FINAL REPORT:

Yanco Creek system environmental flows study

May 2013

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Glossary

Bankfull flow	Completely fill the channel, with little flow spilling onto the floodplain.
Cease to flow	No discernible flow in the river, or no measurable flow recorded at a gauge.
Current flow conditions	Long-term flow series simulating behaviour of the system under the current Murrumbidgee Regulated River Water Sharing Plan. Allocated diversions information is based on data collected from 1990s-2000s and reflects the level of irrigation development around the time the Water Sharing Plan was implemented in 2004
High flow	A continual increase in the seasonal baseflow. A high flow remains within the channel and connects most habitats within the channel.
High flow freshes	Small and short duration peak flow events that exceed the baseflow (high flow) and last for at least several days. Usually in winter and spring in Victoria.
Hydraulic roughness	Refer to Manning's 'n'
Independence of flow events	Where a flow series is being assessed for the recurrence of a particular flow event that exceeds a threshold magnitude, an independence criteria is applied (in this case 14 days). If the flow drops below the threshold magnitude for less than 14 days, the two peaks above the threshold are not considered to be 'independent' and will only be counted as a single event.
Low flow	Flow that generally provides a continuous flow through the channel.
Low flow freshes	Small and short duration peak flow events that exceed the baseflow (low flow) and last for at least several days. Usually in summer and autumn in Victoria.
Manning's 'n'	The Manning coefficient of hydraulic roughness, often denoted as n, is an empirically derived coefficient, which is dependent on many factors, including river-bottom roughness and sinuosity. Values typically range between 0.02 for smooth and straight rivers, to 0.075 for sinuous rivers and creeks with excess debris on the river bottom or river banks.
Overbank flow	Flows greater than bankfull which result in surface flow on the floodplain habitats.
Pre-development flow conditions	Long-term flow series simulating the best estimate of natural flows in the Yanco Creek system, utilising historical inflow series for tributaries and dam locations, no structures, irrigation or other demands, and river loss functions as per the Water Sharing Plan model

Abbreviations

CCD	Coleambally Catchment Drain
CEWH	Commonwealth Environmental Hater Holder
CEWO	Commonwealth Environmental Water Office
CMA	Catchment Management Authority
CRC	Cooperative Research Centre
DC800	Drainage Canal 800
DNRE	Victorian Department of Natural Resources and Environment (now Department of Sustainability and Environment)
DPI	NSW Department of Primary Industries
FCWG	Forest Creek Working Group
IQQM	Integrated water Quantity and Quality Model
MDBA	Murray Darling Basin Authority
NSW	New South Wales
OEH	NSW Office of Environment and Heritage
OoW	NSW Office of Water
RERP	Rivers Environmental Restoration Program
SRA	Sustainable Rivers Audit
WSP	Water Sharing Plan
XS	Cross section
YACTAC	Yanco Creek and Tributaries Advisory Council

1 Introduction

1.1 Background to the study

This environmental flows study was initiated by the Yanco Creek and Tributaries Advisory Council (YACTAC) to address the lack of recognition of the Yanco Creek System in the Water Sharing Plan for the Murrumbidgee Regulated River Water Source 2003. There was also concern about water savings projects removing water from the system without a good understanding of the potential environmental impacts.

Prior to 2006 the Murrumbidgee Water Sharing Plan included a requirement for a 100 ML/d replenishment flow over Warriston Weir to supply stock and domestic water to landholders along the Forest Creek and Forest Creek Anabranch. Water for Rivers successfully negotiated two projects (Forest Creek Stages 1and2) which included alternative stock and domestic supplies to landholders. 34.7GL of Murrumbidgee high security water was converted to environmental water with zero regulated flows the new target over Warriston Weir.

In 2007, Water for Rivers agreed to fund this Environmental Flows Study as well as a report on Wanganella Swamp. The Wanganella Swamp Management Plan was completed in 2011. In 2010, Water for Rivers signed an agreement with State Water and NSW Office of Water for the finalisation of water savings projects in the Murrumbidgee. State Water assumed responsibility for the implementation of these projects, one being this Environmental Flows Study.

This environmental flows study will be useful for inclusion in the next round of water sharing plan development, for sourcing and targeting delivery of environmental flows and as a platform for further environmental works and measures in the Yanco system.

1.1.1 Scope

The Yanco Creek system supplies water to a vast area of the Riverine Plains of New South Wales for agricultural production and also water supply for townships of Morundah, Urana, Oaklands, Jerilderie, Conargo and Wanganella. Along the system there are a number of environmental assets including significant wetland areas that have been impacted by historic water management practices. The community along the creek system is highly committed to improving the ecological health of all the system and has initiated and/or supported several studies and environmental restoration programs, particularly for riparian habitat.

Water management for the entire system is governed by the Water Sharing Plan for the Murrumbidgee Regulated River Water Source 2003. However the environmental flow provisions of the Water Sharing Plan do not target ecological outcomes for the Yanco Creek System.

The aim of this environmental flows study is to derive scientifically based recommendations to identify the benefits for the use of environmental water in the Yanco Creek system from the available sources in the regulated Murrumbidgee or NSW Murray River systems. The scope of the environmental flows study includes:

- Assessment and integration of a substantial amount of existing ecological and hydrological data and reports for each of the Creeks and individual localities.
- Development of environmental flow requirements for a range of ecological attributes of the system as a whole and for each Creek.
- Identification of the relative contribution the system can make to specified environmental flow requirements in the Edward/Murray River.
- Identification of environmental flow requirements and provision of practical and realistic environmental flow recommendations
- Identification of risks or benefits to environmental outcomes on the creeks which may arise due to water efficiency activities and changes to operating regimes.

The scope of this study does not include:

- Development of flow sharing rules for water resource plans
- Identification of water requirements for social and/or economic benefit
- Development of individual wetland watering plans for wetland assets present in the system

Alluvium was engaged by State Water to undertake the environmental flows study. This *Final Report* describes the environmental values and threats in the Yanco Creek system, environmental objectives for flow dependent environmental values, reach by reach environmental flow requirements to meet the objectives, and an assessment of the performance and risk associated with the current water management regime. This report builds on information presented in the *Site Paper* and the *Issues Paper.*

1.2 Method

There are many methods for determining environmental water requirements for flow dependent ecological values (ie. the FLOWS method used throughout Victoria (DNRE 2002), the Tasmanian Environmental Flows Framework, the 80:20 rule applied in the Northern Territory, or the eco-hydrologic approaches used in Queensland). The New South Wales State Government and water managers do not use a standard method for the determination of environmental flows. Therefore, we have developed a method that draws on the elements of the existing flow determination approaches that can be completed within the scope of this project (tasks outlined in Figure 1).

The environmental flows study is aimed at identifying the key environmental values and functions of the Yanco Creek system, and providing recommendations for their specific ecological watering requirements. Environmental values are identified through a desktop exercise and field assessment with a scientific technical panel. The values and their interaction with the natural hydrology and the current modified hydrology form part of this study. The negative and positive impacts of the current hydrology are key project outputs.

This process provides an understanding of how to protect the identified values and determine the watering regime appropriate to achieve the environmental objectives for the Yanco Creek system. This water regime is described in terms of flow components that are important to the values.

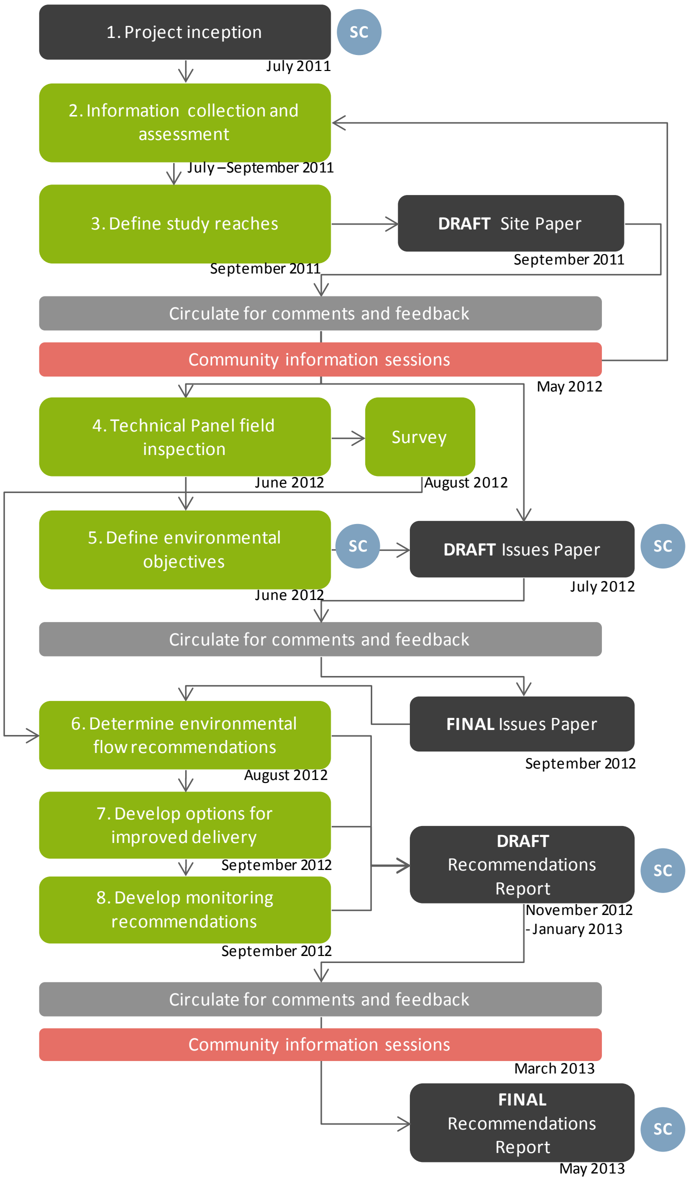

Figure 1. *Project method for investigating an environmentally sustainable water regime for the Yanco Creek system*

The study was undertaken through the tasks outlined in Figure 1. The Draft Site Paper was circulated in September 2011 and comments were received from numerous parties which have been addressed in the Issues Paper (finalised September 2012). This report forms the final deliverable of the study.

1.3 Study area

The study area for this assessment is the Yanco Creek System which is an effluent of the Murrumbidgee River downstream of Narrandera which flows south-west, discharging into the Edward River (part of the Murray River basin) at Moulamein. The Yanco Creek system includes the floodplains of the Yanco Creek, the regulated portion of Billabong Creek, Colombo Creek, the regulated and unregulated portions of Forest Creek, and the significant environmental values serviced by these. The Forest Creek anabranch was not specifically included in the study area[1].

Study reaches

To determine environmental flow requirements for the Yanco Creek system, the study area is divided into reaches that are relatively homogeneous in terms of the following features:

- Location of major tributaries
- Channel morphology and structure
- Floodplain morphology and structure
- Presence of key habitats of value
- System operation
- Flora and fauna structure and value

The Technical Panel has recommended that the Yanco Creek system be assessed as six reaches for the purpose of the environmental flow determination. These reaches are (Figure 2):

1	Upper Yanco Creek	from Yanco off-take to Sheepwash weir pool (Colombo Creek)
2	Mid Yanco Creek	from Tarabah Weir to confluence with Billabong Creek
3	Colombo Creek	from Sheepwash weir pool to Cocketgedong weir
4	Mid Billabong Creek	Cocketgedong weir to Yanco Creek confluence. Sub-reach 4a upstream of Jerilderie, sub-reach 4b downstream of Jerilderie
5	Lower Billabong Creek	downstream of Yanco confluence to Edward River
6	Forest Creek	regulated (sub-reach 6a) and unregulated (sub-reach 6b) sections

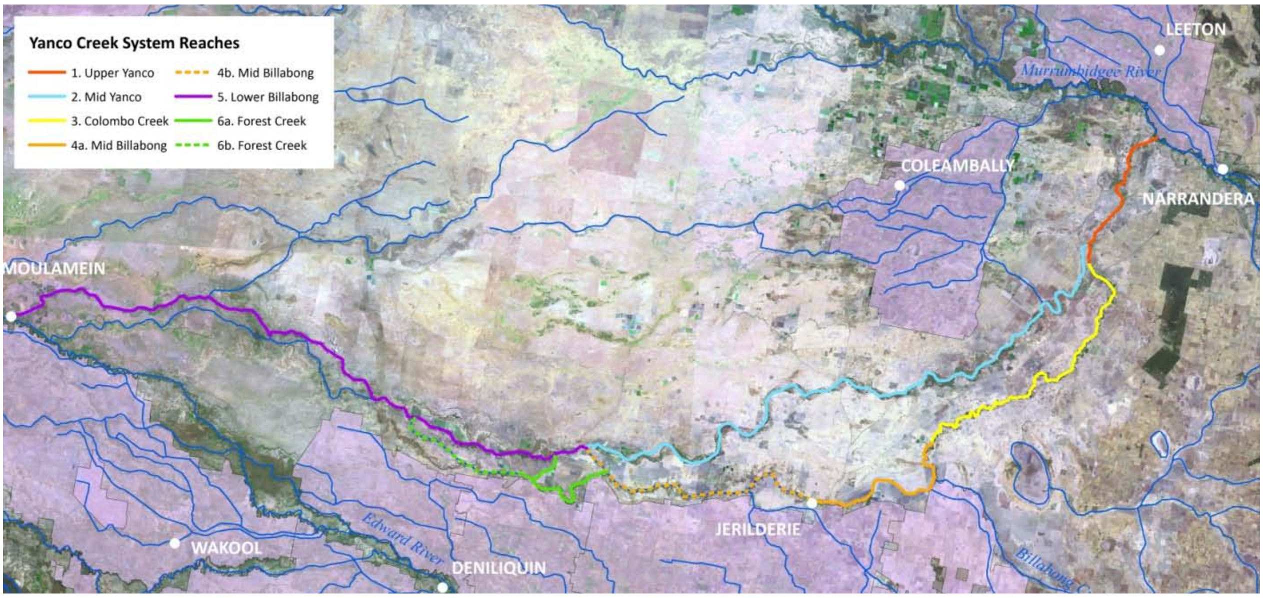

Figure 2. *Yanco Creek system showing the environmental flow study reaches*

[1] Sufficient data for the Forest Creek anabranch was not available to enable inclusion of this section of the system in the study. Modelled daily flow data and ecological surveys are required to undertake such assessment.

The rationale for the recommended reaches is summarised in Table 1.

Table 1. Reach selection criteria and application to the Yanco Creek system

Criteria	Summary of characteristics	Reach
Location of major tributaries / distributaries	Washpen Creek – right bank distributary, leaves Yanco Creek near Morundah and re-enters downstream of Tarabah Weir	1
	Coleambally Catchment Drain (CCD) – right bank tributary drain from Coleambally Irrigation Area, enters Yanco Creek	2
	Drainage Canal 800 (DC800)– right bank tributary drain from Coleambally Irrigation Area, enters Yanco Creek	2
	Unregulated Billabong Creek – left bank tributary, enters Billabong Creek at Colombo Creek confluence	4
	Forest Creek – left bank distributary, leaves Billabong Creek at Forest Creek off-take and re-enters Billabong Creek through numerous creeks including Piccaninny Creek, Eight Mile Creek and unregulated Forest Creek	6
	Forest creek anabranch[2] – left bank distributary, leaves Billabong and Forest creeks downstream of Wanganella Swamp, enters the Edward River upstream of Moulamein	-
Channel morphology and structure	Simple cross section morphology with well connected channel and floodplain. Sandy-silt dominated banks. In channel hydraulic diversity evident with variable loading of large wood throughout.	1, 2
	Homogeneous cross section morphology with broad, shallow banks. Little evidence of in channel diversity.	3
	Broad asymmetric cross section morphology. Alternating steep, high banks with opposite broad, shallow bank.	4
	Deep and steep banks. Frequently inundated narrow floodplain set below broader (infrequently inundated) floodplain. In channel hydraulic diversity evident with variable loading of large wood throughout and deep pools.	5
	Simple cross section morphology with broad, shallow banks.	6
Floodplain morphology and structure	Broad floodplain with numerous relic flow paths now forming scattered floodplain depressions within riparian corridor. Highly sinuous main channel with connection to significant wetland complexes.	1, 2
	Narrow floodplain with generally similar plan form to (low sinuosity) main channel	3, 4, 6
	Moderate width floodplain with some relic flow paths forming scattered floodplain depressions	5
Presence of key habitats of value	Instream hydraulic diversity with variable large wood loading throughout. Connectivity with scattered floodplain depressions, wetland complexes and longitudinally (to Murrumbidgee River)	1, 2
	Persistent weir pools throughout with brief sections of flow downstream of weirs. Drought refugia with limited longitudinal connectivity (presence of weirs).	3, 4b, 5, 6a
	In channel diversity including deep pools, benches and variable loading of large wood.	5
	Connection with Wanganella Swamp	6
System operation	Bulk of water supplied to the Yanco System via off take (volume entering Yanco Creek is well controlled up to 10,000 ML/d in the Murrumbidgee River).	1
	Drainage and regulated flows enter the system via the CCD, DC800, and WWC channels	2, 5
	Flow split between mid Yanco and Colombo Creeks controlled by Tarabah Weir	2, 3
	Fixed crest weirs (no control of flow magnitude) influence system operation throughout	3, 4b, 5, 6a

2 The Forest Creek anabranch was not considered part of the study area

Criteria	Summary of characteristics	Reach
	Colombo Creek joins unregulated Billabong Creek (and continues as Billabong Creek)	4
	Hartwood Weir allows sharing of flows between Billabong Creek and Forest Creek (and downstream Eight Mile Creek/Wanganella Wetland)	5, 6
	No flow beyond regulated Forest Creek (Warriston Weir)	6
Flora and fauna structure and value	Variable width frequently inundated community of River Red Gum dominated overstorey with healthy understorey of diverse rushes, reed and sedges. Black Box present beyond frequently inundated zone	1, 2
	Thick and narrow riparian stand dominated by River Red Gum with *Typha* fringe	3
	Degraded homogeneous corridor with poor longitudinal connectivity	4a
	Wide riparian corridor with good longitudinal connectivity	4b
	Narrow River Red Gum dominated riparian corridor with good longitudinal connectivity	5
	Wide River Red Gum dominated riparian corridor	6a
	Black Box dominated narrow riparian stand	6b

Environmental flows study sites

In the development of environmental flow recommendations, a number of sites were inspected by the Technical Panel during a four day field inspection (18-21 June 2012). These sites (Table 2) are described in further detail in the Issues Paper (Alluvium 2012).

Table 2. Sites inspected by the Technical Panel during field inspection 18-21 June 2012

Reach	Description	Date inspected
1 Upper Yanco Creek	Yanco Creek at Yanco weir	19 June 2012
	Dry Lake, Mollys Lagoon, Back Creek	19 June 2012
	Yanco Creek at Devlins Bridge	19 June 2012
	Yanco Creek at Morundah	18 June 2012
2 Mid Yanco Creek	Yanco Creek at Tarabah Weir	19 June 2012
	Yanco Creek at TSR	19 June 2012
	Yanco Creek at Silver Pines	19 June 2012
	Yanco Creek at Yanco Bridge	21 June 2012
3 Colombo Creek	Colombo Creek at Urana Jerilderie Rd	18 June 2012
	Colombo Creek – Chesneys Weir	18 June 2012
	Colombo Creek ski club, off Coonong Rd	18 June 2012
	Colombo Creek at TSR – Sheepwash weir pool	18 June 2012
4 Mid Billabong Creek	Billabong Creek at Jerilderie	21 June 2012
	Billabong Creek at Brick Kiln	21 June 2012
	Billabong Creek at Old Coree	21 June 2012
5 Lower Billabong Creek	Billabong Creek at Four Mile Weir	20 June 2012
	Billabong Creek at Wanganella	20 June 2012
	Billabong Creek at Millabong	20 June 2012
6 Forest Creek	Forest Creek off-take	20 June 2012
	Warriston weir	20 June 2012
	Forest Creek at Peppinella	20 June 2012
	Eight Mile Creek	20 June 2012
	Wanganella swamp	20 June 2012
	Forest Creek anabranch	20 June 2012

Due to the limited detailed scientific studies or information available, the Technical Panel has relied on the visits to a number of sites in the reach and the aerial survey undertaken during the field inspection of June 2012; and experience in similar river systems in south eastern Australia, especially in the Murray-Darling Basin. High flows at the time of field visits limited the Panel's ability to observe bed and lower bank features and characteristics at a number of sites. Where possible the physical form was inferred from hydraulic and physical forms visible above the water surface and verified following field cross section survey.

1.4 The Final Report (this report)

The approach to determining the environmental flow requirements for the Yanco Creek system is focussed on taking the concepts and theory of environmental flows and translating those through a transparent, robust scientific process into flow magnitudes, frequency, duration and timing that can be used to develop operating regimes for regulating structures.

The structure of this report is shown below, indicating where each of the study terms of reference has been addressed.

Table 3. Structure of this report

Section	Description of content	Relevant study term of reference addressed
1 Introduction	Outline of the background and scope of the study.	-
2 Yanco Creek System	Summary of the current and potential condition of water dependent environmental values of the catchment, and the current threats to the water dependent environmental values within the catchment, specifically resulting from any system operation, water extraction and harvesting Summary description of the system characteristics including hydrology, geomorphology, vegetation, wetlands, fish and macroinvertebrates	Assessment and integration of a substantial amount of existing ecological and hydrological data and reports for each of the Creeks and individual localities.
3 Environmental objectives	Environmental objectives that are described in terms of the ecological or geomorphic functions of the stream flows in the catchment	Development of environmental flow requirements for a range of ecological attributes of the system as a whole and for each Creek.
4 Environmental flow recommendations	Approach applied to determine environmental flow recommendations Environmental flow recommendations for each study reach Performance assessment of the environmental flow recommendations against the current flow regime Risk assessment outlining the potential risks associated with the current and any potential future water management regimes.	Development of environmental flow requirements for a range of ecological attributes of the system as a whole and for each Creek. Identification of environmental flow requirements and provision of practical and realistic environmental flow recommendations Identification of risks or benefits to environmental outcomes on the creeks which may arise due to water efficiency activities and changes to operating regimes
5 System-wide environmental flow opportunities and provision	Description of system scale environmental flow recommendations Discussion of seasonal priorities for environmental flow provision	Identification of environmental flow requirements and provision of practical and realistic environmental flow recommendations.
6 End of system flows	Identification of potential volumes required to achieve environmental flow recommendations in the Yanco system, and the potential flow reduction to the Edward Wakool system.	Identification of the relative contribution the system can make to specified environmental flow requirements in the Edward/Murray River. Identification of risks or benefits to environmental outcomes on the creeks which

Section	Description of content	Relevant study term of reference addressed
		may arise due to water efficiency activities and changes to operating regimes
7 Next steps	Recommendations relating to the development of operational arrangements for implementation of the environmental flow recommendations. Includes discussion of barriers for removal, monitoring requirements and complementary catchment management actions.	
8 References	Full reference list	Assessment and integration of a substantial amount of existing ecological and hydrological data and reports for each of the Creeks and individual localities.
Attachment A Water resource schematics	Diagrams outlining system operation in each reach	
Attachment B Floodplain wetland flow principles	Detailed information regarding watering principles for floodplain wetlands	
Attachment C Hydrology	Reach by reach assessment of pre-development and current hydrology	

2 Yanco Creek system

This section provides a summary of the hydrological and ecological data[3] available for the Yanco Creek system relevant to this study. System characteristics described in this section have been summarised from detailed assessments reported in the Site Paper and Issues Paper (Alluvium 2012). This section contains a summary of:

- water resource development and management in the Yanco Creek system(including the changes from pre-development to current operating conditions)
- hydrological and ecological characteristics of the system

2.1 Overview

The Yanco Creek system is situated in the Riverine plains of southern New South Wales (Figure 3).   The system receives most inflow from the Murrumbidgee River, and also catchment inflows from the unregulated Billabong Creek (upstream of Colombo Creek confluence). The system discharges to the Edward River, an effluent of the Murray River, near Moulamein.

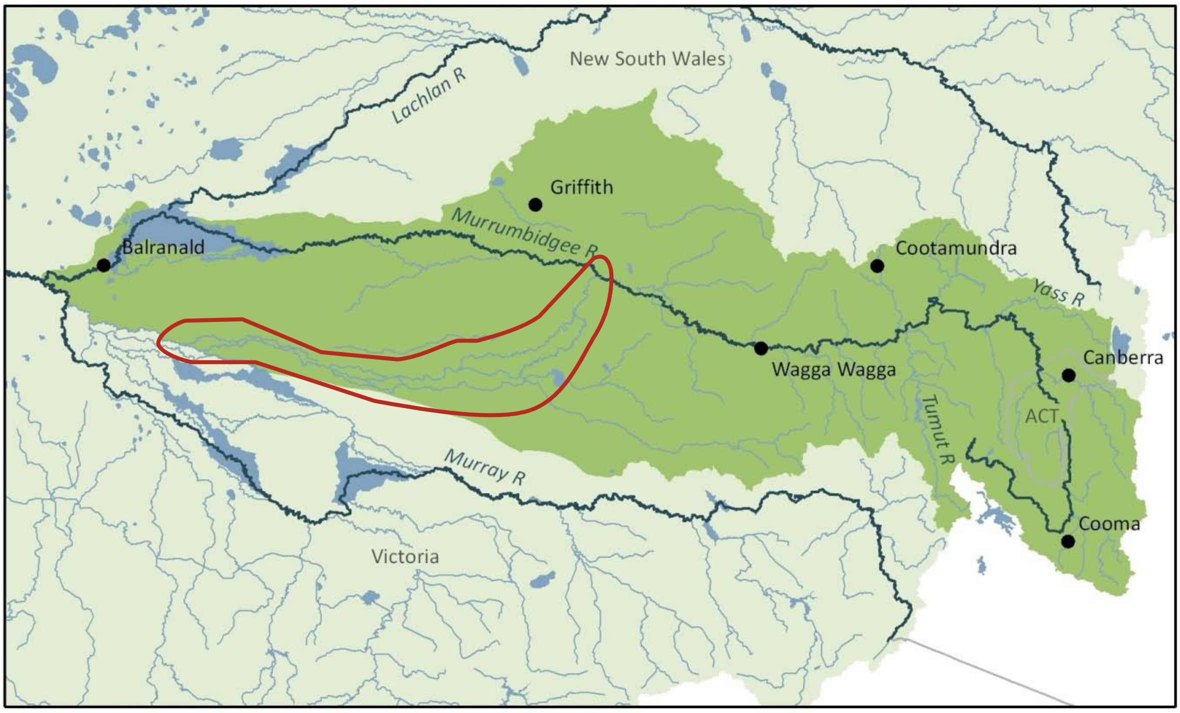

Figure 3. *Murrumbidgee catchment - Yanco Creek system circled in red*

The Yanco Creek commences as an off-take from the Murrumbidgee River at Yanco Weir downstream of Narrandera. It travels in a south west direction before diverging into two separate channels upstream of Morundah. The northern arm retains the name Yanco Creek, whilst the southern arm is initially called Colombo Creek, and then Billabong Creek after the junction with upper (or unregulated) Billabong Creek. The Yanco Creek joins Billabong Creek at Conargo, and the downstream channel is named Billabong Creek (until it's confluence with the Edward River). The Forest Creek system is an anabranch of Billabong Creek, which diverges from the creek upstream of the confluence with Yanco Creek and reconnects shortly before Wanganella. Flows are controlled at the Forest Creek off-take and it is a regulated stream only as far as Warriston Weir. Just downstream of Wanganella, Forest Creek Anabranch leaves the Billabong Creek and eventually rejoins the Billabong just upstream of Moulamein, after which it discharges into the Edward River. The Eight Mile Creek connects the Forest Creek to Forest Creek Anabranch via the Wanganella Swamp.

