddon River.

7.2 Fish

The native fish objectives for the Loddon River, and the specific reaches they relate to are summarised in Table 7-2.

Table 7-2: Environmental flow objectives for native fish in the Loddon River

No.	Objective	Justification	Relevant reaches
F1	Increase population size (with appropriate age structure) of small-bodied native fish species with opportunistic life history strategies including Flathead Gudgeon, Carp Gudgeon, Australian Smelt and Murray-Darling Rainbowfish.	These species would have naturally been abundant and recruited in the reach, but their abundance is likely to have declined as a result of habitat degradation and drought.	All reaches
F2	Increase population size (with appropriate age structure) and distribution of River Blackfish in Tullaroop Creek and enable River Blackfish to re-colonise the Loddon River between Cairn Curran Reservoir and Laanecoorie Reservoir and become self-sustaining over time.	River Blackfish were common and abundant in the upper Loddon River, but are now restricted to a small, potentially fragmented population in Tullaroop Creek.	Increase population in Tullaroop Creek (Reach 2) Create conditions that may allow River Blackfish to re-colonise Loddon River upstream of Laanecoorie Reservoir (Reach 1)
F3	Enhance natural recruitment of stocked Murray Cod populations in Laanecoorie Reservoir, Serpentine Weirpool, Loddon Weirpool, Bridgewater Weirpool and large pools between Laanecoorie Reservoir and Serpentine Creek.	Murray Cod is stocked in Laanecoorie Reservoir, Serpentine Weir, Loddon Weir and several large pools in Reach 3a. Artificial barriers prevent Murray Cod moving into the Upper Loddon River from downstream reaches, but high flows at the right time could enhance spawning and recruitment in existing stocked populations. Individual fish may move into the main river channel during higher flow events and then retreat to the Reservoir as water levels drop.	Reaches 1, 2, 3a and 3b
F4	Enhance natural recruitment of stocked Murray Cod population in Kerang Weirpool and allow fish to disperse from those areas and colonise suitable habitats upstream and downstream of Canary Island.	The main objective for Murray Cod and other large bodied species with an equilibrium life history strategy is to provide habitat upstream and downstream of Canary Island and in the Lower Loddon River that will allow existing fish to survive during low flow periods, to provide flows that will support successful breeding in those areas and to provide conditions that will allow fish to regularly move throughout all reaches and to move between the Middle Loddon River, Lower Loddon River and Murray River.	Reaches 4a, 4d and 5

No.	Objective	Justification	Relevant reaches
F5	Increase abundance (with appropriate age structure) of Golden Perch, Silver Perch, Bony Herring and Unspecked Hardyhead in the reaches upstream and downstream of Canary Island and in the Lower Loddon River and provide opportunities for fish to move through Twelve Mile Creek and the West Branch of the Loddon River at critical times.	Golden Perch, Silver Perch, Bony Herring and Unspecked Hardyhead were common in the Loddon River, but were lost from the Middle and Lower Loddon River during the Millennium drought. The Kerang Weir fishway was installed in 2008, and recent fish monitoring confirms that these species have returned to the Middle and Lower Loddon River. Golden Perch, Silver Perch, Bony Herring and Unspecked Hardyhead are not expected have high rates of spawning and successful recruitment in the Loddon River, therefore the main objective will be to provide flows and habitat that will allow fish to move into the Middle Loddon River from the Lower Loddon River, Murray River and Pyramid Creek. It will be important to provide permanent habitat with moderately deep pools and woody debris and abundant food in the reaches upstream and downstream of Canary Island and in the Lower Loddon River; and provide suitable conditions to allow fish passage through Twelve Mile Creek and the West Branch of the Loddon River in winter and spring.	Maintain permanent habitat and opportunities for movement in Reaches 4a, 4d and 5. Provide movement through Reach 4b and Reach 4c at critical times in all or most years.
F6	Provide conditions that will allow all native fish to move through the reach during key periods to access habitat upstream of Kow Swamp, in the Loddon River upstream of Kerang and further downstream in the Little Murray River and Murray River.	Recent works to provide fish passage at Kerang Weir and planned works to improve fish passage at Kow Swamp and in the Loddon River between Kerang and Loddon Weir will allow fish to move throughout the region. Specific flows will need to be provided at certain times of year to cue fish movement and to allow fish to negotiate the various constructed fishways.	5
F7	Maintain habitat for stocked populations of Golden Perch	Golden Perch is stocked in Cairn Curran Reservoir, Laanecoorie Reservoir, Serpentine Weir, Bridgewater Weir and deep pools within Reach 3a. They are unlikely to successfully breed in this reach, but habitat could be provided to allow them to move throughout individual reaches during high flows.	Reaches 1, 2, 3a and 3b.

7.3 Vegetation

The environmental flow objectives for in-stream and riparian vegetation in the Loddon River, and the specific reaches they relate to are summarised in Table 7-3.

Table 7-3: Environmental flow objectives for in-stream and riparian vegetation in the Loddon River

No.	Objective	Justification	Relevant reaches
V1	Maintain adult riparian woody vegetation (e.g. River Red Gum, *Calistemon*, *Leptospermum*, *Melaleuca* and Lignum – species composition will vary between reaches) and facilitate recruitment adjacent to the river channel and in low lying floodplain areas that are watered via floodrunners	The riparian zone in most reaches of the Loddon River is relatively narrow and in places is comprised almost exclusively of adult River Red Gum with a pasture grass understorey. There is little evidence of recent recruitment in most reaches, although the 2011 floods triggered successful recruitment in sections of the Middle Loddon River where stock have been excluded. An appropriate flow regime combined with complementary actions to exclude stock may allow new River Red Gum recruitment and establish a diverse shrub layer, which will help stabilise banks and reduce future erosion.	All
V2	Maintain floodplain vegetation communities that are connected to the river via floodrunners. These communities are characterised by a River Red Gum overstorey and grassy, sedge or lignum understorey.	The capacity of the main river channel decreases markedly through the Middle Loddon River. Flood runners carry water from the channel to nearby woodlands and wetlands and some such as those in the lower half of Twelve Mile Creek support their own wetland vegetation communities. These flood runners need to be engaged by high flows every few years to maintain distinct vegetation communities on the floodplain.	Lower portion of Reach 4a, all of Reach 4b and all of Reach 4c.
V3	Maintain and increase spatial extent of in-stream vegetation	Instream vegetation is generally poor at sites that have mobile streambed substrates and uncontrolled stock access. Large pools in Upper Loddon River have particularly good patches of submerged vegetation, but Middle and Lower Loddon River is more turbid and therefore will expect greater abundance of floating species such as *Triglochin* and *Myriophyllum*.	All
V4	Increase diversity and spatial extent of native emergent fringing non-woody vegetation along the banks and in floodrunners or anabranches.	The current fringing vegetation community is dominated by *Phragmites*, which was extensive during drought, but cleared out by the 2011 floods. Aim to encourage other species such as *Bolboschoenus*, *Carex* and *Juncus* to also become established.	All

No.	Objective	Justification	Relevant reaches
V5	Limit encroachment of fringing non-woody and riparian woody vegetation into the stream channel.	During the drought, *Phragmites*, *Typha* and juvenile River Red Gum grew into the middle of the channel in many reaches of the Loddon River and in some cases became a potential barrier to fish movement. The main flow paths were cleared during the 2011 floods and more regular flows should limit the future terrestrialisation of the channel.	All
V6	Maintain biofilm productivity, especially on coarse woody debris.	Biofilms that grow on submerged wood and other hard surfaces are an important part of aquatic ecosystems. They are particularly important in the Middle and Lower Loddon River because the turbid water is likely to limit the growth of instream vegetation and there is a large load of submerged wood on which biofilms can grow. Periodic wetting and drying is important for re-setting biofilms and increasing their productivity. Water levels should vary during low flow periods to facilitate these wetting and drying patterns and to increase the range of substrates that are inundated in the photic zone.	All

7.4 Platypus

The environmental flow objectives for Platypus in the Loddon River, and the specific reaches they relate to are summarised in Table 7-4.

Table 7-4: Environmental flow objectives for Platypus in the Loddon River

No.	Objective	Justification	Relevant reaches
P1	Increase size of resident breeding populations in the Upper Loddon River, Kerang Weirpool and Lower Loddon River to increase its resilience to future drought and floods and to provide surplus juveniles that can colonise other reaches of the Loddon River and connected catchments. Should be achieved by facilitating successful recruitment at least every second year and promoting safe dispersal by juveniles in autumn or early winter.	The upper reaches of the Loddon River and the Loddon River near Kerang would have naturally supported permanent breeding populations and provided juveniles platypus that could colonise other areas such as the Murray River between the Goulburn River and Swan Hill and Gunbower Forest. The Platypus populations in the Loddon River are currently fragmented. The upper Loddon River supports resident breeding populations, but they are likely to have declined significantly during the drought. Platypus numbers have also declined in the Kerang Weirpool. Much of the Middle Loddon River is unsuitable for Platypus breeding populations because the banks are not very high and there are limited deep pools, but those reaches are important dispersal corridors.	Reaches 1, 2, 3a, 3b and 5
P2	Maintain a corridor for successful juvenile dispersal	Platypus establish territories and therefore river reaches have a finite carrying capacity. In productive (i.e. average to wet) years, Platypus in the Upper Loddon River and some sections of the Lower Loddon River are likely to produce surplus juveniles that need to disperse to other areas to find unoccupied territories. Such dispersal is critical to maintaining genetic diversity across the landscape and to building resilience to drought and other impacts. Juvenile Platypus disperse between April and June and need adequate water depth, food and resting habitat throughout all reaches at these times.	All reaches

7.5 Water rats

The environmental flow objectives for water rats in the Loddon River, and the specific reaches they relate to are summarised in Table 7-5.

Table 7-5: Environmental flow objectives for water rats in the Loddon River

No.	Objective	Justification	Relevant reaches
WR	Maintain water rats as a component of the system and accept their numbers will fluctuate between drought and non-drought conditions	Water rats are a boom and bust species that can rapidly increase in numbers when food is abundant and decline in abundance when food is scarce (e.g. during drought). As long as small-bodied fish and macroinvertebrates such as yabbies, shrimps and large aquatic insects are reliably present, water rats should persist. Water rats appear to be relatively abundant in the Middle Loddon River, but have possibly declined in the Lower Loddon River in recent years. They are considered a high environmental value in these reaches.	All

7.6 Macroinvertebrates

The environmental flow objectives for macroinvertebrates in the Loddon River, and the specific reaches they relate to are summarised in Table 7-6.

Table 7-6: Environmental flow objectives for macroinvertebrates in the Loddon River

No.	Objective	Justification	Relevant reaches
M	Maintain/increase diversity and productivity of macroinvertebrates and macroinvertebrate functional feeding groups to drive productive and dynamic foodwebs.	Macroinvertebrate community productivity and diversity of functional groups is likely to be determined by range of available habitat types. It will be good at sites with a mix of instream and emergent vegetation, submerged wood and a supply of leaf litter from the riparian zone, but poor at sites that are missing one or more of these habitat elements.	All

7.7 Water quality

The environmental flow objectives for water quality in the Loddon River, and the specific reaches they relate to are summarised in Table 7-7.

Table 7-7: Environmental flow objectives for water quality in the Loddon River

No.	Objective	Justification	Relevant reaches
WQ1	Maintain water quality at a level that is able to support fish and macronvertebrates. In particular maintain adequate concentrations of dissolved oxygen, prevent salinity levels rising above 3,000 EC and prevent excessive water temperatures during low flow periods.	During critically low flow periods dissolved oxygen concentrations in remnant pools can be depleted, salt concentrations due to groundwater inflows may rise and water temperature may become too warm for some sensitive fish and macroinvertebrate species.	All reaches High salinity a particular risk in groundwater gaining reaches including Tullaroop Creek, Loddon River between Cairn Curran Reservoir and Bridgewater and Loddon River immediately downstream of Loddon Weir.
WQ2	Minimise risk of hypoxic blackwater events associated with high flow releases in summer	Hypoxic blackwater events can lead to fish kills and severe stress to other aquatic fauna. Blackwater events are natural and it is important to flush carbon into the river channel to provide energy for foodwebs, but we do not want high flows to trigger a hypoxic blackwater event. High flows in cool months to clear organic loads will reduce the likelihood of hypoxic blackwater events during summer.	All

8. Environmental flow recommendations

The following sections describe the environmental flow recommendations for the Upper, Middle and Lower reaches of the Loddon River.

