FINAL REPORT:

Wimmera River environmental flows study

July 2013

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1 Introduction

A FLOWS study was completed for the Wimmera River in 2002 (SKM 2002) during the development of the FLOWS method (NRE 2002). The recommendations from this study were subsequently expanded, including environmental flow recommendations for regulated tributaries in the Wimmera catchment, into the *Wimmera Glenelg Bulk Entitlement Conversion* report (SKM 2003), which has become the main reference for environmental flow management in the Wimmera and Glenelg systems.

In the decade since the original FLOWS study was completed, there have been considerably developments in environmental water management, including changes to governance infrastructure and advancement in knowledge, as well as an update to the FLOWS method itself (DSE draft unpublished). To build on these advancements, the Wimmera Catchment Management Authority (Wimmera CMA) in partnership with the Glenelg Hopkins Catchment Management Authority (Glenelg Hopkins CMA) has engaged Alluvium to undertake a review of the existing FLOWS studies.

The objective of this project is to improve the information used in decision making regarding the management of water and provision of environmental water in the Wimmera and Glenelg River systems. The intended outcome is to enhance the existing Wimmera and Glenelg environmental flow recommendations by incorporating new information.

1.1 Project scope

The scope of this project includes:

- Review of the compliance point specification and reach delineation
- Review and revise flow dependent objectives
- Improve understanding of temporal flow components
- Improve information at 'b' sites
- Update FLOWS study

This project is not a full FLOWs study, but will build on the large amount of work already done to date on these systems.

1.2 Study reaches

The Review Report identified ten reaches in the Wimmera catchment for update in this environmental flows study (Table 1, Figure 1). A detailed description of each reach is provided in Sections 5 - 6.

Note: Review of the environmental flow requirements for the terminal lakes (Lake Hindmarsh and Albacutya) was not included in the scope of this study. Information regarding the requirements for these lakes can be found in *The Environmental Water Needs of the Wimmera Terminal Lakes - Final Report* (Ecological Associates 2004).

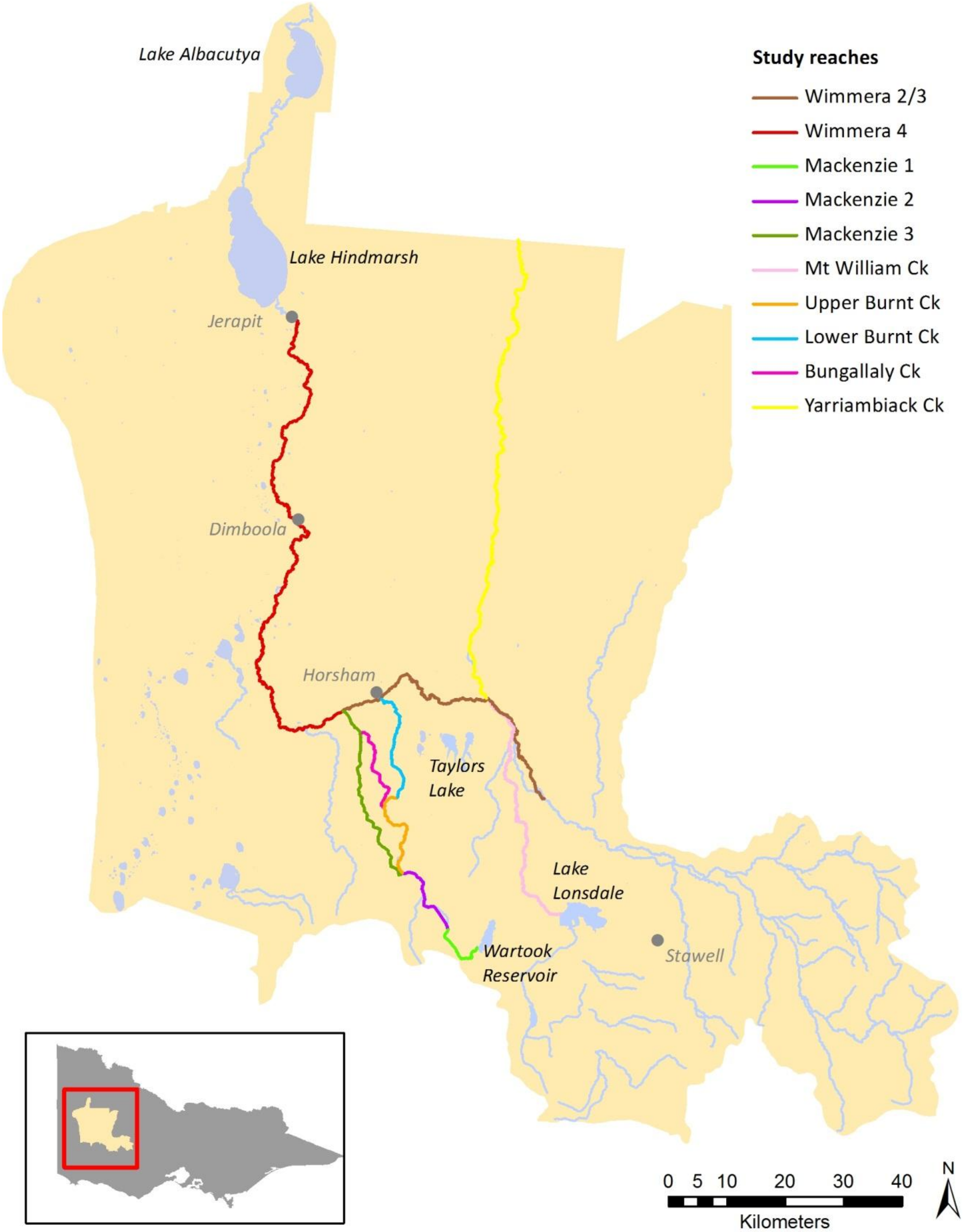


Figure 1. *Study reaches for the Wimmera catchment*

Table 1. Study reaches

Waterway	Reach ID	Description	Different to 2002 study?	Priority for update
Wimmera River	2+3	Huddleston's Weir to MacKenzie River	Yes (combined)	High
	4	MacKenzie River to Lake Hindmarsh	No	High
MacKenzie River	1	Lake Wartook to Dad and Dave Weir	No	Low
	2	Dad and Dave Weir to Distribution Heads Weir	No	High
	3	Distribution Heads Weir to Wimmera River	No	High
Mt William Creek	1	Lake Lonsdale to Wimmera River	No	Moderate
Bungalally Creek	1	Toolondo Channel to MacKenzie River	No	Moderate
Burnt Creek	UPPER	Distribution Heads Weir to Toolondo Channel	No (relabelled)	Moderate
	LOWER	Toolondo Channel to Wimmera River	No (relabelled)	Moderate
Yarriambiack Creek	1	Downstream of the Wimmera River	No	High

1.3 Study limitations

It is important to recognise the following limitations of this study when using the recommendations contained in this report:

- Availability of natural or 'unimpacted' hydrology data
- Hydraulic model quality

'Unimpacted' hydrology refers to the flow regime that would occur if all anthropogenic extractions, water harvesting and impoundments were removed[1]. Modelled unimpacted flow datasets were only available with sufficient length for three sites in the Wimmera system; inflows to Lake Lonsdale, Lake Wartook and Wimmera River flows at Glenorchy. For the reaches downstream of these sites, the recommended flow frequency and duration was determined using the modelled unimpacted flows. However in other reaches, it was necessary to assume that the frequency and duration for each flow component from the nearby reaches where undisturbed flow data was available. This introduces some uncertainty in the validity of the recommended frequency and durations, but does not affect the estimated flow magnitudes, which are based on site by site hydraulic models. If and when unimpacted modelled flow data becomes available it is recommended that spells analysis is revised to update the recommended frequencies and durations.

Hydraulic models have been used to identify the flow magnitude required to meet various ecological objectives. Each model represents a site of approximately 1-2 km length which is assumed to be representative of the reach (and its environmental values). Initially no new models were to be developed for this study, so our recommendations for most reaches were based on available HEC-RAS models. Two exceptions to this were the development of HEC-RAS models using available LiDAR data for Bungalally Creek and Yarriambiack Creek which were purpose built for this study. An evaluation of each model's suitability for determining recommendations is provided in Sections 5 -6 of this report.

[1] Note that unimpacted flow is different from 'natural' flow which refers to the pre-European flow regime and takes into account the impact of landscape-style changes on flow (e.g. vegetation clearing).

1.4 Purpose of this report

This report, the *Wimmera Environmental Flows Study,* provides an update to the 2002 FLOWS study for the Wimmera system. In particular, this report describes:

- the updated environmental values and threats in the Wimmera system
- environmental objectives for flow depending environmental values
- reach by reach environmental flow requirements to meet the objectives
- an assessment of the performance and risk associated with the current water management regime.

The information provided in this report can be used by environmental managers to make informed decisions regarding efficient and effective management of water for environmental benefit in the Wimmera catchment. The report follows the first deliverable for this project, the *Review Report* which identified the priority tasks for updating the environmental flow recommendations for the Wimmera and Glenelg systems. As part of this project a separate report (the *Glenelg Environmental Flows Study*) has been prepared for the Glenelg system.

2 Water resource development in the Wimmera catchment

The Wimmera River lies in the semi-arid north-western part of Victoria. Its catchment covers an area of 24,011 square kilometres, with headwaters and tributaries commencing in the Mount Buangor State Park, the Pyrenees Ranges and the Grampians. The major tributaries include the MacKenzie River, Mount William Creek, Fyans Creek, Burnt Creek and Mount Cole Creek. The lower Wimmera also contains two distributary systems flowing out of the Wimmera River; Yarriambiack and Dunmunkle Creeks. The Wimmera River is an endorheic system, meaning that instead of flowing out to the sea it flows inland and discharges a series of terminal lakes and wetlands including Lake Hindmarsh and Lake Albacutya.

The catchment is highly modified from its natural state, with the majority cleared for agriculture and used for dry land farming (cropping and livestock). Small irrigation areas near Horsham and Murtoa were recently decommissioned. The largest areas of uncleared land with remnant native vegetation are the Grampians National Park in the south of the catchment, and Little Desert National Park to the west; smaller areas of native vegetation are conserved also in Mount Arapiles-Tooan State Park and in the Wimmera Salt Lakes Reserves (containing Pink Lake and Mitre Lake), both in the western parts of the catchment. Lakes Hindmarsh and Albacutya are both just south of Wyperfeld National Park, one of the largest areas of native vegetation remaining in the north-west of the State. The largest towns in the catchment are Horsham and Stawell.

The Wimmera Supply System is a complex network of channels, pipes and storages operated by Grampians Wimmera Mallee Water. The customers supplied by this system are predominantly urban and domestic and stock users. The major on-stream storages are Lake Wartook on the MacKenzie River (29.5 GL), Lake Lonsdale on Mt William Creek (65.5 GL), and Lake Bellfield on Fyans Creek (78.5 GL). Lake Toolondo (92.4 GL), Pine Lake (redundant) (64.0 GL) and Taylor's Lake (27.0 GL) are significant off-stream storages located in the Wimmera catchment. Wimmera River flows are harvested into Taylor's Lake from Huddleston's Weir and MacKenzie River flows via Distribution Heads. Inflows to these storages are also diverted from the Glenelg River catchment via one of the following mechanisms:

- from Moora Moora Reservoir, via the Moora Channel into Distribution Heads on the MacKenzie River
- from Rocklands Reservoir via the Rocklands-Toolondo Channel into Lake Toolondo
- from Rocklands Reservoir or Lake Toolondo into Pine Lake, Taylor's Lake and Green Lake, and
- from Wannon River into Lake Bellfield.

The completion of the Wimmera Mallee Pipeline in 2010 has precipitated changes to the operation of the Wimmera Supply System. Supply volumes required to meet end of system customers' deliveries are considerably less due to reduced seepage and evaporation losses incurred when water was supplied via open, earthen channels. As a result of the pipeline, diversions from the Wimmera River at Glenorchy are no longer required for water supply. Consequently, the weir has been decommissioned so that the reach of river between Glenorchy and Huddleston's Weir is now unregulated. The only major diversion from the Wimmera River now occurs at Huddleston's Weir. Other diversions from the tributaries into the supply system occur from the MacKenzie River, Burnt Creek, Mount William Creek and Fyans Creek.

Flows in the Wimmera River system are naturally highly variable due to the river's location in a semi-arid region of Victoria. Moreover, the natural flow regime has been substantially altered due to land use change, the construction of large numbers of farm dams and construction of the Wimmera Supply System. In some reaches, for example the upper part of Burnt Creek, flows under the current regime are much higher than under natural conditions, due to its use as a conduit for transferring water within the supply system. In other reaches flows are significantly lower, for example the MacKenzie River downstream of Distribution Heads and Burnt Creek downstream of Toolondo Channel (GHCMA & WCMA 2007). Important consequences arising from the altered flow regimes in various parts of the Wimmera system include salinization, especially in the lower reaches of the Wimmera River, nutrient enrichment and increased turbidity as a result of agricultural activities, sediment accumulation in the lower reaches of the streams, loss of fish and macroinvertebrate habitat, and disturbance to fish life cycles (GHCMA & WCMA 2007).

Lake Albacutya is designated as a wetland of international significance under the Ramsar Convention. The lower Wimmera River is of high environmental value and contains sections of intact riparian and instream vegetation, including a section listed under the *Heritage Rivers Act 1992.* The environmental condition of the Wimmera River, however, deteriorates further downstream with highly degraded water quality, including saline pools in the lower Wimmera (SKM 2002). The MacKenzie River has a number of significant instream values, including blackfish and platypus in the upper reaches, and many of its habitat features are considered to be in excellent condition (GHCMA & WCMA 2007). As a result, the MacKenzie River is currently the highest priority in the Wimmera system for receiving environmental water releases.