[3] Data available up to August 2012 (timing of the Technical Panel workshop) has been included in this study. Additional information has and will become available over time and should be considered in any update to the environmental flow recommendations in the future.

The bulk of water supplied to Yanco Creek System from the Murrumbidgee River is via the Yanco off take. Additional flows from the Murrumbidgee enter the system from drainage channels out of the Coleambally Irrigation Area (the Coleambally Catchment Drain, Drainage Canal 800, West Coleambally Channel). Water from the Murray system enters the Billabong and Forest Creeks through numerous Murray Irrigation Area escapes and drains, the main one being Finley Escape.

2.2 Water resource development and management

Irrigation works in the last century have significantly altered the Yanco Creek system flow regime. Prior to irrigation development the system would have flowed only when flooding was occurring in the Murrumbidgee River (flows >40GL at the Yanco off-take) and/or when there was substantial runoff and flows in the upper catchment of Billabong Creek (Molino Stewart 1999). Demand for water in the area led to the construction of a significant number of structures, both publicly and privately owned, that impact on flows along the system. These include the off-take from the Murrumbidgee River, and weirs, regulators, block dams and by-wash dams throughout the creek system (Figure 4).

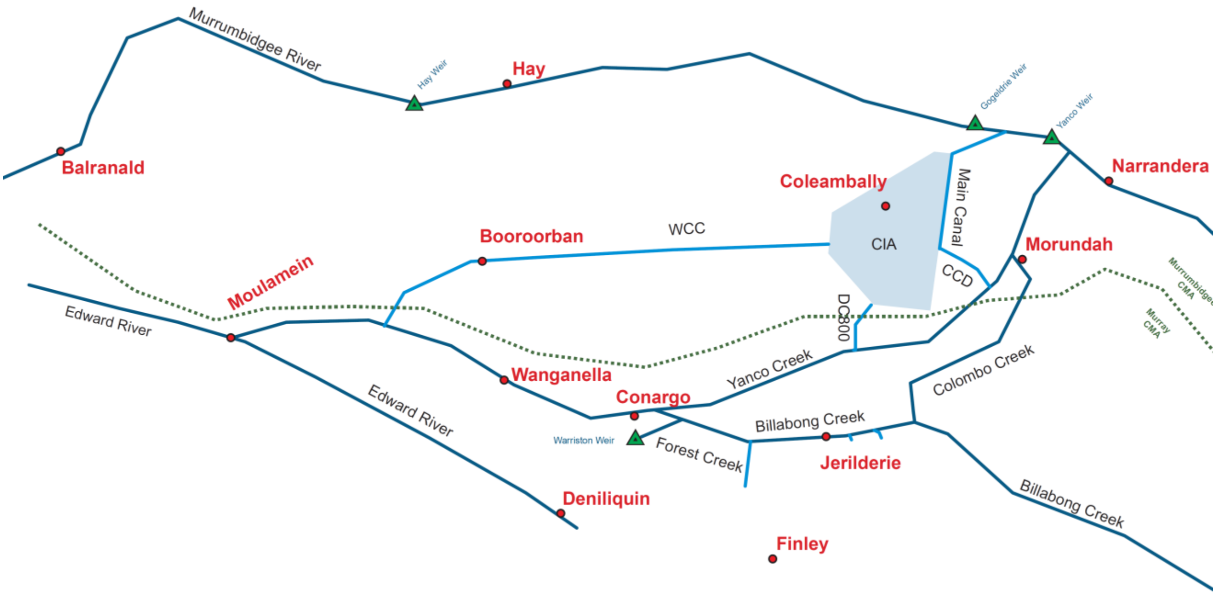

Figure 4. *Yanco Creek system showing irrigation outfalls and major regulating structures (Source: State Water, prep by Mark Rowe 5/5/2011)*

Downstream of Morundah, Yanco Creek has a much greater flow capacity than Colombo Creek and carries the major portion of the unregulated flows that generally occur in winter-spring, whereas Colombo Creek carries the major portion of regulated flows in summer-autumn (Molino Stewart 1999). Both Yanco Creek and Billabong Creek also receive inflows from drains and/or tributary streams. Yanco Creek receives flows from the Coleambally Catchment Drain (CCD) and drain DC 800, both of which carry drainage flows and regulated releases from the Coleambally Irrigation Area. The Billabong Creek receives inflows from a number of creeks and drains, namely the upper (or unregulated) Billabong Creek which has a catchment that extends 160km to the east of Colombo Creek (Molino Stewart 1999). Murray Irrigation Limited (MIL) delivers drainage water and some regulated flows to the Billabong and Forest Creeks. The main MIL channel used for regulated flows is Finley Escape.

Forest Creek is an anabranch of Billabong Creek which has a limited capacity and only receives a fraction of the flood flows of Billabong Creek. Hartwood Weir, downstream of the junction of Billabong Creek and Forest Creek, allows sharing of the regulated flows between the two creeks. Forest Creek flows are confined to a pre-development channel but Eight Mile Creek splits off the Forest Creek in Peppinella and it spreads out in the vicinity of Wanganella Swamp before being confined to a channel again downstream of McCrabbs Regulator. Flows from Forest Creek, Eight Mile Creek and Forest Creek Anabranch tend to return to Billabong Creek via small interconnecting creeks and breakaways due to a difference in height between the two creeks. Many block banks are constructed along these creeks to prevent this return of flow.

It takes approximately 5-6 weeks for regulated flows to pass from the Murrumbidgee irrigation dams through the Yanco Creek system to Moulamein (Beal et al. 2004).

Available environmental water

The Commonwealth Environmental Water Holder (CEWH) and New South Wales both hold entitlements to water for environmental use that can be delivered to the Yanco Creek System to achieve environmental objectives.

Commonwealth environmental water

The Commonwealth has been acquiring water entitlements in the Murray Darling Basin through direct buy-backs from irrigators and savings from infrastructure upgrades with the objective of returning more water to the environment. As at 30 April 2012, the Commonwealth environmental water holdings in the Murrumbidgee and NSW Murray systems, which potentially could be used to achieve environmental objectives in the Yanco Creek system, are greater than 150 GL (Murrumbidgee) and 200 GL (NSW Murray) of general security entitlement. A breakdown of Commonwealth holdings is shown in Table 4 .[4]

Table 4. Summary of Commonwealth environmental water holdings as at 30 April 2012

Southern Connected Basin Valley	Security	Entitlement volume (GL)
Murrumbidgee	High	0.4
	General	153
	Conveyance	1.6
	Supplementary	20.8
NSW Murray	High	2.6
	General	232

Note: The volumes in this table include only entitlements which have been formally transferred to the Commonwealth (i.e. registered with the relevant NSW authority) at 30 April 2012. Registration can occur a number of months after the exchange of contract.

Commonwealth environmental water is required to be managed for the purpose of protecting or restoring the environmental assets of the Murray-Darling Basin. It must be managed in accordance with relevant environmental water plans (including the Environmental Watering Plan under the Basin Plan), any operating rules made under the *Water Act 2007*, and any environmental watering schedules to which the CEWH is party.

NSW environmental water

New South Wales holds water entitlements to water for the environment in the Murrumbidgee and Murray basins which can be delivered to the Yanco Creek System to achieve environmental objectives (Table 5). The bulk of NSW owned water was purchased under the Living Murray Initiative. This program saw the purchase of 115 GL of entitlements across the Murray, Murrumbidgee and Darling Rivers. The NSW Living Murray entitlement is currently managed by the Murray Darling Basin Authority (MDBA).

Table 5. Murrumbidgee environmental water available 2012/13

Account	Maximum GL	GL available at 1/7/12 (64%AWD)
OEH Adaptive Environmental Water		
General Security	27.7	22.2 (includes carryover)
Supplementary	5.7	Available at 10/7/12
Unregulated	5.9	N/A
Environmental Water Allowance (EWA)		
EWA1		56*

[4] (http://www.environment.gov.au/ewater/about/holdings.html)

Account	Maximum GL	GL available at 1/7/12 (64%AWD)
EWA2		36
EWA3		40*
Commonwealth Environmental Water		
High security	0.5	0.5
General security	157.7	100.9
Supplementary	3.2	Available at 10/7/12
Unregulated	20.8	

The NSW RiverBank is a separate purchasing program, coordinated by the Office of Environment and Heritage. Under this program, NSW has purchased more than 20 GL of general entitlement. Table 6 shows the breakdown of entitlements purchased in the Murrumbidgee River under the RiverBank program. Note that no entitlements were purchased in the NSW Murray basin, and the program was scheduled for completion by December 2011. [5]

Table 6. Summary of NSW RiverBank purchases as at 31 October 2011

Basin	Security	Entitlement volume (GL)
Murrumbidgee	General	23.9
	Supplementary	5.7
	Unregulated	6.2

2.3 Water resource plans

Murrumbidgee Water Sharing Plan
The Murrumbidgee Regulated River Water Sharing Plan 2003 (Murrumbidgee WSP) is the statutory water management plan (under the *Water Management Act 2000*) encompassing the Yanco Creek system. The plan is based on recommendations from the former Murrumbidgee River Management Committee (which included representatives from the irrigation industry, indigenous communities, the CMAs, state and local government agencies). It commenced on July 1, 2004, and was suspended from November 2006 to September 2011 due to severe drought conditions.

The Murrumbidgee WSP aims to 'provide equitable sharing of limited water resources to sustain a healthy and productive river and the welfare and well-being of Murrumbidgee regional communities' (DIPNR 2004). The Plan specifies the following environmental water rules:

1. Reserve all water above the extraction limit for the environment
2. Protect low flows in the upper reaches (of the Murrumbidgee River)
3. Provide winter flow variability
4. Establish environmental water allowances
5. Protect end of system flows (on the Murrumbidgee River)

The environmental flow provisions in the Murrumbidgee WSP do not specifically target ecological outcomes for the Yanco Creek system[6].

[5] (http://www.environment.nsw.gov.au/environmentalwater/waterpurchase.htm)
[6] Note that a proposed amendment to the water sharing plan is currently under consideration. This amendment does not propose any change to the environmental water rules or affect the Yanco Creek system.

Annual Environmental Watering Plans

Adaptive environmental watering plans are statutory instruments prepared by the Office of Environment and Heritage in consultation with Environmental Watering Advisory Groups and approved by the NSW Office of Water. Annual plans completed for the Murrumbidgee and NSW Murray identify the primary objectives for environmental water in the catchments, and outline how the available and potential environmental water will be used in each catchment during the year.

The *Environmental Watering Plan for the Murrumbidgee Valley 2011/12* guides the prioritisation of sites for environmental watering in the Murrumbidgee Valley (from Commonwealth and State allocations) during the 2011/12 season. Ten primary objectives have been identified for the use of environmental water in 2011/12 and are shown below: (Note these objectives are unchanged from the 2010/11 objectives)

1. To improve and/or maintain the condition of a diversity of wetland types within the Murrumbidgee Valley
2. To prevent the further decline in stressed wetland vegetation communities, in particular River Red Gum, Black Box and Lignum communities
3. To assist in the best management of RAMSAR wetlands and "native fish in wetlands" demonstration sites
4. To increase and/or maintain the abundance and diversity of wetlands and riparian aquatic vegetation
5. To reinstate a wetting/drying cycle for natural ephemeral floodplain wetlands that have been negatively impacted by river regulation and/or severe drought conditions
6. To provide habitat for wetland-dependent fauna including endangered species such as the Southern Bell Frog and Fishing Bat
7. To trigger and/or maintain colonial waterbird breeding events primarily in the Lowbidgee wetlands
8. To complement naturally occurring higher river flows (or if necessary create high flows) that provide a benefit to wetland/floodplain dependent fauna and flora communities by increasing duration and/or extent of inundation
9. To minimise the adverse impacts that altered flow rates may have on instream fauna, in particular native fish populations
10. To assist in furthering the understanding of biological processes and functions within wetland/riverine habitats that will inform future management of environmental water allocations

Based on these objectives, the following sites in the Yanco Creek system have been identified for potential watering during the 2011/12 season:

- Yanco and Colombo Creeks, to introduce flow variability that has been removed and attenuated by flow regulation, to benefit populations of threatened fish and endangered aquatic ecological communities
- Wanganella Swamp

The *Murray Valley Annual Environmental Watering Plan for 2012/13* outlines the proposed use of environmental water (from Commonwealth and state allocations) in the NSW Murray Valley for the 2012/13 season. The plan sets eight primary objectives (identical to those in the *Environmental Watering Plan for the Murrumbidgee Valley 2012/13*) for environmental watering, and lists Wanganella Swamp as an asset to receive water under a median/wet scenario if a large breeding event is triggered and needs to be maintained.

Based on the primary objectives, the Wanganella Swamp on the Forest Creek floodplain has been identified as a potential site for receiving environmental water during 2012/13. Over 12 GL of environmental water was used to inundate the swamp during 2010/11 to sustain a significant bird breeding event and attracting up to 13,000 pairs of Straw-necked Ibis, as well as national and internationally listed species of waterbirds. If another large bird breeding event is triggered naturally in 2012/13 and there are insufficient inflows to support the event to its end, the environmental watering plan recommends the provision of environmental water to sustain it.

In addition to the State plans, the Commonwealth Environmental Water Office publishes *Annual Water Use Options* for the Murrumbidgee Catchment. The annual options document sets out the proposed approach for the use of Commonwealth environmental water in the catchment based on a range of possible river conditions. The Commonwealth's environmental watering program objectives are dependent upon the prevailing climatic conditions during the period for which they are established. The Commonwealth considers proposals for water use from a range of stakeholders, including state government organisations, and incorporates advice provided by the panel of scientific experts that make up the Environmental Water Scientific Advisory Panel.

2.4 System characteristics

Hydrology

The physical form and condition of ecological values in the Yanco Creek system is shaped not only by the regulation of water, but by the spatial and temporal variability of this supply. That is, both physical form (the shape of the waterway) and ecological values such as fish and vegetation are driven by the hydrological behaviour of the system. In order to appreciate the Yanco Creek system ecology it is important to first understand the system hydrology, including both surface water, and groundwater-surface water interaction. One way to explore the system hydrology is to use a hydrological model. Unfortunately very little groundwater-surface water interaction information was available for the Yanco Creek System as a whole; however the hydrological model (described below) does comprise localised groundwater interaction (losses and gains) throughout the system.

Hydrological interactions along Billabong Creek were investigated in a 2011 report by NSW Office of Water that evaluated the connectivity and infiltration rates along Billabong Creek using a range of techniques (Brownbill et. al. 2011). Billabong Creek was identified as a losing-disconnected reach with an associated well-defined clogging layer near or slightly below the streambed (usually a clay unit 0.5 to 2 m thick, Brownbill et. al. 2011). Hydraulic conductivity in Billabong Creek was classified as low. Local river loss along Billabong Creek was estimated at around 15 to 16 thousand litres per kilometre per day for median and high (tenth percentile) river flows respectively. Regional losses were much lower at around 400 and 850 litres per kilometre per day for median and high river flows.

Two integrated water quantity and quality (IQQM) simulation models have been developed by NSW Office of Water for the Yanco Creek system water resources management planning: one for pre-development (or pre-regulated) conditions and one for current conditions. The IQQM models have been used to generate 100 years of flow data at various locations throughout the system under each condition. The pre-development flow series assumed no development over the entire 100 years (thus allowing direct comparison of the two conditions).

Using the modelled flow series, three key hydrological indicators have been developed: total annual flow, flow duration, and seasonality.

<u>Total annual flow</u> shows, on an annual basis, the quantity of water flowing through the Yanco Creek system under pre-development and current conditions and at various locations. This is a simple way of comparing the number of flow or no-flow, wet and dry years under each condition.

<u>Flow duration</u> illustrates the temporal variation of flows. For example, the flow duration curve can be used to understand the percentage of time that flows exceed 200 ML/d (or the percentage of time there is no flow at all, and so on) in any part of the system under pre-development and current conditions.

<u>Seasonality</u> shows what is driving the various flow-related ecological events tied to particular times of year, or seasons. For example, biological events such as fish migration and spawning which take place only if suitable flows occur and at the right time of year.

The below paragraphs summarise the hydrological behaviour of the Yanco Creek System.

Total annual flow [7]

Under current operating conditions the total annual flow is greatest in upper Yanco Creek between the off-take and Tarabah Weir (average 331 GL/y). This flow from the upper Yanco is split almost equally (on an annual basis) between middle Yanco Creek (average 150 GL/y) and Colombo Creek (average 145 GL/y). Unregulated Billabong Creek contributes on average 60 GL/year to the Colombo Creek flow, resulting in an increased total annual flow volume in middle Billabong Creek (average 205 GL/y). Downstream of the confluence of Yanco and Billabong creeks, the average total annual flow volume increases to 281 GL/y. Forest Creek has the lowest total annual flow (average 45 GL/y).

The total annual volume of flow prior to development was much lower than under current conditions. This is more pronounced in the upper reaches (ranging from three times less in middle Yanco Creek to seven times less in Colombo Creek) than in the lower reaches.

The pre-developed total annual flow volume generally follows the same temporal trend as for current conditions with two notable differences: the split between middle Yanco and Colombo Creeks is approximately two-thirds to one-third under pre-developed conditions; and the unregulated Billabong Creek contributes a greater proportion of flow to the lower reaches (29% of flow in middle Billabong comes from unregulated Billabong Creek, compared with 87% under pre-developed conditions). Under pre-development conditions years of no-flow are frequently observed (e.g. the early 1980s and for the whole of the 2000s).

Total annual flow is generally less variable under current conditions compared with pre-developed. For pre-developed conditions we frequently see average to high total annual flows followed by near no-flow years (and vice versa, for example years 1973 to 1974). Under current conditions the inter-annual variation is generally less pronounced. This represents quite a significant hydrological shift, most evident in reaches 1, 2 and 3, from what was a ‘boom and bust’ system to a more consistently flowing system. This in turn contributes to changes, both historical and ongoing, in geomorphological processes and system ecology.

Note: For ease of plotting, Figure 5 shows total annual flow from 1970-2009 only. The period from 1970-2009 exhibits both extreme wet (early 1970s) and dry (2000s) and is generally representative of the full record.

[7] Total annual flow is calculated by summing the total flow volume for each year of the record. Plots of total annual flow are used to show inter-annual variability and highlight dry, average and wet conditions. Pre-development and current conditions are easily compared using these plots

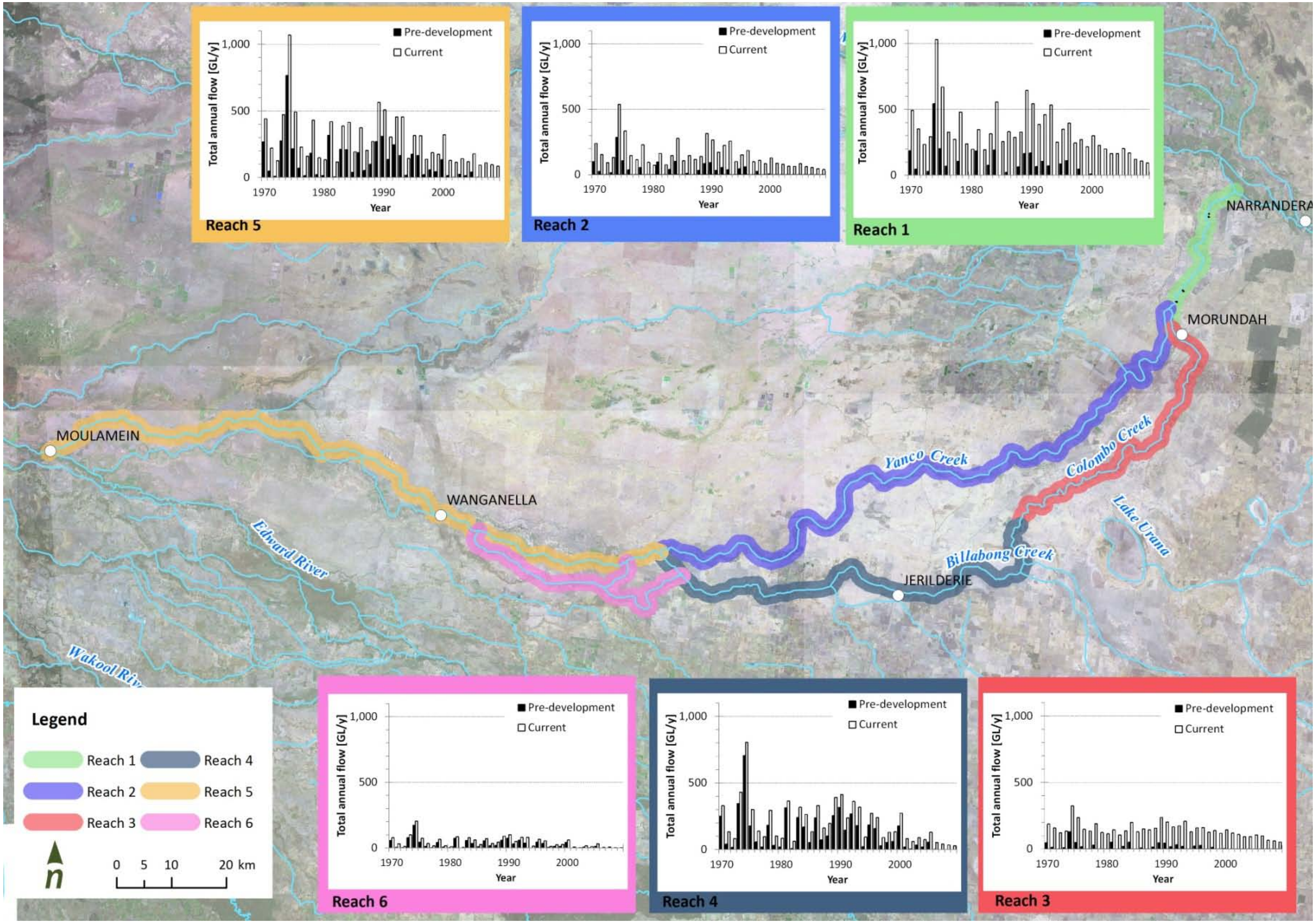

Figure 5. *Modelled system wide total annual flow volume (1970-2009)*

***Flow duration curve*[8]**

Under current conditions the magnitude of infrequent (flood) flows is greatest in middle and lower Billabong Creek (due to the catchment inflow influence of unregulated Billabong Creek). Infrequent (flood) flows are generally of the same or similar magnitude under current conditions and pre-developed conditions (except for Colombo Creek where current flood flows are approximately 50 % larger). Flood flows are greatest in middle and lower Billabong Creek (due to the catchment inflow influence of unregulated Billabong Creek).

Under pre-developed conditions the curves show that flows in the upper Yanco System (Reach 1, 2 and to some degree Reach 3) drop away to 'no-flow' for the majority of time, while under current conditions flows rarely if ever fall below 270 ML/d. The lower Yanco System (receiving inflows from unregulated Billabong Creek) exhibits greater variation in daily flows under pre-developed conditions with at least some flow observed right up to around 80 % of time (this is less notable in Forest Creek where flows persist only to around 30% of time). The lower Yanco System currently shows similar temporal variation in daily flows (shape of curve) as the upper system (except for Forest Creek where the flow duration curve is more closely matched with its pre-developed counterpart). Overall, reaches 1, 2, 3 and 6 show the greatest changes in no-flow, base flow, medium and high flows. Reaches 4 and 5 show a less pronounced change from pre-development to current conditions.

***Seasonality*[9]**

Flows in the Yanco System currently display a typical temperate seasonal pattern, with the lowest average monthly flows in February and March, and the highest average flows in August. For all reaches except Forest Creek there is at least some flow (i.e. not zero) on average, even in the lowest flow months. This should be noted in tandem with the flow duration curve discussion, above, where cease to flow events are markedly absent under current operation which is in direct contrast to the pre-development state. The distribution of daily flows under pre-development conditions for each month shows a similarly temperate seasonal pattern. However the magnitude of average daily flows is consistently smaller in all reaches (except Forest Creek where near pre-development daily flow magnitudes are observed).

The shift in seasonal variation from pre-developed to current conditions can be explored by quantifying the magnitude of variation between seasons. To do this we compare the average daily flow of the low and high flow months respectively. Under current conditions the greatest degree of variation is observed in Forest Creek where average daily flows in high flow months are significantly (roughly ten times) greater than low flow months. Reaches influenced by unregulated Billabong Creek (middle and lower Billabong Creek) are second most variable, while Colombo Creek (and to some degree upper and mid Yanco Creeks) show little variation between seasons. Under natural conditions the same trend is observed at each reach however the variation from low flow season to high flow season is markedly greater. For example in Forest Creek average daily flows in the high flow month is approximately 50 times greater in the lowest flow month (and between 20 and 25 times greater for middle and lower Billabong, and between 10 and 20 for upper and middle Yanco Creek and Colombo Creek). Interestingly, Colombo Creek is not the least variable reach (upper Yanco Creek is) under pre-developed conditions.