8.1 Flow recommendations for the Upper Loddon River

The environmental flow recommendations for each reach of the Upper Loddon River and a discussion of how those flow recommendations relate to specific environmental flow objectives are presented in Table 8-1. The specific flow magnitudes for Reach 1 relate to the flow gauge at Cairn Curran Reservoir, the flow magnitudes for Reach 2 relate to the flow gauge at Tullaroop Reservoir, the flow magnitudes for Reach 3a relate to the flow gauge at Laanecoorie Reservoir and the flow magnitudes for Reach 3b relate to the flow gauge at Serpentine Weir.

The recommended magnitude for summer low flows, winter low flows and summer freshes in Reach 3a are higher than needed to meet the specific environmental flow objectives for Reach 3a, but have been recommended to ensure there is enough water flowing through the system to meet the environmental flow requirements in Reach 3b and Serpentine Creek. The combined low flow requirements for Reach 3b and Serpentine Creek are greater than the natural low flow magnitude for Reach 3a because the operation of the Serpentine Weir pool and Serpentine Creek as an irrigation carrier has made Serpentine Creek wetter than natural and it now supports important environmental values that need to be protected. The minimum flow requirements for Reach 3a, without considering downstream environmental demand, are shown in brackets below the recommended flow magnitude for each flow component in Table 8-1. In very dry years the NCCMA may choose to deliver only the minimum flow requirements for Reach 3a, if it does not have enough environmental water to meet the combined summer low flow demand for Reaches 3b and Reach 1 of Serpentine Creek. The recommended flow magnitudes for summer low flows, winter low flows and summer freshes are likely to be at least partially met in most years by irrigation flows that are delivered to meet customer demand along the Loddon River and Serpentine Creek.

A range of flow magnitudes is provided for the recommended winter fresh in Reaches 1, 2 and 3b. For Reaches 1 and 2 the lower end of the range is considered adequate to meet the ecological objectives in those two reaches. The upper end of the range indicates the maximum flows that can be delivered in each reach to help meet the winter fresh flow requirement in Reach 3a without the risk of drowning juvenile Platypus in nesting burrows. The higher end of the recommended winter fresh flow range for Reach 3b is expected to meet environmental flow requirements for that reach, but a lower flow may need to be delivered to prevent unintended flooding of private land downstream of Loddon Weir.

Cease-to-flow events are not recommended for any reach of the Upper Loddon River, because they are likely to stress the native fish community and reduce habitat and food for Platypus. In a severe drought, it is conceivable that there will not be enough water in the system to deliver all of the recommended environmental flows. In those circumstances, the NCCMA should aim to deliver the minimum summer low flow for as long as possible while still holding enough water in reserve to deliver three flows that are equivalent to the recommended summer fresh in each reach. The NCCMA should monitor water quality in remnant refuge pools during any unavoidable cease-to-flow event and release the recommended summer fresh flows as needed to prevent dissolved oxygen concentrations dropping below 2-3 mg/L and electrical conductivity rising above 3500 EC in those refuge pools.

Table 8-1: Environmental flow recommendations for the Upper Loddon River including: Reach 1- Loddon River between Cairn Curran Reservoir and Laanecoorie Reservoir, Reach 2 – Tullaroop Creek from Tullaroop Reservoir to Laanecoorie Reservoir, Reach 3a – Loddon River from Laanecoorie Reservoir to Serpentine Weir and Reach 3b – Loddon River from Serpentine Weir to Loddon Weir.

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
Cease-to-flow		NA	NA	NA	NA	NA	Not recommended		Likely to be detrimental to water quality, prevent re-colonisation by instream vegetation, limit macroinvertebrate productivity and therefore limit fish and platypus populations.	We do not recommend a cease-to-flow event in this reach because there are relatively few deep refuge pools that can support large numbers of aquatic biota. Cease-to-flow events may have occurred naturally in this reach, but are not recommended because the system has been degraded by altered flows and the objectives are to improve conditions over the short to medium term rather than provide specific stresses. If a cease-to-flow event is unavoidable then sufficient environmental water should be held in storage to deliver up to 3 summer freshes if needed to prevent extremely low dissolved oxygen concentration or high electrical conductivity levels in refuge pools.
Summer low flow	Wet-average	20-35 ML/day	10-15 ML/day	25-35 ML/day (20-35 ML/day)	10-15 ML/day	6 months Dec-May	Vary the magnitude of flow within the prescribed range throughout Dec-May. Higher magnitude in Dec, gradual decline through Jan-Mar then gradual rise from Apr-May	The dry year recommendation can be delivered for most of the season in dry years as long as there is noticeable surface flow throughout the whole reach. Need to avoid sudden and frequent fluctuations in low flow magnitude to avoid disrupting slackwater habitats or stranding biota in habitats	**Fish:** F1, F2, F7. **Vegetation:** V3, V4, V5, V6. **Platypus:** P1, P2. **Water rats:** WR. **Macroinvertebrates:** M. **Water Quality:** WQ1.	**General:** The summer low flow is critical for maintaining a variety of aquatic riverine habitats. Recommended flow in wet-average years should ensure a minimum depth of 10 cm in the channel thalweg in riffle or run habitats and more than 0.8 m depth in pools. It will also wet more than 70% of the bottom width of the channel. The dry year low flow recommendations
	Dry	10 ML/day	5 ML/day	15 ML/day	5 ML/day					

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
								that are likely to dry. Note that two of the main risks in the Upper Loddon River are higher than natural flows and rapid flow fluctuations during the irrigation season that reduce habitat suitability for native fish and in-stream vegetation.		will provide a depth of at least 7 cm in the channel thalweg in riffle and run habitats and will only wet approximately 50% of the channel width. Dry year low flows will reduce the quality and quantity of available riffle and run habitat, but that compromise is acceptable if it allows the NCCMA to maintain continuous flow for a longer period and hold some water in reserve to deliver summer freshes if needed. **Water quality:** Maintains water quality (especially dissolved oxygen concentration) in pools. **Fish:** Maintain pool habitat for resident River Blackfish, Murray Cod, Golden Perch, Mountain Galaxias and Carp Gudgeon populations noting that fish communities vary between reaches. Stable flows in December and January should help prevent juvenile River Blackfish from being washed out of nests and nursery habitats in Reaches 1 and 2. Maintains slackwater habitats which are productive areas for zooplankton and nursery habitats for many native fish, especially opportunistic low flow specialists such as Carp Gudgeon. **Macroinvertebrates:** Continuous flow will maintain riffle, pool and edge habitats for

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
										macroinvertebrates. Varying low flow magnitude over the season will inundate fallen wood to varying degrees, which will promote growth of biofilms, support macroinvertebrates and provide habitat for fish. **Vegetation:** Maintaining a connecting flow through the whole reach for most of the time will limit the encroachment of emergent macrophytes into the middle of the channel (i.e. deepest, fastest flowing portion of the channel) and allow native instream vegetation to colonise the channel margins. **Platypus:** Connecting flow through reach will maintain adequate pool depth to support foraging Platypus and allow Platypus to safely move between pools within their home range to ensure they have adequate access to food. This is especiailly important for lactating females that need an abundant food supply.
Summer fresh	Wet - average	50-80 ML/day	40 ML/day	70-100 ML/day (50-100 ML/day)	50-60 ML/day	1-3 days at peak. Ramp up over 1-2 days and ramp down over 3-4 days.	3 events per year 1 event Dec-Feb with peak at 1 day 2 events Mar-May with peak at 2-3 days	The summer fresh magnitude is relative to the summer low flow and therefore the actual magntidue delivered will likely vary from year to year depending on the magnitude of the summer low flow.	**Geomorphology:** G2 **Fish:** F1, F2, F7 **Vegetation:** V3, V4, V5, V6 **Platypus:** P1, P2 **Water rats:** WR **Macroinvertebrates:** M	**General:** The summer fresh will increase water depth by at least 10-20 cm compared to the summer low flow to inundate low benches, bars and fallen wood throughout the reach. It will also generate a shear stress of at least 1 N/m^2 in moderate to fast flowing sections
	Dry	35 ML/day	30 ML/day	50-70 ML/day	30 ML/day					

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
				(30 ML/day)				No more than one fresh should be actively delivered in Dec-Feb to avoid disturbing slackwaters and River Blackfish nursery habitats during the main fish larval rearing phase. This recommendation may be ignored if water quality deteriorates in dry years and multiple freshes are needed to improve water quality in refuge habitats. More frequent events are OK after February in any year and may help facilitate Platypus dispersal. The summer fresh should be no greater than the maximum flow in the previous winter/spring to avoid flushing too much leaf litter into the stream at a time when it may lead to hypoxic conditions.	**Water quality:** WQ1.	of the channel to flush fine silt and sediment form submerged wood and other hard surfaces. **Vegetation:** Inundate the lower banks and low benches to wet the soil and promote establishment, growth and survival of fringing emergent macrophytes such as reeds and sedges. **Fish**: Promote local movement by adult fish to access alternative habitats. The autumn freshes will be particularly important for facilitating dispersal of juvenile fish including species with 'opportunistic' and 'equilibrium' life history strategies. **Macroinvertebrates:** Wash organic matter into stream to drive aquatic foodwebs Wet submerged wood and flush fine silt and old biofilms to promote new biofilm growth and increase macroinvertebrate productivity **Platypus:** Facilitate downstream dispersal of juvenile platypus in Apr-May to colonise other habitats in the Murray River. **Water quality:** Flow increases may mix or re-oxygenate pools and may dilute salt concentrations that can build up during prolonged low flow periods.