2.1 Surface water hydrology

Available data

A number of streamflow gauges are located throughout the study area (Table 2). Data recorded at these gauges varies in length of record and quality. Some of these gauges have been inactive for many years. Gauge data used for individual reach assessments in this study are described in Attachment A.

Table 2. Streamflow gauges in the Wimmera system

Reach	Gauge ID	Name	Status	Period of record available
Wimmera 2/3	415200	Wimmera River @ Horsham	Active	5 Jan 1889 to present
	415239	Wimmera River @ Drung Drung	Active	9 Aug 1978 to present
	415240	Wimmera River @ Faux Bridge	Inactive	10 Aug 1978 to 13 Apr 1987
	415201	Wimmera River @ Glenorchy weir tail gauge	Active	21 Mar 1980 to present
Wimmera 4	415255	Wimmera River @ U/S Dimboola (Big Bend)	Inactive	20 Jul 1989 to 15 Jul 1993
	415256	Wimmera River @ U/S Dimboola	Active	13 May 1989 to present
	415246	Wimmera River @ Lochiel Railway Bridge	Active	28 Feb 1987 to present
	415247	Wimmera River @ Tarranyurk	Active	27 Feb 1987 to present
	415212	Wimmera River @ Jeparit	Inactive	26 May 1998 to 28 Jul 1998
	415216	Wimmera River @ Antwerp	Inactive	4 Aug 1960 to 7 Apr 1987
	415261	Wimmera River @ Quantong	Active	2 Jul 2009 to present
MacKenzie 1	415202	MacKenzie River @ Wartook Reservoir	Active	30 Mar 1887 to present
MacKenzie 3	415251	MacKenzie River @ MacKenzie Creek	Active	25 Aug 1988 to present
Mt William	415203	Mt William Ck @ Lake Lonsdale (Tail Gauge)	Active	2 Jan 1910 to present
Upper Burnt	415223	Burnt Creek @ Wonwondah East	Active	12 Sep 1965 to present
Bungalally	415249	Bungalally Creek @ MacKenzie Creek	Inactive	9 Jul 1988 to 1 Dec 1993
Yarriambiack	415241	Yarriambiack Creek @ Murtoa (Wimmera Hwy)	Active	7 Jul 1978 to Present

Modelled daily unimpacted flows at Glenorchy (Wimmera River 2/3), Lake Wartook (MacKenzie River 1) and Lake Lonsdale (Mt William Creek) are available for over 100 years (1 January 1903 to 30 June 2004). Unimpacted flows are modelled based on the current land use practises without man made diversions, demands or impoundments in the catchment. This data was derived in 2005 for an update to the Resource Allocation Model (REALM) model for the Wimmera-Mallee system (SKM 2005a). Prior to this, the REALM model used monthly inputs including monthly unimpacted inflows to Lake Wartook and Lake Lonsdale and to Glynwyllyn and between Glynwyllyn and Glenorchy.

The daily flow series have been derived using a combination of rainfall runoff modelling, gauged data, regressions and water balances. Where available the monthly data was disaggregated using nearby streamflow patterns. Modelled daily unimpacted flows from the REALM model used in this study are:

- GLENORCHY INFLOW– representing the unimpacted flow in the Wimmera River at Glenorchy

- WARTOOK INFLOW– representing the inflow to Lake Wartook
- LONSDALE INFLOW– representing the inflow to Lake Lonsdale.

Another dataset of modelled daily unimpacted inflows within the Wimmera catchment was provided by the Wimmera CMA for the period from 1989 to 1999. Given the short period available for this data (only 11 years), the analysis of unimpacted flows in the Wimmera catchment has been undertaken using the longer REALM model dataset.

Seasonality of the flow regime

In general, the annual flow regime of streams in temperate climatic zones can be divided into four seasons, not entirely related to the calendar seasons, but determined by fundamental characteristics of the natural flow regime:

- a ***low flow season***: generally extended periods of low flows driven mostly by baseflow– or periods of no flow, called 'cease to flow' periods – with infrequent shorter periods of high flow – freshes – caused by small localised rainfall events.
- a ***transitional flow season from low to high***: higher flows becoming more common, due to more widespread and frequent storms, but low baseflows still relatively common.
- a ***high flow season***: higher baseflow with frequent, sometimes extended, periods of higher flows from larger, more frequent and more widespread storms.
- a ***transitional flow season from high to low***: lower flows becoming more common as rainfall events become smaller, less frequent and more localised.

Higher rainfall during the high flow season typically keeps the catchment wet so that even between rainfall events the river and tributaries are primed with connected pools. Contrastingly the hot dry weather that usually occurs during the low flow season means that often the pools are dried out and more rainfall is required to start flow in system.

Identifying the seasons in which these four hydrological categories take place is somewhat arbitrary, but a method that has been used is to perform a frequency analysis on daily flow data in each month. In this method, the percentage of individual daily flows in each month that lie within a number of particular flow bands is calculated. The most frequent flow bands and the distribution of frequent flows can be used to identify the characteristics of the various flow seasons (Figure 2 to Figure 4).

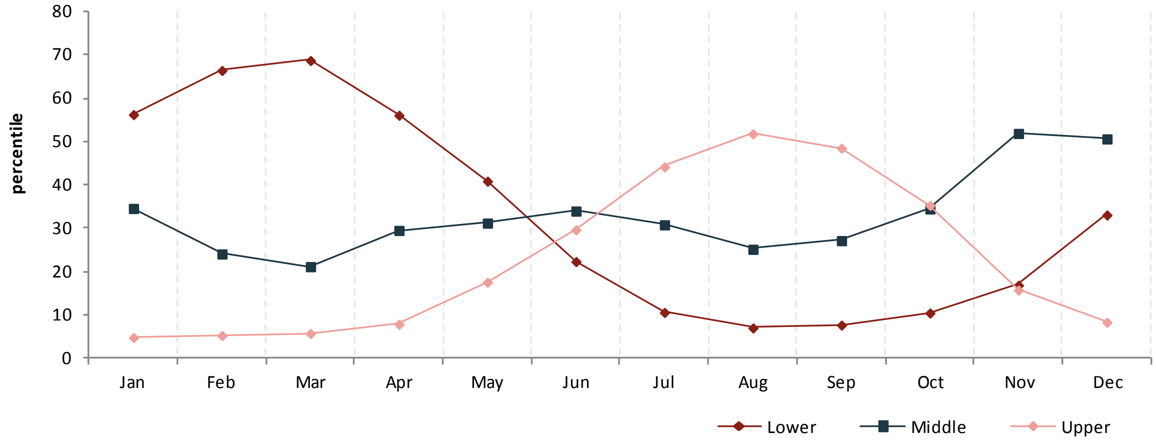


Figure 2. *Proportions of daily flows in the lower, mid and upper third percentiles in each month (Wimmera 2)*

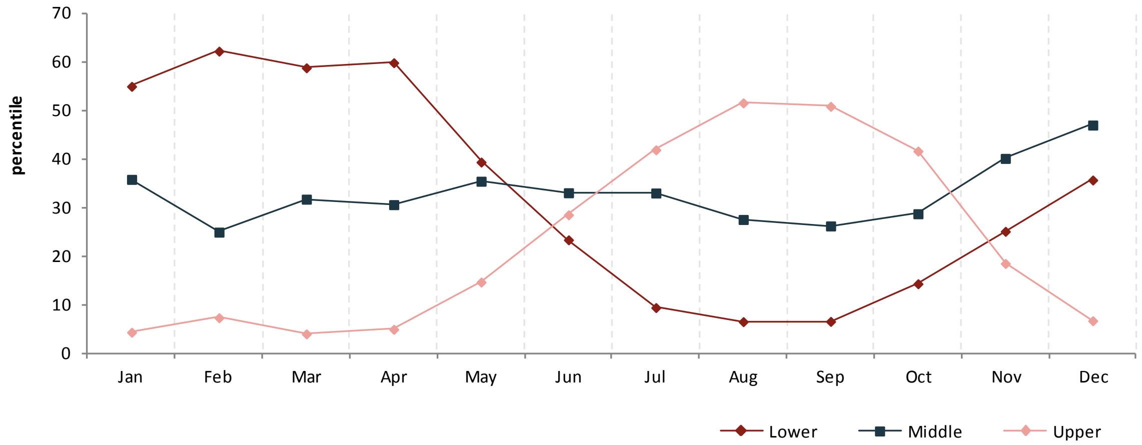


Figure 3. *Proportions of daily flows in the lower, mid and upper third percentiles in each month (Mt William)*

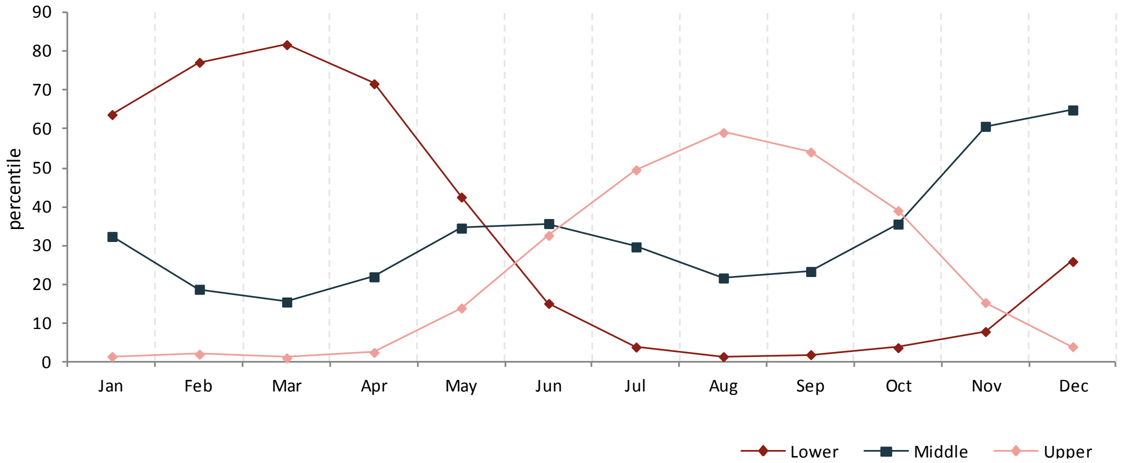


Figure 4. *Proportions of daily flows in the lower, mid and upper third percentiles in each month (MacKenzie)*

From this analysis, the unimpacted flows in the Wimmera system display a typical temperate seasonal pattern (Table 3), characterised by:

- January to May have a constant high proportion in the lower flow band (and constant low proportions in the upper flow bands as well). These are clearly *low flow season* months.
- June is a typical late transitional month, as the flow regime swaps between low and high flows, but the mid-range flows are still the most common.
- July to October has a constant high proportion in the upper flow band (and constant low proportions in the lower flow bands as well). These are clearly *high flow season* months.
- November has a similar flow structure to the transitional June month and is an early transitional month from high flows to low flows.
- December is similar to May and is a late transitional month from high to low flows (it arguably could be a low flow month due to the increased proportion of low flows).

Table 3. Flow seasons for the Wimmera River

Flow season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Low flow season	■	■	■	■	■							
Transition season (low to high)						■						
High flow season							■	■	■	■		
Transition season (high to low)											■	■

These analyses form the basis for the proposed seasons used in this study. The two broad seasons adopted are a low flow season from December to May, and a high flow season from June to November.

Summary of flow characteristics

The 2002 FLOWS study (SKM 2002) describes in detail the impact of development in the catchment on streamflows in the Wimmera River. Key points raised in the 2002 study include:

- Flow in the Wimmera River is highly variable and has been substantially altered downstream of Glenorchy. Regulation of the system has historically altered the natural variability in discharge from May to November.
- Low and zero flows in the system are not uncommon under natural conditions, however under regulated conditions these events have been extended and the frequency and duration exacerbated downstream of Huddleston's Weir.
- High flows in the upper Wimmera tend to be short-lived. Peaks may last for only a few hours and the streams tend to return to low flow conditions within a few days, unless boosted by another rainfall event (SKM 2002)
- Overbank flooding has remained unaltered and closely resembles the unimpacted hydrology.

For this study, a plot of the unimpacted median flows at Glenorchy, Wartook and Lake Lonsdale for each month of the year (Figure 5 to Figure 7) under different annual seasonal conditions (i.e. wet, average, dry and drought years) was developed to demonstrate the magnitude of difference in flow under each condition. Seasonal conditions have been considered in the update of environmental flow recommendations (Sections 5 to 7).