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[8] Flow duration curves represent the ranking of all flows in the record from lowest to highest, where the rank is the percentage of time that the flow value is equalled or exceeded. These plots are used to show the percentage of time that the range of flow values are observed. Pre-development and current conditions are easily compared and contrasted using these plots

[9] Flow seasonality is calculated by averaging the daily flows observed in each month over the entire record. The plots show the pattern of variation, during the year, of the average daily volume of flows in each reach and is best demonstrated using a number of key statistics:

- The maximum and minimum flow values (average over all days in each month over the complete record)
- The mean flow value (average over all days in each month over the complete record)

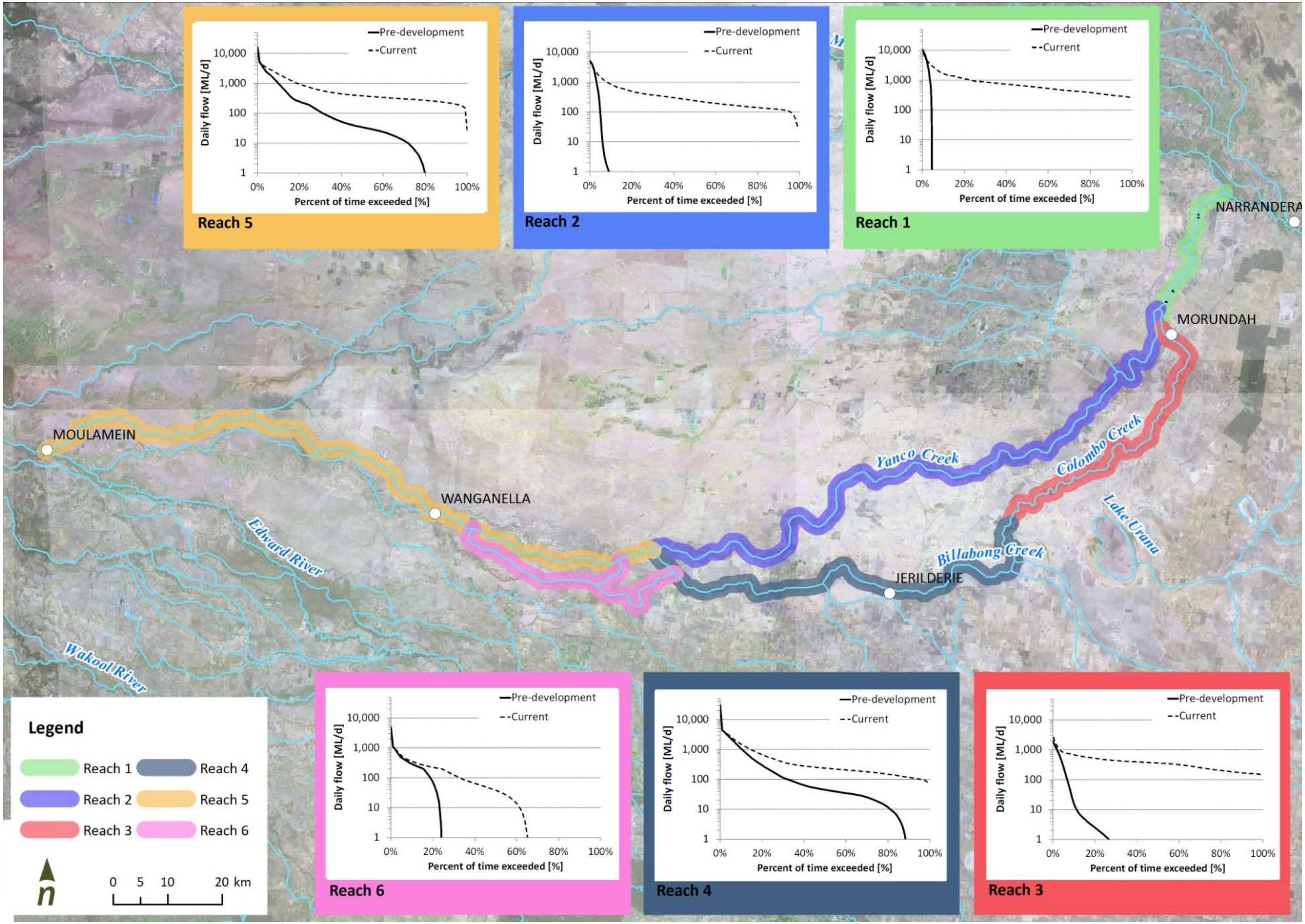


Figure 6. *Modelled system wide flow duration curves*

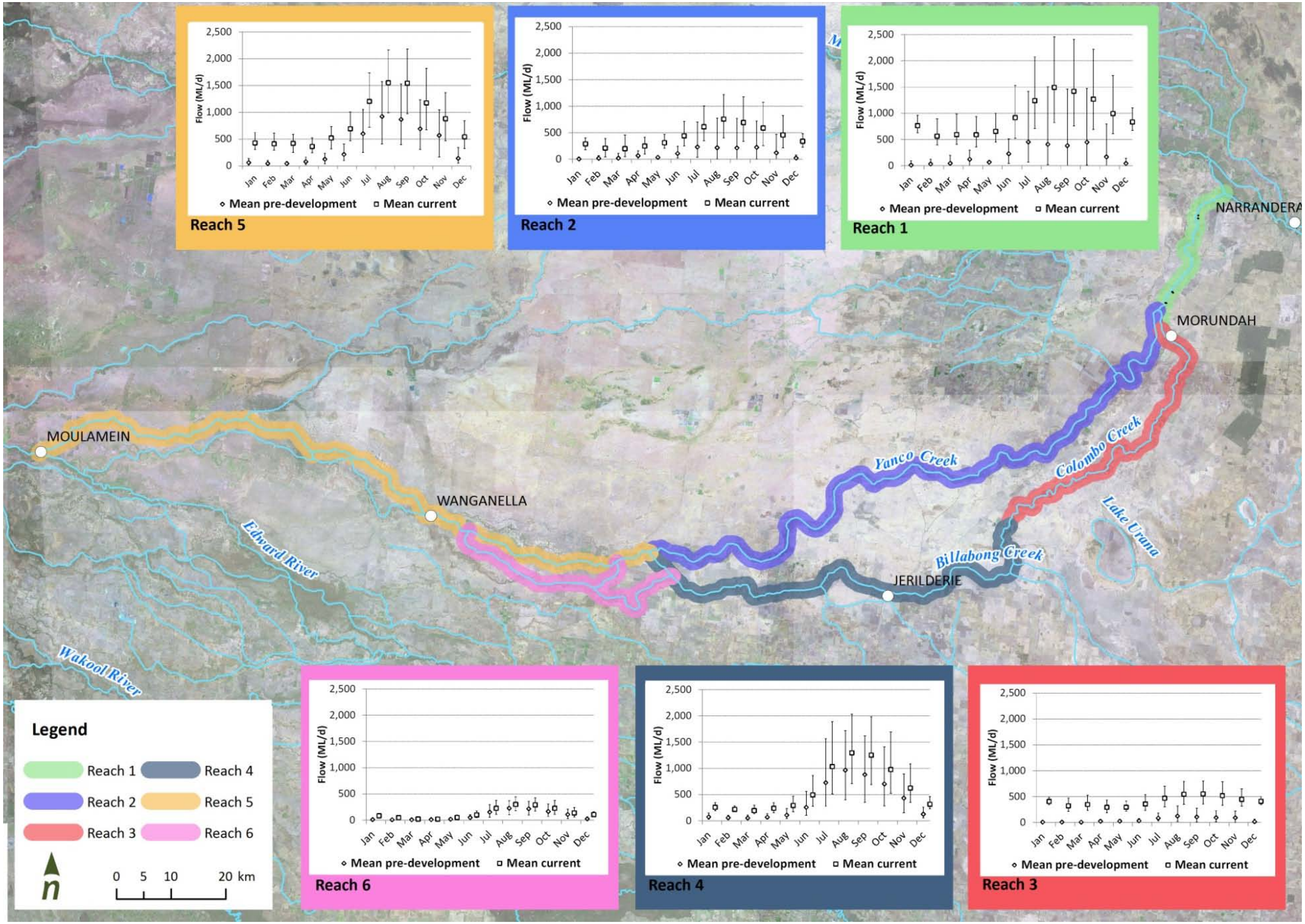


Figure 7. *Modelled system wide seasonality plots*

Physical form

Physical form describes the size, shape and diversity of the river channel. A diversity of habitat types provides the physical basis for a diversity of biota and is an important factor in providing a healthy river. Understanding the history of the current geomorphic form and process of the Yanco Creek system is important for two reasons:

- It allows flows to be targeted at the geomorphic processes that threaten the achievement of the flow objectives (e.g. excessive sedimentation) or support the achievement of the objectives (e.g. provision of flows to maintain benches and pools).
- An understanding of the historic physical form and processes sets the current geomorphology in context and allows the likely future trajectory of change to be considered. For example, if part of the system is on a long-term trajectory of channel contraction, then this informs its likely utility as a means of transferring water into the future.

The Yanco Creek system lies within the lower tract of riverine plains of NSW, which covers the alluvial fans of the Lachlan, Murrumbidgee and Murray rivers west of the Great Dividing Range and extends down the Murray. Discharge from past and present streams control patterns of sediment deposition, soils, landscapes and vegetation. The riverine plains landscape is dominated by Quaternary river channels, floodplains, backplains, swamps, lakes and lunettes. The region comprises three overlapping alluvial fans centred on the eastern half of the Murray Basin. (Office of Environment and Heritage 2011).

Yanco Creek is part of a complex distributary system of paleochannels that emanates from the confined upstream valley at Narrandera (Page at al. 2009). Four sequential phases of paleochannel activity were identified by Page and Nanson (1996): Coleambally, Kerarbury, Gum Creek and Yanco. The present geomorphology of the Yanco system reflects its evolution through the Late Quaternary, with a number of (relatively) small, highly sinuous channels dominated by suspended sediment load (ie. low bedloads) within a large, very flat floodplain formed by the Yanco paleochannel that operated between 20,000 to 12,000 years ago.

The Yanco paleochannel was a powerful floodplain river, with an approximate bankfull width of 250 m (compared to approximate bankfull width of 35m in contemporary system). Bankfull discharge of the Yanco paleochannel is estimated to be between 4-8 times the current bankfull discharge (Page et al. 2009). The Yanco paleochannel was laterally unconfined, with well preserved, large wavelength and meanders (Figure 8), and scroll patterned floodplain formed by lateral migration (Page et al. 2009). The large source-bordering dunes associated with the Yanco channels show it carried large quantities of sandy bedload (Page et al. 2009).

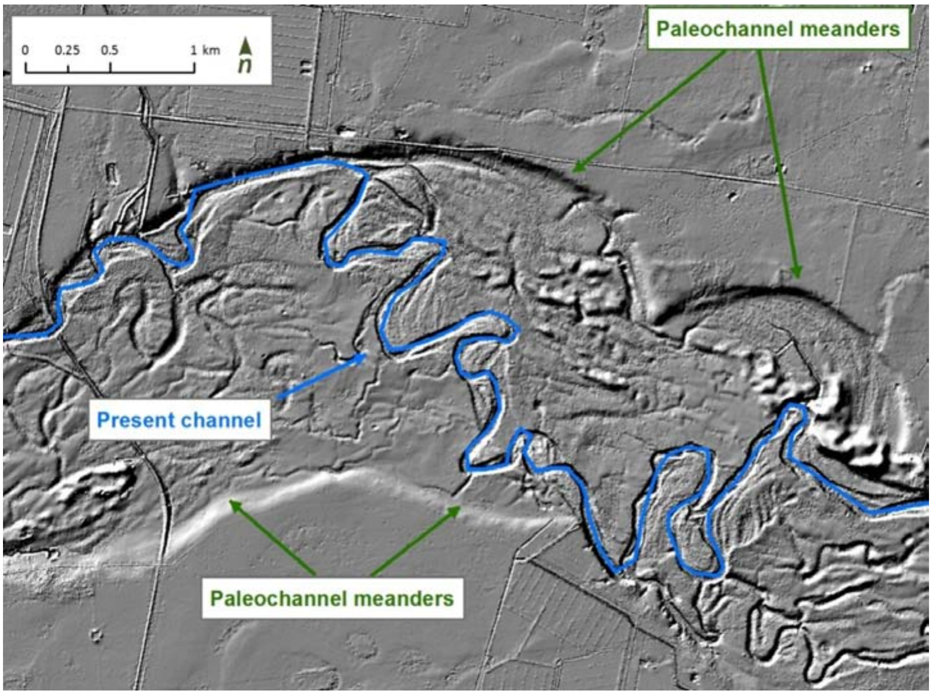


Figure 8. *Comparison of present channel (blue) and paleochannel (green) planform in middle Yanco Creek (upstream of Cobb Highway)*

The formation of the present geomorphology of the Yanco Creek is strongly influenced by the drier climate of the Holocene, which has resulted in the smaller, more sinuous pattern of the channels. In the lower section of the system there is a general floodplain gradient to the north so the floodplain flows generally towards Billabong Creek. Eight Mile Creek appears to be in active aggradation phase, which exacerbates the tendency for flows to move towards Billabong Creek, and reduces the effectiveness of this channel as a delivery route to Wanganella Swamp.

Water dependent vegetation

All vegetation is, to some extent, dependent on a supply of water. Without water, plants, even those adapted to growth in deserts, eventually die. What *water-dependent vegetation* means in the context of this report is vegetation that lives in or near surface or groundwater, and in particular vegetation that is associated with flowing water such as rivers, streams and creeks, or with still water such as wetlands and billabongs.

A number of ways have been proposed to group different types of water-dependent vegetation. One is a structural approach, where plants species are grouped into broad categories such as forests and woodlands, shrublands, grasslands, sedgelands and rushlands, and herblands. A second is to sort the various species into functional groups, such as into terrestrial taxa (that do not tolerate flooding), submerged taxa (that do not tolerate drying), and the large intermediate group of amphibious taxa (that tolerate both flooding and drying). A third method has been to divide the plants up into broad taxonomic associations, such as Black Box woodlands, River Red Gum woodlands or forests (the difference between forest and woodland depends mostly on canopy cover and tree size and density), Lignum shrublands, reed beds, and general aquatic associations of obligately submerged taxa, such as *Vallisneria*. The different approaches have various strengths and weakness, and which one is better often depends on the types of questions that need to be answered, or in this study, the environmental objectives that are set.

Our field inspections and the available literature indicated that there is very little submerged aquatic vegetation in the Yanco System. In most inland rivers in New South Wales, one would expect to find submerged taxa such as *Vallisneria* and *Potamogeton*. Species such as these, however, seem to have been progressively lost since the 1950s and particularly since the expansion of carp in the 1970s. The only exception to this generalisation occurs in unregulated Forest Creek, where a localised community of instream (and emergent) vegetation had evolved in response to the hydrological conditions at this site, probably enhanced by fencing and related restrictions on stock access (Figure 9). At this site, maintenance of the existing diverse range of submerged and emergent plant species could be considered a high priority.

Figure 9. *Instream and emergent vegetation observed in unregulated Forest Creek at Peppinella (image taken 20 June 2012)*

In contrast to the general case with instream vegetation, the river system supports in most places a band of riparian vegetation on the banks and higher benches, dominated almost entirely by River Red Gum (*Eucalyptus camaldulensis*) on those parts likely to be inundated more frequently, and Black Box (*Eucalyptus largiflorens*) on slightly higher ground that receives less frequent and shorter inundation. The density of trees and the resultant density of canopy cover vary for River Red Gum stands, from sparse woodland in drier sites to, more rarely, a dense forest with larger trees and more canopy cover in wetter sites. In a few locations, River Cooba (*Acacia stenophylla*) is present as a canopy-forming tree; flooding is important for this species in order to maintain adult trees, but it is not clear what role periodic inundation has in the species' recruitment.

The width of the riparian zone varies greatly over the study area, from over a kilometre in some locations to narrow bands only a tree or two wide in others. This variation is a result of two factors:

- a geomorphological factor, resulting in differences in the width of the floodplain and higher-level benches across the site
- a land-management factor, the impact of stock grazing, mostly by sheep, on the recruitment of young trees into the population.

The adverse impact of stock access is strongly evident in parts of Reach 4a, middle Billabong Creek, where the water regime is most natural of all parts of the system but the riparian zone is in very poor condition where stock have unlimited access to the stream and its bankside vegetation (Figure 10a).

Although the riparian zone has a canopy layer consisting of mostly either River Red Gum or Black Box, or more rarely River Cooba, there are also important understorey species present as well. In many cases, the understorey condition is limited, probably as a result of grazing pressures. In those spots where grazing does not occur (e.g. near Devlins Bridge in Reach 1, and in parts of Old Coree in Reach 4b, Figure 10b), the understorey is dense and floristically diverse. It can include a range of native grasses, rushes and sedges and, conspicuously, lignum (*Muehlenbeckia florulenta*).

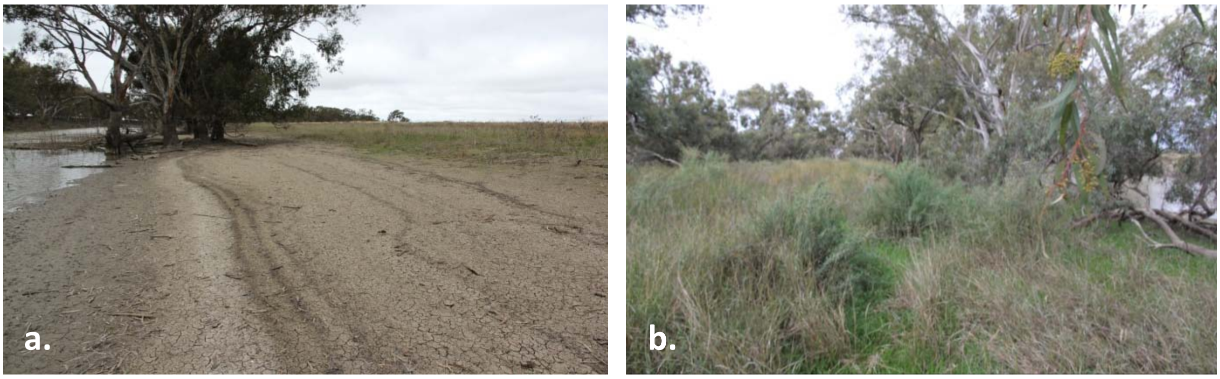


Figure 10. *Differences in riparian vegetation in Middle Billabong Creek - Billabong Creek upstream of Jerilderie (a) and at Old Corree downstream of Jerilderie (b) (images taken 21 June 2012 (a), 22 June 2012 (b))*

The third type of water-dependent vegetation found in the study area is the reeds, rushes and sedges that occur along the river banks and on its benches or in shallow water in the stream margins. These seem to have a restricted distribution, probably as a result of relatively unchanging water levels in many of the waterways. Emergent taxa such as these commonly grow best when water levels fluctuate on a seasonal basis, with high water levels in winter and spring and low water levels in summer. Constant high water levels, especially when the water is enriched with plant nutrients such as phosphorus, differentially encourage the growth of Cumbungi (*Typha* spp.), and this process was evident at a number of sites in the study area (Figure 11).

Figure 11. *Cumbungi (Typha spp.) present in Colombo Creek at Urana-Jerilderie Rd (image taken 18 June 2012)*

Floodplain wetlands
A wide range of floodplain wetlands are present in Reach 1, the upper Yanco, including the Possum Creek complex, Dry Lake and Mollys Lagoon, and the Washpen Creek complex (Figure 12). These are characterised by large expanses of open water that may or may not support obligately submerged vegetation[10], and are fringed mostly by River Red Gum. Reach 6, Forest Creek, also supports the regionally important Wanganella Swamp and Rhyola wetland. Of these, Wanganella Swamp is the more floristically diverse and its water-regime requirements have been addressed in a number of prior studies.

In addition to these large and visually obvious floodplain wetlands, the Yanco system supports a large number of smaller floodplain depressions and billabongs (Figure 12). What is important in the maintenance of floodplain wetlands is to take advantage of subtle variations in the elevation of the various wetlands and their commence-to-flow rates. In this way, a mosaic of wetlands can be maintained in different stages of wetting and drying, by providing overbank flows or bankfull flows to engage flood runners. The overall ecological resilience of the system is enhanced by providing hydrological conditions that facilitate the maintenance of such a mosaic of wetlands under different hydrological regimes. It is worth mentioning too that, in all cases, the maintenance of floodplain wetlands depends not only on hydrological factors but also on land-use practices. In general, wetland plants cannot recruit successfully when subject to high and constant grazing pressure, and the maintenance and rehabilitation of the system's complex array of wetlands (large and small) will require ancillary actions involving catchment management as well as the provision of environmental water.

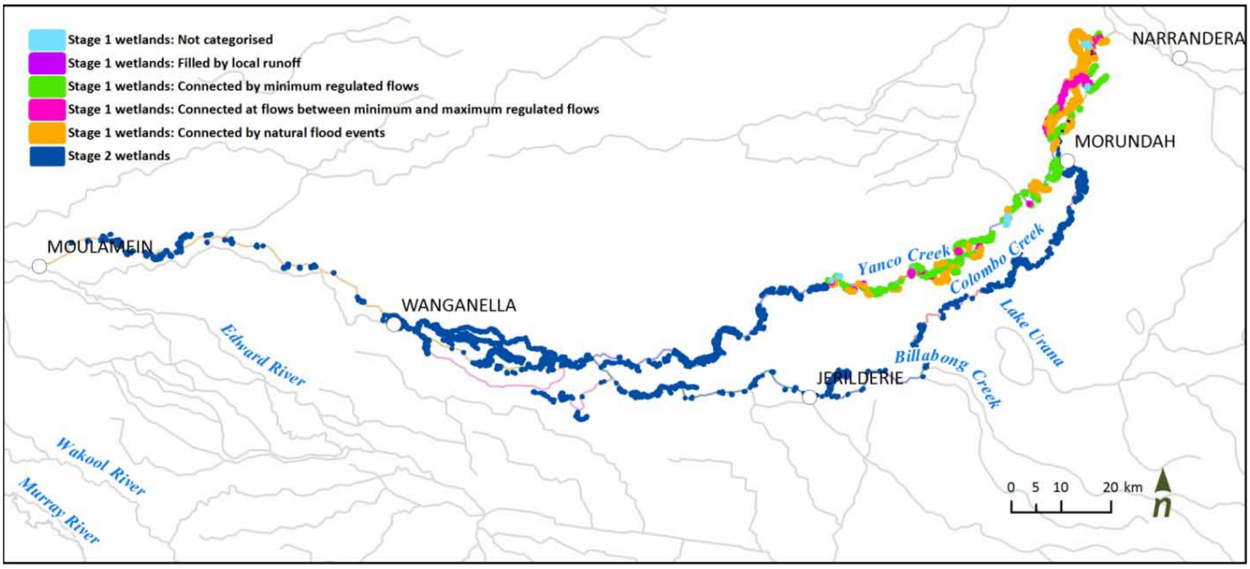


Figure 12. *Wetlands mapped in the Yanco Creek system through two previous projects –Investigation into potential water savings from the Yanco Creek system (off-take to Yanco Bridge) wetlands (Webster 2007) (referred to as Stage 1), and the follow-on Stage 2 study (GIS data only, Webster unpublished)*

Fish
Yanco Creek has a diverse fish community, with at least 14 native species, in the system and adjoining Murrumbidgee River (Baumgartner 2007; Lintermans 2007). Seven species (e.g. Murray Cod, Trout Cod, Silver Perch, Southern Pygmy Perch, Freshwater Catfish, Olive Perchlet and Flat-headed Galaxias) have high conservation significance and are listed as "threatened" under the Fisheries Management Act 1994 and the Commonwealth EPBC Act 1999. The most common species are the small-bodied fish such as Australian Smelt, Unspecked Hardyhead, Murray Rainbowfish and Carp Gudgeons (Wassens et al. 2012) that are also common elsewhere in the lowlands of the Murrumbidgee River catchment (Gilligan 2005). The large and medium bodied fish species are also present, including Murray Cod, Trout Cod, Golden Perch, Silver Perch, Bony Herring and Freshwater Catfish. Along with small-bodied fish, there is some evidence for recruitment of Golden Perch in the large floodplain lakes, such as Dry Lake and Mollys Lagoon (Wassens et al. 2012). A further five non-native species are also present in Yanco Creek, including: Carp, Gambusia, Goldfish, Redfin Perch and Oriental Weatherloach.

[10] Plants permanently submerged; produce floating, aerial or submerged reproductive organs; including floating-leaved plants.

Table 7 outlines the fish species recorded in the Yanco Creek system, and those species expected to occur.

Table 7. Fish species recorded (rec) and expected (exp) to occur in study reaches of the Yanco Creek system, based on combination of site visit and NSW Fisheries Data for the Yanco Creek system. Note: native large-bodied fish = ■[L], native medium bodied fish = ■[M], native small bodied fish = ■[S], native small bodied floodplain specialist fish = ■[F]

			Reach 1		Reach 2		Reach 3		Reach 4		Reach 5		Reach 6	
Common name	**Native**	**Exotic**	**Rec**	**Exp**	**Rec**	**Exp**	**Rec**	**Exp**	**Rec**	**Exp**	**Rec**	**Exp**	**Rec**	**Exp**
Murray Cod#	■[L]		✓	✓	✓	✓	✓	✓	✓	✓		✓		
Trout Cod#	■[L]		✓	✓		✓								
Golden Perch	■[M]		✓	✓	✓	✓		✓	✓	✓		✓		
Silver Perch#	■[M]		✓	✓	✓	✓		✓		✓		✓		
Murray Rainbowfish	■[S]		✓	✓		✓		✓		✓		✓		
Freshwater Catfish	■[L]			✓		✓		✓	✓	✓	✓	✓		✓
Bony Herring	■[M]		✓	✓		✓		✓		✓		✓		
Carp Gudgeons	■[S]		✓	✓		✓	✓	✓	✓	✓		✓		✓
Un-Specked Hardyhead	■[S]		✓	✓		✓		✓	✓	✓		✓		
Australian Smelt	■[S]		✓	✓		✓	✓	✓	✓			✓		
Flat-headed Gudgeon	■[S]		✓	✓		✓		✓		✓		✓		✓
Dwarf-Flathead Gudgeon	■[S]			✓		✓		✓				✓		
Olive Perchlet#	■[F]								✓	✓		✓		✓
Mountain Galaxias	■[F]													
Flat-headed Galaxias#	■[F]			✓		✓								
Southern Pygmy Perch #	■[F]			✓		✓								
Gambusia		■	✓	✓		✓	✓	✓	✓	✓		✓		✓
Goldfish		■	✓	✓		✓	✓	✓	✓	✓		✓		✓
Oriental Weatherloach		■	✓	✓		✓		✓		✓		✓		✓
Common Carp		■	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
Redfin Perch		■	✓	✓			✓	✓		✓		✓		✓

Note: expected for reach 6 is at Wanganella Swamp

Yanco Creek, particularly the upper section, provides good habitat for a range of native fish species because the annual irrigation flows provide hydraulic diversity among the various habitats within the creek. An example of the hydraulic diversity might be relatively shallow areas with faster flow and deeper slow flowing pools. The second habitat aspect is the relatively high abundance of physical habitat such as snags, particularly in the upper reaches. Regular connection with the adjacent floodplain wetlands also provides habitat diversity for the floodplain fish species.