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
										. We note the potential conflict between delivering freshes to grow and maintain littoral vegetation and replenish biofilms on submerged wood and the risk that these events may disturb slackwater habitats and any fish larvae or juveniles in those habitats. Any freshes during Nov-Feb have the potential to wash fish larvae from slackwater habitats. Opportunistic species are likely to have multiple cohorts each season, so one fresh during that time should not significantly affect overall recruitment. We have emphasised the need for 3 events each year over the next 5-10 years to help re-establish fringing vegetation that was removed during the 2011/12 floods. Once those plants are established, the number of freshes may be revised.
Winter low flow	Wet-average	50-80 ML/day	30-40 ML/day	70-100 ML/day (50-80 ML/day)	40-50 ML/day	6 months Jun-Nov	Vary the magnitude of flow within the prescribed range throughout Jun-Nov to match the natural flow regime. Ramp the flow up slowly from June to deliver the highest magnitude in Jul-Sep, then gradually	In wet years or in years when flow needs to be transferred downstream for system operation purposes the flow can be closer to the upper end of the recommended range for most of the season. The lower magnitude recommended for dry years is intended to save water so that other flow components can be	**Geomorphology:** G2 **Fish:** F1, F2, F7 **Vegetation:** V1, V3, V4, V5, V6 **Platypus:** P1, P2 **Water rats:** WR **Macroinvertebrates:** M **Water quality:** WQ1	**General:** The winter low flow will increase water depth by at least 10-20 cm compared to the summer low flow and therefore maintain important seasonal variation. It will also wet the full width of the bottom of the river channel and generate enough shear force to flush fine sediment from the streambed and hard substrates in the fastest flowing sections of the stream. **Vegetation :**
	Dry	35 ML/day	20 ML/day	50 ML/day (30 ML/day)	30 ML/day					

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
							drop flow through Nov.	delivered during the year. Need to avoid sudden and frequent fluctuations in low flow magnitude so that fish and other biota can respond without being stranded.		Spring flow should limit growth of vegetation in the middle of the channel, maintain open water in the thalweg throughout the whole reach and prevent terrestrial plants colonising the lower sections of the river bank and low benches in the channel. Will also maintain soil water in the river bank to water established River Red Gum and woody shrubs such as *Calistemon* and *Malaleuca*; and help establish littoral vegetation that includes a mosaic of species such as *Bolboschoenus*, *Carex* and *Juncus*. Flows during coldest months will be outside the growing season and will have little effect on vegetation. **Fish:** Allow localised fish movement throughout the reach and maintain depth of pool habitats for River Blackfish, Murray Cod and Golden Perch in reaches where those species persist. **Platypus:** Facilitate long distance movement by male platypus especially during the Aug-Oct breeding season. Provide foraging opportunities across a wide range of habitats for females to develop fat reserves prior to breeding. **Macroinvertebrates:** Once water temperatures increase

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
										(generally September-Nov) the depth provided by winter low flows will inundate a wide variety of habitats that will support high macroinvertebrate productivity.
Winter fresh	Wet - average	400 – 700 # ML/day	200 – 400 # ML/day	900 ML/day	450-900 ML/day	Jul-Aug event 1-2 days at peak In at least 2 out of 5 years the Sep-Oct event should have a 2-3 week duration including 4-5 days. Ramp up over 3-4 days and ramp down over 7-12 days.	2 per year (1 in Jul-Aug & 1 in Sep-Oct) in average to wet years. Not expected in dry years, but ensure no more than 3 consecutive years without a winter fresh.	The Jul-Aug event only needs a short duration to encourage Platypus to build nesting burrows higher up the bank. The Sep-Oct event aims to address vegetation objectives and support Murray Cod breeding. The vegetation objectives are likely to be met by an event that lasts only 1-2 days at peak, but the longer duration is needed to enhance Murray Cod breeding. The timing of the spring fresh should vary each year. It may be delivered in November in some years, but should not be delivered in November often or in consecutive years to avoid flushing River Blackfish nests or slackwater habitats that may support developing fish larvae. If the winter fresh is not delivered then the maximum summer event in the following season should not exceed the highest winter low flow event	**Geomorphology:** G1, G2, G3 **Fish:** F3, F7 **Vegetation:** V1, V4, V5, V6 **Platypus:** P1 **Macroinvertebrates:** M **Water quality:** WQ2	**General:** Recommended minimum flow magnitude will increase water depth by approximately 0.5-1.0 m above the winter low flow level and is sufficient to inundate low benches and backwater habitats throughout all reaches. It will also create a shear stress of 0.16-1.2 N/m^2 in pool habitats and 3-5.3 N/m^2 in riffle and run habitats. These shear stresses are sufficient to redistribute fine sediment on benches and bars in the bottom of the channel and scour aged biofilms from hard surfaces included submerged wood. **Vegetation:** Events in September-October will promote recruitment and maintenance of riparian vegetation including *Calistemon* and other woody shrubs on low benches and on the river banks. The event will also water the roots of River Red Gum and other trees growing higher up the bank. Flows of this magnitude at any time may help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:**
	Dry	NA	NA	NA	NA					

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
								to reduce likelihood of a blackwater event. Flows higher than the recommended range may risk drowning Platypus nesting burrows and therefore should be avoided in consecutive years.		High flow event in Sep-October should enhance Murray Cod breeding and allow Murray Cod, Golden Perch and other fish to move throughout each reach. Barriers will prevent migration to the Murray River **Platypus:** Fresh prior to egg-laying (ideally Aug) may encourage females to select a nesting burrow higher up the bank to reduce risk that high flows later in the year will flood the burrow when juveniles are present. **Macroinvertebrates:** Flush organic matter into the stream to allow it to be conditioned, broken down and consumed to support riverine foodwebs. **Water quality:** Flush accumulated leaf litter from bank and low benches into the river channel to provide carbon for aquatic foodwebs. Flushing leaf litter in winter or spring reduces the risk that a high flow event in summer will wash a large load of leaf litter into the channel at a time when high microbial activity may reduce dissolved oxygen concentrations.
Winter High Flow	Any	500-1000 ML/day	1000 ML/day	1500 – 2000 ML/day	1500-2000 ML/day	10 days at peak to enhance Murray Cod	1 event between late September and early November in two	These events are likely to cause flooding downstream of Loddon Weir. It should only	**Geomorphology:** G1, G2, G3 **Fish:** F3, F7	**General:** The recommended winter high flow will increase water depth by 1-1.6 m

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
						breeding, but can achieve vegetation objectives if duration is 2 days at peak. Ramp up over 4-5 days and ramp down over 7-14 days.	consecutive years every decade. This event could replace the second winter fresh in some years.	be delivered once risks have been assessed and potential flood mitigation options have been identified. One option may be to divert water to nearby wetlands once it has passed through Reach 3a and 3b. The hydraulic models used in the FLOWS study are not calibrated for very high flows and therefore monitoring may be needed to determine the minimum flow required to provide flow through anabranches in Tullaroop Creek and Reach 3a. These high flows may inundate Platypus burrows, but the risk is relatively low as long as events are not delivered more than twice per decade. The risk to Platypus will be further lowered if a winter fresh is delivered in August before the winter high flow.	**Vegetation:** V1, V4, V5 **Water quality:** WQ2.	compared to the winter low flow. It is specifically recommended to provide flow through anabranch channels, redistribute sediment on benches and bars in the bottom of the channel and scour aged biofilms from hard surfaces. **Vegetation:** The main purpose of the event is to help re-establish woody and non-woody vegetation on the river bank, on islands in the channel and in anabranch channels. The event will also water the roots of River Red Gum and other trees growing higher up the bank. These flows may also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:** High flow event in Sep-October should enhance Murray Cod breeding. **Water quality:** Flush accumulated leaf litter from bank and low benches into the river channel to provide carbon for aquatic foodwebs at a time that will benefit rather than threaten aquatic biota. Flushing leaf litter from the banks in winter or spring reduces the risk that a high flow event in summer will wash a large load of leaf litter into the channel at a time when high microbial activity may reduce dissolved oxygen concentrations.

Flow component	Wet / Dry	Reach 1	Reach 2	Reach 3a	Reach 3b	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
Bankfull flow	Any	4000 ML/day	3000 ML/day	7300 ML/day	13000 ML/day	1-2 days at peak	Bankfull flow cannot be delivered with existing infrastructure therefore frequency and timing will be determined by natural floods that cause Cairn Curran Reservoir to spill.	The bankfull flow cannot be actively delivered with existing infrastructure and would almost certainly flood private land downstream of Loddon Weir.	**Geomorphology:** G1, G3 **Fish:** F3, F7 **Vegetation:** V1, V5	**General:** Bankfull flow events create the maximum shear stress within the river channel and hence determine the distribution and size of pools and benches throughout the reach. The bankfull flows will scour sediment from pools to maintain their volume and depth and replenish benches and bars within the channel. **Vegetation:** Bankfull flows will help to maintain established trees such as River Red Gum high on the bank and support recruitment of juveniles. Ideally events will happen in consecutive years to help juveniles that recruit in the first year become established. These events will also help to scour vegetation from the middle of the channel and therefore maintain an open clear flow path. **Fish:** Bankfull flows may enhance Murray Cod breeding and allow fish to move throughout each reach.

8.2 Flow recommendations for the Middle Loddon River.

The environmental flow recommendations for all sub-reaches in Reach 4 and a discussion of how those flow recommendations relate to specific environmental flow objectives are presented in Table 8-2. The specific flow magnitudes relate to the flow gauge at Loddon Weir in Reach 4a and Appin South in Reach 4d. The flow magnitudes for Twelve Mile Creek (Reach 4b) and the West Branch of the Loddon River (Reach 4c) are based on the estimated flow split at the downstream end of Reach 4a as advised by GMW.

The highest priority objective for the Middle Loddon River is to increase the abundance and diversity of native fish communities. The environmental flow recommendations described in Table 8-2 aim to maintain habitat that will support large and small-bodied native fish year round in Reach 4a and Reach 4d. Twelve Mile Creek (Reach 4b) and the West Branch of the Loddon River (Reach 4c) have few deep pools that will support large-bodied fish during low flow periods. The environmental flow recommendations for Reach 4b and Reach 4c aim to provide year round habitat for small-bodied native fish, and opportunities for large-bodied native fish to move through the reaches to access habitats further upstream or further downstream in winter/spring and for short periods during autumn. In dry years, there may not be enough water to maintain viable fish habitat throughout Twelve Mile Creek and the West Branch of the Loddon River. We suggest that under those circumstances it will be better to pass most of the available water down Twelve Mile Creek and maximise the habitat quality in one channel, rather than provide marginal habitat in both channels. This approach will also maximise the likelihood of maintaining a continuous flow path and connected fish habitat from Loddon Weir to Kerang Weir. Low flows should preferentially be delivered down Twelve Mile Creek for two reasons. First, it has a lower bed level than Reach 4c and therefore would naturally carry virtually all flow up to 20-30 ML/day. Second, the downstream section of Twelve Mile Creek has more diverse and more intact instream and riparian habitat than the West Branch of the Loddon River, and therefore flow down Twelve Mile will meet more environmental objectives.

Cease-to-flow events are not recommended for the Middle Loddon River, because they are likely to stress the native fish community and reduce habitat and food for Water Rats and any Platypus that may be in the area. In a severe drought, it is conceivable that there will not be enough water in the system to deliver the recommended low flows all year. In those circumstances, the NCCMA should aim to deliver the minimum summer low flow for as long as possible while still holding enough water in reserve to deliver three flows that are equivalent to the recommended summer fresh in each reach. The NCCMA should monitor water quality in remnant refuge pools during any unavoidable cease-to-flow event and release the recommended summer fresh flows as needed to prevent dissolved oxygen concentrations dropping below 2-3 mg/L and electrical conductivity rising above 3500 EC in those refuge pools.

If the Middle Loddon River completely dries, as it did during the Millennium Drought, then there is likely to be little point in resuming environmental flows until there is sufficient water held in storage to deliver a bankfull flow or there is a natural flood. These large flows will be important to flush accumulated organic material from the channel and reset the system. Moreover, a natural flood that fills the storages within the Loddon River catchment, will replenish the available environmental water reserve and allow the NCCMA to deliver most if not all of the recommended environmental flow regime for several years. Using low flows to re-wet a dry system is not likely to be very effective and could lead to severe hypoxic blackwater events or facilitate the growth of *Typha* or other unwanted vegetation in the main channel.

The recommended summer low flows for the Middle Loddon River are potentially larger than would naturally occur, but are considered necessary to increase the abundance and diversity of native fish populations that have been severely impacted by years of flow regulation, drought and other catchment modifications. Moreover, there are fewer deep refuge pools within the Middle Loddon River than would have naturally occurred and therefore fewer habitats that can support fish during critically low flow or cease-to-flow periods. Providing a wetter than natural flow regime does have some potential risks. The greatest risk is that prolonged periods of shallow slow flowing water through summer will provide ideal growing conditions for *Typha* and possibly *Phragmites*. These plants may grow into the middle of the channel and in extreme cases, completely choke the channel. The NCCMA will need to actively monitor the growth of emergent vegetation in the middle of the channel, especially through Twelve Mile Creek and the West Branch of the Loddon River, which will have the shallowest habitats. If vegetation does begin to encroach into the channel, the NCCMA will need to either review the low flow regime or use other means (e.g. mechanical or chemical) to control the vegetation and maintain clear flow paths and diverse instream habitats.

Table 8-2: Environmental flow recommendations for Reach 4: Loddon River between Loddon Weir and Kerang Weir. Separate recommendations are shown for each sub-reach.