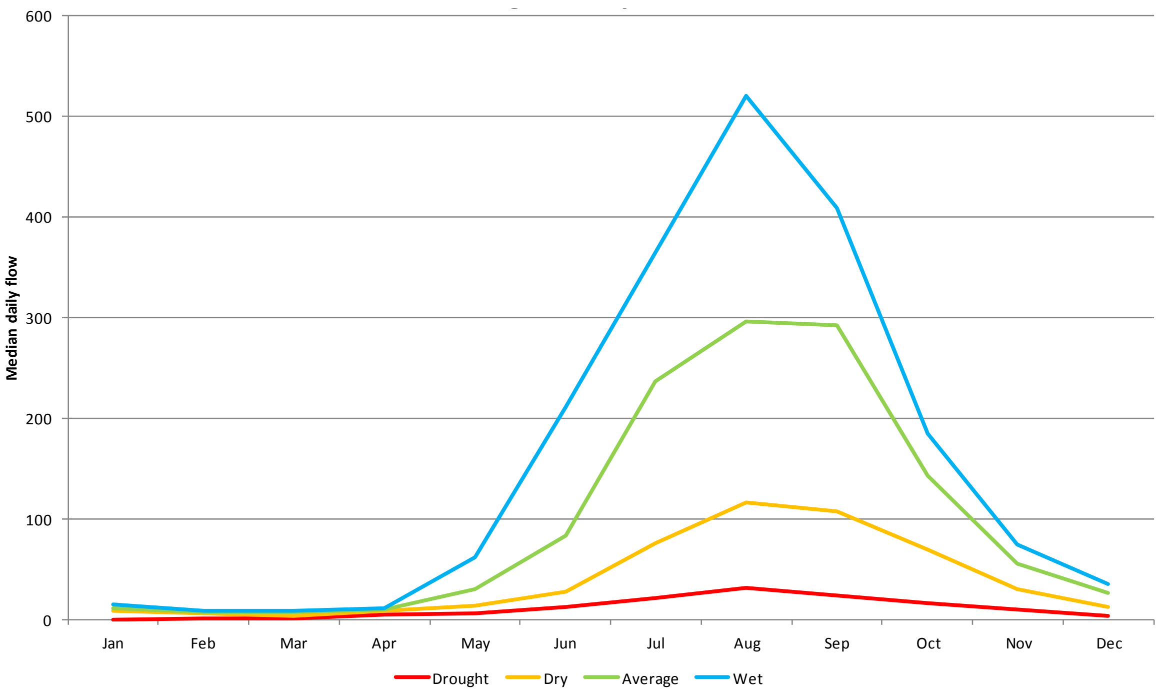


Figure 5. *Median monthly flows under different seasonal conditions (unimpacted modelled daily data at Glenorchy) – Wimmera 2/3*

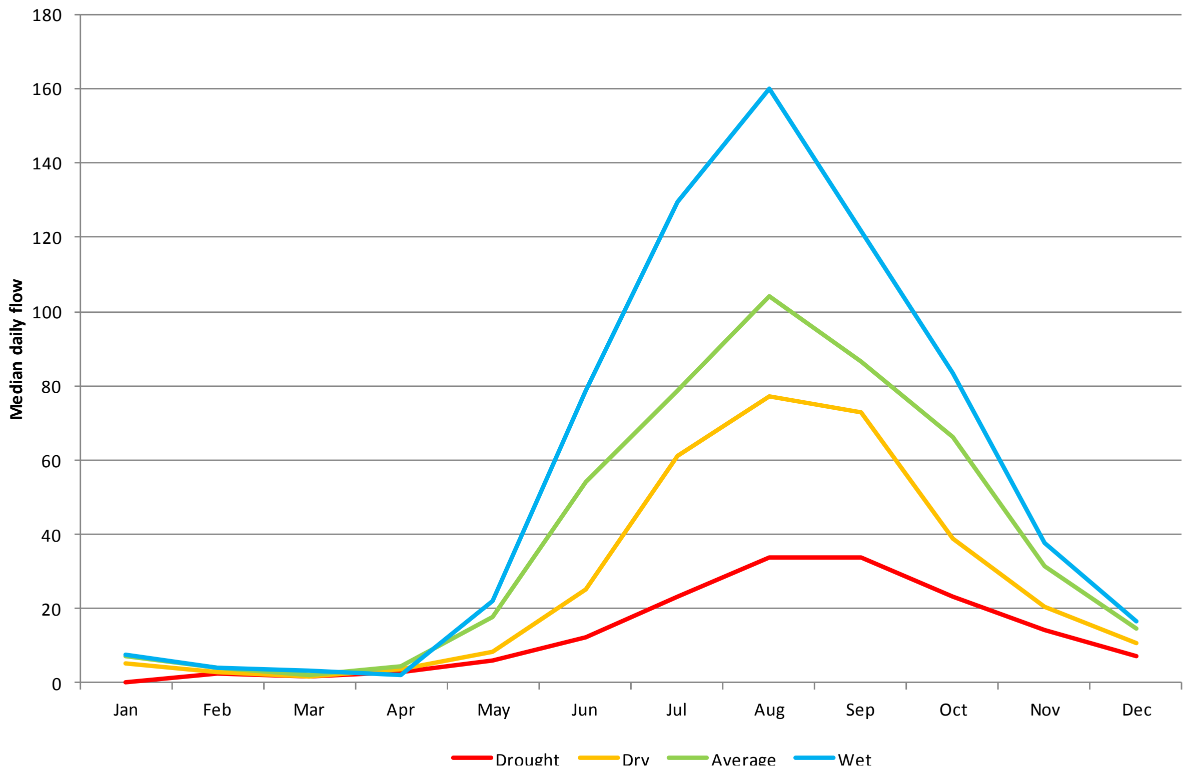


Figure 6. *Median monthly flows under different seasonal conditions (unimpacted modelled daily data at Wartook)- MacKenzie River 1/2*

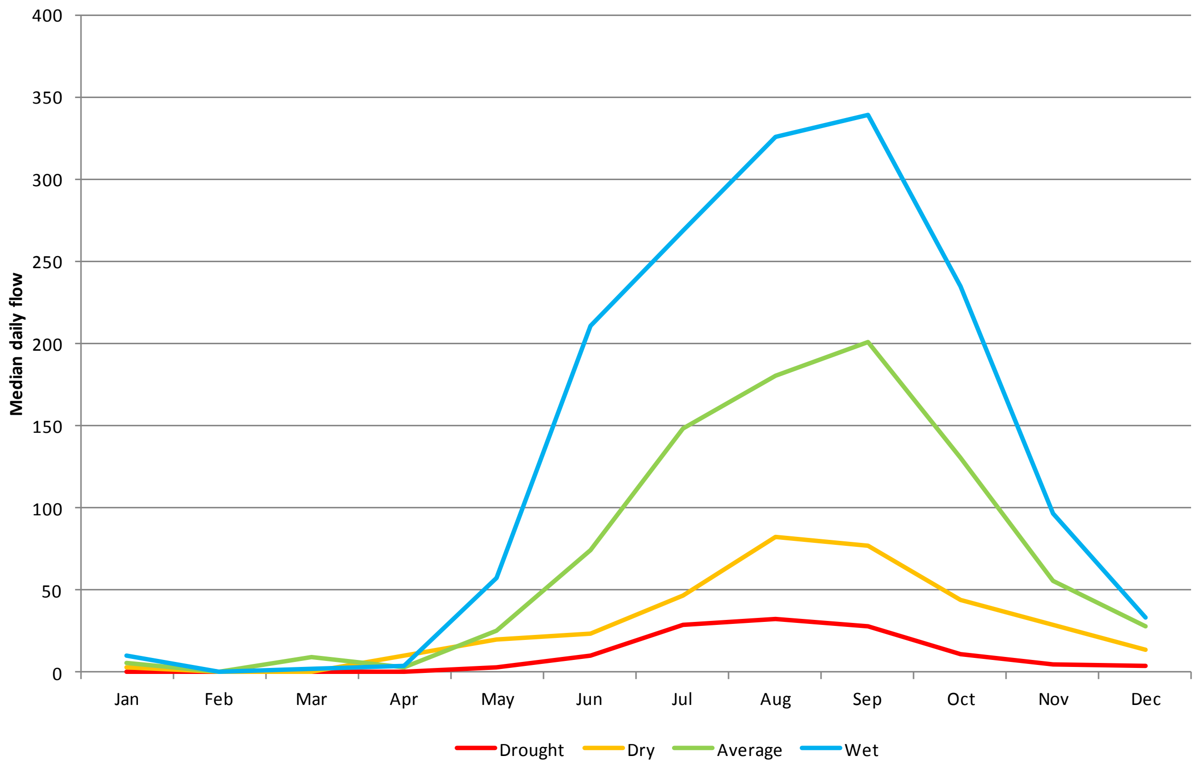
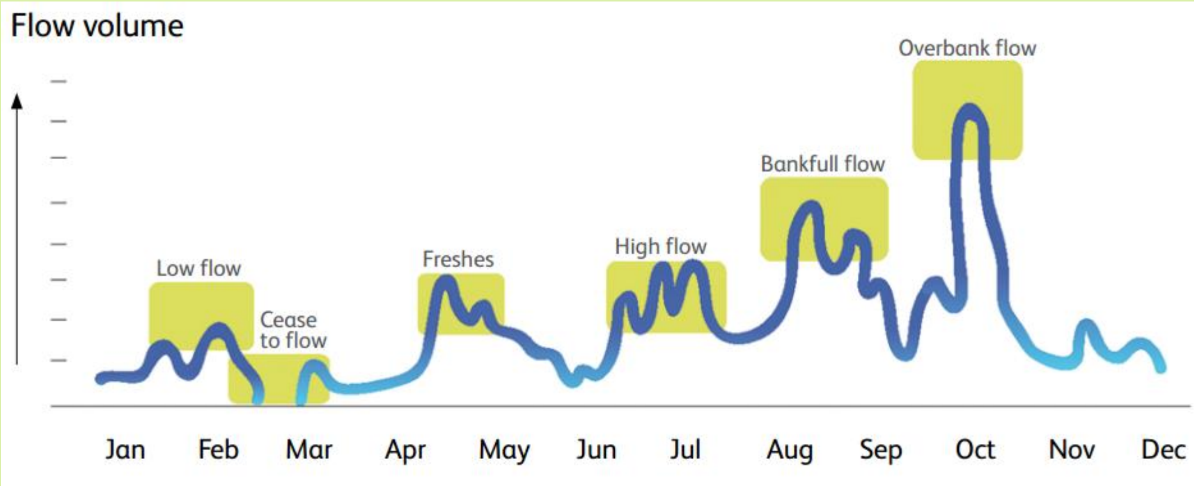


Figure 7. *Median monthly flows under different seasonal conditions (unimpacted modelled daily data at Lake Lonsdale) – Mt William Creek*

Further assessment of the hydrology of the Wimmera River system can be found in the previous FLOWS study (SKM 2002, SKM 2003).

Note regarding flow components:
The characteristic flow components capture the relationships between hydrologic variability and ecological values for the purpose of environmental flow determination. Flow components are defined by the magnitude, frequency, duration and timing of flow to characterise this otherwise inherently complex flow regime. These components will be discussed throughout this report. Definitions and a graphical representation of flow components are provided in Figure 8.



Type of flow	Description
Cease to flow	This may lead to either total or partial drying of the river channel, depending on the specifics of the system.
Low flows	Low flows generally provide a continuous flow through the channel. This may either maintain the flow above a 'cease to flow', or provide habitat as a change from 'high flows'.
Freshes	Small or short duration peak flow events. These are flows that exceed the base flow and last for at least several days. Freshes are a key contributor to the variability of flow regimes, providing short pulses in flow.
High flows	Persistent increases in the seasonal base flows that remain within the channel. High flows do not fill the channel to 'bankfull'.
Bankfull flows	Flows of sufficient size to reach the top of the river bank with little flow spilling onto the floodplain.
Overbank flows	Flows greater than 'bankfull', resulting in inundation of the adjacent floodplain habitats.

Figure 8. *Illustrative guide to flow components (source: VEWH 2013).*

2.2 Groundwater

The geology of the Wimmera region is diverse, ranging from the Cambrian metasediments and Devonian granites in the uplands, through to the younger Tertiary strata of the Murray Basin on the Wimmera plains, most notable for the purpose of this study being the Parilla Sands aquifer that hosts the regional water table. In the upper catchment, however, Palaeozoic metasediments form localised fractured rock aquifers which host limited alluvium associated with streams flowing from the Grampians.

Depth to water table
The depth to water table (Figure 9) for the Wimmera system shows that there are extensive connections between the Parilla Sands water table and the river over much of its length. This is consistent with previous studies which have identified reaches where saline groundwater inflows occur to many parts of the river, including deep river pools (see below). The depth to water table plot also shows groundwater contributions to headwater streams, which monitoring data demonstrates are significant.

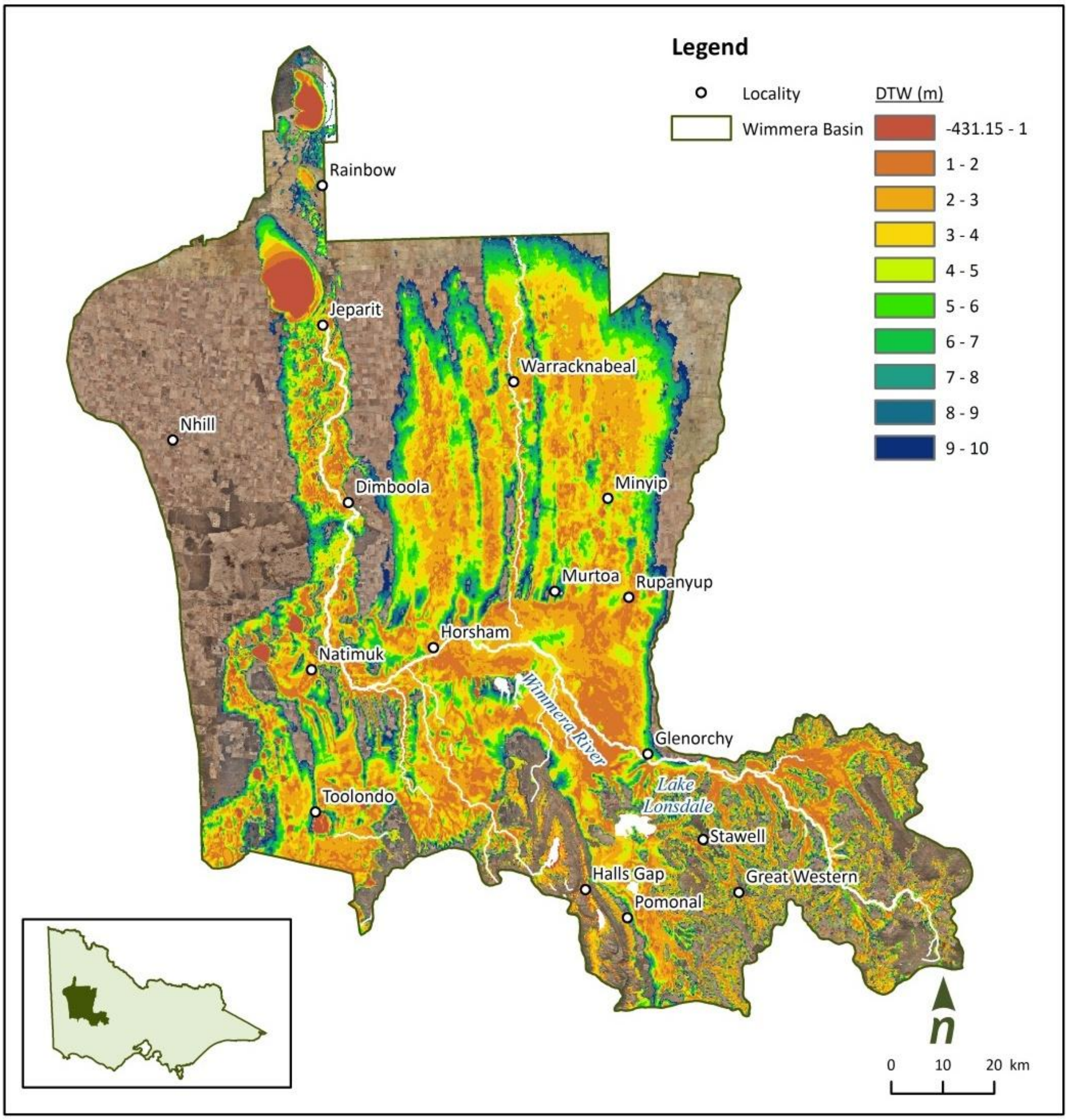


Figure 9. *Depth to water table – Wimmera catchment*

Baseflow filter

The groundwater-driven baseflow component of recorded streamflow has been estimated using a baseflow filter, notably the Lyne-Hollick method (Nathan and McMahon 1990). The method does not have a strong physical hydrological basis, but is designed to generate an objective, repeatable and easily automated index that can be related to groundwater flow contributions to streams. There are acknowledged limitations (Brodie et al. 2007), including:

- Baseflow digital filters tend to overestimate groundwater flow contributions to streams
- River regulation, water use and other management activities can significantly affect the baseflow regime.