Macroinvertebrates

The term aquatic macroinvertebrates refers to a diverse group of non-vertebrate animals found in the river channel. This includes animals such as insects (e.g. groups such as mayflies, caddisflies, and beetles), crustacea (yabbies, amphipods), dipterans (fly larvae such as chironomids), aquatic snails and aquatic worms. Macroinvertebrates form an important component of the aquatic ecosystem, both as part of the natural biodiversity and as a vital component of the food chain (they form the major component of the diets of most native fish).

The major determinants of the abundance and composition of the aquatic macroinvertebrate fauna are the flows, available habitat, sources of food and water quality. In the main, the key habitats for macroinvertebrates in lowland rivers are the benthic sediments, instream vegetation and woody debris in the channel. An additional habitat in lowland rivers is the zone of tree roots along the edge of the channel. These roots provide shelter from high flows and predators, trap leaves and other organic debris in which the macroinvertebrates live.

The major food sources for most macroinvertebrates are algae, biofilms (layers of bacteria and other micro-organisms that cover elements in the water) and terrestrial organic material (leaves, twigs etc) that fall into the stream from the riparian zone.

Very little is known of the diversity and composition of the macroinvertebrate fauna of the Yanco Creek system. Only one record of a survey, at a single site on the Yanco Creek at Morundah in 1998 (Reach 2), could be located. The fauna at that site was typical of lowland rivers, with species associated with snags (e.g. freshwater prawns, beetles and shrimps), aquatic plants (e.g. caddisflies and shrimp), relatively slow-flowing open water (e.g. water bugs) and fine sediments (e.g. freshwater worms). It would seem likely that similar types of communities would be prevalent throughout the remaining parts of the system due to the types of habitats that can be found elsewhere.

However, Yanco Creek lies in the area covered by the listed "Lower Murray Aquatic Ecological Community" (NSW DPI 2007). The lower Murray aquatic ecological community includes all native fish and aquatic invertebrates within all natural creeks, rivers and associated lagoons, billabongs and lakes of the regulated portions of the Murray, Murrumbidgee and Tumut rivers, as well as all their tributaries and branches (including Yanco Creek). The community includes 23 native fish species and over 400 recorded native invertebrate species (although all native fish and other aquatic animal life within its boundaries are accorded the status of endangered species).

3 Environmental objectives

Environmental objectives were determined by the Technical Panel and Steering Committee for each study reach. The objectives reflect the environmental values identified throughout the system by the community (during community information sessions held in May 2012), through literature review, and assessment by the Technical Panel. Objectives were determined in the context of current water resource management, and the social and economic values of the region. The environmental objectives are summarised in Table 8 and discussed in further detail in this section.

Table 8. Environmental objectives for the Yanco Creek system

	Reach*							
Environmental objective	**1**	**2**	**3**	**4a**	**4b**	**5**	**6a**	**6b**
Maintain riparian vegetation condition, extent and composition	■	■	■		■	■	■	■
Rehabilitate riparian vegetation condition, extent and composition				■				
Maintain diversity and abundance of instream vegetation								■
Maintain a mosaic of wetlands	■	■			■	■		■
Maintain channel form and promote habitat diversity	■	■		■		■		■
Maintain drought refuge habitat			■		■		■	
Support self sustaining populations of macroinvertebrate taxa from the endangered Lower Murray Aquatic Ecological Community	■	■	■	■	■	■	■	■
Support self sustaining populations of macroinvertebrate taxa found in mid-Murrumbidgee wetlands	■	■	■					
Maintain and/or improve large-bodied native fish community	■	■	■	■	■	■	■	
Maintain and/or improve medium-bodied native fish community	■	■	■	■	■	■	■	
Maintain and/or improve small-bodied generalist native fish community	■	■	■	■	■	■	■	■
Maintain and/or improve small-bodied native fish – floodplain specialists	■	■				■		■

* Yanco Creek System reaches include:

Upper Yanco Creek	From Yanco off-take to Sheepwash weir pool (Colombo Creek)
Mid Yanco Creek	From Tarabah Weir to confluence with Billabong Creek
Colombo Creek	From Sheepwash weir pool to Cocketgedong weir
Mid Billabong Creek	Cocketgedong weir to Yanco Creek confluence (sub-reach 4a upstream of Jerilderie, sub-reach 4b downstream of Jerilderie
Lower Billabong Creek	Downstream of Yanco confluence
Forest Creek	Regulated (sub-reach 6a) and unregulated (sub-reach 6b) sections

For every environmental objective, the Technical Panel have defined the characteristics of flows required to achieve the objectives and the hydraulic criteria to measure achievement. These hydraulic criteria were applied during the environmental flow determination (Section 4).

3.1 Maintain and/or rehabilitate riparian vegetation condition, extent and composition

Description

Riparian vegetation plays a crucial role in the ecological structure and function of streams in inland Australia. Living trees provide habitat for a wide range of animals, ranging from small invertebrates (e.g. insects) to large vertebrates, including water- and bush-birds. Fallen limbs and bark provide habitat and shelter for animals on the floodplain floor, especially invertebrates and reptiles. Wood that falls into the stream similarly provides habitat for aquatic animals, especially fish. Leaf fall and bark shedding provide organic matter that fuels floodplain and aquatic food webs, mostly via decomposition and consumption by macroinvertebrates. The larger trees shade the stream, lowering water temperatures and providing shade for fish. Smaller plants, such as shrubs and other elements of the understorey, also protect the soil against erosion during floods and during heavy storms. Finally, the plants provide a critical aesthetic element that makes Australian streams and creeks look the way they do.

The wording of the environmental objective needs to be teased out, from two perspectives. First, there is a difference between maintaining and restoring/rehabilitating the values. Maintenance refers to actions that are intended to preserve existing values. In contrast, rehabilitation intends to improve those values to some pre-agreed end point. Some people draw the distinction between rehabilitation (improving condition of a value towards a target that is not necessarily pre-European) and restoration (returning it to a pre-European condition). It is a distinction worth preserving.

Second, the value that we are talking about here is riparian vegetation in its entirety. This includes not only the adult trees, but aspects of their condition or health, species composition of the canopy layer and of the understorey, and the ecological processes that allow the community to persist in time in a sustainable way. In other words, the environmental objective is not merely to maintain 'x' number of large trees per hectare, but to ensure that the plants are in good condition, that the floristic diversity is appropriate for the site and its intended uses, and that young plants can recruit into the population in order to replace those older ones that will eventually die. The last process is a crucial element, as there are many locations in the Yanco System where stock access means that young plants cannot survive (e.g. eaten or trampled), and thus eventually the entire community will be lost as the older specimens die out.

Relevant reaches

Where the current condition of riparian vegetation is good, the environmental objective is to 'maintain' the current condition, extent and composition of riparian vegetation. This objective applies to reaches 1, 2, 3, 4b, 5, 6a and 6b. In reaches with poor riparian vegetation condition (Reach 4a), the objective is to 'rehabilitate' instead of 'maintain'.

Flow objectives

The water-regime requirements of different plant species that occur in the Yanco System are summarised in Table 9. This table shows the known water-regime requirements for the four dominant riparian, aquatic and floodplain plant taxa in the Yanco Creek system. Note that there is inevitably some inconsistency among the various data sources for given plant taxa, and the table seeks to find a 'common ground' where recommendations are not the same.

Table 9. Summary of water regime requirements of structurally dominant riparian and floodplain plant species[11].*Vallisneria* spp. are used as a type-species for submerged taxa.

Component of water regime	***Vallisneria* spp. (eelgrass, tape grass, vallis)**	**River Red Gum**	**Black Box**	**Tangled Lignum**
Ideal time	Annual (or if variable, inundation in winter-spring to allow for successful recruitment)	August-December	Not known for adults, but recession in spring-summer likely to be beneficial to seedlings	Not well known for adults– possibly summer-autumn. Autumn-winter required for recruitment of young plants.

[11] table based on information from diverse sources, including Murray-Darling Basin Commission (1992), Roberts and Marston (2000, 2011), Murray Flow Assessment Tool (Young *et al*. 2003), Victorian Environmental Assessment Council (2006) and Rogers (2011).

Component of water regime	***Vallisneria* spp. (eelgrass, tape grass, vallis)**	**River Red Gum**	**Black Box**	**Tangled Lignum**
Frequency to maintain adults				
Natural average	Annual	4–9 years/decade	2–3 years/decade	2–5 years/decade
Minimum required	Annual	3–7 years/decade	1–2 years/decade	1–3 years/decade
Duration to maintain adults				
Natural average	9-12 months	1–5 months	2–6 months	3-7 months
Minimum required	> 9 months	0.5–1 month	1–2 months	1–3 months
Maximum period between floods to maintain adults	0 months	<6 years	<5–10 years	<5 years
Maximum period of inundation	Constant	<18 months	<4 months	Not known
Requirements for recruitment of young plants	Not well known. Can reproduce sexually and asexually Water depths probably <2 m	Large flood in winter or spring, followed by wet winter-spring or shallow summer flooding. Inundation in subsequent years	Not well understood. Seedlings cannot tolerate inundation for >~2 months. Ideal inundation period is probably < 1 month. Poor recruitment has been noted across the M-D Basin for many decades.	Inundation for 10–40 days. Note adults are intolerant of prolonged inundation. Inundation timing is crucial for recruitment, as seeds need to germinate soon after release (in autumn).
Notes	Requires water >50 cm in summer to avoid thermal damage to leaves. Water otherwise <2 m to keep leaves in photic zone.	Optimal water regime varies from forests (more frequent and longer) to woodlands (less frequent and shorter). Follow-up floods improve recruitment.	Adults can tolerate a wide range of wet-dry conditions, and the understorey is could be an important factor is devising the most appropriate regime for a given site.	Larger shrubs require longer inundation than smaller specimens. Shallow water (<15 cm) required for recruitment.

For some species (e.g. River Red Gum), periodic inundation is required to maintain adults in good condition and to allow seedlings to establish. River Red Gum, for example, requires inundation in August to December for between 1 and 5 months and at a frequency of between almost every year to three-or-four times per decade. Subtle differences in water regime will contribute to differences in the density of the stand, with more frequent watering tending to give rise to forests and less frequent watering tending to give rise to woodlands, other things being equal. In contrast to River Red Gum, Black Box requires inundation only 2−3 times per decade, seemingly without the seasonal element of winter-spring timing being so important, and can survive periods without watering of up to 10−20 years, albeit with serious decreases to tree health. Criteria such as these were used to inform the calculation of flow recommendations that aimed to provide hydrological conditions that would maintain healthy communities of riparian vegetation[12].

Hydrological requirements such as these are suitable for the maintenance and restoration/rehabilitation of riparian vegetation, but bankfull and overbank flows serve other ecological functions as well. For example, they entrain organic debris that has accumulated on the banks and on the floodplain into the river, thus providing aquatic fauna with a food supply. It is assumed that the frequency, duration and periodicity of overbank flows required to maintain riparian vegetation is sufficient also for these other ecological processes as well.

[12] The dry periods between flows is also important to maintain vegetation health

Different criteria are required to maintain submerged and emergent vegetation that grow in the stream channel and on the stream benches. In these cases, the plants of interest are either obligately aquatic (e.g. *Vallisneria* and *Potamogeton*) or else are mostly emergent reeds, rushes and sedges (e.g. *Phragmites*, *Juncus*, *Eleocharis* etc).

The idea behind providing these types of flows for submerged and emergent vegetation is two-fold. First, there is the requirement to provide periodic watering to maintain emergent taxa. Most require episodic flooding over summer to keep the soil wet. There is good evidence that fluctuating water levels also promote the growth of desirable taxa of emergent plants, such as *Phragmites* and *Eleocharis,* over less desirable *Typha*. It was this consideration that informed the decision to aim for fluctuations of 0.1−0.2 m for the required inundation events for emergent plants species on benches and in shallow the floodplain wetlands closely associated with the river. Second, periodic inundation prevents colonisation of the stream channel and benches by terrestrial plants, especially agricultural weeds. Benches that are not inundated for long periods over winter become quickly colonised by terrestrial taxa: the winter inundation is aimed at drowning out and preventing the colonization of aquatic habitats by non-aquatic plant species. In the case of the streambed, a minimum depth of 0.5 m required for submerged plants will also prevent the colonization of the stream by terrestrial taxa.

3.2 Maintain diversity and abundance of instream vegetation

Description
The water-dependent vegetation in unregulated Forest Creek (Reach 6b) differs substantially from that in other parts of the Yanco system. Although there is still a (narrow) riparian zone of River Red Gum, Black Box and River Cooba, a valuable component in Reach 6b is the mosaic of submerged and emergent vegetation that has developed in the stream channel and in the very shallow areas that fringe it. In this case, the environmental objective is to maintain the abundance and diversity of the instream and fringing vegetation. As noted above, submerged and emergent vegetation was not an obvious feature of other reaches, except when stock access had been controlled (e.g. in small parts of Reaches 1 and 4)

Relevant reaches
This environmental objective is only applicable to Reach 6b (unregulated Forest Creek).

Flow objectives
The thinking behind setting flow objectives for Reach 6b mirror closely those outlined above for the other reaches in the system, with the exception that greater emphasis is given to those components of the flow regime required to maintain obligately aquatic vegetation and emergent taxa. The same criteria of a minimum water depth (0.5 m) to provide adequate habitat for submerged taxa and to prevent colonization by terrestrial taxa apply here as well. Similarly, a requirement for periodic inundation of benches via a fluctuating water regime is designed to facilitate the growth of a diverse range of emergent and amphibious taxa, such as reeds, rushes and sedges.

3.3 Maintain a mosaic of wetlands

Description
To maintain a mosaic of wetlands of different size, shape and depth, and with different water regimes, ranging from ephemeral to near-permanently inundated, flow regimes for the floodplain wetlands will need to vary. The flow regime will need to include a range of commence to flows and inundation periods, in order to provide the various wetting and drying cycles needed to support fringing River Red Gum (i.e. inundation every 1–5 years, over spring–summer) to the far less frequent inundation required for Lignum (i.e. inundation only 1–3 times per decade). Table 10 summarises the available information on environmental water requirements to maintain broad groups of aquatic plants in wetlands of south-eastern Australia.

Table 10. Hydrological requirements to maintain broad groups of plant types in wetlands of the Murray-Darling Basin. Sources: [A] Victorian Environmental Assessment Council (2006, Table 5.6) and [B]Rogers (2011, Table 2.5). NP = information not provided in sources

		Water regime			
Group	**Typical species**	**Frequency of inundation**	**Duration of inundation[13]**	**Timing of inundation**	**Depth of inundation**
Submerged angiosperms[B]	*Vallisneria* spp. *Triglochin* spp.	Annual	12 months	Spring to summer	50-100 cm (Permanently flooded)
Rushes and sedges[B]	*Eleocharis* spp. *Cyperus* spp.	Annual	2-4 months	Spring to summer	+ 20 cm Fluctuating water levels with regular flooding and drying)
Reeds[B]	*Phragmites australis* *Eleocharis* spp. *Cyperus* spp.	Annual	6 months	Spring to summer	+ 30 cm (Shallow fluctuating and drying)
Cumbungi[B]	*Typha* spp. *Juncus* spp. *Eleocharis* spp.	Annual	9-12 months	Spring to summer	0-200 cm (Permanent to regular flooding with some depth)
Rushlands[A]	*Juncus* spp.	7-10 years per decade	2-10 months	July to January	Not indicated
River Red Gum forest[B]	*Eucalyptus camaldulensis*	1 in 3 years	2-6 months	Spring to summer	NP
River Red Gum woodland[B]	*Eucalyptus camaldulensis*	1 in 3-5 years	2-4 months	Spring to summer	NP
Black Box woodland[B]	*Eucalyptus largiflorens* *Acacia stenophylla*	1 in 10 years	2 months	Summer to autumn	NP
Tangled Lignum[B]	*Muehlenbeckia florulenta* *Atriplex* spp.	1 in 3-10 years	1-6 months	Summer to spring	60 cm

Relevant reaches

The objective to maintain a mosaic of different wetland types is relevant to reaches 1, 2, 4b, 5 and 6b.

Flow objectives

The first generic recommendations for wetting and drying cycles in floodplain wetlands of inland NSW were established by Briggs (1988). Her preliminary recommendations can be rounded out by including the findings of research undertaken in the lower Murray-Darling Basin in the intervening two decades (e.g. Walker, Thomas & Sheldon 1992; Walker 2006; Boon et al. 2009 etc). On this basis, we propose the following seven generic principles for floodplain wetlands in inland south-western NSW where the intention is to return them to an ecological condition that most resembles that occurring in pre-European times:

[13] Duration of inundation relates to the period and frequency that water can/should remain on the floodplain in wetland depressions, based mostly on conditions needed for River Red Gum and to a lesser extent for other emergent wetland plants that occur in wetlands (e.g. rushes and reeds) and for the maintenance of sediment biogeochemistry. The duration of inundation would be achieved by bankfull or overbank flows that fully wet the top of the bank and go out into the floodplain to various degrees (depending on elevation) and which then fills floodplain depressions, wetlands etc. The accumulated water on the floodplain and in wetlands then slowly evaporates or drains into the subsoil until it is 'dry' (i.e. lack of surface water) before the next flood and the next inundation period starts all over again.

The 'duration' of the environmental flow recommendations outlined in this report are instead, the number of days that the flow in the river is expected to occur at that magnitude to provide for plant health and recruitment for RRG in the riparian zone, for wetlands in floodplain depressions, and for Black Box on higher parts of the floodplain.

- Maintaining stable, high water levels is generally incompatible with the maintenance of high ecological values
- Water levels need to fluctuate seasonally
- Temporary wetlands require periodic inundation, with periodic drawdown of water levels and complete drying
- Wetlands should be flooded in late winter or early spring, and remain inundated for at least three to eight months.
- Rates of inundation and drawdown need to be controlled
- Multiple wetting-drying cycles may be required for environmental rehabilitation
- Ecological connectivity among wetlands should be acknowledged and maximised

A full description of these principles is provided in Attachment B of this report. The principles apply to situations where it is desirable – and possible – to modify water regimes to rehabilitate floodplain wetlands, however there are a number of situations when altering a wetland's water regime is not advised, or at least should be undertaken with great caution (Boon et al. 2009). Examples include when:

- potential or active acid sulfate soils are present
- the wetland lies over shallow saline groundwater
- there is the possibility of saline intrusions from adjacent saline water bodies
- a high-value wetland system has evolved in response to chronic inundation
- the introduction of a dry phase may lead to unexpected and undesirable changes in land use.

In the Yanco System, the greatest risk is to attempt to impose an ephemeral water regime on wetlands that have been permanently inundated, often for decades. The desired mosaic of wetland types is to produce the same mosaic of wetland types rather than restoring the pre-European condition of each wetland. Importantly, current permanent wetlands may be retained as permanent if they are in good condition. Likewise ephemeral wetlands may be less ephemeral and vice versa. Largely the basis of the wetland mosaic is maintaining the current condition if it is seen to be in good condition.

Significant ecological risks may be incurred with attempts to implement a drying phase in wetlands that have been chronically inundated and in which a particular and valued biota has established itself over time. Since river regulation and extraction have been undertaken for over a century along the Murray, Murrumbidgee and lower Darling Rivers, it is possible that over time permanently inundated wetlands have evolved ecological communities that are now of high ecological value. Even though the re-instatement of a more natural wetting and drying regime may seem theoretically desirable, in such cases any hydrological change from existing conditions may have undesirable ecological consequences. Boulton and Brock (1999, p 150) noted that 'Drying of a permanent wetland usually extinguishes most of the aquatic biota and recovery is much slower than in nearby naturally temporary wetlands'. For example, long-established populations of native fish and amphibians could be compromised by the reintroduction of a drying phase in chronically inundated wetlands.

There may also be impacts on wetland plants, of which adverse effects on obligately submerged species are likely to be the most significant. Ellis and Meredith (2005), for example, reported that submerged angiosperms (e.g. *Vallisneria* spp.) could be killed by drying a wetland and may fail to recolonise it upon reflooding. The following section summarizes what is known about the effects of water-level drawdowns on submerged aquatic plants. In principle, obligately submerged taxa such as Ribbon Weed *Vallisneria* spp. lack well-developed anatomical or physiological mechanisms to withstand desiccation and should die if exposed to the air for long periods (Brock and Casanova 2000). Salter, Morris and Boon (2008) showed that, in some brackish-water wetlands of the Gippsland Lakes in south-eastern Victoria, moderate to severe air drying reduced the biomass of *Vallisneria australis* by up to 95%. This result is consistent with the findings of Rogers (2011), who concluded that Australian *Vallisneria* spp. often had a growth cycle similar to that of annual species, in that if the time for their canopy to develop fully was too short there was a marked decline in reproductive output and in growth rate once reproduction had ceased. Even so, there are strong evolutionary reasons why even submerged plant taxa should have developed some tolerance to episodic desiccation, and indeed they can often withstand exposure to the air if they remain as thick mats on damp sediments, as shown by the repeated lack of success of attempts to control problematic growth of submerged angiosperms by water-level drawdowns alone.

Little is known of the hydrological requirements for obligately submerged plants to recruit sexually (Roberts and Marston 2000, 2011; Rogers 2011), but Salter et al. (2010) showed that germination of *Vallisneria australis* seed was slowed by drying and significant germination still occurred 20–30 weeks after dried seeds had been re-wetting. The final percentage germination of seeds that had been dried and then rewetted was about twice that of seeds that remained wet. Moreover, sediment-stored seeds germinated only after drying, which suggests that water level drawdowns might promote germination of *Vallisneria australis* in the field. This result is also consistent with the conclusions reached by Rogers (2011), who reported the presence of *Vallisneria* spp. in wetlands that experienced a wide range of wetting and drying regimes, from near-permanent inundation to regular drying.

In summary, near-permanent water is required in wetlands for obligately submerged angiosperms such as *Vallisneria* spp. They can withstand episodic drawdowns of water levels, but there are likely to be strong impacts on biomass accumulation during the following growing season. It is not clear what water regime is required for sexual recruitment, but it is likely that asexual (clonal) spread will be extensive in many species during the wet (inundated) phase, especially over summer when vegetative growth is fastest.

3.4 Maintain channel form and promote habitat diversity

Description

Channel form describes the size, shape and diversity of the river channel. The physical form of a river can be described at a range of spatial scales, from the catchment to the microhabitat scale (Sear 1996), which can each correlate with habitat types (Frissell et al. 1986). A diversity of habitat types provides the physical basis for a diversity of biota (Treadwell et al. 2006, Newson 2002), and consequently is an important factor in providing a healthy river. Physical features that provide habitat niches include meanders, pools, benches, bars, bank undercuts and variations in substrate. Each of these physical features interacts with flow to create hydraulic habitats (e.g. secondary flow structures at meanders, or areas of slack water on benches) that are preferentially used by different biota (Sagnes, Merigoux and Peru 2008). A diversity of channel form therefore provides a diversity of both physical and hydraulic habitats.

Field observation and inspection of cross-sections from the topographic survey of representative sites shows the predominant physical features in the channels of the Yanco system to be deep pools and benches. The maintenance of the pools and benches is an important geomorphic objective.

Relevant reaches

This environmental objective applies to all reaches in the Yanco Creek system unaffected by weir pools (i.e. reaches 1, 2, 4a, 5, 6b)

Flow objectives

The physical form of a stream depends on its flow regime, the characteristics of its bed and bank sediment, the riparian and instream vegetation, valley controls (such as confinement and valley slope), the sediment inflow regime. The geomorphic processes and form change over time if any of the factors, for example changes in the flow regime through regulation (Gregory, Benito & Downs 2008), removal of riparian vegetation (Simon & Collison 2002) and interruptions in the sediment supply from upstream (Petts & Gurnell 2005).

The central management option considered in an environmental flow study is the flow regime. Maintaining the deep pools and benches that provide the diversity of channel form in the Yanco System requires identification and provision of critical flow components within the flow regime.

Pools and benches have been identified as ecologically important physical features by a number of authors (Thoms, Ogden & Reid 1999, Shi, Petts & Gurnell 1999) and have become a central focus of environmental flow allocation studies in Australia. The role of these features in ecosystem health in the Yanco System is described in other sections.

Bankfull flow is important for formation and maintenance of channel form and diversity (US Department of Agriculture 2007; Knighton 1998). It is commonly used as an analog for the *dominant discharge*, i.e. the single flow that determines channel features such as cross-sectional capacity (Wolman & Leopold 1957) or the flow considered to do most geomorphic work in terms of sediment transport (Wolman & Miller 1960).

Changes in the frequency of bankfull flow are likely to lead to changes in channel form, potentially leading to the removal of physical features important as habitats. Providing bankfull flows is therefore important to maintain the gross channel form (i.e. the general size and shape of the channel) and in particular deep pools. There is some evidence (Vietz et al. 2012) that bankfull flows (or flows close to bankfull) are also important for bench maintenance.

The geomorphic and hydraulic processes leading to the formation and maintenance of benches has been the subject of some research (e.g. Page and Nanson 1992, Vietz et al 2012), and the occurrence of large inchannel events has been identified as important for promoting flow separation and fine-grained sediment deposition.

The flow processes required to meet the environmental objective are:

- Maintenance of gross channel physical form and inchannel features (bankfull flow)
- Bench maintenance flow (1 m depth over benches)
- Sediment mobilisation flow (flow that generates shear stress of 1.1 N/m^2 to mobile coarse sand that accumulates in pools)

The flow components to achieve these flow processes are bankfull and overbank flows.

3.5 Maintain drought refuge habitat

Description

During drought periods, large areas of aquatic habitats are placed under stress, due to low or absent flows and poor water quality. Under these conditions, species of plants and animals can become locally extinct, or suffer declines in condition or breeding ability that severely reduce population sizes. While historically, native biota have adapted to surviving periods of drought by developing resistance traits (the ability to survive through low flows and poor water quality) or resilience traits (the ability to rapidly breed and spread following the breaking of the drought).