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
Cease-to-flow	NA	NA	NA	NA	NA	Not recommended	Cease-to-flow events should be avoided where possible.	Likely to be detrimental to water quality, prevent re-colonisation by instream vegetation, limit macroinvertebrate productivity and therefore limit fish and platypus populations.	We cannot identify a specific ecological function that we would want a cease-to-flow event to achieve. We note that this reach of the Loddon River would have naturally ceased to flow (based on anecdotal information as hydrological models for this reach are unreliable), but think the risks of deliberately creating a cease-to-flow event in this reach are too high given the need to improve the condition of environmental values and the lack of potential refuge pools that can support large numbers of aquatic biota.
Summer low flow (Wet and average years)	50 ML/day	25 ML/day	25 ML/day	30 ML/day	6 months Dec-May	Vary the magnitude of flow within the prescribed range throughout Dec-May. Higher magnitude in Dec, gradual decline through Jan-Mar then gradual rise from Apr-May	Need to avoid sudden and frequent fluctuations in low flow magnitude to avoid disrupting slackwater habitats or stranding biota in habitats that are likely to dry. There is also a risk that maintaining a permanently wet system will enhance the growth of *Typha* and possibly *Phragmites*, which may encroach into the middle of the channel and reduce	**Fish:** F1, F5 **Vegetation:** V3, V4, V6 **Water rats:** WR **Macroinvertebrates:** M **Water quality:** WQ1.	**General:** The main objective of the summer low flow is to create a permanently flowing system that supports an abundant and diverse native fish community that is connected to the Murray River. The low flow recommendations for the reaches are based on providing at least 10 cm of flow through the shallowest habitats in Twelve Mile Creek and the West Branch of the Loddon River whenever possible.
Summer Low Flow (Dry years)	25 ML/day	20 ML/day	5 ML/day	10-15 ML/day					

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
							channel capacity and fish passage.		Any continuous flows through the reach will be sufficient to maintain pool and run habitats in the Loddon River in Reaches 4a and 4d, which are important summer habitats for fish, macroinvertebrates and water rats. It is expected that a flow of 50 ML/day from Loddon Weir will deliver 25 ML/day down Twelve Mile Creek and the West Branch of the Loddon River. At lower flows, a greater proportion of the total flow volume passes down Twelve Mile Creek, which is the natural flow path for the Loddon River past Canary Island. In dry years the aim will be to maintain a continuous flow through Twelve Mile Creek and support refuge pools in Reach 4c. **Water quality:** Continuous flow through reach should maintain water quality in pools although dissolved oxygen monitoring may be needed to ensure levels are adequate to support aquatic life. **Fish:** Low flow will maintain pool habitat for large-bodied fish such as Murray Cod, Bony Herring and Golden Perch and slackwater habitats that are productive areas for zooplankton and nursery habitats for native fish. The recommended flows will also maintain

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Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
									shallow habitats for small-bodied native species such as Carp Gudgeon, Flathead Gudgeon, Unspecked Hardyhead and Murray-Darling Rainbowfish. **Macroinvertebrates:** Continuous flow will maintain habitat for riffle dwelling macroinvertebrates and the quality of pool and edge habitats. Varying low flow magnitude over the season will inundate fallen wood to varying degrees, which will promote growth of biofilms, support macroinvertebrates and provide habitat for fish. **Vegetation:** Maintaining a connecting flow through the whole reach for most of the time will allow native instream vegetation to colonise the channel and allow fringing non-woody emergent vegetation to colonise the margins of the channel. **Water rats:** Continuous flow will maintain pool habitats and an abundant food supply for water rats.
Summer fresh	50-100 ML/day	25-60 ML/day	25-40 ML/day	30-75 ML/day	3-4 days at peak. Ramp up over 1-2 days and ramp down	2-3 events per year: 1 event in Dec-Feb and 2 events Mar-May	The upper range of the recommended flows should be delivered whenever possible. Flows at the lower end of the	**Geomorphology:** G2 **Fish:** F1, F4, F5 **Vegetation:** V3, V4, V5, V6	**General:** Summer freshes will increase water depth by 5-15 cm, and increase wetted width of channel by 0.4-2.5 m

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
					over 3-4 days.		range may be delivered in dry years as long as they provide a significant increase in depth and wetted width compared to the summer low flow at that time. Do not actively deliver more than 1 fresh or a very large fresh in Dec-Feb to avoid disturbing slackwater habitats during the main fish larval rearing phase. More frequent events are OK after February in any year and may help facilitate platypus and fish dispersal. The summer fresh should be no greater than the maximum flow in the previous winter/spring to avoid flushing too much leaf litter into the stream during warm conditions that may cause a large drop in dissolved oxygen concentration.	**Platypus:** P2 **Water rats:** WR **Macroinvertebrates:** M	compared to the summer low flow and will generate enough shear stress to flush fine silt from hard surfaces. Its main purpose is to promote a mosaic of fringing vegetation, provide opportunities for fish movement and assist juvenile Platypus to disperse. **Vegetation:** Inundate the lower banks and increase wetted width of the channel to promote a mosaic of fringing emergent macrophytes such as reeds and sedges. These flows will also help to maintain woody shrubs such as *Calistemon*. **Fish**: Promote local movement by adult fish to access alternative habitats. Flow of 100 ML/day should drown all fish barriers within the Middle Loddon River including the flow gauge weir at Appin South. The autumn freshes will be particularly important for facilitating the upstream movement of juvenile Golden Perch and Silver Perch and adult Bony Herring from the lower Loddon River and Murray River. **Macroinvertebrates:** Wash organic matter into stream to drive aquatic foodwebs Wet submerged wood and flush fine silt and old biofilms from hard surfaces to promote new biofilm

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
									growth and increase macroinvertebrate productivity **Platypus:** Facilitate downstream dispersal of juvenile platypus in Apr-May to colonise other habitats in the Murray River. Note – because recommended summer low flows are reasonably high, the summer freshes provide little extra benefit to water quality.
Autumn high flow	400 ML/day	~200 ML/day	~200 ML/day	~400 ML/day	3 weeks for whole event. Ramp up over 3-4 days, hold at peak for 6 days and gradually draw down over 10 days.	1 event in April-May in wet and average years. Not expected in dry years	The flow should not break out of the banks and cause unwanted flooding. In order to attract fish into the Middle Loddon River it will be necessary ensure that flows coming out of the Middle Loddon River are greater than flows in Pyramid Creek, because the migrating fish will naturally move into the reach that has the greatest flow. The flow will need to last long enough to attract fish from the Murray River and allow them to move through the Lower Loddon and Middle Loddon reaches.	**Fish:** F4, F5 **Platypus:** P2	**Fish:** The primary purpose of this flow is to cue and facilitate the upstream movement of 1+ year old Golden Perch, Silver Perch, Bony Herring and potentially Murray Cod from the Murray River to allow them to colonise the Middle Loddon River. **Platypus:** The high flow will help juvenile Platypus disperse from the Upper Loddon River to the Lower Loddon River and Murray River.
Winter low flow	50-100 ML/day	25-60 ML/day	25-40 ML/day	30-75 ML/day	6 months Jun-Nov	Vary the magnitude of flow within the prescribed range throughout Jun-Nov to match the natural flow regime. Ramp the flow	The upper end of each flow range should be delivered in as many years as possible. In dry years, flows at the lower end of the range may be delivered provided they represent a significant increase in	**Geomorphology:** G2 **Fish:** F1, F4, F5 **Vegetation:** V3, V4, V5, V6 **Platypus:** P2	**General:** The recommended winter low flow will increase water depth by up to 15 cm and wetted width by up to 2.5 m compared to the summer low flow and

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
						up slowly from June to deliver the highest magnitude in Jul-Sep, then gradually drop flow through Nov The upper end of each flow range should be delivered in as many years as possible. In dry years, flows at the lower end of the range may be delivered provided they represent a significant increase in depth and wetted width compared to the summer low flow.	depth and wetted width compared to the summer low flow. Need to avoid sudden and frequent fluctuations in low flow magnitude so that fish and other biota can respond without being stranded.	**Water rats:** WR **Macroinvertebrates:** M	will maintain important seasonal variation. It will also generate sufficient shear stress to flush fine silt from hard surfaces. A flow of 50 ML/day will wet most of the width of the streambed and a flow of 100 ML/day should drown all artificial barriers between Loddon Weir and Kerang Weir. **Vegetation :** Prevent plants from encroaching into the middle of the channel (spring flows should limit growth of vegetation in the middle of the channel and maintain open water in the thalweg throughout the whole reach). Prevent terrestrial plants colonising the lower sections of the river bank and low benches in the channel Maintain soil water in the river bank to water established River Red Gum and woody shrubs such as Bottlebrush and Tea Tree. Water and help establish littoral vegetation zone that includes a mosaic of species such as Bolboschoenus, Carex and Juncus. **Fish:** Allow localised fish movement throughout the reach and maintain depth of pool habitats for Murray Cod, Golden Perch, Silver Perch and Bony Herring.

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
									Platypus: Provide foraging habitat, resting habitat and safe passage for juvenile Platypus that are likely to disperse through the reach from upstream populations during June. **Macroinvertebrates:** Once water temperatures increase (generally September-Nov) the depth provided by winter low flows will inundate a wide variety of habitats that will support high macroinvertebrate productivity. **Water rats:** Provide foraging habitat and abundant supplies of small fish and large macroinvertebrates for water rats to feed on.
Winter high flow	450-750 ML/day (The magnitude for this flow event will need to be based on the maximum flow that can be delivered without causing unwanted flooding on private land)	~225-375 ML/day	~225-375 ML/day	~450-750 ML/day	2-3 weeks with 7-10 days at peak between mid September and late October. Ramp up over 3-4 days and ramp down over 5-10 days. Exact timing may need to be determined in consultation with affected	1 event per year in wet and average years. Not expected in dry years	The high flow is mainly targeting floodplain vegetation and fish migration objectives and therefore needs to be delivered after mid-September when water temperatures and air temperatures begin to rise. Events delivered before mid-September will not have their intended ecological benefit. Ideally the event will be provided from the winter fresh or winter high flow events that are recommended for the reaches upstream of Loddon Weir. Those	**Geomorphology:** G1, G2, G3 **Fish:** F1, F4, F5 **Vegetation:** V1, V2, V4, V5 **Water quality:** WQ2	**General:** The recommended high flow will fill some flood runners and inundate some connected wetland and floodplain habitats throughout Reaches 4a, 4b and 4c. Those habitats need to be inundated to improve the health and increase recruitment of riparian and floodplain vegetation. **Geomorphology:** These flows are likely to provide the maximum shear stress within the river channel and therefore help scour

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
					landowners		recommendations include a shorter duration event in August. The August high flow event is not needed in Reach 4 because Platypus are not expected to breed in this reach. An August event will not have any adverse ecological outcomes and therefore passing those flows through the reach will be acceptable from an environmental perspective. More work is needed to determine the maximum magnitude that can be delivered without causing unwanted flooding on private land. A flow of 450 ML/day just breaks out of the channel, but doesn't water much of the floodplain. A larger flow will water more of the floodplain and therefore have greater environmental benefit.		some pools and redistribute sediment on benches and bars. The low gradient of the stream means that the flows will not be able to re-create large pools that have filled in as a result of increased sediment loads in the river. **Water quality:** High flows will flush accumulated leaf litter from bank and low benches into the river channel to provide carbon for aquatic foodwebs at a time that will benefit rather than threaten aquatic biota. Flushing leaf litter from the banks in winter or spring reduces the risk that a high flow event in summer will wash a large load of leaf litter into the channel at a time when high microbial activity may reduce dissolved oxygen concentrations. **Vegetation:** Inundate banks, flood runners and low lying parts of the floodplain to promote recruitment and maintenance of riparian vegetation including River Red Gum, Lignum, *Calistemon* and other emergent vegetation. These flows may also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path. **Fish:** High flow event in Sep-October

Flow component	Reach 4a	Reach 4b	Reach 4c	Reach 4d	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
									should enhance Murray Cod breeding and provide a cue to trigger Golden Perch and Silver Perch to migrate to the Lower Loddon River and Murray River to breed. These flows may also aid the dispersal of fish such as including Bony Herring, Murray-Darling Rainbowfish and Unspecked Hardyhead throughout the reach.