This means that baseflow analysis should ideally only be undertaken in unregulated reaches, which renders the results of the analysis useful in qualitative or semi-quantitative terms for the Wimmera River. Nevertheless, the Lyne-Hollick filter was applied to the streamflow time series data for the sites below (Table 4), with the optimum alpha parameter identified as 0.98 to 0.99.

Table 4. Baseflow analysis sites

Streamflow gauge number	Site name
415200	Wimmera River @ Horsham
415203	Mount William Creek @ Lake Lonsdale (Tail Gauge)
415223	Burnt Creek @ Wonwondah East
415246	Wimmera River @ Lochiel Railway Bridge
415247	Wimmera River @ Tarrenyurk
415251	MacKenzie River @ McKenzie Creek
415256	Wimmera River @ Upstream of Dimboola

The analysis shows that there are significant periods of zero flow at most stations, indicating that groundwater flow contributions in these reaches are ephemeral. Examples of the baseflow series for the Wimmera River upstream of Dimboola and the MacKenzie River at Mackenzie Creek are shown below (Figure 10).

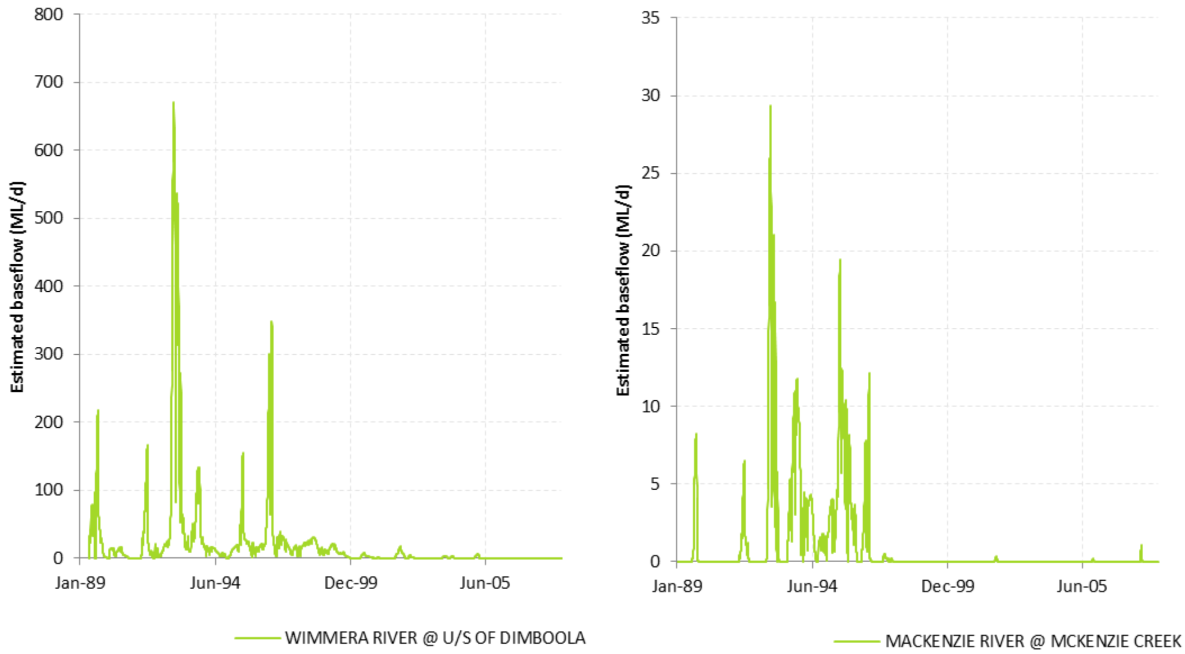


Figure 10. *Estimated baseflow at two Wimmera sites (calculated using the Lyne-Hollick filter)*

Previous studies on river-aquifer interaction

A comprehensive river-aquifer connectivity assessment was undertaken for the Murray-Darling Basin Sustainable Yield project (CSIRO 2008). While it was designed to provide information on the links between surface water and groundwater resources, the Wimmera catchment was not formally assessed, due to a reported lack of information.

However, the groundwater table in the Wimmera region predominantly occurs in the regionally extensive and saline Parilla Sands aquifer. Thus any potentially gaining river reaches (i.e. those parts of the Wimmera River that may be incised below the water table) are susceptible to saline groundwater flow contributions. The baseflow analysis and depth to water table results (see above) indicate that there is substantial river-aquifer interaction.

Low risk of effects due to groundwater pumping

Most groundwater extraction occurs west of the Wimmera River from the confined Murray Group Limestone aquifer, and in locations 30 to 40 km from the Wimmera River around the townships of Nhill, Goroke and

Gymbowen which are not serviced by the surface water. The regional groundwater flow in the Murray Group Limestone aquifer is also to the west and north-west, away from the Wimmera River. For these reasons the groundwater–surface water connectivity of the Wimmera River is classified as very low, manifesting over large time scales (i.e. greater than 50 years) (SKM 2012).

A recent modelling study (SKM 2012) classified the Wimmera River and its adjoining aquifers as having low connectivity (in the context of a low risk if streamflow depletion due to groundwater pumping, which is remote from the river). It is stressed that this is a risk-based modelling study rather than a study based on the analysis of measurements.

Saline pools

A number of previous studies have identified the influence of deep saline pools (>50,000 mg/L) in the Wimmera River (SKM 2002), which are believed to be due to saline groundwater inflows. These pools are also considered to also cause density-driven anoxic and/or temperature stratification, which invokes considerable complexity when developing environmental flow strategies, due to conflicting effects. For example, the following issues have been identified from investigations on the Edward-Wakool River system in southern NSW (Green 2001), although similar findings were reported in the previous environmental flow study for the Wimmera River (SKM 2002):

- Low river levels/flows prior to a sudden pulse usually results in mobilisation of a "salt slug".

- Under moderate flows, saline flows from any deep holes may be carried downstream, with variable effects depending on dilution effects; the moderate flows may not entirely flush the saline pool, and the groundwater flows subsequently replenish the saline pools (within about three months; SKM 2002).

- Higher flows can be turbulent enough to disturb the stratification and thus mobilise the entire salt load within the pool, with variable effects downstream depending on dilution.

- Higher flows or flood events can export a large amount of salt volume (not necessarily with high salinity due to dilution), which originates not only from the river channel but also from adjacent wetlands/billabongs where other saline intrusions or concentrations occur; this is an important salt export process from the system.

- The amount of water required to disturb and flush saline water from the holes varies due to the holes having different depths and morphology, as well as different groundwater inflows (volume and salinity) due to different penetration into the water table.

Salinity levels in the Wimmera have been monitored for a pool downstream of Horsham since March 2010. Results show very high salinity levels, with considerable variation in levels during the period and for different sampling depths. The relationship between streamflow in the Wimmera and salinity levels in the system cannot be easily identified from the results due to their complexity. However the large amount of data available should provide a good sample for a detailed analysis to better understand the effects of a range of flows on the water quality of downstream flows, and the subsequent replenishment of the saline pool.

3 Environmental objectives

Environmental objectives were identified by the Wimmera CMA in consultation with their Rivers and Streams Advisory Group. The objectives therefore reflect the environmental values of the Wimmera system considered important by both waterway managers and the community. Objectives were determined in the context of the current water resource management, likely environmental conditions and social and economic values of the region. The environmental objectives are discussed in further detail in the following sections.

3.1 Catchment environmental values

Water dependent environmental values for the Wimmera River catchment were identified by Wimmera CMA and Technical Panel through literature review and field assessment (details provided in the Review Report (Alluvium 2012)) and are summarised in Figure 11. These represent the overarching values that are sought to be maintained and or improved through the management of water for environmental benefit.

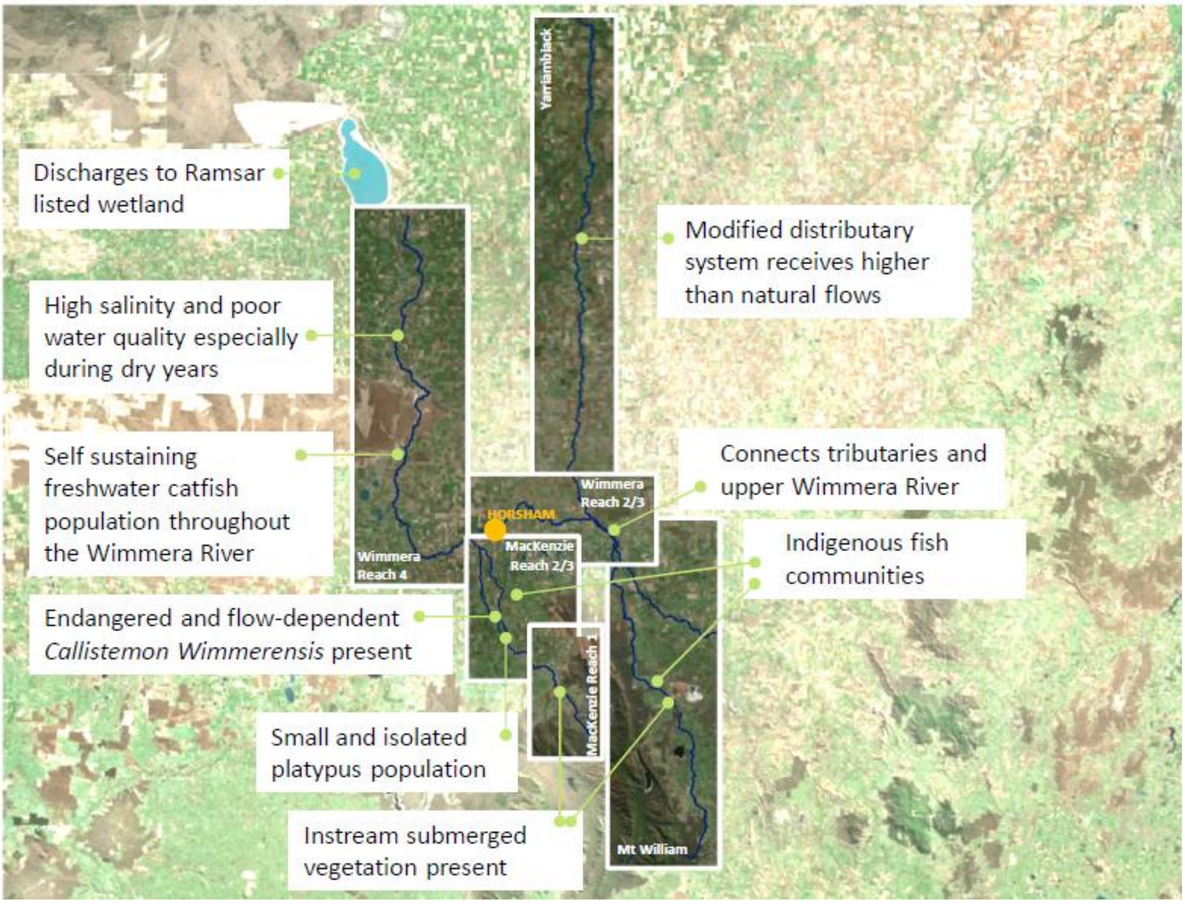


Figure 11. *Key water-dependent environmental values in the Wimmera River catchment.*

The environmental values are discussed in further detail under the relevant sub-headings in this section.

3.2 Catchment influences

A number of issues that influence the condition of environmental values in the Wimmera River system are:

- **Flow regulation** – diversions from natural watercourses in the Wimmera (e.g. the Wimmera River at Huddleston's Weir) and use of other watercourses (e.g. Burnt Creek upstream of Toolondo Channel) to transfer water for urban supply substantially alter the natural flow regime. Operation of the supply system impacts the flood frequency (slightly), magnitude and duration of events, and flow seasonality in the Wimmera system. These changes have implications for water quality, geomorphic condition and instream, riparian and terminal lake flora and fauna condition.