The desirable ecological condition for refuge habitats have been identified (eWater CRC 2012):

- areas that contain persistent water and are large enough to maintain populations
- areas with water quality that is good enough to support species
- areas with little or no physical disturbance
- areas with access between habitats following the drought

The potential for species to survive droughts depends on the availability of suitable and adequate habitat for biota to live during dry periods. Human intervention has reduced the natural ability of species to survive drought conditions through a number of activities – reductions in flows, sedimentation of habitats, stock access to rivers and clearing of riparian vegetation that reduce the ability to survive during the drought, and the construction of barriers that reduce the ability to recolonise and spread following the drought.

Because of these changes, maintaining refuges during drought periods is essential if species are to continue into the future. Many of the natural drought refuges (deep pools, off-stream wetlands) have been reduced in size and occurrence across the Murray-Darling landscape. The weir pools present on the Yanco Creek system provide an opportunity to be managed as additional secure drought refuge areas.

Relevant reaches

Three of the reaches in the Yanco Creek system contain a number of weir pools with essentially no sections of flowing water between them (i.e. the head of one weir pool coincides with the tail of the next weir pool downstream) – Colombo Creek, Billabong Creek between Jerilderie and the confluence with Yanco Creek and the regulated section of Forest Creek from the junction with Billabong Creek and Warriston Weir.

Flow objectives

Within each weir pool, there are three main habitat areas – fringing vegetation, open water and the sediments at the bottom of the weir – similar to the habitats found in natural drought refuge pools. Each provides a distinct habitat environment for different types of biota (e.g. large-bodied fish in open water and smaller fish amongst fringing vegetation). In a natural drought refuge, as the drought progresses (assuming no flow), the volume of water declines due to evaporation and seepage, and water quality declines as water temperatures increase and dissolved oxygen decreases. Deeper pools may thermally stratify (warm water on the surface and colder water below with little or no mixing), leading to further declines in dissolved oxygen in the lower levels and the potential for algal blooms. As the volume declines, fringing vegetation becomes less inundated, reducing the amount and suitability of habitat.

By manipulating flows into the weir pools during drought periods, it should be possible to maintain the volume of water, and hence habitat availability, and to prevent declines in water quality. This is achieved by providing an inflow that is at least as great as the evaporation rate, and is sufficient to prevent long periods of stagnation and declines in water quality.

Equations to calculate evaporation rates from open waters in the Murray-Darling Basin have been derived by McJannett et al. (2008), but require detailed knowledge and time series of water temperature, wind speed, solar radiation and pressure, which are not available.

Criteria for achieving the flow required to prevent water quality declines during droughts are difficult to determine. The response of individual weir pools to periods of very low inflows is likely to be quite specific to each pool, determined by factors such as surface area, depth and aspect (due to the mixing effect of wind), and reported flows required to prevent stratification or algal blooms are quite variable.

In the lower Darling River, Mitrovic et al. (2003, 2011) found that discharges which resulted in a flow velocity of 0.03 – 0.05 m/sec were sufficient to prevent prolonged periods of persistent thermal stratification, which also suppressed the development of the cyanobacteria *A. circinalis* blooms. Two papers by Webster et al. (1997, 2000) showed that cyanobacterial blooms occurred in Maude Weir pool (just downstream of Hay on the Murrumbidgee) when flows were <500 ML/day, and that blooms did not occur at flows of >1,000 ML/day. Webster et al. didn't give a volume for the weir pool, however it is estimated to be ~5,000 ML. This means that cyanobacterial blooms did not occur at the Maude Weir pool if the turn-over time was ~5 days, but developed if the turn-over time exceeded ~9-10 days. Although cyanobacteria were encouraged by long turn-over times of 9-10 days, shorter turn-over times instead encouraged the diatom *Melosira*. Short turn-over times (i.e. larger incoming flows) created rapid mixing of the water-column from top to bottom of the weir pool, and this allowed the relatively heavy diatoms to stay suspended in the water column rather than sinking to the bottom and falling out of the photic zone.

At Maude Weir pool with short turn-over times (e.g. <5-7 days) cyanobacteria are selected against, as the water column remains well mixed (i.e. does not thermally stratify) and algal cells are mixed down into the deeper layers which, in turbid waters, are too dim for rapid growth. Under these well-mixed conditions, heavy cells that cannot control their buoyancy, such as the very common diatom *Melosira*, are selected for as they are kept high in the water-column by the turbulent flow. Conversely, long turn-over times (>10 days) allow the water-column to stratify strongly; under these conditions, diatoms sink and cyanobacteria (e.g. *Anabaena*) are selected for.

Oliver et al. (1999) worked on weir pools along the Darling. In Bourke Weir pool, cyanobacterial blooms developed when flows were <800 ML/day. The weir pool has a volume of 4,500 ML, so this corresponds to a turn-over time of ~6 days. Moderate cyanobacterial populations developed at flows of 500 ML/day (= turn-over time of 9 days). Both figures are reassuring similar to the ~5-7 days and ~9-10 days estimated from the data of Webster et al.

It is important to note that the development of a cyanobacterial bloom is dependent not only on flow, but also on the initial abundance of cells that initiate the bloom. If, for example, the initial cell number is low, it can take 9-26 days for problematic blooms to develop in Bourke Weir pool. In other words, whether a cyanobacterial bloom develops is not controlled only by flushing rate, but also by the size of the innoculum and the water temperature. This may not be an important consideration for Yanco Creek system, but it does show that long turn-over times will not automatically generate a cyanobacterial bloom.

It is therefore recommended to provide flow rates for both a 7-day and a 14-day estimated turn-over time for the weir pools. The shorter rate (a weekly turn-over) is more likely to prevent cyanobacterial blooms, but will require more water and could encourage a diatom bloom. The longer rate (once every 14 days) is more likely to result in a cyanobacterial bloom, but will use less water and is likely to discourage *Melosira*.

3.6 Support self sustaining populations of macroinvertebrate taxa from the endangered Lower Murray Aquatic Ecological Community and those found in mid-Murrumbidgee wetlands

Description
Because of the paucity of data on the diversity and composition of macroinvertebrates in the Yanco Creek system, there are no specific objectives for macroinvertebrate communities in the system. However, Yanco Creek lies in the area covered by the "Lower Murray Aquatic Ecological Community" so that flows can be used to help promote the survival and sustainability of that community. In addition, the upper reaches of the system lie in the area covered by the Murrumbidgee Catchment Management Plan (MCMA 2008) and opportunities exist to support the objectives of the plan to "protect and enhance the terrestrial and aquatic biodiversity of the Murrumbidgee catchment in order to restore balance to the terrestrial and aquatic ecosystems" (p. 46).

Relevant reaches
All reaches in the Yanco Creek system lie in the area covered by the "Lower Murray Aquatic Ecological Community", while only Reach 1 and parts of Reaches 2 and 3 lie in the Murrumbidgee Catchment management Authority region.

Flow objectives
Maintaining or improving the macroinvertebrate community requires the maintenance of a suitable baseflow in reaches at all times. The baseflow should be sufficient to inundate the major habitats for macroinvertebrate production (primarily the stream bed, at least parts of woody debris and the fringing vegetation and exposed tree roots). A variable low flow regime that sequentially inundates and exposes parts of the woody debris can increase the productivity of algal biofilms, and hence the amount of available food (Ryder 2004).

Additional to adequate low flows, short periods of higher flows (freshes) are required to prevent the build up of fine sediment on structural habitat at times of year when flows are low. Higher scouring flows are required to disturb the algae/bacteria/organic biofilm present on woody debris (a major food source for macroinvertebrates). This disturbance is believed to maintain a diversity of available food sources.

In wetlands, providing a mosaic of different wetting and drying cycles (from permanent to ephemeral) would support the wide range of macroinvertebrate that would be found in Murrumbidgee wetlands.

3.7 Maintain and improve large and medium-bodied native fish community

Description
Medium and large-bodied fish populations have declined in many areas of the Murray-Darling Basin and this has often been associated with river regulation and habitat removal. Several large-bodied fish are nationally

threatened and remain in areas where there is permanent flow and good instream habitat, such as the Murrumbidgee River and Yanco Creek system (such as Murray Cod and Trout Cod). Delivery of appropriate flows to stimulate movement, spawning and recruitment is important to maintain the health of existing populations and also to stimulate recruitment and improve the abundance of exiting fish and maximise their distribution.

Characteristics of the life history for large-bodied fish (Murray Cod, Trout Cod, Freshwater Catfish) are:

- Cod can live for 40+ years and mature at 3-4 years for males and 4-5 years for females.
- Adults are often associated with 'home snags' but move from mid-August to mid December.
- Adult fish have moderate numbers of eggs and spawn between early October and early December.
- Stable or rising flows are associated with spawning.
- Female fish may partner one or more males and males guard the nest.
- Larvae remain at the nest for 5-13 days and then may drift downstream for up to 7 days.
- Juvenile fish settle and are often associated with snags or instream cover.

Characteristics of the life history for medium bodied fish (Golden Perch, Silver Perch, Bony Herring) include:

- Fish can live for 25+ years and mature at 2-3 years for males and 3-4 years for females
- Adult fish develop large numbers of eggs over winter and early spring and spawn from October-January.
- Increasing temperature and river flow triggers fish to spawn.
- Eggs and larvae are pelagic and can drift downstream for up to 2 weeks
- Juveniles settle and then disperse with upstream migration by 1+ year old fish

Relevant reaches
Large and medium bodied fish are expected to be present in all reaches of the Yanco Creek system except for Forest Creek (Reach 6). Fish surveys are recommended to confirm the actual distribution of species in each reach to refine the applicability of this environmental objective to reaches over time.

Flow objectives
Important flow processes to achieve the environmental objective are:

- Stimulate key life-history processes (e.g. egg production, movement, spawning, recruitment)
- Maximise habitat availability, snags, littoral margins, wetlands, major offstream water bodies (e.g. Dry Lake and Mollys Lagoon)
- Enhance juvenile dispersal and colonisation of newly available habitats and maximise fish distributions
- Enable threatened fishes (i.e. Murray Cod, Trout Cod, Freshwater Catfish) to complete life-history and build resilience among these populations

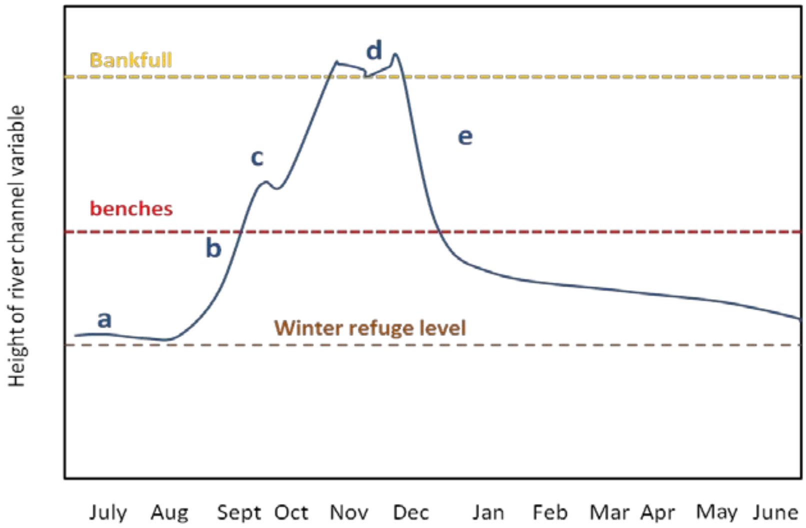
The ability of fish to move to preferred habitats for feeding, spawning and recruitment is achieved with an appropriate environmental flow. Key life-history processes (e.g. movement to spawning areas) are initiated by appropriately timed flow events. The flow objectives are directly linked to fish outcomes with some fish being stimulated to complete their spawning by rising flows.

Large and medium bodied fish have reasonably predictable ecological responses to environmental water delivery. Rising spring flows will initiate movement and potentially spawning and flows should also aim to maximise the time for fish to find a mate, spawn and in the case of Murray Cod enhance access to suitable spawning sites. Daily variation (e.g.+/-150 mm of bank height) also help to stimulate important ecological processes such as migration.

The aims of the environmental flow are to:

- promote movement of large/medium-bodied fish on the ascending limb of a flow rise
- increase habitat availability including snags and undercuts where fish select nest sites and spawn
- promote successful spawning, egg survival and larval dispersal.

The shape of the hydrograph (Figure 13) is provided as a guide only, the timing and minimum duration (see table) of the flows are more important than whether there is one or several peaks.



Key	Flow component	Timing	Duration	Fish rationale
a	Winter connection	Jan-July	Continuous	Connect pools
b	Ramp up	Mid August	5-7 days	Stimulate movement
c	Inundate benches	September-October	21 days	Inundate spawning areas
d	Peak	November	7-12 days	Spawning, hatching and larval dispersal
e	Ramp down	Mid December	5-12 days	Restore connecting flows

Figure 13. *Conceptual hydrograph for large and medium bodied fish species*

3.8 Maintain small-bodied generalist native fish community

Description
Small-bodied fish populations have declined in some areas of the Murray-Darling Basin but in many areas, such as Yanco Creek, there are still strong and healthy populations of these fish. Small fish are important indicators of functioning systems and these play an important role in a healthy and diverse fish community. Delivery of appropriate flows to enhance, spawning and recruitment is of moderate importance to generalist species. Flows stimulate primary production and can benefit the maintenance of small-bodied fish communities.

Characteristics of these small-bodied generalist native fish (mainly Carp Gudgeons, Flat-Headed Gudgeons, Australian Smelt, Unspecked Hardyhead and Murray Rainbowfish) include:

- probable life-span is 1-3 years
- adult fish can spawn at low flows and rising flows in the main river or off-channel
- larvae can recruit in off-channel habitats and fish move between the main channel and lagoons

Relevant reaches
Small bodied generalist fish are expected to be present in every reach of the Yanco Creek system.

Flow objectives
Important flow processes to achieve the environmental objective are:

- stimulate key life-history processes (e.g. egg production, movement to littoral habitats, spawning, recruitment)
- maximise habitat availability, littoral margins, wetlands, major off stream lakes
- enhance juvenile dispersal and colonisation of newly available habitats and maximise fish distributions
- enable threatened fishes(Flat-headed Galaxias) to complete life-history and build resilience among these populations

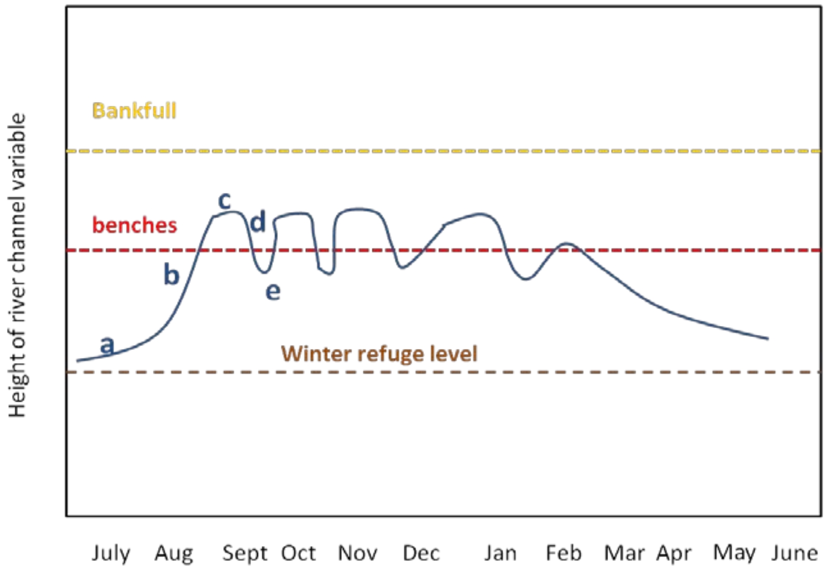
The ability of fish to move to preferred habitats for feeding, spawning and recruitment is achieved with an appropriate environmental flow. Key life-history processes (e.g. movement to littoral spawning areas and low lying wetlands) are initiated by appropriately timed flow events. The flow objectives are directly linked to fish outcomes with some fish having maximised recruitment with access to shallow littoral areas and backwaters.

Small-bodied fish are active in spring and summer, migrating, spawning and recruiting during low and rising flows. Often these fish spawn and inhabit shallow littoral margins and stream benches and will also move into low lying wetlands. Environmental flows for small-bodied fish can achieve their objectives (spawning and recruitment) with frequent smaller flow peaks that increase access to shallow marginal habitat.

The aims of the environmental flow are:

- Promote opportunities for small-bodied fish to access shallow littoral habitat or low lying wetlands.
- Inundate stream benches, woody debris and riparian vegetation.
- Promote successful spawning, egg survival and larval dispersal over spring and summer.

The shape of the hydrograph (Figure 14) is provided as a guide only, the timing and minimum duration (see table) of the flows are more important than whether there is one or several peaks. Three or four pulsed flows over spring and summer are required with 2-3 weeks between pulses.



Key	Flow component	Timing	Duration	Fish rationale
a	Winter connection	Jan-August	Continuous	Connect pools
b	Bench inundation spike	September	5-7 days	Stimulate movement
c	Inundate benches	September-January	14 days	Inundate spawning areas
d	Recession below benches	September-January	14 days	Dispersal of young fish
e	Ramp down	January	5 days	Restore connecting flows

Figure 14. *Conceptual hydrograph for small bodied generalist fish species*

3.9 Maintain small-bodied native fish – floodplain specialists

Description

Some small-bodied fish can be classified as floodplain specialists which require access to floodplain wetlands to recruit and then periodic high water access to other wetlands, or the main channel to disperse. If these species are present (galaxiids, pygmy perch and Olive Perchlet) then they can spawn and recruit in wetlands but they need to move among these habitats. The few data that exist suggest these fish mainly move at high water and mostly to other wetlands rather than main river habitats. Identifying the 'commence to flow' for the key wetlands is an important component of this model.

Small-bodied floodplain specialist fish populations have declined in some areas of the Murray-Darling Basin and floodplain specialists (e.g. pygmy perch, Olive Perchlet and galaxiids) are now rarely found in large areas of their former range. Floodplain specialists are flow dependent species that need to colonise new habitats and spawn during over-bank flow conditions. Delivery of appropriate flows to enhance, spawning, recruitment, dispersal and re-colonisation is of great importance to floodplain species

Characteristics of these small-bodied native fish – off channel specialists (mainly pygmy perch, Olive Perchlet and galaxiids) include:

- Fish can live up to 10 years.
- Life-history of these fish is data deficient and populations have declined. Movement among off-channel habitats and along river channels is important.
- These fish require bankfull and floodplain engagement flows once or twice per decade to disperse.

Relevant reaches

Limited data is available on the distribution of small bodied floodplain specialists in the Yanco Creek system. These fish species are expected to be present in reaches 1, 2, 5 and 6b. Survey is recommended to confirm presence of these species, especially in unregulated Forest Creek (reach 6b).

Flow objectives
Important flow processes to achieve the environmental objective are:

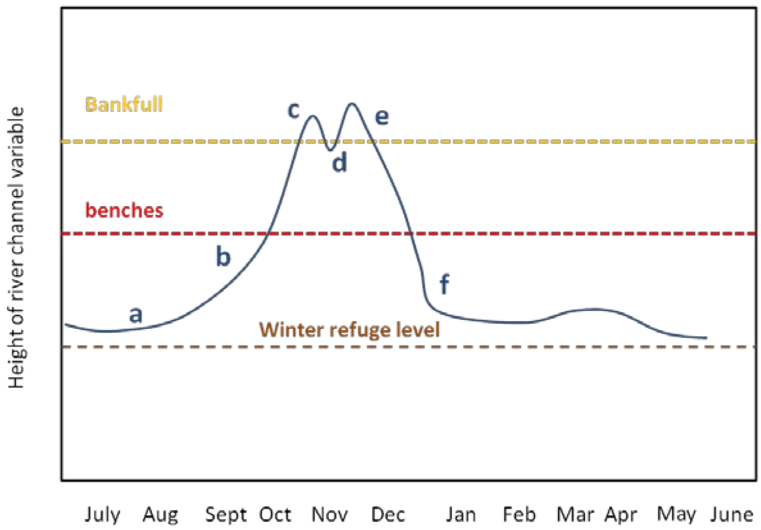
- Stimulate key life-history processes (e.g. egg production, movement to spawning habitats, spawning, recruitment).
- Maximise habitat availability, floodplain swamps, littoral margins, wetlands, major off stream lakes (e.g. Dry and Mollys lakes).
- Enhance juvenile dispersal and colonisation of newly available floodplain habitats and maximise fish distributions.
- Enable threatened fishes (i.e. Southern Pygmy Perch, Olive Perchlet) to complete life-history and build resilience among these populations.

The ability of fish to move to preferred floodplain habitats for feeding, spawning and recruitment is achieved with an appropriate environmental flow. Key life-history processes (e.g. dispersal among wetlands) lying wetlands) is initiated by appropriately timed flow events. The flow objectives are directly linked to fish outcomes with some fish having maximised recruitment with access to shallow littoral areas and backwaters.

The aims of the environmental flow are:

- Promote opportunities for small-bodied floodplain specialist fish to move among wetlands.
- Enable colonisation migrations of fish to newly accessible wetlands.
- Promote successful spawning, egg survival and dispersal over spring and summer.

The shape of the hydrograph (Figure 15) is provided as a guide only, the timing and minimum duration (see table) of the flows are more important than whether there is one or several peaks. Three or four pulsed flows over spring and summer are required with 2-3 weeks between pulses.



Key	Flow component	Timing	Duration	Fish rationale
a	Winter connection	Jan-August	Continuous	Connect pools
b	Ramp up	September	5-7 days	Stimulate movement
c	Inundate wetlands	October-December	2-5 days	Inundate spawning areas
d	Mini recession	October-December	2-5 days	Lateral dispersal of fish
e	Ramp up	October-December	5 days	Colonisation of wetlands
f	Recession	Mid December	10 days	Drawdown to normal operations

Figure 15. *Conceptual hydrograph for small bodied floodplain fish species*

4 Environmental flow recommendations

The following sections outline the approach to environmental flow determination and the reach specific information and hydraulic modelling developed in this process.

For each reach, a summary of the environmental values is provided and lists the environmental objectives relevant to that reach. The environmental flow recommendations are presented in a standard table format, outlining the timing, magnitude, frequency and duration of each environmental flow recommendation. The rationale for each recommendation is provided in the right columns of the table. A typical cross section from the hydraulic model is also presented to illustrate the different habitat inundated with each environmental flow recommendation.

The performance of environmental flow recommendations against the current flow regime is also provided for each reach, followed by a discussion of the potential ecological risks associated with not achieving (or over achieving) the flow recommendations.

4.1 Approach to determining environmental flows

Locations of survey cross sections for each selected site were identified by the Technical Panel, pegged and the survey requirements specified. These cross section locations were selected to best represent the features of the channel (pools, runs, riffles, benches etc) in the hydraulic model. A total of 15 cross-sections were surveyed at four of the six representative reach sites.

The approach to the survey, hydraulic modelling and environmental flow determination for the reaches are discussed in the following sections.

Environmental flow assessment sites

One stretch of river was identified in each reach for detailed investigation. These 'sites' are selected on the basis that they are representative of the features that are characteristic of each reach. Detailed cross-sectional surveys were undertaken at four sites to enable a hydraulic model of the river channel to be developed. This model was used by the Technical Panel to help relate river flow to physical, chemical, biological and ecological processes in the river. The information provides the foundation for the development of environmental flow recommendations for each site.

The representative site for each reach was selected by the Technical Panel during a field inspection of a range of potential sites (Table 2 and Table 11). A number of sources of survey information (both existing and newly acquired for this study) were consolidated to set up hydraulic models for each reach, including LiDAR, bathymetric survey of weir pools and cross section survey carried out using total station and differential GPS.

Table 11. Representative sites for study reaches

Reach	Site description	Primary source (in channel)	Supplementary source (floodplain)
1	Yanco Creek at Devlins Bridge	Cross section survey	LiDAR
2	Yanco Creek at Yanko Bridge	Cross section survey	LiDAR
3	Colombo Creek weir pools	Bathymetric survey	LiDAR
4a	Mid Billabong Creek at Brick Kiln	Cross section survey	LiDAR
4b	Mid Billabong Creek weir pools	Bathymetric survey	LiDAR
5	Lower Billabong Creek at Millabong	Cross section survey	LiDAR
6a	Forest Creek weir pools	Bathymetric survey	LiDAR
6b	Forest Creek at Peppinella	LiDAR	LiDAR

Hydraulic modelling
Hydraulic modelling is used to simulate and assess the way that water behaves in the physical environment. The models are based on the physical size and shape of the waterway (or weir pool) and allow for quick and easy analysis of multiple variables (depth, velocity, shear stress, etc.) at any chosen flow rate.

Two different approaches to modelling were taken for this study based upon the predominant behaviour of the reach (i.e. free flowing or weir pool dominated):

- Free flowing reaches (majority of the system) were modelled using feature survey and a one-dimensional hydraulic model (details below)

- Weir pool dominated reaches (Colombo Creek, middle Billabong Creek below Jerilderie, regulated Forest Creek) were modelled using LiDAR (details below)

Free flowing reaches
Proportionally more points were surveyed in the low flow channel than in the floodplain (Figure 16) in order to ensure a greater level of confidence in low flow recommendations which are often the most problematic and contentious in environmental flow determinations. The cross-section survey was then imported into the digital terrain modelling package 12D, which was then used to generate a one dimensional hydraulic model (HEC RAS) of the surveyed site.