8.3 Flow recommendations for the Lower Loddon River

The environmental flow recommendations for the Loddon River between Kerang Weir and Little Murray River (Reach 5) and a discussion of how those flow recommendations relate to specific environmental flow objectives are presented in Table 8-3. The specific flow magnitudes relate to the flow gauge at Kerang Weir.

The highest priority objective for the Lower Loddon River is to increase the abundance and diversity of native fish in the reach and to facilitate the movement of fish between the Murray River, Lower Loddon River, Pyramid Creek, Gunbower Creek, and Middle Loddon River as part of the Native Fish Recovery Plan. Many of the flow recommendations are based on the flows that are needed to facilitate fish passage through the Kerang Weir Fishway and on previous research in the Lower Loddon River that has identified specific flow magnitudes and durations to trigger fish movement. The environmental flow recommendations for the Lower Loddon River also complement the flow recommendations for Pyramid Creek that were developed in 2014 (Jacobs, 2014b).

The environmental flow recommendations for the Lower Loddon River have less variation between wet and dry years because the system is highly modified and still used as an irrigation carrier and because the Kerang Weir fishway will not work effectively at low flows. In very dry years it may not be possible to deliver the recommended minimum low flows all year round. In such circumstances, we recommend providing a connecting flow through the whole reach to maintain pool depth, at least 10-20 cm of flow through shallow runs and adequate water quality (i.e. dissolved oxygen >2-3 mg/L and electrical conductivity <3500 EC). Periods of lower than recommended flows should be interspersed with some larger events that will at least allow small or medium sized fish to move through the Kerang Weir fishway. If we experience another drought similar to the Millennium Drought, the NCCMA should aim to maintain a connecting flow through the reach for as long as possible while still holding enough water in reserve to deliver three flows that are equivalent to the recommended summer fresh. The NCCMA should monitor water quality in remnant refuge pools during any unavoidable cease-to-flow event and release the recommended summer fresh flows as needed to prevent dissolved oxygen concentrations dropping below 2-3 mg/L and electrical conductivity rising above 3500 EC in those refuge pools.

Table 8-3: Environmental flow recommendations for Reach 5: Loddon River between Kerang Weir and Little Murray River.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
Cease-to-flow	0 ML/day	Not recommended	Not recommended	Cease-to-flow events may have occurred naturally in this reach, but are not recommended because the system has been degraded by altered flows and the objectives are to improve conditions over the short to medium term rather than provide specific stresses. Moreover, there are few deep refuge pools that can support large numbers of aquatic biota during cease-to-flow events.	Likely to be detrimental to water quality, prevent re-colonisation by instream vegetation, limit macroinvertebrate productivity and therefore limit fish and platypus populations.	We cannot identify a specific ecological function that we would want a cease-to-flow event to achieve. We note that this reach of the Loddon River would have naturally ceased to flow, but think the risks of deliberately creating a cease-to-flow event in this reach are too high given the need to improve the condition of environmental values.
Summer low flow	60-100 ML/day	6 months Dec-May	Vary the magnitude of flow within the prescribed range throughout Dec-May. Higher magnitude in Dec, gradual decline through Jan-Mar then gradual rise from Apr-May	60 ML/day is the minimum flow required for small and medium sized fish to move through the Kerang Weir fishway. The aim will be to ensure a minimum flow of 60 ML/day at all times, but flows could increase to 100 ML/day for extended periods without creating too much velocity for developing fish in slackwater edge habitats. It will be important to vary the low flow magnitude to prevent notching of the banks and to wet and dry submerged wood and other substrates that biofilms will grow on. However, also need to avoid sudden and frequent fluctuations in low flow magnitude that may either flush biota from particular habitats as flows increase or strand them as habitats dry.	**Fish:** F1, F5, F6. **Vegetation:** V3, V4, V5, V6 **Platypus:** P1, P2. **Water rats:** WR **Macroinvertebrates:** M **Water quality:** WQ1.	**General:** The Loddon River downstream of Kerang was desnagged in the 1970's and the altered flow regime and sediment inputs from the surrounding catchment have filled or partially filled many of the pools that would have naturally characterised the reach. The recommended flow of 60 ML/day will maintain a depth of approximately 0.9 m throughout the run habitats in the channel and a flow of 100 ML/day will maintain a depth of approximately 1.1 m. These depths are sufficient to maintain a variety of habitats for fish, macroinvertebrates, Platypus and aquatic vegetation. **Water quality:** Continuous flow through the reach should maintain water quality at an adequate level to support aquatic biota in all habitats at all times. **Fish:** The low flow will maintain pool and run habitats

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
						for large and small bodied native fish including Golden Perch, Murray Cod, Silver Perch, Bony Herring, Unspecked Hardyhead and Murray-Darling Rainbowfish and ensure passage for all small to medium sized fish through the Kerang Weir fishway at all times. Those fish will be able to move between the Murray River, Loddon River and Gunbower Creek systems at all times. The recommended flows should also maintain slackwater habitats at the margin of the channel to support developing fish. **Macroinvertebrates:** Continuous flow will maintain run and pool habitats for macroinvertebrates. Varying low flow magnitude over the season will inundate fallen wood to varying degrees, which will promote growth of biofilms that will drive macroinvertebrate abundance. **Vegetation:** Maintaining a permanent connecting flow through the whole reach will limit the encroachment of emergent macrophytes into the middle of the channel (i.e. deepest, fastest flowing portion of the channel) and allow native instream vegetation to colonise the channel margins. **Platypus:** Connecting flow through reach will maintain adequate pool depth to support foraging Platypus and allow Platypus to safely move between pools within their home range. This is especially important for lactating females that need to move throughout their home range to access large quantities of food. Juvenile Platypus will also be

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
						able to move through the reach when they disperse in search of new territories. **Water rats:** The low flow will maintain pool habitats and an abundant food supply.
Summer fresh	220 ML/day	2-3 days at peak. Ramp up to peak over 1-2 days and ramp down over 2-3 days. The whole event should last for approximately 1 week.	3 events per season: 1 between Dec and Feb 2 between Mar and May.	A flow of at least 220 ML/day is required to allow large bodied fish such as adult Murray Cod and Golden Perch to move through the Kerang Weir fishway. Do not actively deliver more than 1 fresh or a large fresh in Dec-Feb to avoid disturbing slackwater habitats during the main fish larval rearing phase. More frequent events are OK after February in any year and may help facilitate platypus dispersal. The summer fresh should be no greater than the maximum flow in the previous winter/spring to avoid flushing too much leaf litter into the stream during warm conditions that may cause a large drop in dissolved oxygen concentration.	**Geomorphology:** G2 **Fish:** F4, F5, F6. **Vegetation:** V4, V5, V6 **Platypus:** P2 **Macroinvertebrates:** M	**General:** 220 ML/day is the minimum flow required to allow large-bodied native fish to move upstream through the Kerang Weir fishway. The recommended flow will increase water depth by approximately 25 cm compared to a summer low flow of 100 ML/day and will generate sufficient shear stress to flush fine silt from submerged wood and other hard surfaces. It will promote wetting and drying of biofilms on submerged wood during the growing season and promote the growth of non-woody emergent vegetation on the low banks of the river. **Vegetation:** Recommended flow will inundate the lower banks and low benches in the channel to wet the soil and promote establishment, growth and survival of fringing emergent macrophytes such as *Phragmites*, *Juncus* and *Carex*. It should help establish a mosaic of riparian vegetation across a 20-30 cm high zone above the summer low flow level. **Fish**: Enable all fish to move upstream through the Kerang Weir fishway and therefore connect fish populations in the Murray River, Loddon River and Gunbower Creek systems.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
						Macroinvertebrates: Wash organic matter into stream to drive aquatic foodwebs Wet submerged wood and flush fine silt and old biofilms from hard surfaces to promote new biofilm growth and increase macroinvertebrate productivity **Platypus:** Facilitate downstream dispersal of juvenile platypus in Apr-May to colonise other habitats in the Murray River.
Autumn high flow	900 ML/day	10 days at peak. Ramp up over 5 days and ramp down over approximately 14 days	1 event in March – April in wet and average years Not expected in dry years, but avoid more than 2 consecutive years without an event.	Previous monitoring has shown that 900 ML/day at Benjeroop is needed to cue Golden Perch and Silver Perch to move upstream into Pyramid Creek and then the Gunbower Creek. The flow matches that recommended for Pyramid Creek and needs a total duration of approximately 3 weeks, including 10 days at peak, to allow fish time to respond and move throughout the system. A flow of 900 ML/day will fill most of the bottom half of the river channel and only leave 1-1.5 m of river bank above the water that Platypus can use to build nesting burrows. Therefore the autumn high flow should not exceed 900 ML/day or happen earlier than mid March because it could risk drowning juvenile Platypus in their burrows.	**Fish:** F5, F6	**Fish:** The recommended flow is specifically intended to cue movement of 1+ year old Golden Perch and Silver Perch and probably Murray Cod from the Murray River into the Loddon River, Pyramid Creek and Gunbower Creek. This seasonal movement is important to maintain populations in these systems and to increase connections between the populations.
Winter low flow	200-220 ML/day May drop to 60	6 months Jun-Nov	Vary the magnitude of flow within the	June to August is not a critical time for fish movement and therefore any flow	**Geomorphology:** G2 **Fish:** F1, F4, F5, F6	**General:** The recommended winter low flow will increase

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
	ML/day for short periods if lower flows are needed to perform operational works on the Pyramid Creek system. .		prescribed range throughout Jun-Nov to match the natural flow regime. Ramp the flow up slowly from June to deliver the highest magnitude in Jul-Sep, then gradually drop flow through Nov.	reductions for operational reasons should be restricted to that period. Flows should remain above 200 ML/day from September to November because migratory species such as Golden Perch and Silver Perch will be moving between upstream reaches and the Murray River.	**Vegetation:** V1, V4, V5, V6 **Platypus:** P1, P2	water depth by approximately 25 cm compared to the summer low flow and therefore maintain important seasonal variation. It will also generate enough shear stress to flush fine silt from hard surfaces in moderate to fast flowing habitats. **Vegetation :** If the recommended flow is delivered during spring (i.e. Sep-Nov) it will prevent fringing and riparian plants from growing in the middle of the channel and thereby maintain open water in the thalweg throughout the whole reach. It will also help establish a mosaic of native fringing species such as *Bolboschoenus*, *Carex* and *Juncus* on the lower section of the river bank and on low benches and prevent terrestrial plants colonising those habitats. The flow will also maintain soil water in the river bank to water established River Red Gum and woody shrubs such as *Callistemon* and *Leptospermum*. **Fish:** Enable all fish to move through the Kerang Weir fishway and therefore provide unrestricted access to all reaches of the Lower Loddon River, Middle Loddon River, Murray River and Gunbower Creek when the Box Creek Regulator is built. **Platypus:** Facilitate long distance movement by male platypus especially during the Aug-Oct breeding season and dispersal of juveniles in June. Provide foraging opportunities across a wide range of habitats for females to develop fat