- **Deterioration of water quality** – the primary flow-related water quality issues in the Wimmera River are high levels of salinity and nutrients and low levels of dissolved oxygen (Anderson and Morison 1989). High salinity levels may have lethal or sub-lethal effects on flora and fauna such as reduced growth rates, reduced reproductive success and reduced health and vigour. Excessive nutrients have reduced the quality of aquatic habitats through eutrophication, channel restriction and subsequent bank erosion and sedimentation. Depletion of dissolved oxygen in pools reduces the condition of important habitat including refuge for fish during summer low flows (SKM 2003).

- **Stream bed and bank condition** – clearing of vegetation in the catchment has resulted in sheet and bank erosion, bed incision of tributary streams and sediment delivery to the Wimmera River and regulation has altered the changes in channel morphology (SKM 2002).

- **Environmental entitlement** – a limit on the volume of water available to the deliver environmental flows in the Wimmera system is set out in the Wimmera and Glenelg Rivers Environmental Entitlement. Delivery of environmental water is subject to the operational arrangements made with the storage manager (Grampians Wimmera Mallee Water) and other entitlement holders.

- **Exotic species** – European Carp *Cyprinus carpio* are a serious problem in Victorian streams, especially their impacts on submerged and semi-emergent vegetation (Koehn et al. 2000). High flows in 2009 resulted in high recruitment of exotic species, particularly carp, redfin and gambusia (SKM, 2010) and growth of weedy plants.

- **Amenity and recreation values –** the use of water in the Wimmera system to maintain amenity and recreation is important to the community and may not always align with achieving environmental objectives. A number of pools in the system created as part of regulation hold significant social values namely town weirs and water storages.

This study recommends actions to improve the flow regime to achieve environmental objectives (discussed in Section 3.3). However, the issues listed above also require complementary management in order for environmental flows to achieve their intended purpose.

3.3 Environmental flow objectives

The environmental objectives were developed by Wimmera CMA and the requirements to achieve each objective in the study reaches have been documented by members of the Technical Panel. The objectives are structured and described in the following sections under these themes:

- Self sustaining fish populations
- Healthy and diverse water dependent
- Diverse and abundant macroinvertebrates
- Healthy platypus communities
- Geomorphic processes
- Water quality

For each theme the Technical Panel has described the current state of the asset, the environmental flow objectives and characteristics of the flows required to achieve them, and the ‘non-flow’ limitations to achieving the environmental objectives described. A full list of the environmental flow objectives and specific measureable criteria to meet each objective is provided in **Attachment B**.

3.4 Self-sustaining fish populations

The six environmental objectives relating to self sustaining fish populations identified by the Wimmera CMA are:

- Maintain a self-sustaining freshwater catfish population in lower Wimmera River

- Maintain intact endemic fish communities in Mt William Creek and the upper MacKenzie River
- Restore endemic fish community diversity and abundance in the Wimmera River
- Provide adequate water quality/habitat for fish refuge locations in dry periods
- Facilitate dispersal and establishment of endemic fish species in wet periods
- Provide adequate water quality to maintain introduced recreational native species

Description

There has been numerous fish surveys conducted on the Wimmera River since the 1980s, many to assess the status of stocked fish populations (e.g. Douglas and Brown 2000). The composition of the fish fauna is relatively well understood (Table 5), and as well as a number of exotic species, there are a several native species (golden perch, silver perch, freshwater catfish and Murray cod) that have been actively translocated into the river system beginning in the 1970s and 1980s (SKM 2002). Of these three species, only catfish have established a self-sustaining population, while stocking of silver perch and yellowbelly is ongoing (SKM 2010, DPI 2007). Two other native diadromous species (*Galaxias maculatus* and *Anguilla australis*) have also colonised the upper reaches of the Wimmera catchment, most probably via the inter-basin transfer system connecting the Wimmera and Glenelg Rivers (SKM 2003a). Of these two only *G. maculatus* has (and is capable) of developing self-sustaining populations.

Table 5. Summary of fish species present in each of the reaches based on (SKM 2010) and (SKM 2006a).

	Species name	Common name	Wimmera	McKenzie 1/2 & Burnt Upper	McKenzie 3 & Burnt Lower	Bungalally & Yarriambiack*	Mt William Creek
Endemic	*Gadopsis marmoratus*	River Blackfish		■			
	Galaxias olidus	Mountain Galaxias	■	■	■		■
	Nannoperca australis	Southern Pygmy Perch		■	■		■
	Philypnodon grandiceps	Flatheaded Gudgeon	■	■			■
	Retropinna semoni	Australian Smelt	■		■		■
Non-endemic	*Anguilla australis*	Short finned eel		■	■		
	Bidyanus bidyanus	Silver Perch	■		■		
	Galaxias maculatus	Common Galaxias		■	■		■
	Hypseleotris klunzingeri	Carp Gudgeon (Complex)	■	■	■		■
	Maccullochella peelii peelii	Murray Cod	■		■		
	Macquaria ambigua	Golden Perch	■		■		
	Tandanus tandanus$	Freshwater Catfish	■		■		
Exotic	*Carassius auratus*	Goldfish	■	■	■		■
	Cyprinus carpio	Carp	■		■	■	■
	Gambusia holbrooki	Gambusia	■	■	■	■	■
	Perca fluviatilis	Redfin	■	■	■		■
	Salmo trutta	Brown Trout		■			
	Tinca tinca	Tench			■		■

*based on field observations, $ Listed under the Flora and Fauna Guarantee Act, Victoria.

The Sustainable Rivers Audit (Davies et al. 2008) summarised the Wimmera fish community as being in poor condition, with the Lowland Zone in very poor condition but the Slopes Zone in near reference condition. The SRA report (2008) noted that surveys conducted during 2004/2007 found most predicted native species, but these accounted for only 10% of the total biomass, which was dominated by alien (exotic) and introduced species. Native species richness was also reduced in the lowland sections. More recently surveys have been conducted annually at 12 sites in the lower Wimmera River as part of the VEFMAP project (WCMA 2011, SKM 2010). Summarised results of these surveys support the general findings of the SRA, including showing high numbers of introduced species relative to endemic natives. Fish numbers were found to have declined from 2005-2008 due to the effects of drought, and associated loss of fish habitat. Higher flows in 2009 saw improved fish numbers, but exotic species, particularly carp, had higher recruitment than native ones (SKM, 2010). Further analysis of this data will be prepared by VEFMAP in due course. The large volume of data collected for VEFMAP makes this a major task, and not one that can be emulated for this study.

Relevant reaches

One of the major decisions in revising the environmental flow objectives was trying to determine appropriate goals for Bungalally Creek and Yarriambiack Creek, and the lower reaches of the MacKenzie River and Burnt Creek, which receive only limited flows due to diversions into the Toolondo Channel. These river sections are not only highly intermittent, but because of their smaller channels also sustain no permanent refuges (Figure 12). This differentiates them from the upper sections of the MacKenzie River and the mid and lower reaches of the Wimmera River which contain important refuge areas (Figure 13). On this basis, the CMA established a set of fish objectives that focus primarily on those sections of the river that sustain permanent refuge habitats. At the same time, it was recognised that during prolonged wet periods, fish will likely move into and out of less permanent habitats. For this reason, the maintenance of longitudinal connectivity was applied to all reaches (Table 6). Achieving this objective invokes the need to manage any barriers that may limit fish passage at the prescribed flows.

Figure 12. *Burnt Creek illustrating the small channel with insufficient depths to sustain permanent refuges (March 2013)*

Figure 13. *Large permanent refuges on upper MacKenzie River (left) and the reach 2 on the Wimmera (March 2013)*

Table 6. Relevant fish objectives for each of the reaches examined.

Fish objective	Wimmera River	MacKenzie River	Mt William Creek	Burnt Creek	Bungalally Creek	Yarriambiack Creek
Maintain a self-sustaining freshwater catfish population in lower Wimmera River	■					
Maintain intact endemic fish communities in Mt William Creek and the upper MacKenzie River		Reach 1&2 only	■			
Restore endemic fish community diversity and abundance in the Wimmera River	Reach 2/3 only					
Provide adequate water quality/habitat for fish refuge locations in dry periods	■	Reach 1&2 only	■			
Facilitate dispersal and establishment of endemic fish species [1]	■	■	■	Upper only		
Provide adequate water quality to maintain native recreational species [2]	Reach 4 only					

[1]This objective was initially identified for the Bungalally, Yarriambiack and Lower Burnt Creeks, however following discussion with Wimmera CMA it was agreed that since these creeks do not sustain permanent refuge habitats, it is appropriate to exclude these from our recommendations.

[2]This does not preclude endemic fish species being in this reach. (Similarly restoring endemic fish populations in reach 2/3 of the Wimmera will also sustain recreational species).

Flow objectives

While the reach-level objectives vary significantly, it is worth noting that the persistence of fish populations in highly intermittent river systems such as the Wimmera depends on the presence of permanent refuge areas, which allow isolated populations of fish to survive during droughts, which can disperse and recolonise previously dry reaches when flows return (SKM, 2006a; Bond et al., 2008; Davies et al., 2008; SKM, 2010). These cycles can occur across large-spatial scales, and it is therefore important to consider local refuges in a regional context in managing flows and other aspects of the riverine environment.

Against this backdrop, flow variability can play a key role in maintaining healthy native fish populations, in particular by:

- Maintaining suitable habitat for each life-history stage
- Providing opportunities for movement between different habitats
- Acting as a trigger for spawning, including spawning migrations
- Maintaining productive food sources
- Regulating populations of some invasive species

The flow recommendations for native fish outlined in this report thus seek to address these five key areas, noting that the achievement of some of them will also depend on relevant vegetation, geomorphic and macroinvertebrate objectives also being met. These include a mix of both high flows – bankfull and in-channel pulses, and seasonally varying minimum flows to provide access to and connectivity between different habitats. For example, fish habitats are maintained both from channel forming flows (flow pulses and bankfull flows), which maintain channel features such as scour pools, and as the minimum flows required to maintain a sufficient diversity and area of specific hydraulic environments within the channel. Periodic high flows are now particularly important in the Wimmera because of the threats to native fish from saline groundwater, which can rise rapidly during low flow and 'cease to flow' periods. Reviews of the salinity tolerances of native and introduced freshwater fish (Hart et al., 1991; James et al., 2003; SKM, 2010) show that most lowland fish species have relatively high tolerance to high salinities. For example, available estimates of the LD_{50} (the lethal dose at which 50% of individual animals die) for native fish in the Wimmera range from ~10,000-50,000 mg/L (~16,600-83,300 µS/cm). Early life-stages tend to be more sensitive, but still approach ~10,000 mg/L among lowland species ; James et al., 2003). These concentrations are frequently exceeded in the Wimmera River during extended dry periods, due to saline groundwater discharge. For this reason, periodic freshes have been recommended to dilute and flush saline pools. These freshes require a sufficient duration to prevent simply creating a 'slug' of saline water that moves down the river and mixes otherwise stratified fresh and saltwater layers.

A further requirement of fish populations is the ability to move between habitats, whether to reach specific spawning sites or to colonise areas from which local populations have been lost due to drought and other disturbances. Flows play a critical role in these movements, in some cases acting as a trigger for movement, and in others ensuring that any potential barriers are inundated. For example, golden perch dispersal is triggered by flow pulses (Dave Crook, unpublished data), as are movements of many other species. Such movements can be associated with spawning (including pre-spawning movements), but are also important in allowing fish to access – both by moving into and away from – refuge habitats.

A further goal of the flow objectives for fish is to ensure sufficient production of food resources occurs to ensure that fish populations are not energy limited. Most species of fish in the Wimmera River prey primarily on invertebrates (insects and crustaceans), with fish a secondary component of the diet. For this reason, the flows required to sustain an energy base for fish are largely covered under the invertebrate flow recommendations. It is however worth noting once again that flow variability, and in particular the periodic inundation of off-channel habitats tends to support higher levels of overall ecosystem productivity (e.g. Baldwin & Mitchell, 2000). The nature of this relationship is not well quantified for most river systems but periodic high flows, including floodplain inundation, are likely required to support a high native fish biomass.

Table 7. Environmental flow objectives for fish in the Wimmera catchment

Environmental objective	Flow objective	Flow component	Timing	Frequency and duration
Maintain a self-sustaining freshwater catfish population	Maintain sufficient area of pool habitat greater than 1.5m deep, complex edge habitats submerged (e.g. tree roots, logs).	Low flow	All year	Continuous/ near continuous
	Protect flows during the spawning/nesting	Low flow	Oct - Dec (nesting period)	Wet and average years (maximum of 4 years without)

Environmental objective	Flow objective	Flow component	Timing	Frequency and duration
Maintain intact endemic fish communities	Maintain sufficient area of pool habitat greater than 1.5m deep	Low flow	All year	Continuous/ near continuous
	Maintain shallow water littoral habitats for small bodied species (e.g. pygmy perch, flathead gudgeon)	Low flow	All year	Continuous/ near continuous
Restore endemic fish community diversity and abundance	Provide flow variability to maintain water quality and a diversity of habitats (increase of about 0.1-0.2 m recommended)	Low Flow fresh	Base on unimpacted hydrology	All years. Frequency & duration based on unimpacted median
		High Flow fresh	Jun - Nov	
Provide adequate water quality/habitat for fish refuge locations in dry periods	Maintain oxygen and salinity levels within tolerances of native species	Low flow	All year	Continuous/ near continuous
	Flush salt from waterholes	High flow fresh	Jun - Nov	All years, based on monitored salinity levels.
	Prevent artificial extension of unimpacted cease to flow spells			
Facilitate dispersal and establishment of endemic fish species	Flow pulses to provide stimulus for fish movement (needs to inundate in-stream barriers by at least 0.1m)	Low Flow fresh	Base on unimpacted hydrology	Wet and average years only frequency & duration based on unimpacted median
		High Flow fresh	Jun - Nov	
Provide adequate water quality to maintain introduced recreational species	Prevent high salinities that exceed the tolerances of golden perch, silver perch and freshwater catfish (~15,000 mg/L)	High flow fresh	As necessary based on real-time monitoring	All years

System limitations to achieving environmental objective for fish
The achievement of healthy and self-sustaining native fish assemblages will not be met through flow management alone. Key issues in the Wimmera include the legacies of broad-scale catchment clearing and stock access to streams. Salinity effects arising from land-clearing have been considered as part of the flows assessment, but the effects of riparian clearing and stock access on nutrient and sediment loads, basal resource availability, and water temperature (among other factors; e.g. Hansen et al., 2010) must also be addressed if the full benefits of improved flow management are to be realised. The other main issue pertaining to fish are the effects of small in-stream barriers on movement. While one of the goals of flow pulses is to inundate low-flow barriers, weirs, culverts and dams all can act to disrupt those movements, and not all can be sufficiently overtopped by small flow pulses to allow upstream and downstream movement. SKM (2006b) found that none of the native species in the Wimmera and MacKenzie Rivers require fish passage and suggested that barriers may help limit carp movement. However to achieve fish dispersal objectives it is important that any potential barriers are identified, and where necessary modified to reduce their effects on fish passage.