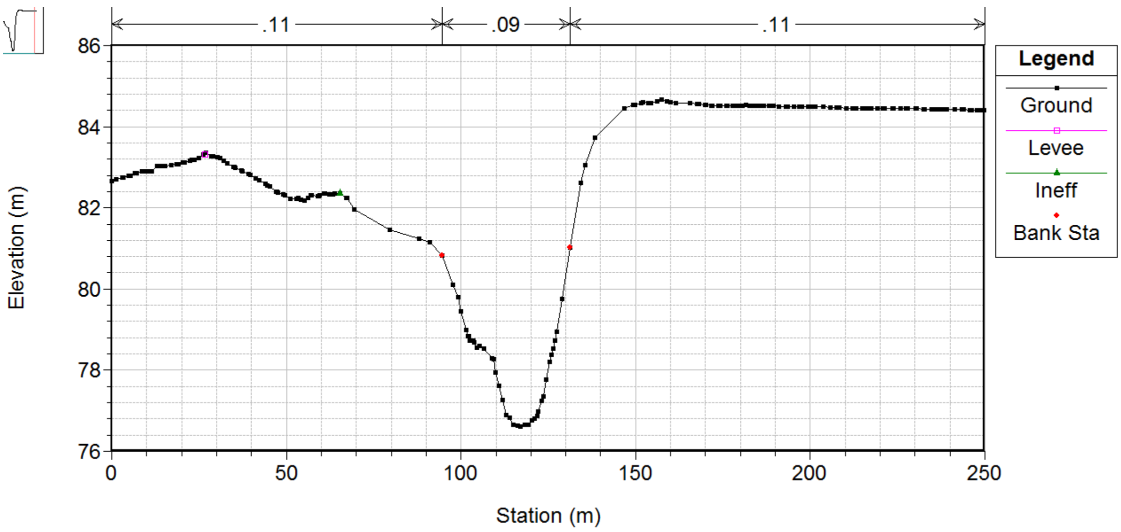


Figure 16. *Survey cross section (lower Billabong Creek, chainage 623) showing feature survey to top of bank (note concentration of points in low flow channel and benches as compared to channel banks) and supplementary LiDAR survey into the floodplain.*

There are three primary variables in HEC RAS modelling:

- Channel geometry (from survey data)

- Upstream and downstream boundary condition (rating curve from gauge or slope)

- Hydraulic roughness (Manning's *n*).

Upstream and downstream slope was used for boundary conditions, as calculated from the longitudinal profile (LiDAR or feature survey). Table 12 lists the boundary condition and hydraulic roughness adopted for the hydraulic model. These parameters were adopted on the basis of field observations and results from various model calibration runs.

Table 12. Hydraulic parameters adopted in HEC RAS model of reaches in the Yanco System

	Boundary condition		Manning's roughness (n)	
Reach	Downstream	Upstream	Channel	Floodplain
1. Upper Yanco Creek	0.0002	0.0002	0.053	0.070
2. Mid Yanco Creek	0.006	0.006	0.090	0.12
4a. Mid Billabong Creek	0.00009	0.00009	0.060	0.070
5. Lower Billabong Creek	0.00019	0.00019	0.090	0.11
6b. Forest Creek	0.0003	0.0003	0.080	0.090

Model calibration
The water level on the day of survey and for the March 2012 flood event (as indicated by tree markings, Figure 17) was collected along with the feature survey. This allowed the HEC RAS models to be calibrated for low flows (day of survey) and high flow (recent flood event). Flow magnitudes were taken from the nearest gauge to each reach site.

Figure 17. *Flood level indicated by tree markings (circled in red), lower Billabong Creek at Millabong (Reach 5)*

The presence of instream timber, instream vegetation such as emergent and submerged plants, and riparian vegetation, can increase the roughness of the channel and affect flow dynamics. The presence of these various factors was modelled in three different ways at the relevant cross-sections:

- By increasing the Manning's *n* roughness value used in the HEC RAS model simulation
- Using blocked obstructions

Both these approaches were used to calibrate the hydraulic model to the flows and water-surface elevations recorded on the day of survey and at the March 2012 flood event[14]. Flows provided by the nearest gauge to each site were daily average flows. Where instream timber cause significant blockage of the channel blocked obstructions were used to calibrate the hydraulic model to observed water-surface elevations.

Weir pool dominated reaches
Modelling of weir pool reaches focussed on:

- The elevation required to engage the weir pool floodplain
- The minimum passing flow rate required to maintain particular water quality objectives

[14] Cross section survey was not collected at Forest Creek and therefore the model for this reach was not calibrated to observed water levels. The hydraulic roughness for this reach was informed by visiting the site and comparing with findings from other calibrated sites.

The elevation of floodplain engagement was determined using LiDAR imagery. The standard weir equation (below) was used to determine the flow rate required to achieve floodplain engagement in the vicinity of the weir itself.

$q = CH^{3/2}$ Where q is the unit discharge of the weir (m/s), C is the weir coefficient (typically 1.6) and H is the head of water above the weir

This approach assumes that the degree of floodplain engagement observed at the weir is indicative of the whole weir pool. Bathymetric survey data previously collected by State Water was made available for this study. The rating table for each weir pool (only where bathymetry was collected – not all weir pools in the Yanco System) was used to calculate the minimum flow required to achieve a minimum residence time in each pool. A number of assumptions were used in this approach, including:

- Daily evaporation rates (collected from Bureau of Meteorology) for the month of January represent the worst case (highest rate of evaporation) in the average year
- The weir pool is mixed (i.e. residence time is proportional to total pool volume and flow rate)

This approach included:

- Determination of elevation of floodplain engagement (LiDAR)
- Calculate head above weir (weir geometry)
- Calculate flow rate (weir equation)
- Determination of weir pool area at floodplain engagement elevation (rating table)
- Determination of volume of evaporation (daily) for January month (regional daily evaporation rate, BoM)
- Sum minimum flow rate and daily evaporation rate to give total minimum passing flow rate to achieve desired flow recommendation

All models developed for this study were used in the environmental flow determination workshops with the Technical Panel held in Melbourne on 14 and 16 August 2012.

4.2 Reach 1: Upper Yanco Creek

Reach 1 includes the Yanco Creek and its floodplain from the Murrumbidgee River off-take at Yanco Weir to Morundah, and including Colombo Creek upstream of the Sheepwash Weir pool (Figure 18). This reach includes the tributaries Washpen Creek and Woolshed Creek, and numerous wetlands, including Dry Lake - one of the largest wetlands in the Yanco Creek system. Flow controls in Reach 1 include:

- Yanco weir – off-take point for Yanco Creek from the Murrumbidgee River (limited control of flows >10,000 ML/d)
- Mollys Regulator and Gum Hole Regulator - recently installed to assist management of the wetting and drying cycles in Mollys and Gum Hole Lagoons and Dry Lake
- Spillers Regulator – influences flows entering Washpen Creek
- Tarabah Weir – distributes flows between the Yanco and Colombo creeks near the downstream end of the reach
- Cheverells Creek Regulator – diverts water from upstream Colombo Creek to Cheverells Creek

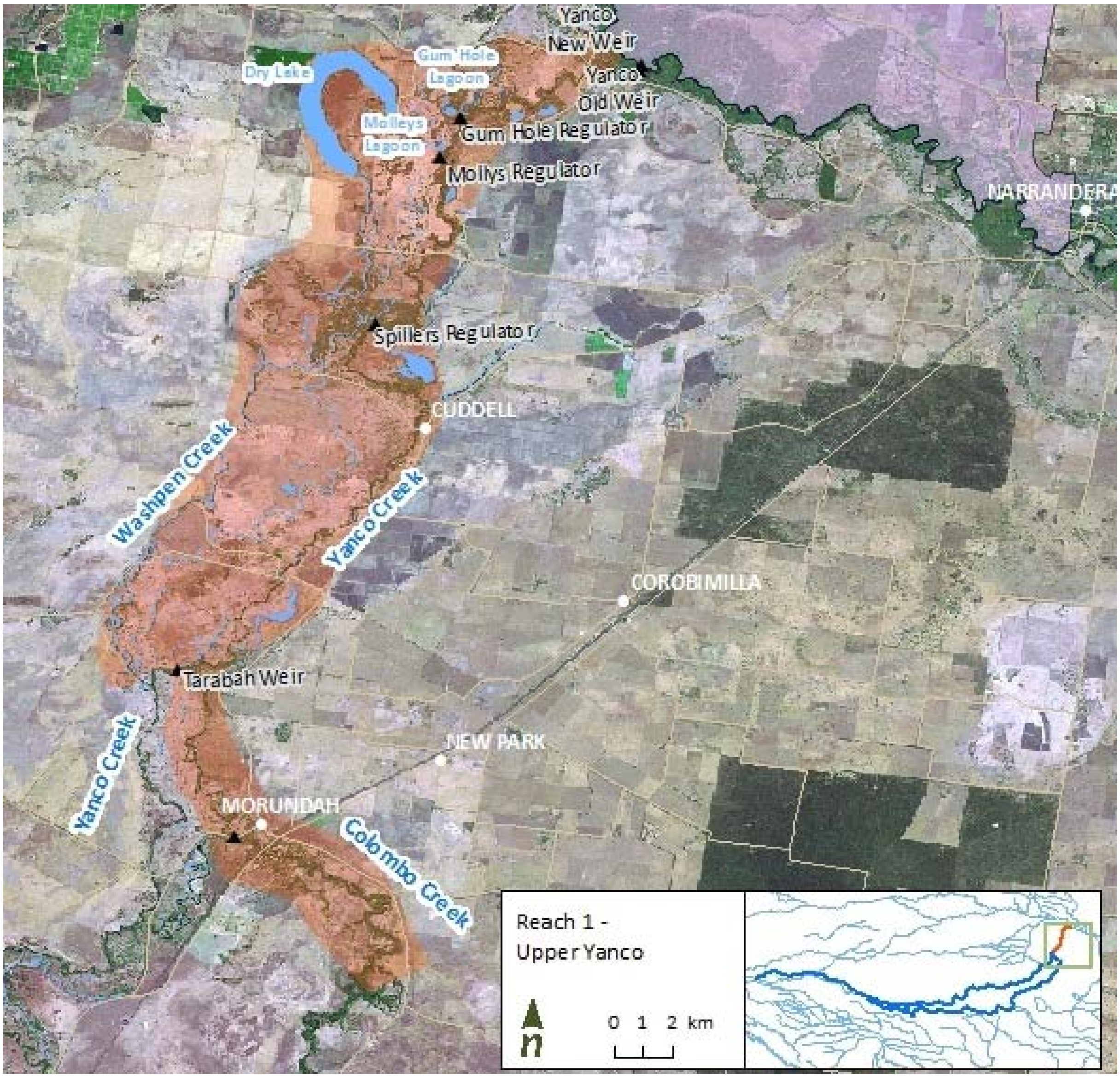


Figure 18. *Reach 1: Upper Yanco Creek*

Summary – environmental values

Physical form

The channel and floodplain in this reach are hydraulically well connected, with evidence of recent floodplain inundation on the inside of meanders downstream of the Devlins Bridge. Channel cross-section morphology is simple, with stable banks. Large wood was present in the channel (Figure 19), and is likely to be more abundant at lower levels in the channel that could not be seen due to high flows.

Figure 19. *Yanco Creek looking downstream from Devlins Bridge*

The inchannel geomorphology of the reach was characterised by deep pools and small benches. A number of small (<10 m long) floodplain depressions are present throughout the reach. Riparian vegetation in this reach appears to be well structured, in good condition and is likely to provide substantial resistance to erosion. Upper bank sediments at this site were generally sandy silts.

Figure 20. *Riparian zone at Devlins Bridge, showing River Red Gum overstorey and dense and floristically diverse understorey*

Water dependent vegetation

At the Yanco Weir inspection site River Red Gum (*Eucalyptus camaldulensis*) was the dominant overstorey tree species with little Black Box (*Eucalyptus largiflorens*) evident. The floodplain appeared narrow but frequently inundated, which probably accounts for the scarcity of Black Box, a species which requires less frequent inundation and, in fact, is adversely affected if watered for too long or too frequently. A more detailed inspection at Devlin's Bridge also indicated a River Red Gum dominated overstorey with a dense and healthy understorey of diverse rushes, reed and sedges (Figure 20).

Under the current flow regime, it would be expected that submerged aquatic plants, especially Water Ribbons (*Triglochin procera*) and Ribbonweed (*Vallisneria australis*), would occur in the channel (Sainty and Jacobs 1988). Neither taxon was observed during the field inspection. It is not clear why this is the case, although the presence of carp is likely to be an important factor (Koehn, Brumley & Gehekre 2000). If this is indeed the case, there is probably little that can be done to facilitate the recovery of submerged plants in the main channel.

Floodplain wetlands

Possum Creek complex

Possum Creek wetland complex consists of a number of lagoons totalling around 30 ha located on Yanco Creek just downstream of the off-take. A single narrow, shallow inlet connects this complex to Yanco Creek (currently no inlet regulator) (Webster 2007).

Gum Hole, Dry Lake and Molly's Lagoon

Gum Hole is a small (7ha), shallow, wetland that has suffered from prolonged inundation during regulated flow periods. A new regulator was installed in 2010 under the Rivers Environmental Restoration Program (RERP) with the aim of restoring a more natural wetting and drying regime. Mollys Lagoon consists of two main wetlands totalling 9ha connected at two points to Yanco Creek via narrow, shallow inlet channels (Webster 2007). Mollys Lagoon is about four metres deep and because it is well shaded, holds water for several years. Dry Lake is the largest (410ha) wetland in the upper Yanco Creek system. It is ephemeral and with suitably high flows in the Yanco Creek, overflow from Mollys Lagoon makes its way into Dry Lake and the overflow returns to the Yanco via Back and Washpen Creeks. Dry Lake typically fills to a depth of about 2 metres in September-October and dries by April-May the following year if not topped up prior. Since regulation of the Murrumbidgee it has filled about every 2 years. During the recent dry spell it filled in 2000 and not again until 2010. It is likely to be important for waterbird and fish habitat because of its ephemeral nature, size and proximity to adult fish populations in the Murrumbidgee.

A second regulator was installed under the RERP program, in the main flood runner that fills Mollys Lagoon. The first 600m of the flood runner was lowered by up to 600mm to allow environmental flows to be diverted into Mollys Lagoon and Dry Lake at a lower Yanco Creek level. This earthwork had the unintended consequence of reducing the flooding frequency of an ephemeral creek that runs past the Wirani woolshed. This will be rectified by the construction of a boarded regulator on the upstream side of a road culvert in the flood runner.

The vegetation that fringes Dry Lake: a mixture of mostly River Red Gum and some Black Box form the overstorey. Around the moist edges of the lake were amphibious emergent taxa such as Nardoo (*Marsilea mutica*) and Parrots Feather (*Myriophyllum* spp.); species of sedges (*Carex* spp,), spike rushes (*Eleocharis* spp.), rushes (*Juncus* spp.) and Common Reed (*Phragmites australis*) would be expected to be present as well. White Cypress (*Callitris glaucophylla*), Yellow Box and Buloke are found on the lunettes adjacent to the lake. The exotic Lippia (*Phyla canescens*) was also present. Lippia is an invasive weed that it not easily controlled with currently available techniques, including grazing[15]. Lignum is abundant on the floodplain adjacent to the discharge channel from Dry Lake.

Washpen Creek complex
Some 10 wetlands make up this complex along the Washpen Creek, covering around 90 ha, connected to the Washpen Creek only during large, natural flood events (Webster 2007).

Aquatic macroinvertebrates
The composition and diversity of species present in the main channel in Reach 1 is likely to be similar to that found further downstream in the mid-Yanco Creek (as the data are from Morundah at the junction of the two reaches), consisting of species that live in open slow-flowing water, or on instream wood, instream vegetation and fringing habitats (such as vegetation and the network of exposed roots and leaf packs along the edge of the channel). Off stream macroinvertebrate communities in wetlands have not been sampled in the reach but the communities are likely to reflect the results of other sampling within the Murrumbidgee area. Hardwick et al. (2002[16]) describe macroinvertebrate communities of Murrumbidgee billabongs as 'biologically diverse' with differences in assemblages between permanent, temporary and irrigation drainage water lagoons.

Native fish
Data provided by NSW Fisheries lists four fish species in Yanco Creek near Narrandera; three native (Silver Perch *Bidyanus bidyanus*; Murray Cod *Maccullochella peelii*; and Golden Perch *Macquaria ambigua*) and one non-native (Common Carp *Cyprinus carpio*). The low number of species previously recorded suggests a poor fish assemblage in Reach 1 of Yanco Creek. However, due to the high degree of connectivity to the Murrumbidgee River, especially during unregulated high flows, and due to the condition of the Yanco Creek observed during site visits, a similar fish assemblage to that present in the Murrumbidgee River downstream of the Yanco Weir may be expected in Reach 1 (Table 7).

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[15] See http://www.csiro.au/en/Outcomes/Food-and-Agriculture/LippiaBiocontrol/Lippia-in-the-Murray-Darling-Basin.aspx
[16] Hardwick, L., Maguire, J., Foreman, M. and Frazier, P. (2002) Providing Water to Murrumbidgee Billabongs – Maximising Ecological Value. Third Australian Stream Management Conference, Brisbane, 27–29 August.

Reach 1 environmental objectives
Ecological values are influenced and/or characterised by:

- direct connection to Murrumbidgee River, providing a link to Murrumbidgee River fish community
- connectivity throughout the reach, providing passage to aquatic life
- good instream habitat, including instream large wood
- presence of a mosaic of floodplain wetlands, including Dry Lake and Mollys Lagoon
- good structure and longitudinal continuity of riparian forest

As a result of historic development, the connection with the Murrumbidgee River is now more consistent, resulting in the higher flows and more persistent water in Upper Yanco Creek that is characteristic of a lowland stream. This reach of the system can be managed to maintain the high quality of the current habitat. The environmental flow objectives for this reach focus on providing conditions suitable for improving the existing native fish community (including Trout Cod), maintaining the condition of riparian forest vegetation and encouraging variability of the water regimes (ranging from ephemeral to near-permanently inundated) to maintain a mosaic of wetlands.

The environmental objectives for Reach 1 are:

- Maintain riparian vegetation condition, extent and composition
- Maintain a mosaic of wetlands
- Maintain channel form and promote habitat diversity
- Support self sustaining populations of macroinvertebrate taxa from the endangered Lower Murray Aquatic Ecological Community and those found in mid-Murrumbidgee wetlands
- Maintain and improve large, medium, and small-bodied (generalist and floodplain specialist) native fish community

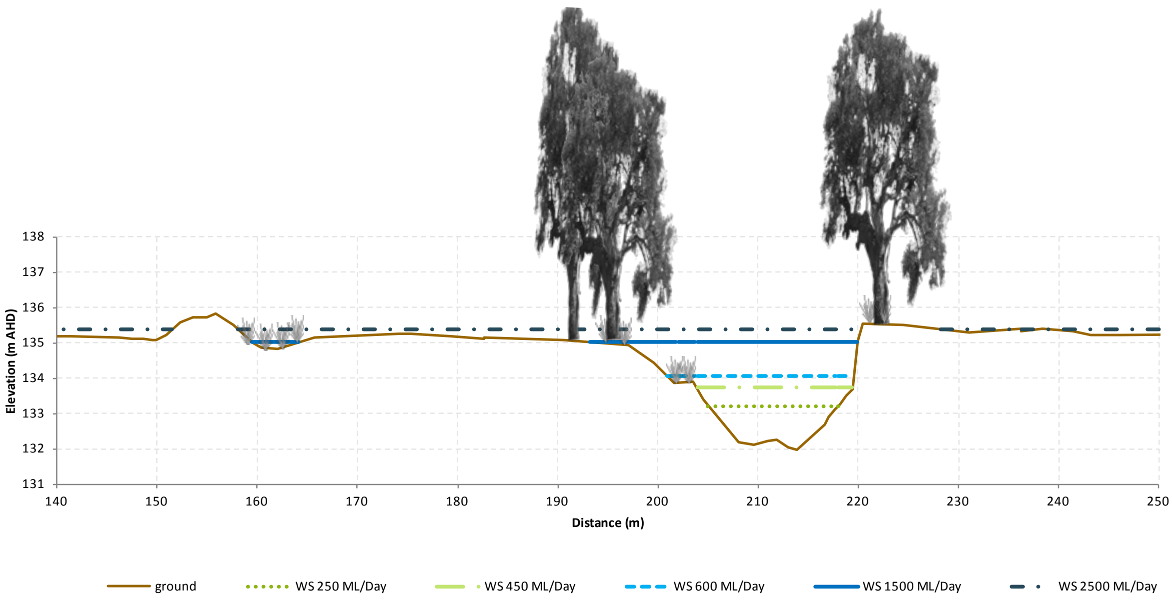
Information regarding the important flow characteristics to achieve each of environmental objectives is provided in Section 3.

Reach 1 environmental flow recommendations

Environmental flow recommendations to achieve the environmental objectives for the upper Yanco Creek are summarised in Table 13 and also shown graphically in Figure 21.

Table 13. Environmental flow recommendations for Upper Yanco Creek (Reach 1)

Period	Flow component	Magnitude	Frequency	Duration	Objectives achieved
All year	Baseflow	250 ML/d [17]	Continuous	Continuous	Provides habitat conditions suitable for large-bodied fish (including Trout Cod and Murray Cod) movement[18]. Inundates suitable habitat (low benches in the channel)[19] for small bodied fish. Wets channel to provide suitable habitat for macroinvertebrates.
Nov - May	Freshes	450 ML/d	2 / period	1 day	Inundates instream large wood to sustain biofilms on wood.
Aug - Dec		600 ML/d	2 / period	14 - 21 days	Provides conditions suitable for large-bodied fish movement and spawning[20].
Sep - Dec	Bankfull	1500 ML/d	1 / period	1-2 days	Maintains in channel benches, physical form and habitat diversity.
Sep - Dec	Overbank	2500 ML/d	1 / 2 years	2-5 days	Preserve and maintain vegetation in and surrounding billabongs and floodplain wetlands (includes rushes, reeds, sedges and River Red Gum forest). Inundate wetlands to provide conditions suitable for dispersal and breeding of small bodied fish and floodplain specialist species.



[17] While the baseflow recommendation is expressed as a constant minimum flow rate, it is critical that there is variability within the provision of this recommendation (i.e. water level fluctuations). Constant water levels in the system favour the proliferation of *Typha* (Cumbungi) and also create notches in the banks, leading to simplification of channel form and reduction in bench habitat.

[18] 800mm depth of water over runs, velocity of 0.3 m/s, >1.5m depth in deepest refuge pool

[19] 200mm depth of water over benches

[20] 200mm depth of water over high inchannel benches

Figure 21. *Cross section of the Upper Yanco Creek hydraulic model (XS 670) showing the environmental flow recommendations and habitat inundation*

Reach 1 Performance and risk assessment

Environmental flow performance

The achievement of the environmental flow recommendations in Reach 1 was assessed against 99 years (1910-2009) of the modelled 'current flow regime' provided by NSW Office of Water.

Baseflow performance is assessed as a percentage of the number of years that the environmental flow recommendation is achieved (i.e. the recommended flow is equalled or exceeded on every day in the year). The achievement of the baseflow recommendations for Reach 1 under pre-development and current flow regimes (Table 14) indicates that while the baseflow recommendation was rarely achieved prior to river regulation, it is achieved all the time under current management arrangements.

Table 14. Achievement of Reach 1 baseflow recommendations under pre-development and current flow regimes

Period	Pre-development (percent of years)	Current (percent of years)
Jan-Apr (lower flow season)	*1%*	*100%*
May-Dec (higher flow season)	*6%*	*100%*

Measuring the performance of freshes, bankfull and overbank flows are shown through two different components of the flow recommendation:

- Number of events target - expressed as the percentage of years in the flow record that the recommended number of events is achieved
- Duration of events target - expressed as the percentage of target events achieved that persist for the recommended duration.

Figure 22 shows the number of events that occur in each year (during the specified flow period) for each fresh, bankfull or overbank environmental flow recommendations. The recommended number of events is shown as a red line on the graph. These graphs show overall moderate compliance under the current flow regime with the recommended number of environmental flow events, in particular:

- Moderate compliance with Fresh 450 ML/d (target 2 events / period), occurring in 56% of target years
- Poor compliance with Fresh 600 ML/d (target 2 events / period), occurring in only 15% of target years
- Moderate compliance with Bankfull 1500 ML/d (target 1 event / period), occurring in 69% of target years
- Good compliance with Overbank 2500 ML/d (target 1 event every second year), occurring 52 of 99 years.

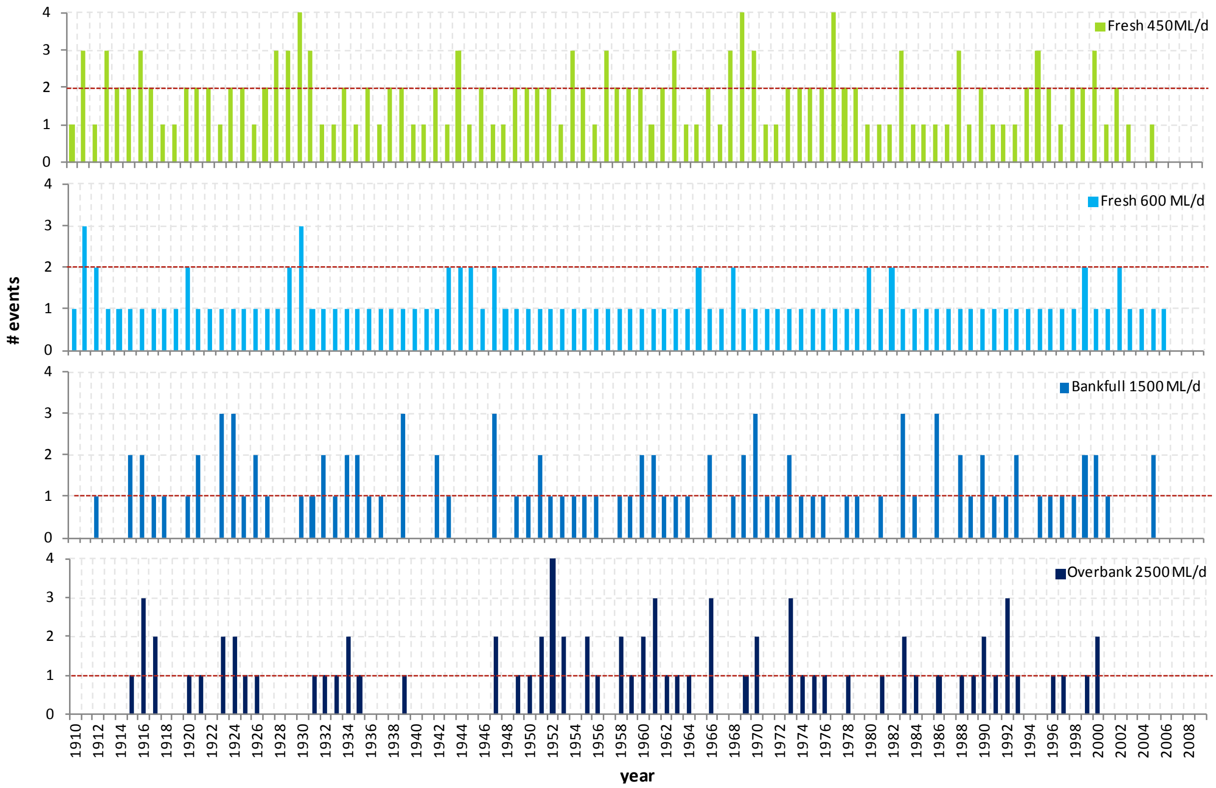


Figure 22. *Reach 1 – current conditions. Number of events achieved*

Figure 23 shows the duration of each event (fresh, bankfull or overbank) for all years of current modelled flow. This graph shows good to very good compliance under the current flow regime with the recommended duration of environmental flow events, in particular:

- Very good compliance with Fresh 450 ML/d (target 1 day duration), exceeded 100% of target events
- Good compliance with Fresh 600 ML/d (target 14 days duration), exceeded 95% of target years
- Very good compliance with Bankfull 1500 ML/d (target 1-2 days duration), exceeded 98% of target years
- Good compliance with Overbank 2500 ML/d (target 1-2 days duration), exceeded 90% of target years

It is worth noting that the failure of the number of events target is because the durations of spells above the threshold are very long – in some cases most of the season – therefore while the durations are complied with the number of events is less so.