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
						reserves prior to breeding.
Winter fresh	900 ML/day	10 days as peak. Ramp up over 5 days and ramp down over approximately 14 days.	1 event in September-October in wet and average years Not expected in dry years, but avoid more than 2 consecutive years without an event.	A 900 ML/day flow at Benjeroop is needed to cue Golden Perch and Silver Perch to move to the Murray River to spawn. The flow matches that recommended for Pyramid Creek and needs a total duration of approximately 3 weeks, including 10 days at peak, to allow fish time to respond and move throughout the system. The timing of the event will meet fish breeding requirements and is also in the growing season for aquatic and riparian vegetation. The winter fresh should not exceed 900 ML/day because the river banks are not very high and therefore there is little capacity for Platypus to build nesting burrows at a height that will not be drowned out by higher flows. The autumn high flow has a similar recommended magnitude and it should be sufficient to encourage Platypus to build their nests as high as possible up the bank to avoid potential flood risks.	**Geomorphology:** G1, G2 **Fish:** F4, F5, F6. **Vegetation:** V1, V4, V5, V6 **Water Quality:** WQ2	**General:** Flows of 900 ML/day will increase water depth by approximately 1 m compared to winter low flow (100 ML/day) and has been shown to trigger fish movement in the lower Loddon River. It will also generate enough shear stress to redistribute fine sediment on benches and bars in the bottom of the channel and scour aged biofilms from hard surfaces. **Fish:** The main purpose of the spring fresh is to cue the migration and spawning of Golden Perch and Silver Perch. These species will most likely migrate to the Murray River to spawn. The high flows may also enhance Murray Cod spawning within the lower Loddon River and aid the dispersal of fish such as Bony Herring, Murray-Darling Rainbowfish and Unspecked Hardyhead throughout the reach. **Vegetation:** Promote recruitment and maintenance of riparian vegetation including Lignum, River Red Gum and other woody vegetation on the river banks. The event will also water the roots of River Red Gum and other trees growing higher up the bank and limit colonisation by terrestrial plant species. It will therefore create a mosaic of woody and non-woody riparian vegetation on the river bank. These flows may also help scour established macrophytes from the middle of the channel and therefore maintain a clear flow path.

Flow component	Magnitude	Duration	Frequency and timing	Condition tolerances	Ecological objectives	How the flow component supports the ecological objectives
						Water quality: The recommended flow will flush accumulated leaf litter from bank and low benches into the river channel to provide carbon for aquatic foodwebs at a time that will benefit rather than threaten aquatic biota.
Bankfull flow	2,000 ML/day	3-4 days at peak	3-4 per decade, but no more than 1-2 events per decade during the Platypus breeding season (i.e. August-March).	It will be difficult to deliver a flow of this magnitude in the Lower Loddon River with existing infrastructure. Even if it can be delivered, the magnitude will probably need to be capped to limit the risk of unwanted flooding on private land. Bankfull flows in successive spring seasons will probably be most beneficial for vegetation as the first event will promote recruitment of juveniles and the second event will help the seedlings from the previous year grow to a size that can withstand subsequent dry periods. Bankfull flows in winter will meet geomorphological objectives, but have little effect on fish or vegetation.	**Geomorphology:** G1, G2 **Fish:** F4, F5, F6 **Vegetation:** V1, V5,	**General:** Bankfull flow events create the maximum shear stress within the river channel and hence determine the distribution and size of pools and benches throughout the reach. The loss of bankfull flows (due to the construction of upstream storages) and input of sediment from the surrounding catchment has reduced the size and depth of pools within the reach. **Vegetation:** Bankfull flows will help to maintain established trees such as River Red Gum high on the bank and support recruitment of juveniles. Ideally events will happen in consecutive years to help juveniles that recruit in the first year become established. These events will also help to scour vegetation from the middle of the channel and therefore maintain an open clear flow path. **Fish:** Bankfull flows may enhance Murray Cod breeding depending on when they occur.

9. Threats to meeting objectives

Altered flow regimes are one of many threats to environmental values in the Loddon River and most large rivers throughout south east Australia. Improving flow regimes on their own will not necessarily achieve the environmental objectives described in this report. Table 9-1 describes the main non-flow related factors that affect the environmental values of the Loddon River and that may need to be addressed through complementary actions to increase the likelihood that environmental flows will have their intended effect.

Table 9-1: Description of non-flow related threats to environmental values in the Loddon River system and how they may prevent environmental flow objectives being met.

Threat	Potential effect on environmental values and environmental flow objectives	Potential complementary actions to address the threat
Dams, Weirpools and other instream barriers	• Trap sediment, which starves downstream reaches of sediment to form in-channel benches and other related features. • Downstream streambed becomes armoured and is less suitable as a substrate for plants and macroinvertebrates. • Restricts the upstream and downstream movement of native fish. This is particularly important in the Loddon River, where many large-bodied species would have naturally migrated between the Loddon River and Murray River. • Restricts downstream supply of plant propagules, which may limit the type and amount of plants that can grow in downstream reaches. • Restricts the downstream supply of drifting macroinvertebrates • Restricts the downstream supply of fine and coarse particulate matter, which is an important food source for macroinvertebrates and fish, hence limiting the potential productivity of downstream foodwebs • Cold water releases from below the thermocline in large dams can reduce temperatures in downstream waterways, which may interrupt fish breeding seasons and reduce the growth rate and productivity of aquatic macroinvertebrate, biofilm and plant communities. • Weirpools may become a favourable habitat for pest species such as Carp and aquatic weeds. These species may then spread to upstream and downstream reaches.	• Construct fishways or replace small structures with Doppler velocity gauges • Install multi-level offtakes to allow water to be released from near the surface of the water column rather than below the thermocline

Threat	Potential effect on environmental values and environmental flow objectives	Potential complementary actions to address the threat
Unrestricted grazing by livestock and pest species such as rabbits	• Animals actively graze on new plant growth and therefore reduce the abundance of established riparian and fringing emergent vegetation and limit future recruitment. • Reduce diversity of riparian and fringing emergent vegetation and create opportunities for terrestrial and aquatic weeds to become established. • Hooved animals trample the river banks, increasing the potential for erosion in some places, compacting the soil and thus preventing plant growth in other areas and physically damaging growing plants. • Rabbits can undermine banks by grazing and by building burrows. • Large numbers of cattle and sheep in the riparian zone can introduce large nutrient loads to waterways and hence increase the risk of algal blooms and cause excessive growth of filamentous algae.	• Fencing to exclude or control stock access. • Pest control programs to reduce the abundance of rabbits.
Land clearing and other activities that reduce the cover of instream and riparian vegetation	• The streambed and river bank become more susceptible to erosion during high flows. • Cleared landscapes are more hydraulically efficient, therefore local run-off will be higher during storm events and that water will carry larger loads of litter and nutrients, which may cause an imbalance in stream foodwebs. • Lack of instream and emergent vegetation will reduce substrates and habitats for biofilm growth and macroinvertebrates. • Lack of instream and emergent vegetation will reduce potential cover for Platypus and make them more vulnerable to predators. • Lack of mature riparian trees will over time reduce the supply of large wood (which is an important habitat item for fish, macroinvertebrates and Platypus) to the channel.	• Active revegetation programs on the river bank, floodplain and in the river channel. • Erosion control works in areas where gully erosion is severe • Establish buffer zones to filter water and nutrients that may wash into the stream during heavy rain events. • Active re-introduction of large wood to provide habitat for fish, macroinvertebrates and Platypus.
Catchment activities such as mining and land clearing that have increased sediment loads to the river	• Extensive land clearing can cause gully erosion, which will increase sediment loads to the river. That sediment can fill important refuge pools and smother riffle habitats and cover wood and other features within the river channel. The loss of deep pools is a particular threat to native fish and Platypus populations that use those habitats for food and are the main refuge habitats during dry periods when there is little surface flow.	• Excavate deep pools within the river channel to create foraging and potential refuge habitat for fish and Platypus.

Threat	Potential effect on environmental values and environmental flow objectives	Potential complementary actions to address the threat
Pest fish species such as Carp, Redfin, Trout and Gambusia	• Exotic species compete with native fish species for food and habitat and therefore limit the size of native fish populations. This is especially true for Carp, which can account for a large amount of the fish biomass in inland rivers. • Exotic species such as Redfin, trout and Gambusia may actively prey on native fish • Foraging by Carp can remove instream vegetation and increase water turbidity, which will limit future growth and recruitment of submerged vegetation.	• Active pest species removal programs • Carp screens to limit their dispersal
Recreational fishing	• Anglers are likely to target Golden Perch, Murray Cod, Silver Perch and possibly River Blackfish and may therefore limit the extent to which environmental flows can improve those populations. • Angling is likely to be a particular threat in dry periods when the populations are in decline and fish are restricted to refuge habitats where they may be easily caught.	• Limit or prohibit fishing in certain reaches especially in the short term while efforts are being made to restore depleted populations. • Prevent fishing at barriers where migrating fish are forced to congregate. • Educate anglers about the current status of fish populations and the need to limit the number of fish that are removed from those populations.
Active fish stocking programs	• Murray Cod, Golden Perch and Trout are stocked in the Loddon River catchment. Trout will prey on and compete with native fish and stocked populations of Murray Cod and Golden Perch may interfere with genetic diversity of native populations. • The presence of large numbers of stocked fish may make it difficult to determine whether environmental flows have increased natural recruitment in native fish populations.	• Cease all stocking of exotic species such as Trout • Cease stocking of native fish or use reliable markers so that stocked fish can be identified in fish surveys and therefore distinguished from natural recruits.
Small native fish populations in nearby catchments such as the Murray River.	• The native fish community in the Loddon River has very small population sizes. Its recovery will rely on recruitment from populations in nearby connected systems, but if those systems also have small populations then recovery will be slow.	• Fish recovery works need to operate at the Basin scale rather than just in individual rivers or river reaches. This is being partly addressed through the Native Fish Recovery Program that includes the Loddon River and Murray River.
Illegal fishing activities such as the use of Opera House nets	• Opera House nets and other similar types of illegal fishing equipment are a significant threat to diving mammals such as Platypus and Water Rats, turtles and diving birds.	• Increase policing of illegal fishing activities in all waterways, especially in areas where Platypus are likely to be present.
Unprotected irrigation pumps	• Irrigation pumps in the river can suck up Platypus and other animals. This is a particular problem in autumn and early winter when small juveniles are dispersing throughout the system. The Platypus are attracted to the pumps because they are often placed in deep holes and often have emergent vegetation and other structural habitat nearby.	• Install appropriate guards at the opening of all irrigation pumps. These should be retrospectively fitted to all existing pumps and be mandatory for any new pumps that are installed in the river. This will be particularly important in the reach downstream of Kerang if the irrigation channel is decommissioned and all irrigation customers are transferred to direct river extraction.

Threat	Potential effect on environmental values and environmental flow objectives	Potential complementary actions to address the threat
Predators such as foxes and cats	• Foxes and cats will take Platypus especially if Platypus are forced to leave the water due to insufficient flow or to move past an obstacle. Predation rates will also be higher in areas that have limited riparian vegetation and other cover to protect Platypus.	• Programs to actively reduce the abundance of feral predators. • Re-vegetation works to provide adequate cover for Platypus. • Design weirs and other structures that will allow Platypus to move past them without having to traverse overland.
Stormwater runoff	• Stormwater run-off from Kerang represents a significant threat to water quality in the Kerang Weirpool and downstream reaches.	• Improve stormwater management practices in town.

10. Monitoring requirements

The monitoring recommendations to assess the extent to which environmental flows meet specific objectives for native fish, aquatic and riparian vegetation, Platypus, Water Rats, Macroinvertebrates and water quality are described below. No specific monitoring is recommended for geomorphology, because it is unlikely that environmental flows will be large enough to scour pools within the river channel and there are no reliable methods for accurately quantifying the extent to which freshes clean fine silt from hard substrates.

10.1 Fish

Fish monitoring should focus on five things:

1. Annual fish surveys to describe changes in the distribution and diversity of fish and potential changes in size class within populations in all reaches. This is general condition monitoring that is currently being conducted in all reaches of the Loddon River, except Twelve Mile Creek as part of the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP).