3.5 Healthy and diverse water dependent vegetation

The overarching environmental objective relating to water-dependent vegetation of the Wimmera system is to *maintain healthy and diverse mosaics of water-dependent vegetation*.

In some cases, this high-level objective can be applied to all the different types of water-dependent vegetation in the river system, including that on the floodplain, in the riparian zone, and for submerged and emergent vegetation in in-stream environments. This all-encompassing objective would apply, for example, to Wimmera and MacKenzie Rivers. In other cases, for example with Burnt, Bungalally and Yarriambiack Creeks, the ephemeral nature of their flow regime means that submerged and emergent aquatic vegetation in in-stream habitats is of less interest. In these cases, the high-level objective refers to riparian and floodplain environments only.

Water dependent vegetation of the Wimmera system
There are a number of sources of information on water-dependent vegetation in the Wimmera River system, including:

- Vegetation descriptions in the original SKM FLOWS studies
- Vegetation maps (using EVCs, or Ecological Vegetation Classes) available from the interactive biodiversity mapsite of DSE or from other sources
- Detailed descriptions of vegetation, often undertaken as part of VEFMAP studies
- Information gleaned as part of the field inspections of early March 2013.

As commented on in the companion Glenelg River FLOWS study (see Alluvium 2013), the Issues paper for the original FLOWS study of the Wimmera River undertaken by SKM (SKM 2001) used the presence of rare or threatened plant species as the only indicator of vegetation values. This report reported that there were 135 threatened species of plant in the Wimmera River catchment, of which 24 were deemed to be water-dependent (SKM 2001, page 59). A focus on rare or threatened species was criticised by Dyer & Roberts (2006) and, as we have noted also for the Glenelg River study, such a focus is of little practical use when attempting to describe the vegetation values and issues for the Wimmera River when developing environmental flow recommendations.

Some additional information on in-stream, riparian and wetland vegetation is provided in SKM (2002, pages 17−26), but the environmental objectives (as listed on page 30) are system-wide and, again, given solely in terms of rare or threatened species:

- Sustainable Lizard Orchid communities (maintenance: overbank flows in spring)
- Dwarf Flat-sedge communities (maintenance and recruitment: overbank flows in spring)
- Sustainable Yarra Gum communities (maintenance and recruitment: overbank flows in spring)
- Sustainable Bead Glasswort communities (maintenance and recruitment: overbank flows in spring)
- Sustainable Slender Darling-pea communities (maintenance and recruitment: overbank flows in spring)
- Sustainable Tiny Arrowgrass communities (maintenance and recruitment: overbank flows in spring).

There has been considerable progress with devising environmental flows for inland rivers in Victoria since the early FLOWS studies, and the approach nowadays is to identify environmental values and environmental objectives not in terms of listed species but instead in terms of aquatic, riparian and wetland plant communities, often with EVCs acting as a high-level surrogate. Once the crucial vegetation types have been identified and assessed, information is extracted from literature sources and from anecdotal reports on the hydrological requirements to maintain either individual species or broad plant types. If the former are used, it is often as a surrogate for the latter. This approach requires spatially explicit information on the vegetation present in each study reach, and this information is most often obtained with a mixture of field inspections and vegetation maps from pre-existing sources. Figure 14 shows the type of vegetation mapping currently available, using as an example the Wimmera River near Dimboola. Often it is useful to compare present-day vegetation (i.e. in terms of 2005 EVCs) with modelled pre-European (i.e. 1750) distributions, in order to envisage the types of vegetation that might be amenable to system-wide rehabilitation and as a ‘reality check’ on final recommendations.

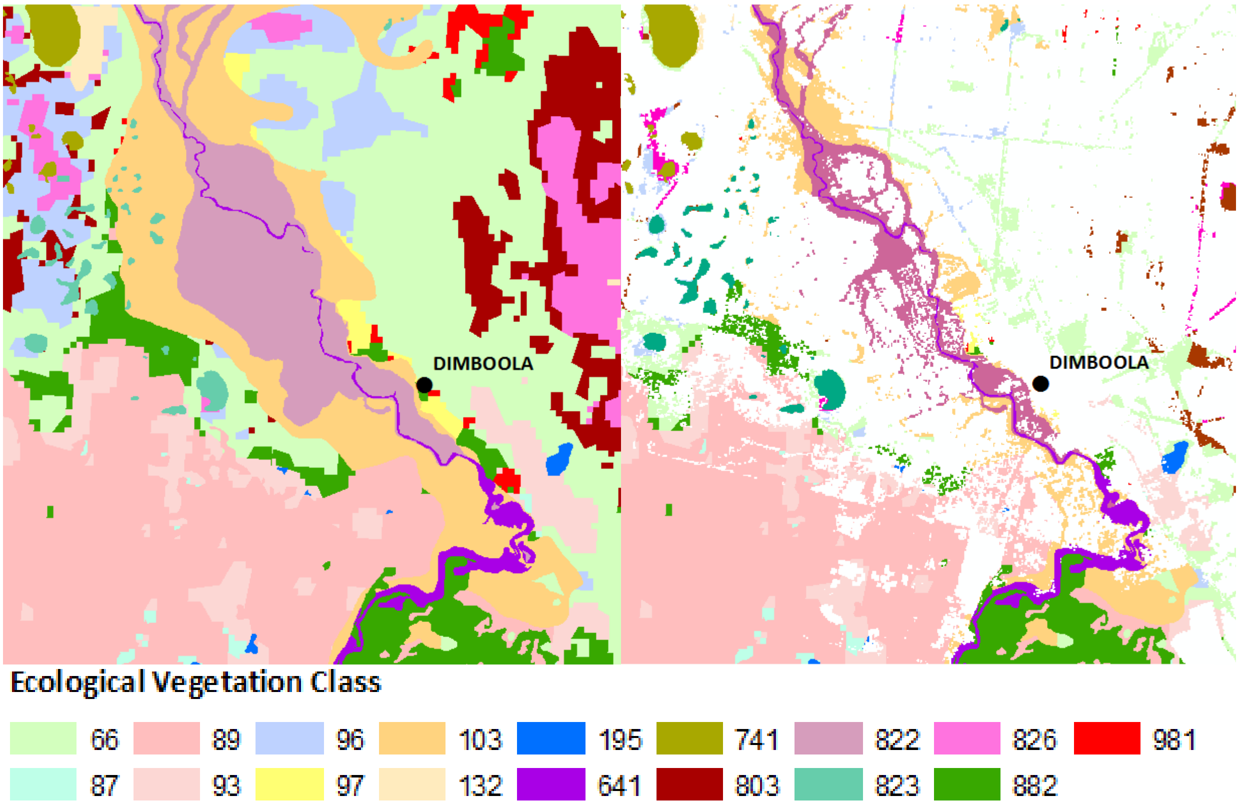


Figure 14. *Example of vegetation mapping that can be used when devising environmental flow recommendations: vegetation of the Wimmera River near Dimboola (left shows modelled 1750 EVCs, right shows EVCs mapped in 2005). Source: DSE biodiversity interactive mapsite.*

In contrast to the case with fish (see above, section 3.4) and macroinvertebrates (see below, section 3.6), there have been relatively few studies of the water-dependent vegetation of the Wimmera system. An example of supplementary information on vegetation available from VEFMAP studies is the report by SMEC (2011) on monitoring along the Wimmera and MacKenzie Rivers. This study monitored water-dependent vegetation at five monitoring sites, one on the MacKenzie River and four on the Wimmera River, at Gross Bridge, Polkemmet, Big Bend, and the Wundersitz Crossing. Between 15 and 18 transects were intended to be assessed at each site for woody habitat, vegetation profiles, and River Red Gum condition. Unfortunately, a number of assessments (e.g. of soil composition, the large woody debris assessments, etc) could not be undertaken because of the severe flooding that had taken place in mid-2010 to early 2011, just before field work commenced. Moreover, it was difficult to compare the results that were obtained with those of earlier assessments, because field work had been undertaken in different seasons.

Nevertheless, the report drew some conclusions as to the condition of the riparian zone at the five sites that were surveyed. First, it concluded that the recent flooding had provided such a severe ecological disturbance to the vegetation that any benefits thought to accrue from prior environmental flows were overwhelmed by the destructive force of the floods. In the case of the Mackenzie River, it concluded that recent flooding had reduced the biodiversity value of most of the riparian communities surveyed (page12), and that this vegetation had been, until the floods, slowly changing in response to chronically drier conditions (page 22). For the Wimmera River, there was some indication that the condition of River Red Gums had improved at some transects, but again it was impossible to differentiate the effects of prior environmental flows from the effects of the recent extensive flooding.

A number of specific studies of River Red Gum condition have been undertaken along the Wimmera River (Brett Lane & Associates 2008, 2007, 2009), which are similar to studies undertaken at roughly the same time elsewhere in north-central and north-western Victoria in response to widespread concern about the loss of these plant communities during the drought (e.g. Brett Lane & Associates 2009). This period also saw the progressive development of more powerful monitoring techniques to assess the condition of riparian vegetation, and especially River Red Gum condition (e.g. see Cunningham et al. 2007; Souter et al. 2010).

Future monitoring activities should take into account the advances that have been made in general approaches and specific field techniques for assessing the effect of drought and of environmental watering on eucalypt condition.

The other riparian species that has received some attention in the Wimmera River system is the Wimmera Bottlebrush (*Callistemon wimmerensis*), a newly recognized species of small tree in the family Myrtaceae. It was discovered in 2004 and was originally thought to have a very limited distribution in the Wimmera-Glenelg system. Although it has been found in both the MacKenzie and Glenelg systems, its relatively limited range, demonstrated impact of altered water regimes, and the species' likely susceptibility to climate change have resulted in its listing as critically endangered under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*. The hydrological requirements of the species are poorly understood, but it seems that periodic inundation is essential to maintain adult populations and may be needed also for sexual recruitment. Marriot (2006a, 2006b, 2010), for example, reported that the condition of Wimmera Bottlebrush improved markedly after environmental flows, with new growth being apparent on stressed trees within two weeks of inundation, and that condition declined markedly in years with no flow. Marriott (2006a) further concluded that Wimmera Bottlebrush '…appears to be totally dependent on seasonal flooding [winter-spring] and as a result is confined to the banks of the MacKenzie River'.

These three literature-based sources of information often benefit from on-site observations obtained during inspections of the field sites during a FLOWS study. The limitations of such field inspections are two-fold. First, they are usually done only once, and this timing may not coincide with the best period to assess the vegetation. Inspections are often done during low-flow periods in summer or autumn, when the river bed can be easily observed and is not covered with quickly flowing water; in contrast, native vegetation often flowers in spring-summer and some important species (e.g. *Phragmites australis*, Common Reed) are dormant during the winter-autumn period. Second, the field inspections necessarily are limited quick overviews at a small number of sites, and this makes it difficult to obtain a comprehensive whole-of-system overview. This, however, is where the landscape-scale vegetation maps become useful, especially in identifying vegetation at sites that could not be visited – for timing or access reasons – during the field inspections.

Notwithstanding these two limitations, the field inspections undertaken in early March 2013 largely reinforced our initial descriptions of the types of vegetation shown in the maps obtained from web-based sources. A good example is provided by the Yarriambiack Creek system, a north-flowing distributary of the Wimmera River that ends in a series of terminal lakes. In pre-European times it is likely that it would have flowed only intermittently. Currently, however, the lower sections of the creek are routinely inundated by flows from the Wimmera River, owing to the construction of the original weir and offtake in the 1850s and a replacement structure in the 1960s. A number of weir pools (e.g. at Jung, Brim and Warracknabeal) also occur along the creek. As a result of the increased availability of water, especially in the southern-most sections of the creek, a range of water-dependent plant taxa are now found in-stream and in the riparian zone in the wetter reaches. Water Ribbons (*Triglochin procerum*) and River Red Gum (*Eucalyptus camaldulensis*), for example, are now abundant at the field-inspection site.
Because of time constraints, the full length of Yarriambiack Creek was not explored during the field inspection. To rectify this limitation, vegetation maps obtained from DSE Interactive Mapsite were viewed, and they show that three EVCs occur along the creek near its confluence with the Wimmera River:

- EVC 103 Riverine Chenopod Woodland
- EVC 641 Riparian Woodland
- EVC 823 Lignum Swampy Woodland.

The maps show that as the creek flows to the north, EVC 641 is progressively lost and EVC 803 Plains Grassy Woodland becomes more common. Both EVC 103 and EVC 823 are found along the length of the creek, with the latter being the more common longitudinally. It is noteworthy that EVC 641 is the main River Red Gum-dominated riparian vegetation type along the lower reaches of the creek, compared to EVC 56 Floodplain Riparian Woodland found along the Wimmera River. An important difference between the two EVCs is that although both have River Red Gum as their main canopy tree, River Red Gums are denser (15% tree canopy cover) in EVC 56 than they are in EVC 641 (10% tree canopy cover); presumably this reflects a difference in water regime between the two streams.