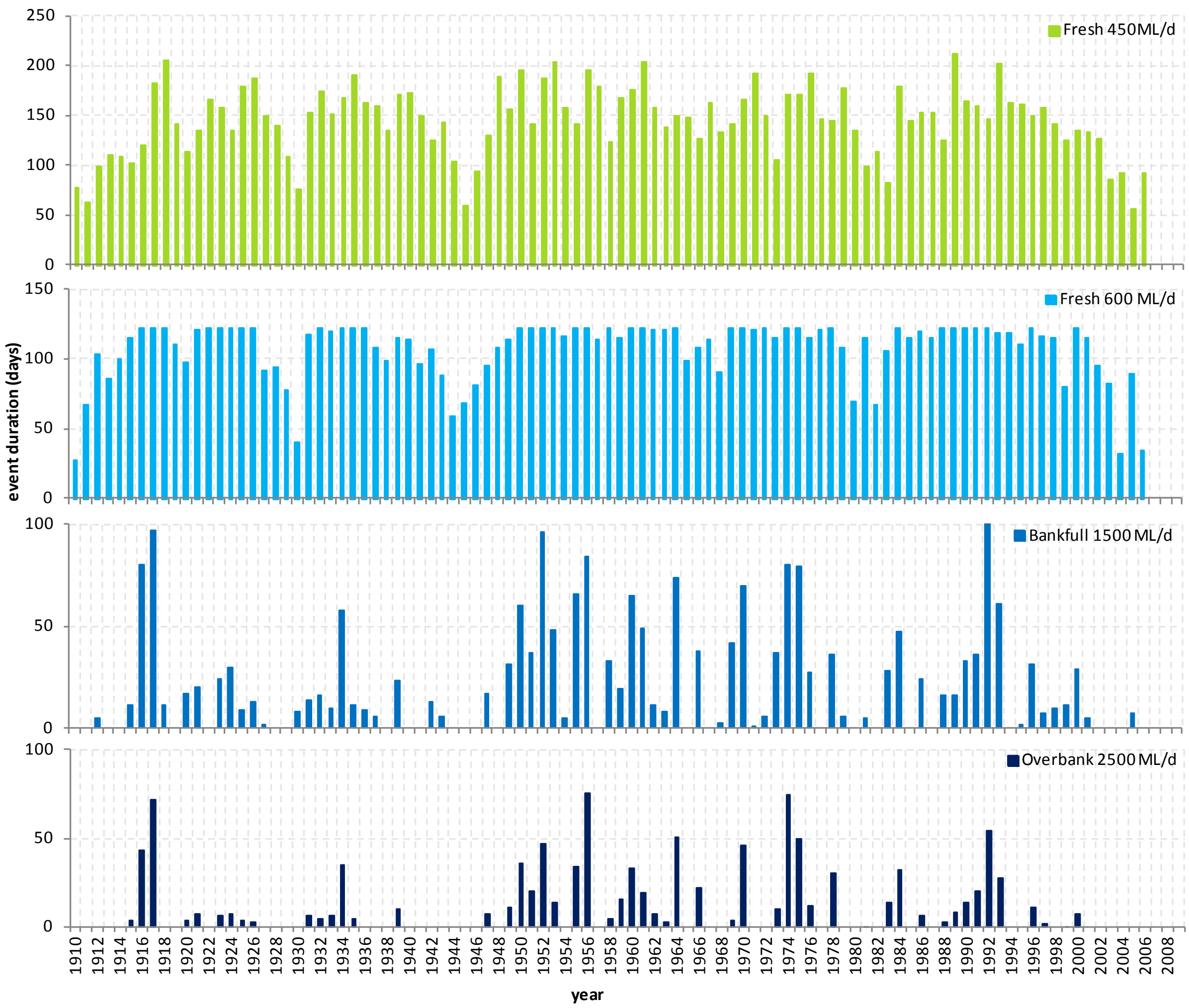


Figure 23. *Reach 1 – current conditions. Total duration of flows above recommendation threshold*

Potential risks to achievement of objectives under the current flow regime

Baseflow

Under the current modelled flow series the baseflow recommendation is achieved all of the time. This flow provides suitable habitat for macroinvertebrates and opportunities to move for small-bodied and some medium-bodied fish throughout the year. In this reach under the current management rules there is a very low risk of not achieving the environmental objectives associated with baseflow.

Freshes

The performance of freshes in Reach 1 indicates that there is a notable lack of flow variability in the current flow regime in the reach. This is demonstrated through the long duration of smaller freshes (>100 day duration) and moderate to poor compliance with the targeted number of events (events must be 14 days apart). This 'oversupply' (in the environmental flow context) is potentially detrimental to achieving the habitat diversity required for large-bodied fish that inhabit the reach.

The lack of variability of the current flow regime is a likely contributor to the uniformity of the channel and lack of instream habitat diversity (i.e. low number of benches, steep banks throughout the reach). This will continue unless flow is varied in accordance with environmental flow recommendations. Other forms of instream habitat diversity, such as large woody debris, will be very important in this reach to provide some habitat diversity in the absence of flow variability.

It is likely that a fish community dominated by generalist species (e.g. carp gudgeons and non-native fish) are favoured under the static water conditions, where there is little flow variability. Fish which require greater flow variability (e.g. golden perch) are unlikely to complete their life-history.

Bankfull

The bankfull flow maintains in channel benches, physical form and habitat diversity, and provides opportunities for fish to disperse. Frequency and duration of bankfull flows under the current flow regime is similar to that of the pre-development flow regime. While this flow component cannot be delivered through regulated flows, it is important to protect this flow component to ensure that the pre-development/current frequency and duration is maintained.

In this reach under the current management rules there is a low risk of not achieving the environmental objectives associated with bankfull.

Overbank

The frequency of overbank events is similar under pre-development and current conditions. However, sequential years of no overbank flow will result in visible signs of vegetation stress on river banks and in floodplain wetlands (as observed through the recent drought) and lack of recruitment of juveniles. In drought periods where overbank flows have not occurred for six years or more presents a high risk to the condition of River Red Gum and Black Box communities. Without overbank flows fish species (such as golden perch) requiring inter-weir and reach scale movement and recruitment (tens to hundreds of kilometres) will not have the opportunity to complete the full life cycle.

While this flow component cannot be delivered through regulated flows, it is important to protect this flow component to ensure that the pre-development/current frequency and duration is maintained. In this reach under the current management rules there is a low risk of not achieving the environmental objectives associated with overbank.

4.3 Reach 2: Mid Yanco Creek

Reach 2 comprises the Yanco Creek and its floodplain downstream of the Colombo Creek off-take (upstream of Morundah at Tarabah Weir), until its junction with Billabong Creek at Puckawidgee (near Conargo). Two drainage channels (CCD and DC800) discharge from the Coleambally Irrigation district into this reach of Yanco Creek. Structures restricting flows in Reach 2 include Tarabah Weir, Nine Mile Dam, and McCaughey Block Dam. The Four Mile Weir on Yanko Station is in disrepair and is flooded out, even at low flows. The Nine Mile and McCaughey Dams completely block the flow in the original Yanco Creek channel but water is diverted around these via the Mundoora Anabranch which has an off-take structure which is in disrepair and flooded out. The Wilson Anabranch leaves the Mundoora Anabranch near its confluence with the Yanco Creek and rejoins the Yanco Creek about 10km downstream. There is a block dam near the end of the Wilson Anabranch which creates a wetland. With high flows this block dam is circumvented to the north and in very high flows such as the 2012 flood it is overtopped. Wilson Anabranch recently had a new door fitted onto the off-take regulator so that regulated flows can be excluded from the Anabranch. Agreements have been reached with affected landholders to transfer existing pumps from the Anabranch to the Yanco Creek.

A new fishway was completed at Tarabah Weir in 2011. This fishway opened up waterways from Boonoke Homestead Weir and Hartwood Weir on the Billabong Creek to Berembed Weir on the Murrumbidgee River.

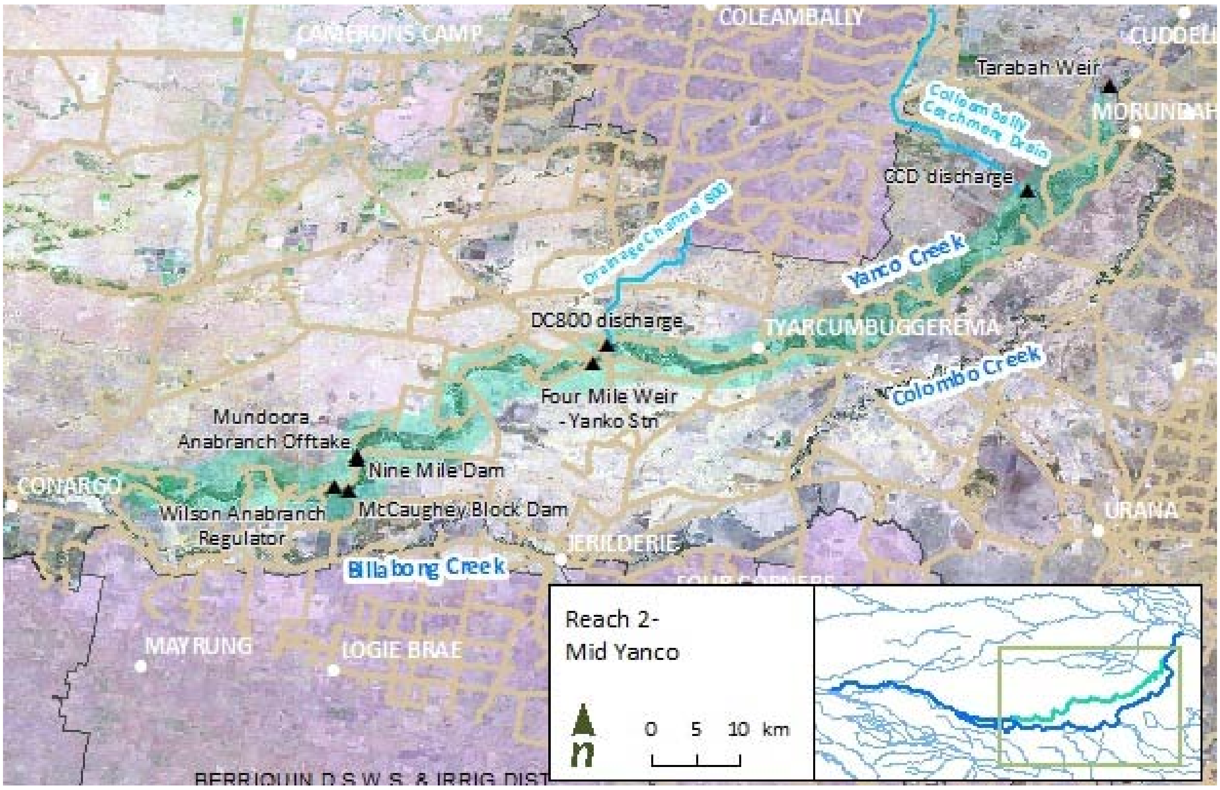


Figure 24. *Reach 2: Mid Yanco Creek*

Summary – environmental values

Physical form
The level of flows at the time of field visits meant we could not observe bed and lower bank features and characteristics. Where possible we inferred these from hydraulic and physical forms visible above the water surface. The physical form of the site was diverse, with a number of benches. The upper banks were steep, and there was evidence of active erosion forming undercut banks (Figure 25).

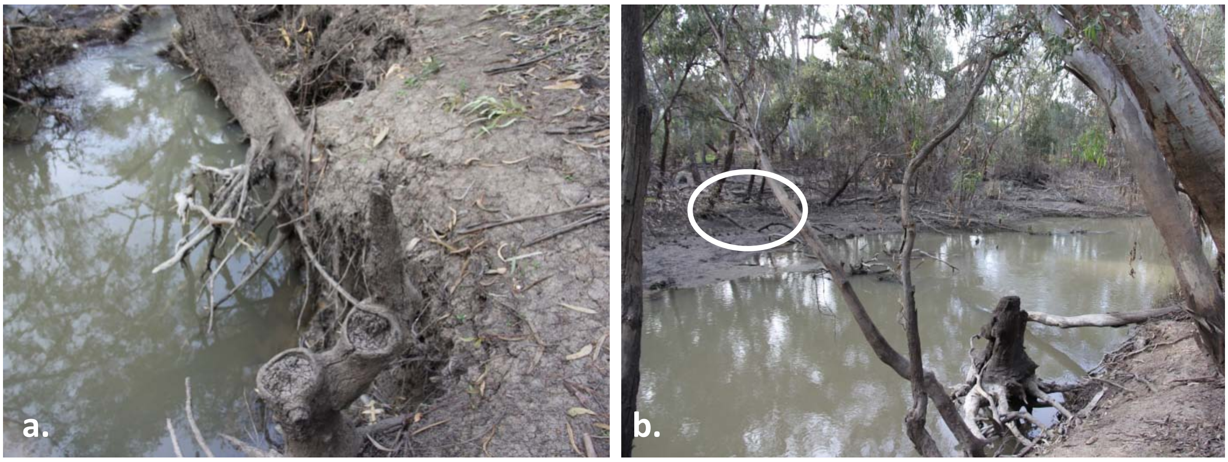


Figure 25. *Undercut bank (a) and range of horizontal surfaces on far bank (b).*

Riparian vegetation
The field site inspected in Reach 2 is just upstream of Yanco Bridge (Kidman Way). The riparian zone here was dominated by River Red Gum and River Cooba (*Acacia stenophylla*). Black Box or Lignum (*Muehlenbeckia florulenta*) were not observed at the site, nor were submerged aquatic plants seen in the main channel of the river. Black Box and Lignum may, however, be present elsewhere along the reach. Abundant organic debris was present along the banks and in the riparian zone and high flows would be required to entrain this material into the main channel of the river.

The absence of submerged aquatic taxa is puzzling and again can perhaps be attributed to the presumed presence of large populations of carp and / or the occurrence of two recent large floods (2010 and 2012).

Floodplain wetlands
There are a number of floodplain wetlands within Reach 2, including:

- Cheverells wetland - an effluent stream. The wetland area totals around 32 ha. Vegetation consists mainly of lignum scrubland and wallaby grass on the outer fringe of River Red Gum.
- Silver Pines, Arrawidgee and Bundure - four wetlands totalling 58 ha make up the Silver Pines complex, three wetlands totalling 15 ha in the Arrawidgee complex and 11 wetlands cover 36 ha in Bundure.
- The Frontage - this complex consists of six wetlands covering around 8 ha upstream of Kidman Way.

In addition to these documented wetlands, there are a large number of smaller wetlands scattered within the riparian zone of the reach. This is not surprising, given its periodically high flows. These small, seemingly ephemeral or seasonal wetlands were ~20 m from the main channel of the Middle Yanco and were vegetated mostly with phragmites. They had no submerged or semi-emergent aquatic plant species.

Aquatic macro invertebrates
A single record of macroinvertebrate fauna has been located in the Yanco Creek system, taken at Morundah in 1998 and part of the First National Assessment of River Health (FNARH). The data shows a typical community found in slow flowing lowland rivers (Table 15).

Table 15. Macroinvertebrate fauna found in Yanco Creek in 1998

Date	Site and habitat	Aquatic Invertebrate Families Present	Species where known	Common Name
Autumn 1998	Yanco Creek @ Morundah pool edge	Atyidae	*Paratya australiensis*	Shrimps
		Palaemonidae	*Macrobrachium* spp.	prawns
		Parastacidae	*Cherax* spp.	yabbies
		Collembola		springtails
		Hydrometridae	*Hydrometra* spp.	water measurers
		Vellidae	*Microvelia* spp.	water striders
		Hydroptilidae	*Hellyethira* spp.	caddies flies
		Oligochaeta		worms
		Corixidae	*Micronecta, Sigara* spp.	water boatmen
		Elmidae	*Coxelmis n- fasciata*	riffle beetles
		Notonectidae	*Anisops* spp.	back swimmers
		Pyralidae		aquatic moths
		Dytiscidae		water beetles
		Chironomidae:Tanypodinae, Orthocladiinae, Chironominae		midges
		Carabidae		scarab beetles
		Ecnomidae		caddis flies
		Temnocephalidea		flatworms
		Leptoceridae	*Triplectides* spp.	Cased caddisflies

Native fish

A similar fish assemblage to that present in Reach 1 is expected at Reach 2 (Table 7), based upon the similar condition of riparian zones, flow characteristics and densities and complexities for instream woody debris (snags) estimated during site visits. The Yanco Creek at Reach 2 may be considered to offer instream habitat characteristics of good to very good quality for native fish, albeit that the stream is relatively narrow (30-40m) and shallow (<2m), with deeper holes expected at meander bends. Even at low flows, the Yanco Creek at Reach 2 appears to maintain a diversity of flow velocities, and it is this hydrodynamic variability (faster flow and slower flowing areas), that are likely to support a greater diversity of fish species than for Reaches that exhibit reduced hydrodynamic diversity. Accordingly, maintaining the 'free flowing' hydrodynamics as observed at Reach 2, particularly during low-flow magnitudes, is essential to support a high diversity of native fish species. The numerous backwater lagoons observed at Reach 2, (i.e. at Pine Ridge) likewise increase the diversity of habitats available to fish at Reach 2. In low flow periods, it is apparent that several, if not the majority of permanently inundated backwaters retain water and viable fish habitats. Whilst it may be desirable to restore a degree of partial drying to such habitats to reinstate successional processes, it is likely that the permanent backwater habitats offer refuge to a different suite of species than are likely to occur in the Yanco Creek. Accordingly, such habitats may be important refuges for off-channel specialist species during low-flow or drought periods.

Reach 2 environmental objectives

Ecological values are influenced and/or characterised by:

- direct connection to Reach 1 and the Murrumbidgee River
- connectivity throughout the reach, providing passage for aquatic life
- extensive floodplain wetland complexes
- extensive riparian forest (longitudinal and lateral)
- good instream habitat, including instream large wood

Due to the connection with Reach 1 and the Murrumbidgee River via the fishway at Tarabah Weir, the reach can be managed as a typical lowland stream with a high level of health. As with Reach 1, the main reason for this is the high quality of the current habitat. However, Reach 1 appears to provide more suitable fish nursery habitat, due to the higher density of larvae coming from the Murrumbidgee River. The objectives provide for improving the existing native fish and invertebrate community, maintaining the condition of extensive riparian vegetation and encouraging variability of the water regimes (ranging from ephemeral to near-permanently inundated) to maintain the existing mosaic of wetlands.

The environmental objectives for Reach 2 are:

- Maintain riparian vegetation condition, extent and composition
- Maintain a mosaic of wetlands
- Maintain channel form and promote habitat diversity
- Support self sustaining populations of macroinvertebrate taxa from the endangered Lower Murray Aquatic Ecological Community and found in mid-Murrumbidgee wetlands
- Maintain and improve large, medium, and small-bodied (generalist and floodplain specialist) native fish community

Reach 2 environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for the mid Yanco Creek are summarised in Table 16 and also shown graphically in Figure 26.

Table 16. Environmental flow recommendations for Mid Yanco Creek (Reach 2)

Period	Flow component	Magnitude	Frequency	Duration	Objectives achieved
All year	Baseflow	200 ML/d[21]	Continuous	Continuous	Provides conditions and habitat suitable for large-bodied fish movement[22].
Dec - Feb	Freshes	250 ML/d	3 / period	1 day	Inundates instream large wood to sustain biofilms on wood.
Aug - Dec		350 ML/d	2 / period	14 -21 days	Provides conditions for small bodied fish movement and spawning[23].
Sep - Dec	Bankfull	800 ML/d	1 / period	2 – 5 days	Maintains in channel benches, physical form and habitat diversity.
Sep - Dec	Overbank	1000 ML/d	1 / every third year	1-2 days	Preserve and maintain vegetation in and surrounding billabongs and floodplain wetlands (includes rushes, reeds, sedges and River Red Gum forest and Black Box communities). Inundate wetlands to provide conditions suitable for dispersal and breeding of small bodied fish and floodplain specialist species.

[21] While the baseflow recommendation is expressed as a constant minimum flow rate, it is critical that there is variability within the provision of this recommendation (i.e. water level fluctuations). Constant water levels in the system favour the proliferation of *Typha* (Cumbungi) and also create notches in the banks, leading to simplification of channel form and reduction in bench habitat.
[22] 800mm depth of water over runs, >1.5m depth in deepest refuge pool
[23] 400mm depth over inchannel benches

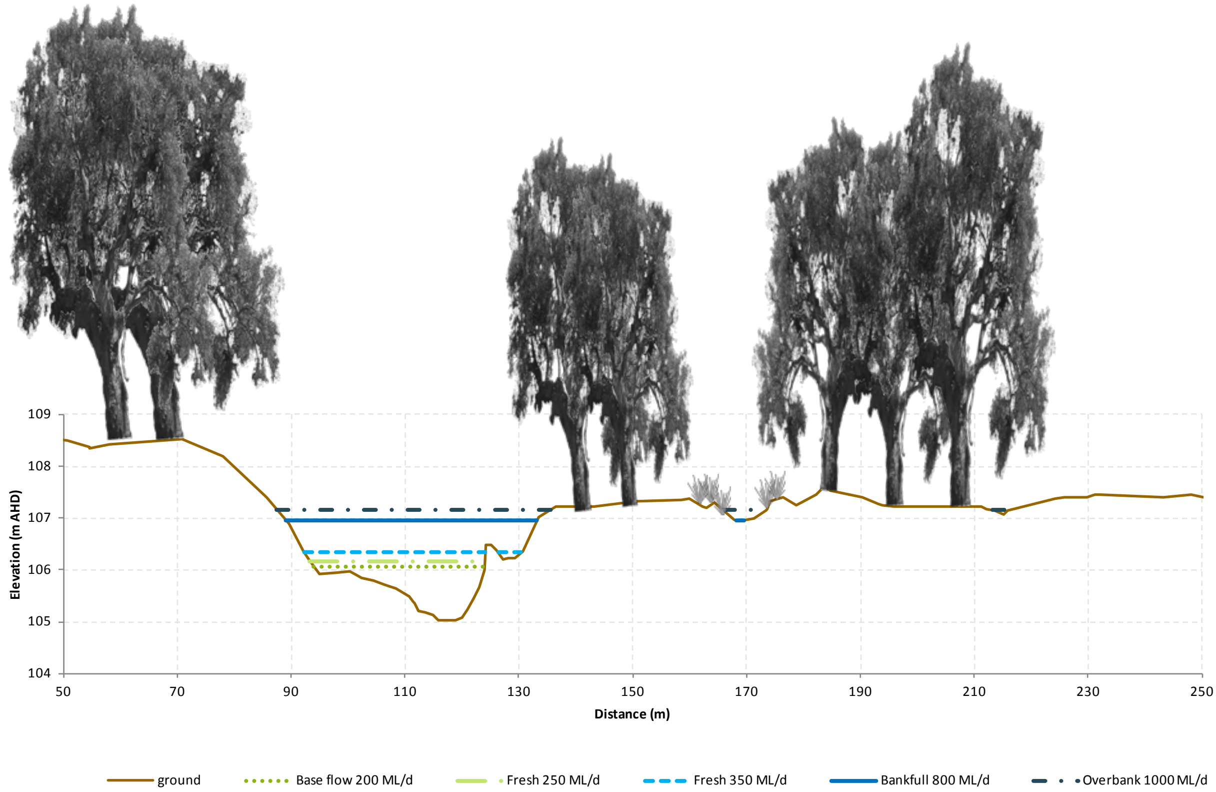


Figure 26. *Cross section of the Middle Yanco Creek hydraulic model (XS 545) showing the environmental flow recommendations and habitat inundation*

Reach 2 performance and risk assessment

Environmental flow performance

The achievement of the baseflow recommendations for Reach 2 under pre-development and current flow regimes (Table 17) indicates that the baseflow was rarely achieved prior to river regulation, and has poor (low flow period) to moderate (high flow period) compliance under current management arrangements.