2. Acoustic tracking and PIT tagging (PIT tag readers are currently fitted to the Kerang Weir fishway) to monitor the movement of migratory species such as Golden Perch, Silver Perch and Bony Herring between the Murray River, Lower Loddon River and Middle Loddon River during high flow events in spring (pre-spawning migration) and autumn (upstream migration of juveniles and sub-adults).

3. Larval sampling and targeted electrofishing surveys to monitor Murray Cod spawning and recruitment in all reaches where flows are recommended to support Murray Cod recruitment.

4. Install artificial spawning tubes and conduct targeted electrofishing and fyke net surveys to monitor spawning, recruitment and changes to the distribution of River Blackfish in the Loddon River and Tullaroop Creek upstream of Laanecoorie Reservoir.

5. Targeted electrofishing surveys in summer or autumn, with appropriate age class analysis to monitor spawning and recruitment of low flow specialists such as Murray-Darling Rainbowfish in the Middle and Lower Loddon River. Existing VEFMAP surveys may provide sufficient data to meet this monitoring objective.

10.1.1 Supplementary studies to address other fish knowledge gaps

The other main knowledge gap for native fish relates to the ability of fish to move past artificial barriers in the Middle Loddon River. More work is needed to determine whether fish can negotiate the flow gauge weir at Appin South, what flows are required to drown that structure to provide fish passage and whether alternative options (e.g. install a fish ladder or replace the weir with a Doppler flow measuring device) should be considered to improve fish passage.

The lack of a single hydrological model for the entire Loddon River system makes it difficult to reliably determine the natural or unimpacted flow regime for the Middle and Lower Loddon River. Such information would be particularly useful for corroborating anecdotal reports that the river would contract to a series of large pools in most summers and would be used to determine the type of flow stress and level of connection with other parts of the system that native fish would have naturally experienced in those reaches.

10.2 Vegetation

The vegetation monitoring program should use repeat quantitative transect surveys and repeat photo point monitoring to assess changes in the composition and extent of vegetation in the river, on the banks and in adjacent floodplain habitats.

All of the environmental flow objectives for instream vegetation, fringing emergent vegetation (including unwanted encroachment into the main channel) and woody riparian vegetation can be assessed by conducting repeat quantitative measurements along fixed transects at selected sites in each reach in spring at 0, 1, 2, 6 and 10 year intervals from the commencement of environmental flows. More frequent sampling may also be needed if bankfull and overbank flows occur during the monitoring period. The fixed transects should run from the top of one bank to the top of the opposite bank and include the section of channel that is inundated during the summer low flow period. Transects can also be established across flood runner channels and stratified random sampling points established in floodplain wetland habitats that are likely to be targeted by environmental flows in Reach 4a to assess vegetation changes in those habitats in response to high or bankfull flows. Photographs taken at fixed locations at each site on each sampling occasion will provide a qualitative assessment of vegetation changes and will be a useful tool to help interpret the quantitative data and to demonstrate changes to a lay audience.

Grazing by livestock is likely to prevent environmental flows meeting the stated vegetation objectives. If the CMA wants to quantify the effect of controlled and uncontrolled grazing on riparian and in-stream vegetation responses to environmental flows then monitoring should be conducted at sites that are grazed and at the same number of sites where grazing is excluded. If the CMA does not have sufficient resources to investigate grazing effects, then all proposed vegetation monitoring should be conducted at sites that are not grazed so that environmental flow effects can be measured without the influence of significant confounding factors.

The type of monitoring described above is compatible with the vegetation monitoring component of VEFMAP. The NCCMA may elect to use the VEFMAP program as it is, or supplement that program with monitoring at additional sites, additional sampling events or other methods. A range of suitable methods for quantitatively measuring the composition, extent and condition of riparian and in-stream vegetation are described in Cunningham *et al.* (2007) and MDBA (2010). Baldwin *et al.* (2005) offers general guidance on suitable monitoring approaches for floodplains and wetlands and Scholz *et al.* (2007) is an example of how such methods have been applied in the Victorian Mallee.

The vegetation monitoring program described here is essentially a condition monitoring program. The aim will be to accurately describe temporal changes to the composition, condition and extent of different vegetation communities in different parts of the river channel and in selected floodplain habitats and then try and correlate those changes with the flow regime what was delivered prior to each sampling event. The specific monitoring questions and flow components of interest for each vegetation objective are described in Table 10-1. More formal hypothesis testing is not practical because there are no suitable control rivers or reaches that are physically similar and will not receive any environmental flows. No specific monitoring is recommended for biofilms and periphyton because the relative importance of those communities in the Loddon River is unknown and studies to address that knowledge gap are better suited to a targeted research program (see SECTION).

Table 10-1: Specific monitoring questions and relevant flow components associated with the main vegetation flow objectives in the Loddon River.

Vegetation flow objective	Specific monitoring question	Specific events targeted for investigation
Maintain and/or increase diversity and spatial extent of in-stream vegetation	Is the spatial extent and diversity of in-stream vegetation (e.g. Water Ribbons, Pondweed) increasing in response to environmental flows?	Low flow (all year) Summer fresh
Increase diversity and spatial extent of native emergent non-woody vegetation along the banks.	How does the extent and diversity of fringing emergent vegetation (e.g. Common Reed) respond to environmental flows?	Summer low flow Summer fresh Bankfull
Maintain adult riparian woody vegetation (e.g. River Red Gum, Bottlebrush, Tea-tree and Paperbark) and facilitate recruitment in areas adjacent to the river channel.	Are native trees and shrubs in the riparian zone responding to environmental flows, in terms of 1) condition of adults and 2) successful recruitment?	Summer low flow Winter-spring fresh Bankful

Vegetation flow objective	Specific monitoring question	Specific events targeted for investigation
Maintain floodplain vegetation communities connected to the river via flood runners.	Is the floodplain vegetation in appropriate reaches (e.g. Reach 5) responding to environmental flows, in terms of 1) condition of adults and 2) successful recruitment of River Red Gum overstorey, and 3) maintenance of a structurally and floristically diverse grassy, sedge or lignum-dominated understorey?	Winter-spring fresh Bankful
Limit encroachment of fringing non-woody and riparian woody vegetation into the stream channel.	Are environmental flows limiting (or in the case of Reaches 4 & 5, facilitating) the encroachment of undesirable taxa (e.g. Common Red, Cumbungi, River Red Gum) into the stream channel?	Low flow (all year) Freshes (all year) Bankful

10.2.1 Supplementary studies to address other vegetation knowledge gaps

The main vegetation knowledge gaps and risks in the Loddon River and recommended approaches to address those gaps are described in Table 10-2.

Table 10-2: Knowledge gaps associated with environmental flow vegetation objectives in the Loddon River.

Knowledge gap	Objective / risk	Recommendation	Who	Priority
Why are there few areas of in-stream vegetation in the Loddon River?	Maintain and/or increase diversity and spatial extent of in-stream vegetation	Research program examining the effect of critical environmental factors (e.g. water velocity, turbidity, propogule availability) on the establishment and survival of in-stream vegetation.	CMA/Research organisation	Medium−Low
Will providing low flow year-round in Reach 4 (mostly to meet fish objectives) facilitate encroachment by undesirable taxa, especially Common Reed and Cumbungi?	Limit encroachment of fringing non-woody and riparian woody vegetation into the stream channel.	Targeted monitoring program to describe vegetation responses to the provision of environmental flows in Reach 4.	CMA	High
What role do biofilms play in food webs of the Loddon River and how can their responses to environmental flows be monitored?	Maintain biofilm productivity, especially on coarse woody debris.	Research program examining the trophic importance of biofilms on coarse woody debris and identifying cost-effective methods of monitoring the effects of environmental flows on biofilm performance.	CMA/Research organisation	Low

10.3 Platypus

Platypus are difficult and expensive to monitor through live-trapping techniques: nets have to be checked regularly overnight for welfare reasons, the number of individuals captured per site is characteristically very low, and animals can become net-shy (i.e. actively avoid capture) after being captured on one or a few occasions.

Accordingly, the best strategy for generating baseline population data and tracking changes in populations over time may be the following:

1. Require fisheries consultants working in the Loddon River catchment and nearby connected catchments on behalf of the North Central CMA, other government agencies or Goulburn-Murray Water to consistently record the number and sex of any platypus captured during fish surveys.

2. North Central CMA to maintain a central register for Platypus sightings in the North Central region, promote the existence of the register through community groups and other stakeholder organisations and encourage sightings to be reported by management staff and community members.

10.4 Water rats

Many of the problems associated with Platypus monitoring described above also relate to Water Rats. The Water Rat objectives described in this environmental flows study have been classified as secondary objectives and therefore no targeted Water Rat surveys are recommended. However, as with Platypus, the NCCMA could maintain a register of Water Rat sightings throughout the catchment and encourage anyone who may be working on the river and community members to report any Water Rat sightings so they can be recorded on the register.

10.5 Macroinvertebrates

We currently don't know the total biomass of macroinvertebrates or the relative biomass of different functional feeding groups in each reach of the Loddon River. Moreover, we don't know what the biomass could be and how it and productivity varies with flow.

Macroinvertebrate monitoring to address these knowledge gaps will need to be quantitative because the focus is on biomass rather than presence/absence. Monitoring will also need to target specific habitats. Standard Rapid Bioassessment sampling techniques will not provide quantitative data and therefore it may be necessary to use artificial substrates such as constructed snags, leaf packs or macrophyte stems. The question we would ask is there a change in macroinvertebrate biomass in these habitats under different flow regimes or is biomass determined more by the total amount of any given habitat. Monitoring may also look at biofilm production on substrates that macroinvertebrates are excluded from.

One problem with biomass monitoring is that biomass is likely to change throughout the season due to changes in water temperature, therefore monitoring conducted before and after particular flow events will be confounded. Assessing macroinvertebrate responses to environmental flows in lowland rivers such as the Loddon is potentially more of a research question than a monitoring question. Given that the macroinvertebrate objectives described in this environmental flows study have been classified as a secondary objective, targeted macroinvertebrate monitoring is probably a low priority.

10.6 Water quality

Any water quality monitoring program should focus on dissolved oxygen concentration, electrical conductivity and water temperature. All parameters will be used to determine whether water quality during low flow conditions is adequate to support aquatic life, while the dissolved oxygen and water temperature data will be used as an early warning of a potential hypoxic blackwater event and the severity of such an event. The optimal approach would be to install probes in selected pools at the downstream end of each reach so that dissolved oxygen and EC can be measured continuously or at short intervals. Selecting sites at the downstream end of each reach is important because losses through seepage and evaporation mean that under low flow conditions, the downstream end of each reach will have less flow than the upstream end and hence there will be less water movement to oxygenate the water and dilute salt. Moreover, water quality is likely to deteriorate as a function of distance downstream of the storage release point. In reaches that gain groundwater, the magnitude of flow at the downstream end of the reach may be greater than at the upstream end, but monitoring at the downstream end of the reach will still be important as it will identify whether freshwater surface flows are sufficient to dilute any saline groundwater inputs. There are relatively few very deep pools within the Loddon River and so monitoring near the surface of the water column under low flow conditions should be adequate.

Continuous monitoring probes have already been installed at six sites in the Upper and Middle Loddon River (see Table 10-3) . Tullaroop Creek at Mullins Road (site 407322 at the downstream end of Reach 2), Loddon River at Turners Crossing (Site 407321 at the downstream end of Reach 3a) and Loddon River at Yando Road (Site 407323 at the downstream end of Reach 4a) are probably the most useful sites because they are near the downstream end of their respective reaches. The site at Yando Road will be particularly useful for monitoring potential hypoxic blackwater events because it is in the vicinity of previously reported blackwater events.

Table 10-3: Water quality monitoring sites in the Loddon River catchment.