These vegetation types and the change in EVCs with distance from the Wimmera River are consistent with an ephemeral stream flowing through a semi-arid landscape. Along the Wimmera River, the riparian vegetation is dominated by River Red Gum with a reasonably dense canopy cover (i.e. EVC 56). In the most southerly parts of Yarriambiack Creek, River Red Gum continue to be the dominant riparian tree species (EVC 641), but with a sparser crown density than along the Wimmera River. Vegetation types typical of drier conditions and less frequent inundation become progressively more common as the creek flows to the north: EVC 56 and EVC 641 give way to the Black Box and River Red Gum-dominated EVC 823 along the creek itself, with the Black Box-dominated EVC 103 further away; and at the northern-most sections, the vegetation is dominated by EVC 803, a community typified by largely terrestrial taxa such as Yellow Gum (*Eucalyptus leucoxylon*), Yellow Box (*Eucalyptus melliodora*), Grey Box (*Eucalyptus microcarpa*) and Buloke (*Allocasuarina luehmannii*). EVC 823 Lignum Swampy Woodland is common along much of the creek; this plant community is dominated by Black Box, River Red Gum and River Coobah (*Acacia stenophylla*) as canopy trees and with Tangled Lignum (*Muehlenbeckia florulenta*) as a critical understory component.

If the near-permanent inundation of the southern-most parts of Yarriambiack Creek were to be replaced by a more natural wetting and drying regime, it is likely that the riparian vegetation would revert to a more 'natural' pre-European composition and condition. The abundant River Red Gum that currently dominates the southern-most parts would become less abundant, although it is difficult to predict the degree to which they could persist in the long term. River Red Gum have a dual root system, consisting of a vertical tap-root that can penetrate deeply into the soil in search of water, and a more shallow system of surface roots that allow the plant to gain access to moisture in surface soils (Roberts & Marston 2011). It is likely that surface roots have developed preferentially under the regime of abundant water that typifies post-1850 conditions; if so, the withdrawal of surface-water supplies could leave the extant plants without a deeply set root system well-adapted to more natural, drier conditions.

Unlike the extant River Red Gum, the other plant taxa common along the creek line – Black Box, River Coobah, Tangled Lignum – are all well adapted to episodic inundation via overbank flows. If the artificial conditions provided by water backing up from the Wimmera River were to be removed, these taxa would probably become dominant and replace the dense stands of River Red Gum in the southern-most reaches. Their continued survival and recruitment would then be dependent upon natural high flows, particularly bankfull and overbank flows. Submerged and semi-emergent taxa such as Water Ribbons would become less abundant, but are still likely to persist in the longer term. Water Ribbons have below-ground turions that allow them to survive long periods of soil desiccation and to regrow when the stream bed becomes inundated. As long as water remains in the stream long enough for the plants to complete their life cycle and lay down new turions, they can survive long periods without inundation and with only intermittent wetting.

In contrast to the situation with Yarriambiack Creek, the field inspection of Burnt Creek confirmed the temporary nature of flows in this tributary. Tentative environmental objectives and associated flow recommendations made before the field inspection had to be modified in the light of the field observations, which suggested the creek experienced many 'cease to flow' periods. For this reason, the specific flow objectives for this reach were modified to include only riparian and floodplain vegetation, as in-stream submerged and emergent vegetation would largely be absent from the creek. Moreover, any flow that did occur in-channel episodically would see the opportunistic growth and recruitment of submerged and emergent plant taxa. Similar arguments hold for Bungalally Creek and for parts of MacKenzie River.

Field inspections included visits to a number of sites in the downstream parts of the Wimmera River system, including to Tarranyurk, Wundersitz Crossing, the Dimboola Weir Pool, and at Big Bend near the Little Desert National Park. The effects of intrusions of saline groundwater were apparent at the first site, as shown in the figure below (Figure 15), where the water is exceptionally clear and death of some of the fringing macrophytes has become apparent. Salt scalds were also apparent at the toe of the bank, as indicated by the red arrows in Figure 15.

Figure 15. *Wimmera River at Tarranyurk. The red arrows indicate salt scalds at the toe of the bank.(March 2013)*

Relevant reaches

The overarching environmental objective relating to water-dependent vegetation of the Wimmera system is to 'Maintain healthy and diverse mosaics of water-dependent vegetation'. This is a whole-of-system objective and needs to take into account the different values and hydrological conditions in each of the reaches. Table 8 below summarises the vegetation sub-objectives relevant for each part of the Wimmera system.

Table 8. Relevant reaches for vegetation objectives

Vegetation objective	Wimmera River	MacKenzie River	Mt William Creek	Burnt Creek	Bungalally Creek	Yarriambiack Creek
Adequate flow to protect and restore riparian and floodplain EVCs	■	■	■	■	■	■
Maintain submerged and emergent aquatic vegetation quality, diversity and extent for fish habitat		Reach 1 & 2 only	■			
Maintain adequate surface water salinity to enable growth and reproduction of submerged aquatic macrophytes	■					
Maintain adequate surface water salinity for growth and reproduction of emergent vegetation	■					
Stimulate flowering and recruitment of *Callistemon wimmerensis* and maintain condition of current mature species		Reach 3 only				

Flow objectives

Water-dependent vegetation plays a crucial role in the ecological structure and function of streams in inland Australia. Trees in the riparian zone 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; large pieces of fallen timber also trigger the creation of deep scour holes in the stream, and these provide additional habitat, including drought refuges, for aquatic animals during dry periods. Leaf fall and bark shedding provide organic matter that fuels floodplain and aquatic food webs, mostly via decomposition by microbes, followed by consumption by macroinvertebrates and fish. Section 3.6 discusses further the way that aquatic macroinvertebrates are dependent upon aquatic and riparian plants for their sources of food. 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, water-dependent plants provide a critical aesthetic element that makes Australian streams and creeks look the way they do.

Emergent vegetation, especially plants such a Common Reed *Phragmites australis* and the spike-rushes *Eleocharis* spp., similarly provides habitat for a wide range of animal species. Through the provision of detritus and the availability of submerged surfaces on which microbes can grow, emergent plants also provide a source of organic carbon and nutrients to aquatic and riparian animals. They have critical roles in stabilizing stream banks and protecting them from erosion, and in accumulating sediments on benches and other low-lying channel features. As noted below in the section 'system limitations', large, tough emergent macrophytes have a role to play in stabilising accumulations of sand on in-stream benches throughout the Wimmera system.

The environmental objective is to 'maintain healthy and diverse mosaics of water-dependent vegetation'. Two components of this objective deserve teasing out. First, the objective is to *maintain* the vegetation. There is a crucial difference between *maintaining* and *restoring/rehabilitating* natural 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 objective is to maintain *mosaics* of vegetation. The vegetation of interest, therefore, includes not only visually obvious adult trees in the canopy layer, but aspects of their condition or health, species composition of canopy trees, the shrub layer and ground layer in 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 water-dependent vegetation is 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.

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 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.

Table 9 below shows a summary of the range of flows that are required to maintain different types of water-dependent vegetation.

Table 9. Summary of water regime requirements of structurally dominant riparian and floodplain plant species[2]. *Vallisneria* spp. are used as a type-species for submerged taxa.

Component of water regime	*Vallisneria* spp. (Eelgrass, Water Ribbons etc)	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.
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 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.

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.

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.

[2] 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).

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 and often invasive Cumbungi (*Typha* spp.). 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.

The flow requirements to achieve the water dependent vegetation environmental objectives in the Wimmera system are summarised in Table 10.

Table 10. Flows required for healthy and diverse water dependent vegetation

Environmental objective	Flow objective	Flow component	Season	Frequency and duration
Adequate flows to protect and restore riparian/floodplain EVCs	Inundate riparian zone (bankfull) and floodplain (overbank) in order to maintain condition of adults and facilitate sexual recruitment	Bankfull	Spring – Summer	Frequency as per unimpacted flow regime[3]
		Overbank	Spring – Summer	
Maintain submerged and emergent aquatic vegetation quality, diversity and extent for fish habitat	Maintain adequate depth of permanent water in stream channel (greater than 50cm depth) to limit terrestrial encroachment into aquatic habitats and permit long term survival and recruitment of submerged plant taxa (maximum water depth of about 2m for obligately submerged taxa).	Low flow	All year	Continuous/near continuous
	Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches and on lower banks. Variations in water depth of approximately 10-20 cm over low-flow levels in each of the two flow seasons.	Low flow fresh	Spring – Summer	Frequency as per unimpacted flow regime[4]
		High flow fresh	Autumn – winter	
Maintain adequate surface water salinity to enable growth and reproduction of submerged aquatic macrophytes	Provide flows that will, where possible, limit surface water salinity to <4,000 µS/cm and preferably <1,500 µS/cm.	Low flow fresh	Summer - autumn	As required
Maintain adequate surface water salinity for growth and reproduction of emergent vegetation	Provide flows that will, where possible, limit surface water salinity to <4,000 µS/cm and preferably <1,500 µS/cm.	Low flow fresh	Summer - autumn	As required
Stimulate flowering and recruitment of *Callistemon wimmerensis* and maintain condition of current mature species	Inundate riparian zone (bankfull) and floodplain (overbank) in order to maintain condition of adults and facilitate sexual recruitment	Bankfull	Spring – Summer	Frequency as per unimpacted flow regime[5]
		Overbank	Spring – Summer	

[3] If this information is not available, refer to Table 9.
[4] If this information is not available, 2-4 times in each period
[5] If this information is not available, trial a once per year inundation and monitor outcomes

System limitations
Maintaining healthy and diverse vegetation communities in the Wimmera catchment cannot be achieved through the provision of the recommended environmental flow regime alone. Other threats can limit the achievement of objectives in parts of Wimmera system. These limitations are described below.

These limitations are in large part a function of catchment management, and include four main factors:

- Weeds and other 'out-of-balance' plant species
- Presence of exotic fish
- Grazing pressure
- Sand build-up
- Salinization in lower sections of the Wimmera River.

Grazing has a number of impacts on water-dependent vegetation, especially on riparian species. First, it will limit recruitment of palatable native species, such as juvenile River Red Gum. As a result, excessive grazing pressures often lead to the replacement of native shrub and trees species in the riparian zone and on the top of banks by grassy groundcover species. Second, soil compaction and erosion of river banks at drinking points further prevent the establishment of juvenile plants in the riparian corridor. Third, grazing introduces exotic pasture grasses and weed species, via animal dung. Indeed, weeds are among the most pervasive of all threats to floodplain ecosystems in south-eastern Australia. Through the process of selective herbivory, it can lead also to the over-consumption of palatable native species, such as sedges, and their replacement by tougher and less easily consumed species. To some degree, the issue of excessive grazing pressure is not as severe in the Wimmera River system as it is elsewhere in the State, as significant resources have been allocated in recent years to fence-off large portions of the stream-side zone.

Carp are a serious problem in almost all streams north of the Great Dividing Range in Victoria. The adverse impacts of large carp on aquatic systems, and especially on submerged and semi-emergent vegetation, has been described by Koehn et al. (2000). Ongoing control of carp infestations should be a priority for river managers.

A range of post-European changes to land-uses in the catchment, including clearing and altered fire regimes, have contributed to increased deposition of sand in the stream thalweg in the lower Wimmera River (Refer Section 0). Sand slugs have developed at many points in the river, contributing to a general shallowing of the channel and thus the loss of deep-water habitats for aquatic animals. River regulation resulting in a reduction in flow may also have contributed to a loss of deep-water habitats. These sand depositions, however, provide excellent substrata on which emergent macrophytes such as Common Reed can establish. As more sand is deposited, existing stands of plants can become smothered. If the deposition is too deep and too rapid, the smothered plants will die. To some extent, the colonisation of sand slugs by tough emergent plants such as Common Reed could provide a more stable substratum that will allow the channel to re-deepen in areas that are devoid of vegetation.

Salinisation was evident in the downstream reaches of the Wimmera River. This matter was raised earlier, when the field inspection confirmed the role played by intrusions of saline groundwater on vegetation in the lower parts of the Wimmera River (see Figure 15, the Wimmera River at Tarranyurk). Previous parts of the report have addressed also the issue of saline pools developing in the stream during periods of low flow, when saline groundwater seeps in to the river channel. Because this groundwater is so salty, it is appreciably denser than freshwaters in the river itself. Thus it sinks to the bottom of the pools and is mixed into the overlaying layers only with substantial flows. The flows required to achieve this mixing – and the environmental problems that might occur should saline waters be entrained into the rest of the river – have been outlined in Section 2.2 of this report.

The effects of highly saline waters on aquatic and riparian vegetation are well known. Many taxa of large canopy-forming trees, including River Red Gum and Black Box, can utilise saline groundwater as water supplies during dry periods. Submerged and emergent plants, however, are often far more sensitive to salt. As an example, Hart *et al.* (2003) concluded that many aquatic 'freshwater' plants in Australia were salt-sensitive and that salinities of 1−2 g/L (approx. 1,700−3,300 µS/cm) were likely to be lethal. They concluded that riparian vegetation was similarly salt-sensitive, but that adverse effects on nominally freshwater species were likely to be apparent at slightly higher salinities, of >2 g/L. James *et al*. (2003) reached similar conclusions, and thought that the salinity threshold for the majority of submerged freshwater macrophytes in Australia was 1−2 g/L, that for 'widespread macrophytes' was likely to be higher, at around 4 g/L(approx. 1,700 − 3,300 µS/cm).