Table 17. Achievement of Reach 2 baseflow recommendations under pre-development and current flow regimes

Period	Pre-development (percent of years)	Current (percent of years)
Jan-Apr (lower flow season)	*1%*	*39%*
May-Dec (higher flow season)	*6%*	*70%*

Figure 27 shows the number of events that occur in each year (during the specified flow period) for each fresh, bankfull or overbank environmental flow recommendations. The recommended number of events is shown as a red line on the graph. These graphs show overall compliance under the current flow regime with the recommended number of environmental flow events, in particular:

- Very poor compliance with Fresh 250 ML/d (target 3 events / period), occurring 3% of target years
- Moderate compliance with Fresh 350 ML/d (target 2 events / period), occurring 62% of target years
- Moderate compliance with Bankfull 800 ML/d (target 1 event / period), occurring 65% of target years
- Very good compliance with Overbank 1000 ML/d (target 1 event / 3 year period), occurring 55 of 99 years

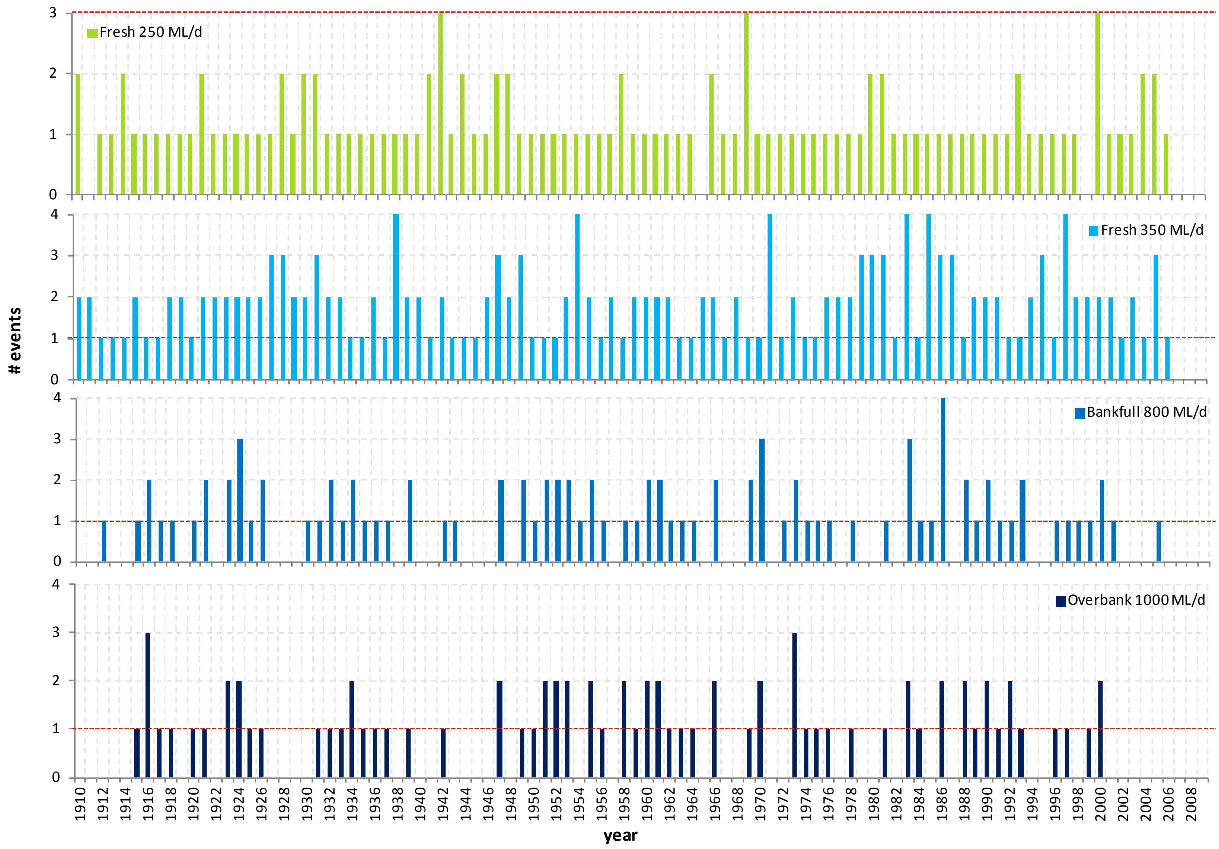


Figure 27. *Reach 2 – current conditions. Number of events achieved*

Figure 28 shows the duration of each event (fresh, bankfull or overbank) for all years of current modelled flow. This graph shows moderate to very good compliance under the current flow regime with the recommended duration of environmental flow events, in particular:

- Very good compliance with Fresh 250 ML/d (target 1 day duration), exceeded 100% of target events
- Moderate compliance with Fresh 350 ML/d (target 14 day duration), exceeded 63% of target events
- Very good compliance with Bankfull 800 ML/d (target 2 day duration), exceeded 98% of target events
- Very good compliance with Overbank 1000 ML/d (target 2 day duration), exceeded 97% of target events

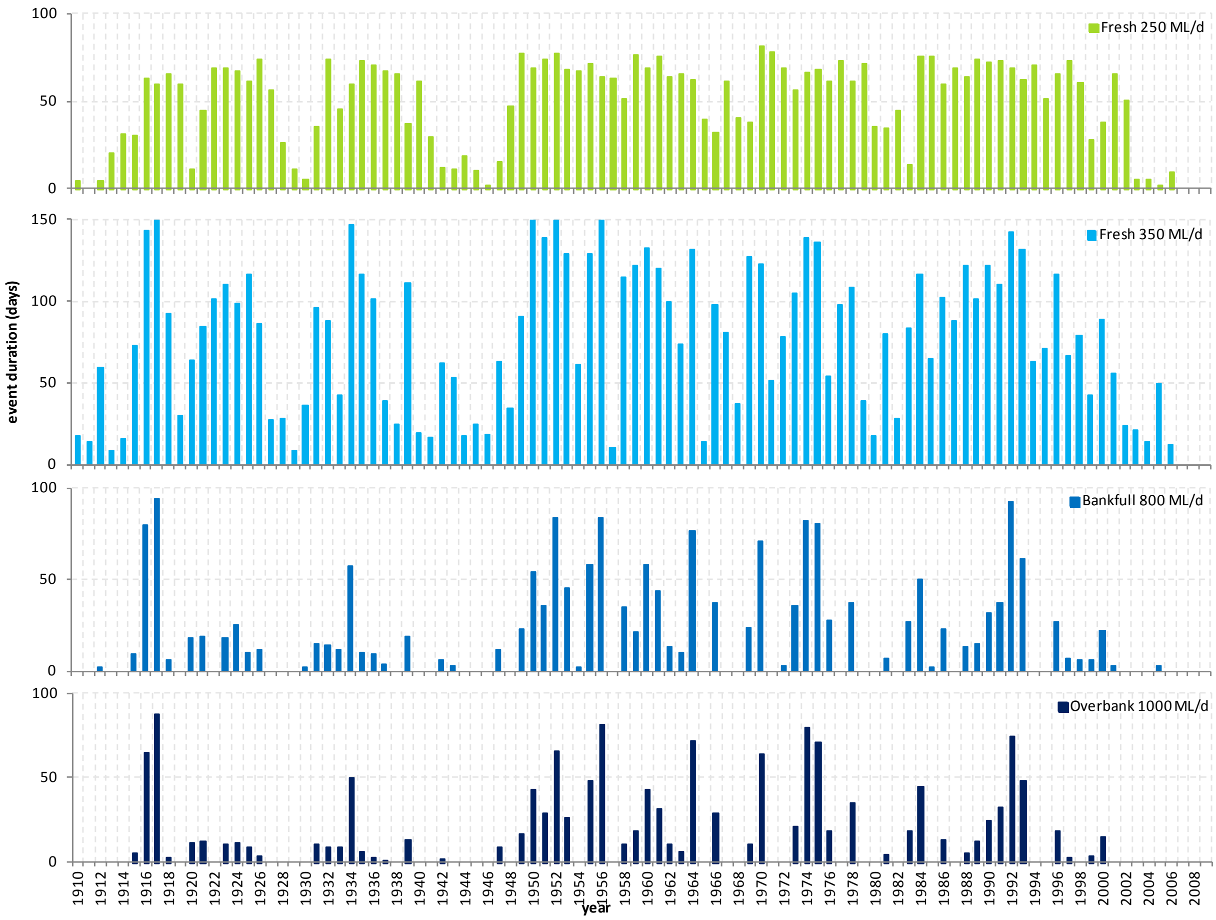


Figure 28. *Reach 2 – current conditions. Total duration of flows above recommendation threshold*

Potential risks to achievement of objectives under the current flow regime

Baseflow

Under the current flow regime the baseflow recommendation is achieved less than 40% of the time in the low flow period, and 70% of time during the higher flow season. These flows provide suitable habitat and opportunities for small-bodied fish to move in the summer low flow season, and sustain algae on large woody debris during the winter higher flow season.

In this reach under the current management rules there is a moderate risk of not achieving the environmental objectives associated with baseflow, especially during the January to April period. This may result in limited movement of large of medium bodied fish during this time and could lead to limited recruitment opportunities.

Freshes

The performance of freshes in Reach 2 indicates that there is a lack of flow variability in the current flow regime in the reach (although better performing than Reach 1). This is demonstrated through the long duration of smaller freshes (>30 day duration) and moderate to very poor compliance with the targeted number of events (events must be 14 days apart). This 'oversupply' (in an environmental flow context) is potentially detrimental to achieving the habitat diversity required for large-bodied fish that inhabit the reach.

The lack of variability of the current flow regime is a likely contributor to the uniformity of the channel and lack of instream habitat diversity (i.e. low number of benches, steep banks throughout the reach). This will continue unless flow is varied in accordance with environmental flow recommendations. Other forms of instream habitat diversity, such as large woody debris, will be very important in this reach to provide some habitat diversity in the absence of flow variability.

It is likely that a fish community dominated by generalist species (e.g. carp gudgeons and non-native fish) are favoured under the static water conditions, where there is little flow variability. Fish which require greater flow variability (e.g. golden perch) are unlikely to complete the full life cycle.

Bankfull

The bankfull flow maintains in channel benches, physical form and habitat diversity, and provides opportunities for fish to disperse. Frequency and duration of bankfull flows under the current flow regime is similar to that of the pre-development flow regime. While this flow component cannot be delivered through regulated flows, it is important to protect this flow component to ensure that the pre-development/current frequency and duration is maintained.

In this reach under the current management rules there is a low risk of not achieving the environmental objectives associated with bankfull.

Overbank

The frequency of overbank events is similar under pre-development and current conditions. However, sequential years of no overbank flow will result in visible signs of vegetation stress on river banks and in floodplain wetlands (as observed through the recent drought) and lack of recruitment of juveniles. In drought periods where overbank flows have not occurred for six years or more presents a high risk to the condition of River Red Gum and Black Box communities. Without overbank flows fish species (such as golden perch) requiring inter-weir and reach scale movement and recruitment (tens to hundreds of kilometres) will not have the opportunity to complete the life-history.

While this flow component cannot be delivered through regulated flows, it is important to protect this flow component to ensure that the pre-development/current frequency and duration is maintained. In this reach under the current management rules there is a low risk of not achieving the environmental objectives associated with overbank.

4.4 Reach 3: Colombo Creek

Reach 3 comprises Colombo Creek, an effluent of the Yanco Creek upstream of Morundah, which discharges into the Billabong Creek downstream of Cocketegedong Weir. A number of weirs regulate flows for private diversions, and this reach encompasses the weir pool influenced sections of Colombo Creek.

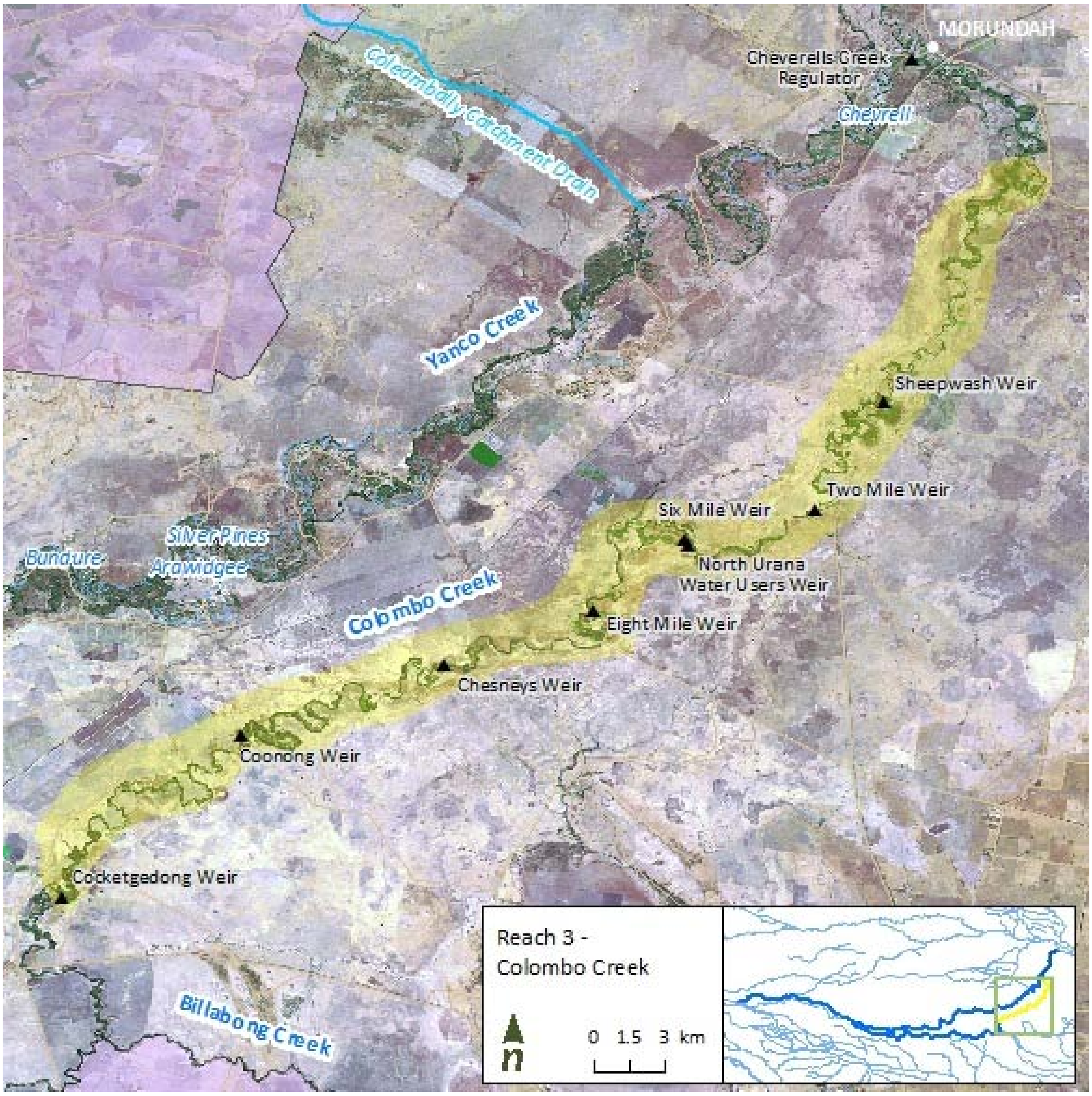


Figure 29. *Reach 3: Colombo Creek*

Summary – environmental values

Physical form

At the site on the Urana-Jerilderie Road Colombo Creek has a regular, relatively homogenous cross-sectional form (based on the area of the channel that was above the water surface and could be observed. The banks were shallow, with no evidence of active erosion (despite recent high flows). There was no visible evidence of pools or benches or other active channel physical diversity, but the presence of macrophytes on the channel margin indicates the potential presence of benches or other horizontal surfaces.

Bank sediment at the site was predominantly sandy silts, with some gravels (Figure 30). It was not possible to observe bed sediments due to the level of flow, but they are likely to be similar to the bank sediments, given fine grained nature of sediment observed in transit.

Figure 30. *Typical upper bank sediments at the Urana-Jerilderie Road site*

Chesney's weir on Colombo Creek has failed and is in the process of being outflanked by headward erosion. The structure appeared to still be impounding water at the level of the concrete base of the structure. Upstream of the weir the water was sluggish, with no observable flow velocity. It is likely that sediment deposition has occurred in this reach (and other similarly impounded reaches in Colombo Creek and elsewhere in the Yanco system). The significant hydraulic control provided by multiple impounding weir structures has implications for the effectiveness of environmental flows in these reaches.

The meander immediately downstream of Chesney's weir has a sheer outer bank and appears to be migrating across the floodplain. Red Gums of various ages and sizes are scattered on the banks downstream of the weir; they are providing some control on lateral migration in discrete locations, but are sparse and unlikely to provide much resistance at the reach scale. An area of fast flow is present at the meander, indicating a shallow area of the channel in this location.

Riparian vegetation and floodplain wetlands

Inspections at three sites along the reach (Urana-Jerilderie Road; Colombo Creek ski club; and near Morundah Station) indicated that the main channel was almost permanently inundated and a riparian zone dominated by Cumbungi (*Typha* spp.). The water present was highly turbid and some *Azolla* was present floating on the surface (Figure 31).

There is similarly little or no appropriate information available on vegetation types or required water regimes for floodplain wetlands in this reach, although a number of small floodplain depressions, presumably inundated by high river flows, were seen during the field inspection.

Figure 31. *Colombo Creek at Urana-Jerilderie Rd.*

Aquatic macroinvertebrates

There are no data on aquatic macroinvertebrate fauna for the reach. Because of the presence of permanent or near permanent water in weir pools, the composition and diversity of species present should be typical of deep very-slow flowing or still lake systems with thick fringing vegetation. These can be divided into four groups, based on the four main habitats in weir pools – the littoral zone, the deep bed, the open water and the water surface.

In the Colombo Creek weirs, the littoral zone consists primarily of dense beds of emergent vegetation such as *Typha*. This provides a complex habitat (leaves, stalks and detritus) with large abundances of food for invertebrate grazers (particularly algae growing on the surface of the vegetation), but also provides shelter from predation by large fish. This harbours the most diverse fauna, with the most common forms of macroinvertebrates found here are gastropods (snails), caddisfly larvae, mayfly larvae, dragonflies and beetles.

The deep bed is predominantly silt or organic material and is home to burrowers (e.g. worms, dipteran larvae). In the open water habitat, free swimming species such as Hemiptera (e.g. water boatmen) feed on the abundant planktonic microfauna (e.g. *Daphnia*). Wood debris in the weir also provides abundant habitat for species that dwell on hard surfaces, including taxa that specifically favour wood as habitats (e.g. some beetles). The water surface is home to specialised macroinvertebrates, such as water striders and whirligig beetles which are adapted with either flattened feet to utilise the surface tension, or water-repellent cuticles.

While the fauna of the weir pools in Colombo Creek is unknown, the healthy stands of macrophytes, persistent water levels and good water quality, would suggest that a healthy and diverse fauna would be found there.

Native fish

Data provided by NSW Fisheries lists seven fish species collected in Colombo Creek near Morundah; three native (Carp Gudgeon *Hypseleotris* sp; Murray Cod *Maccullochella peelii*; and Australian Smelt *Retropinna semoni*) and four non-native (Common Carp *Cyprinus carpio*; Goldfish *Carassius auratus* ; Eastern Mosquitofish *Gambusia holbrooki;* and Redfin *Perca fluviatilis*). Weir pools dominate the habitat characteristics throughout Reach 3, except most probably for immediately downstream of each inchannel weir, where flow velocity, even at the low flows observed during the site visit, was moderate to high. Accordingly, the fish community is most likely to reflect that typical of weir pools, except for immediately downstream of each weir, where migratory species may have accumulated, or species that exhibit an affinity for flowing habitat are present (e.g. Murray-Darling Rainbowfish, Silver Perch etc.). Due to the prevailing lack of hydrodynamic diversity, the overall species assemblage is however likely to be reduced as compared to that expected at Reaches 1 and 2. Accordingly, eight native and four non-native fish may be expected at Reach 3 (Table 7).

Each main channel weir in Reach 3 poses an impassable barrier to upstream fish movement at low flows. Such barriers limit the colonisation potential, and rehabilitation opportunities for populations of migratory species throughout Reach 3 and into upstream reaches from further downstream. As such, it is likely that the population structure for the large-bodied migratory species at Reach 3 is fragmented, or, that those species are only present at very low abundances. Provision of fish passage at impassable instream barriers is likely to offer the greatest rehabilitation opportunity for migratory fish, which are most of the large-bodied native fish, and some small bodied species at Reach 3. As for reaches 1 and 2, a thorough fish survey is recommended at Reach 3 to increase understanding of the potential impacts and benefits of future flow management interventions to enhance native fish.

Reach 3 environmental objectives

Ecological values are influenced and/or characterised by:

- Permanent water present in weir pools, providing drought refuge and waterbird habitat
- Thick cumbungi (*Typha* spp) fringe
- Short fast water habitats at block bank/weirs

The diversion of irrigation water down Colombo Creek means that the weirs will fill every year and be full while there is flow through the system. Losses can be expected to be small over the colder non-irrigation season meaning that water will be essentially permanent through most normal and wet years, and will be present at the start of any dry year when irrigation releases may be lower, and flows in the remainder of the Yanco system may also be reduced. The pools represent an excellent example of a drought refuge, being predictably in good condition prior to the onset of dry periods.

The environmental objectives for Reach 3 are:

- Maintain riparian vegetation condition, extent and composition
- Maintain drought refuge habitat
- Support self sustaining populations of macroinvertebrate taxa from the endangered Lower Murray Aquatic Ecological Community and found in the mid-Murrumbidgee wetlands
- Maintain and/or improve large, medium and small-bodied native fish community

Reach 3 environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for Colombo Creek are summarised in Table 18. Note: freshes and bankfull flows are not discussed in this reach as they are not specifically required to meet the environmental objectives outlined above.

Table 18. Environmental flow recommendations for Colombo Creek (Reach 3)

Period	Flow component	Magnitude	Frequency	Duration	Objectives achieved
All year	Baseflow[24]	Maintain weir pools	Continuous	Continuous	Maximise habitat potential in weir pools for macroinvertebrates, fish and water birds.
Sep – May		55 ML/d	Continuous	Continuous	Prevent water quality decline in weir pools – 14 day residence time.
		105 ML/d	Continuous	Continuous	Prevent water quality decline in weir pools – 7 day residence time.
Sep - Dec	Overbank	1600 ML/d	1-2 / every ten years	4 days	Preserve and maintain vegetation in and surrounding billabongs and floodplain wetlands (includes rushes, reeds, sedges and River Red Gum forest and Black Box communities). Inundate wetlands to provide conditions suitable for dispersal and breeding of small bodied fish and floodplain specialist species.

Reach 3 performance and risk assessment

Environmental flow performance
The achievement of the baseflow recommendations for Reach 3 under pre-development and current flow regimes (Table 19) indicates that while the baseflow was rarely achieved prior to river regulation, the required flow is achieved all the time under current management arrangements.

Table 19. Achievement of Reach 3 baseflow recommendations under pre-development and current flow regimes

Baseflow	Period	Pre-development (percent of years)	Current (percent of years)
55 ML/d	Sep-May	*4%*	*100%*
105 ML/d	Sep-May	*4%*	*100%*

[24] While the baseflow recommendation is expressed as a constant minimum flow rate, it is critical that there is variability within the provision of this recommendation (i.e. water level fluctuations). Constant water levels in the system favour the proliferation of *Typha* (Cumbungi) and also create notches in the banks, leading to simplification of channel form and reduction in bench habitat.

Figure 32 shows the number of events that occur in each year (during the specified flow period) for the overbank environmental flow recommendation. The recommended number of events is shown as a red line on the graph. This graph shows good compliance under the current flow regime with the recommended number of environmental flow events, specifically:

- Good compliance with Overbank 1600 ML/d (target 1 event / 5 year period), occurring 85% of target years

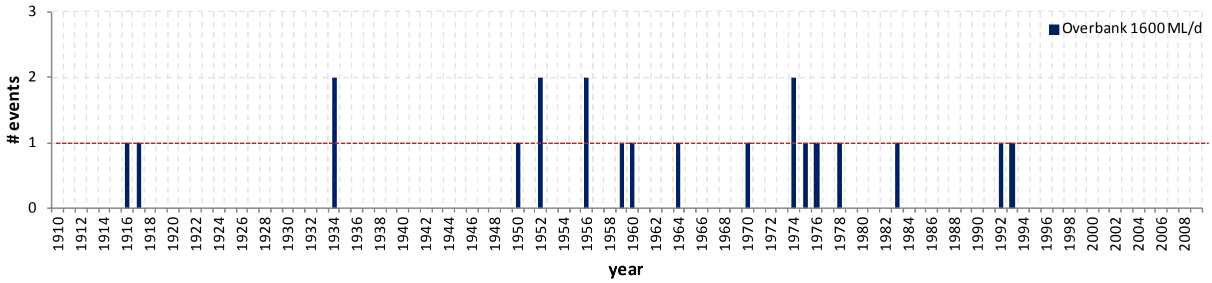


Figure 32. *Reach 3 – current conditions. Number of overbank events achieved*

Figure 33 shows the duration of the overbank flow for all years of current modelled flow. This graph shows good compliance under the current flow regime with the recommended duration of environmental flow events, specifically:

- Good compliance with Overbank 1600 ML/d (target 4 day duration), exceeded 83% of target years

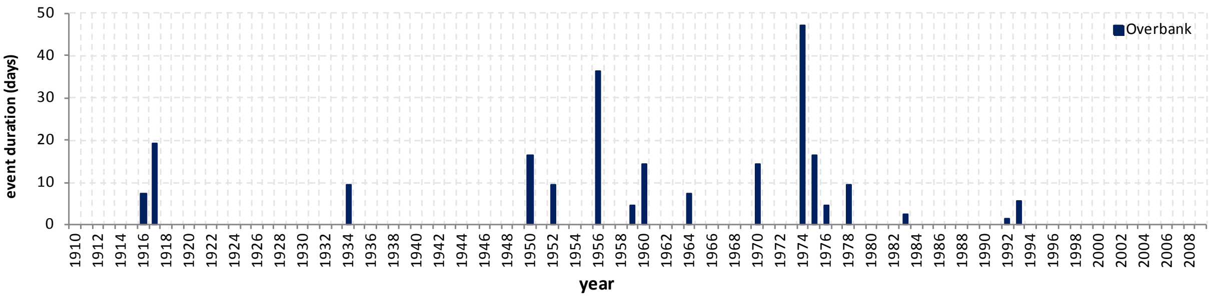


Figure 33. *Reach 3 – current conditions. Total duration of flows above recommendation threshold*

Potential risks to achievement of objectives under the current flow regime

Baseflow

Under the current flow regime the baseflow recommendation is achieved all of the time. This flow provides suitable habitat for macroinvertebrates, small-bodied fish and water birds throughout the year. In this reach under the current management rules there is a very low risk of not achieving the environmental objectives associated with baseflow.

Overbank

The frequency and duration of overbank events is good under current management conditions. However, sequential years of no overbank flow may result in visible signs of vegetation stress on river banks and lack of recruitment of juveniles. Drought periods where overbank flows have not occurred for greater than 10 years present a high risk to the condition of local fish species and may result in local species fragmentation and decline (as a result of no dispersal or exchange of fish).

While this flow component cannot be delivered through regulated flows, it is important to protect this flow component to ensure that the desired frequency and duration is achieved. In this reach under the current management rules there is a low risk of not achieving the environmental objectives associated with overbank.