Site	Name	Continuous DO/Temp/EC	Spot WQ	Spot nutrients
407322	Tullaroop Creek @ Mullins Road	2007-2014		
407203	Loddon River @ Laanecoorie	2008-2014		
407321	Loddon River @ Turners Crossing	2007-2014		
407229	Loddon River @ Serpentine Weir	1997-2014 (only temp & EC)	1996-2014	1996-2014
407320	Loddon River downstream Loddon Weir	2007-2014		
407323	Loddon River @ Yando Road	2007-2014		
407205	Loddon River @ Appin South		2005-2014	2005-2014
407242	Loddon River @ Murray Valley Highway		2006-2013	2006-2013
407202	Loddon River @ Kerang Weir		1990-2014	1990-2014

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Appendix A. Community engagement

The North Central CMA assembled separate Community Advisory Groups (CAGs) for the Upper Loddon River, Middle Loddon River and Lower Loddon River. The membership of those groups is presented in Table A 1.

Table A 1: Membership of the Community Advisory Groups for the Upper Loddon River, Middle Loddon River and Lower Loddon River.

	Upper Loddon River	Middle Loddon River	Lower Loddon River
Chair	Shane O'Loughlin	Laurie Maxted	Di Bowles
Community member	Graeme Erb	Barry Barnes	Ben Hall
Community member	Jim Lawson	Murray Haw	Robert Hampton
Community member	Cathy McCallum	Paul Haw	Angela Hird
Community member	Veronica Palmer	Geoff Leamon	Elaine Jones
Community member	Barry Rinaldi	Ian Penny	Rob Loats
Community member	Alison Teese		Colin Myers
Community member			Robert Stevenson

The CAGs provided input during the objectives setting phase of the project and provided comment on the draft flow recommendations prior to them being finalised.

A.1 Community input to the environmental flow objectives

The North Central CMA and Jacobs project team met separately with the three CAGs at the beginning of the project to understand the communities' vision for the Loddon River and the values they would like to see maintained or improved through environmental flows. Andrew Sharpe, Louissa Rogers (NCCMA), Phil Slessar (NCCMA) and Brad Drust (NCCMA) facilitated workshops with CAGs in the Upper Loddon catchment (Newbridge) and Middle Loddon catchment (Durham Ox) on the 28th January 2015; and Andrew Sharpe and Louissa Rogers facilitated a workshop with the CAG for the Lower Loddon catchment (Kerang) on the 29th January 2015 to discuss and document changes to the Loddon River that community members have observed over their lifetime and to understand the environmental values and objectives that the community associate with the river. The main issues and observations raised by each CAG are summarised in Table A 2.

The observations and values identified by the CAG were documented immediately after the community meetings and were discussed by the Environmental Flows Technical Panel (EFTP) during site visits that were conducted on the 3rd and 4th February 2015 and during the FLOWS objectives setting workshop that was held at Huntly on 5th and 6th February. The FLOWS objectives workshop was facilitated by Jacobs and was attended by members of the EFTP and the Project Steering Committee. The community observations provided important context to support the field observations of the EFTP and the technical literature review that each member of the EFTP conducted. After the FLOWS objectives setting workshop, Jacobs prepared draft Flows Objective Reports for the Upper Loddon River, Middle Loddon River and Lower Loddon River. The NCCMA distributed those draft reports to the CAG members for comment. Those comments were used to finalise the Flows Objectives reports for each part of the catchment and to set the final environmental flow objectives for each reach.

Table A 2: Summary of issues raised by CAG members during preliminary community consultation meetings.

Issues raised by Community Advisory Group members
Upper Loddon River
• Sand has infilled many of the deep pools that used to characterise the upper reaches of the Loddon River, particularly in Tullaroop Creek near Carisbrook. This sand has probably come from historical mining activities higher in the catchment and erosion in sub-catchments. The rate of sand movement is not known. The sand combined with willows has caused the river channel to become much wider and flatter than it was and therefore now provides less habitat for fish, platypus and other biota. • The river historically had moderate floods in most winters, but there have been very few winter floods in the last 20 years and the recent large floods have been in summer. • Anglers used to frequently catch large numbers of a variety of species including Redfin, Trout, Golden Perch and Murray Cod. River Blackfish were also caught in Tullaroop Creek. Very few fish have been caught in the last 20 years, although there have been better catches since the 2011 floods. Angling is important for the community. Anglers would like to be able to go fishing and catch something they can eat; they don't necessarily mind what species it is. • Carp appear to be have moved further upstream in recent years. They are probably less abundant downstream of Laancecoorie Reservoir compared to 20 years ago, but are becoming more abundant in Tullaroop Creek. • Platypus used to be abundant in the Upper Loddon River, particularly in Tullaroop Creek. Rinaldi used to regularly see two families near his property at Carisbrook. Adult platypus were observed swimming in flood waters in 2011, but the community thinks that numbers have dropped since that flood and sightings are now very rare. • The community would like the river to have good water quality. By that they mean that it should be relatively clear (it was very clear historically, but has become much more turbid since Carp arrived), have low salt concentrations and no Blue Green Algal blooms. During the drought there were frequent algal blooms near Carisbrook and water in Tullaroop Creek was very salty. • Many landowners have fenced their riparian zones and some areas have been actively replanted. There is some concern that these efforts have not been very successful. In some places the fences and planted wattles were destroyed by the floods. Some community members are concerned that the large number of trees that have fallen into the river have reduced the hydraulic capacity of the river channel and therefore increased the risk that land and towns such as Carisbrook will flood. Community members discussed the need to use light grazing to control weeds and flood and fire risks associated with fenced off riparian zones. • During the drought, *Phragmites* and *Typha* choked much of the river channel and reduced its hydraulic capacity. Much of that was removed during the floods and is starting to grow back at the margins of the channel. • River Red Gum were originally only on the banks now they are growing further on the floodplain in fenced off areas, which suggests that grazing by livestock has played a large part in restricting the recruitment of these trees. • The Loddon Stressed Rivers Project has helped fence approximately 600 Km of river frontage in the Loddon River catchment. Approximately half of that has been on the Loddon River and the rest has been in tributaries or distributary channels. Approximately 150 km of river frontage doesn't need fencing because it is in other reserves, but there is still approximately 150 km of river frontage that still requires fencing to exclude livestock.

Issues raised by Community Advisory Group members
Middle Loddon River
• Community members would like to see flow in the river all year round and good water quality. The community is particularly aware of blackwater events and would like to prevent them. There was a discussion about the need for variable water levels to prevent notching of the banks and that seasonal fluctuations are important for biological processes. The NCCMA probably needs to do more to inform the community about the importance of seasonal flow patterns and wetting and drying on the bank to drive ecological productivity. • Paul Haw provided a detailed history of changes to this part of the Loddon River. Before the irrigation system was developed, the Middle Loddon River used to dry in most years but also had regular medium sized floods. Local community members recall the river flooding in most winters until the mid 1990s. The 2011 flood was the largest in memory, but also occurred in summer, which was not good. • There are relatively few deep pools in the reach and therefore not likely to be much refuge habitat for fish and other biota during very low flow or cease-to-flow events. The main exception is a section of Twelve Mile Creek just downstream of the regulator that still has some reasonable pools, which have formed around fallen River Red Gums. It is accepted that constant flows have contributed to the infilling of pools and flattening of the streambed and there is a willingness to provide some larger flows to scour and maintain pools • The channel capacity declines markedly through the Middle Loddon River as flood-runners carry water from the main channel onto the floodplain. There is an acceptance by some landowners to allow environmental water to inundate some private property in the reach as long as the floods occur in winter or early spring and are not too large. • Community members agreed that Twelve Mile Creek is the natural flow path for the Loddon River past Canary Island and has greater environmental values than the West Branch of Loddon River that runs down the west side of Canary Island. Moreover, they are happy that the majority of low flows are directed down Twelve Mile Creek instead of the West Branch of the Loddon River. There is a proposal to repair the Twelve Mile Creek regulator and fix a sill at a low level (approximately equivalent to leaving only 2-3 boards in the bottom of the current structure). This repaired structure would allow most of the low flow to pass down Twelve Mile Creek, with a small volume still watering the West Branch of the Loddon River. • River Blackfish were historically caught in the Middle Loddon River, but were displaced by exotic species such as Redfin and Carp. All fish were lost from the Middle Loddon River during the drought. • Community members commented that Carp had caused many problems in the Loddon River including damage to instream and fringing vegetation through direct foraging and associated increased turbidity. In removing instream vegetation they have also reduced habitat for native fish and frogs. The loss of frogs has resulted in a substantial loss of snakes that would have naturally fed on the frogs.

Issues raised by Community Advisory Group members
Lower Loddon River
• High priority is to maintain and improve a diverse native fish community in the river. The community is particularly interested in improving the abundance of large-bodied angling species, but know that it is also important to provide flows, habitat and food for small-bodied native fish. • The Lower Loddon River has silted up considerably over the years due to the operation of Pyramid Creek as an irrigation carrier and poor land management that has contributed to local bank erosion. This silt has filled virtually all the deep holes in the river and created a silt bed that has been colonised by *Typha* and Phragmites, which has choked the channel in places. • The community would like permanent flow in the reach with appropriate flow variability to prevent bank erosion and to facilitate required ecological processes. They did not want environmental flows to exceed the capacity of the channel, because they are concerned about flooding and do not see any great value in watering the floodplain given it doesn't have any wetlands. • Community members spoke about the large amount of work that has been done to fence off riparian zones, but also highlighted inconsistencies in rules about grazing between Parks Victoria (i.e. no grazing) and DELWP (i.e. some controlled grazing to manage risks) and inconsistencies in the adherence to such rules. Many community members that have river frontage in the lower Loddon River commented on potential weed problems in areas that had been fenced and excessive lignum growth that may represent a fire risk and flood risk. The community would like more information about what is a reasonable target for riparian zone management, what the risks are and how they should manage weeds, and excessive native plant growth. • Stormwater run-off from Kerang is a risk to water quality in the reach. • Other issues in the reach include pest species such as Carp, foxes and rabbits. • Angela Hird spoke about the need for the local community to value the Loddon River more and that more needed to be done to educate them about its ecological and recreational values so they will use it and look after it. • The community raised the issue that Sheepwash Creek was the natural continuation of the Loddon River and that some work should be done to investigate environmental values and flow requirements for that system. The NCCMA took that comment on notice and may look at it through a separate project. • Some community members said they could catch cod from the river with their hands when they were kids, they also caught catfish. Native fish became less abundant when carp were introduced. • Community members have seen more Golden Perch in the Lower Loddon River in recent years than at any time since the 1980s. • During the drought there were some native fish in remnant pools, but community members think since the floods there are now more carp. • Used to be fish kills associated with blackwater events. These were relatively common, and killed many different types of native fish. That is bad on one level, but it also demonstrated that there were or still are lots of different native fish species in the reach. • Historically the Lower Loddon River had lots of turtles, but these have become rarer. The community attribute that to egg predation by foxes. • The whole reach of the Lower Loddon River was desnagged in the 1970s, since then some trees have fallen into the river and they now provide some habitat for fish and other biota, but there are not as many snags as other parts of the Loddon River.

A.2 Community input to the revised environmental flow recommendations

The EFTP and Project Steering Committee conducted a FLOWs workshop at the Jacobs office on 26-27th February 2015 to revise the environmental flow recommendations for each reach of the Loddon River. Jacobs prepared a draft report that described the current condition of the Loddon River, the environmental flow objectives for each reach of the river and the environmental flows that needed to be delivered to help meet those objectives.

Andrew Sharpe and Louissa Rogers met with community members in the Upper Loddon, Middle Loddon and Lower Loddon catchment to present the draft revised environmental flow recommendations for each reach, to answer any questions and seek community feedback. The North Central CMA provided all CAG members with a copy of the draft environmental flows report after the meeting and invited CAG members to provide specific feedback. That feedback has been received and has been used to finalise the environmental flow recommendations and to prepare the final version of the report.