Notes on salinity thresholds

Literature sources - salinity thresholds to maintain freshwater systems:

The information on salinity tolerance in aquatic and riparian plants of south-eastern Australia is quite extensive and includes a number of comprehensive reviews, many of which were published in a 2003 special issue of the *Australian Journal of Botany*: see Briggs & Taws (2003), Davis *et al*. (2003), Hart *et al*. (2003), James *et al*. (2003), and Neilsen *et al.* (2003). A more general literature also exists on the way terrestrial and aquatic plants respond to salinity (e.g. Kozlowski 1997; Barrett-Lennard 2003; Bornette & Puijalon 2011). In addition to these sources is the database prepared for Land & Water Australia a decade ago that aimed to collate all available information on the salt tolerance of the Australian freshwater biota (Bailey *et al.* 2002). It has yet to be updated, but formed the basis for some of the papers in the 2003 special issue of the *Australian Journal of Botany*.

Plant responses to salinity:

Two broad groups of plants can be differentiated on the basis of their sensitivity to salt. The first consists of species that are always or are characteristically found in saline environments and can complete their entire life cycle under saline conditions: these plants are termed 'halophytes' and, for inland systems, include most of the taxa found in inland saltmarsh and other saline semi-aquatic environments, such as where saline groundwater discharges into surface soils. In contrast, the second group − 'glycophytes' − cannot complete their life cycles in saline environments. If they are present in saline environments at all, they tend to occur opportunistically, often occupying spatial or temporal niches only when or where the salinity is lowered, for example by a restriction of tidal inundation or after heavy rain has ponded fresh or low-salinity water into surface depressions. Such plants are usually eliminated soon afterwards, as evaporation increases the salinity of the water and/or soil.

The differentiation between halophytes and glycophytes depends to a large degree on the salinity threshold chosen to separate saline from non-saline environments. This is a contentious issue and there is no hard-and-fast rule as to what constitutes a saline environment or a 'salt-tolerant' plant. Williams (1998) argued that resource managers typically use a value of 0.3 g/L to differentiate fresh from saline waters whereas ecologists have found that 3 g/L better differentiated fresh from saline waters on ecological and biological grounds. The threshold used in New South Wales to separate freshwater from saline aquatic systems is 3 g/L, and this is consistent with Commonwealth criteria.

Biological salinity thresholds:

Hart *et al.* (2003) concluded that many aquatic 'freshwater' plants in Australia were salt-sensitive and that salinities of 1−2 g/L were likely to be lethal. They concluded that riparian vegetation was similarly salt-sensitive, but that adverse effects on nominally freshwater species were likely to be apparent at slightly higher salinities, of >2 g/L. James *et al*. (2003) concluded that the salinity threshold for the majority of submerged freshwater macrophytes in Australia was 1−2 g/L, that for 'widespread macrophytes' was likely to be higher, at around 4 g/L.

Bailey *et al*. (2002) analysed 49 entries from 12 reports on 26 genera of emergent, submerged or floating plant species for their salt sensitivity. Forty-two percent of the genera appeared to be restricted to aquatic systems with salinities <5 g/L. This finding was consistent with Brock & Shiel (1983), who found that macrophytes with freshwater affinities typically occurred in Western Australian aquatic systems at salinities <4−5 g/L. Nevertheless, 40% of genera analysed in the Bailey *et al*. (2002) study came from brackish to hyper-saline waters (i.e. defined as salinity >8 g/L). The authors reported that a number of plant genera found in nominal freshwaters had a high tolerance to salt: examples included *Ruppia tuberosa* and *Lepilaena preissii* (230 g/L and 150 g/L, respectively), *Bolboschoenus caldwelli, Cyperus gymnocaulus, Pachycornia* (Tribe Salicornia) and *Suaeda*, all occurring at 25 g/L, and *Phragmites australis* (15 g/L).

Bailey *et al*. (2002) noted that soil-water salinity, rather than surface water salinity, would more likely reflect the salinities that vegetation (particularly emergent vegetation) were exposed to. As there can be large discrepancies between surface water and soil water salinities, any thresholds derived from the salinity tolerance of vegetation based on surface water salinities must be viewed cautiously. Lissner & Schierup (1997), for example, examined a number of reed beds sites along the coast of Denmark, and found that soil water salinities were <5 g/Lat depths of 5−25 cm despite exposure to flood waters with much higher salinities, ~9−30 g/L, up to twice a day. In these cases, the reeds were presumably obtaining water not from the saline surface waters but from the fresher sub-surface supplies. An additional problem comes with plant taxa that take up saline waters episodically, when conditions demand: Black Box (*Eucalyptus largiflorens*), for example, can utilize saline groundwater that is up to one-half seawater salinity (i.e. ~ 20 g/L) (Roberts & Marston 2011). Roberts & Marston (2011, page 9) thus called it a 'salt-tolerant' species; most botanists, however, would be reluctant to call it a halophyte.

3.6 Diverse and abundant macroinvertebrates

The environmental objective relating to macroinvertebrates for the Wimmera system is to 'achieve SEPP compliant macroinvertebrate communities'.

Description

There have been a relatively large number of studies looking at the aquatic macroinvertebrate communities in the Wimmera River. The majority of studies have been either for river health monitoring (conducted by the EPA or the Wimmera CMA) or have been specific studies looking at the effects of environmental flows. These began nearly thirty years ago, (e.g. Metzeling et al. 1993) who reported on four sites sampled between 1985 and 1988, followed by Zampatti *et al*. (1997) who sampled eight sites as part of an assessment of environmental flows between 1993 and 1995. In 1993, the Monitoring River Health Initiative (MRHI) began as a nation-wide survey of river health using macroinvertebrates (Metzeling, 2001, Vertessey and Cameron (1999) with some 54 sites sampled in the Wimmera Basin between 1993 and 1999.

Sampling has been more intensive since 2000. Between December 2004 and March 2005, the EPA biological monitoring program sampled 11 sites, twice a year to assess the impact of environmental flows in the lower Wimmera River (Westbury *et al*., 2007). Under the sustainable rivers audit (SRA), 34 sites were sampled in March 2005.

Annual sampling at a large number of sites began in 2005 (Butcher, 2006), who studied 35 sites as part of river health monitoring and 16 sites as part of an assessment of environmental flows for the Wimmera CMA. This sampling continued until April 2012. Over that time, the number and location of sites, but settled to 20 baseline monitoring sites that have been regularly sampled. Many of the sampling locations do not fall within the reaches network relevant to this study.

It is not possible to conduct a detailed review of all the data collected in the Wimmera River catchment to date, concentrating on areas likely to be influenced by environmental flow releases. The results of sampling over the past decade must be placed in context of the extended drought period. While many of the samples suggested poor conditions, it needs to be remembered that the "reference" sites that established the baselines were sampled in the pre-drought periods. This was recognised in the 2004-05 summary of condition (EPA and Wimmera CMA 2008)

Comparing the data collected in each year with those prior to the drought (1994) at a site on the Wimmera River (Riverside) shows that macroinvertebrate condition was consistently lower during the drought than before or after (Figure 16).

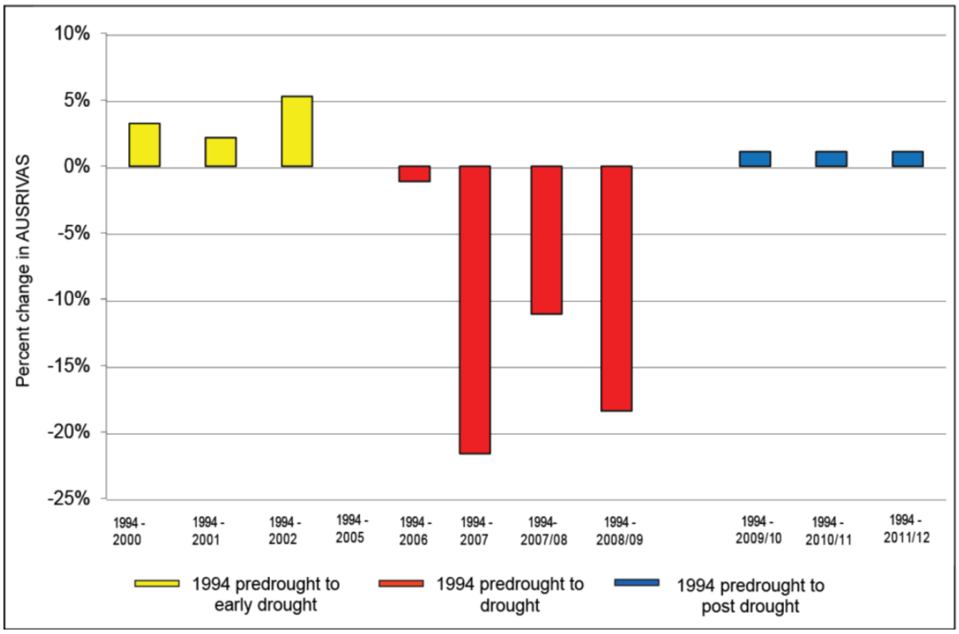


Figure 16. *Percentage change in AUSRIVAS at Wimmera River at Riverside (WR32) compared to data collected pre-drought in 1994 (Brooks and Butcher 2012).*

Relevant reaches

The environmental objective relating to macroinvertebrates applies to all reaches of the Wimmera system.

Flow objectives

The major determinants of the abundance and composition of the aquatic macroinvertebrate fauna are flows, type, quantity and quality of habitat, sources of food and water quality. In the main, the key types of habitat for macroinvertebrates in rivers are the benthic sediments, in-stream and edge vegetation, woody debris and leaf packs that accumulate in various sections of the stream. Where sand or fine sediments form the main stream bed substrate, the zone of plants at the water's edge, leaf packs and woody debris in the channel contain the highest diversity and abundance of macroinvertebrates, although a distinct community (of generally low diversity) can be found in the sandy bed habitats themselves.

The quantitative availability of such habitats is predominantly driven by the low flow components of the flow regime throughout the year. The lateral extent of low flows in the channel determines which parts of each habitat are inundated, and to what depth. Most aquatic macroinvertebrates require persistent water availability, so that habitats remain either inundated (primarily wood debris and the structural elements of in-stream vegetation) or kept moist (leaf packs and the stream bed itself).

However, the quality of these habitats is also important, and this is largely determined by higher components of the flow regime. Sediment deposited on habitats is generally detrimental to macroinvertebrate communities, reducing diversity and favouring certain types of macroinvertebrates. Regular pulses of water (freshes) with sufficient power to move fine sediments and sand are required to maintain clean habitat surfaces. Where habitats are densely packed (e.g. thick in-stream vegetation and cobble riffles) much higher flows may be required to scour habitats of sediments.

In many lowland streams where elevated turbidity reduces in-stream primary production, the major basis of the in-stream food chain is derived from organic material from outside of the stream channel. Dissolved organics, leaves and twigs that are washed from vegetated benches in the channel and from the river banks or floodplain are essential to maintain macroinvertebrate communities. This organic material is broken down by mechanical action or bacteria and the resulting detritus (and the bacteria themselves) form the basis of macroinvertebrate food webs. Higher flows that inundate benches and overbank flows that wash organic material into the stream are therefore an important component of any flow regime for macroinvertebrates. Of course, this relies on the presence of vegetated riparian zones.

Within the stream channel, algae and other biofilms that grow on surfaces (such as wood debris and in-stream vegetation) form and additional source of food. High scouring flows that disturb the algae/bacteria/organic biofilm present on in-stream surfaces. It is believed to maintain a diversity of available food sources and increase overall food production. Similarly, regular wetting and drying of wood debris through variations in low flows can also increase the availability of food resources.

Macroinvertebrates are sensitive to changes in water quality (probably more so than other biotic stream components such as fish and platypus). Elevated water temperature, salinity, turbidity and nutrients, and decreased dissolved oxygen are the most commonly reported water quality parameters that determine macroinvertebrate community composition and production. While it is always preferable to address any alterations in water quality at the source of disturbance (through sensitive land management), this is not always practical considering the scale and flows can be used to provide a temporary respite from changes in water quality, through adequate low flows that prevent stratification or freshes that dilute elevated nutrients or salinity.

The flow requirements to achieve the macroinvertebrate environmental objectives in the Wimmera system are summarised in Table 11.

Table 11. Flow requirements for macroinvertebrates

Flow objective	Flow component	Season	Frequency / duration
Maintain edge habitat in deeper pools and runs	Low Flow	All year	Continuous
Maintain shallow water habitat availability	Low Flow	All year	Continuous
Increase biofilm abundance on wood debris as a food source	Low Flow	All year	Continuous
	Low Flow Fresh	Summer- Autumn	3-4 per year to introduce variability
Flush surface sediments from hard substrates (riffles, wood, fringing roots and vegetation)[6]	(High Flow) Fresh	Lead up to summer (late high flow season - Nov)	1 per year
Prevent water quality decline in pools during low flows	Low Flow & Low Flow Fresh	Summer	3-4 per year, 14 days
Disturb the algae/bacteria/organic biofilm present on rocks or wood debris[7]	High Flow fresh	Late low flow season (May/June)	1 per year
Entrain organic debris from benches in the channel and from the floodplain	High Flow fresh[8]	Winter – Spring	1 per year
	Bankfull	Anytime	1 per year
	Overbank	Anytime	1 per year

System limitations

Maintaining diverse and abundant macroinvertebrate populations in the Wimmera catchment cannot be achieved through the provision of the recommended environmental flow regime alone. Other threats can limit the achievement of objectives in parts of Wimmera system. These limitations are described below.

Riparian vegetation quality

The riparian zone influences in-stream habitat conditions through shading, inputs of organic material (both fine as in leaves and twigs, and large as in logs and trees), and stabilisation of banks, reducing erosion, and filtering run-off. Vegetation clearing and grazing reduces these influences, making in-stream habitats less suitable for macroinvertebrates (through sedimentation and reductions in leaf inputs).

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[6] Requires shear stress of least 1.1 N/m2 to mobilise coarse sand
[7] Requires velocity greater than 0.55 m/s to scour surface algae and biofilm
[8] Requires inundation of benches

In extreme cases (complete riparian clearance and uncontrolled stock access), it is unlikely that flow alone could overcome the limitations to in-stream habitat, so the objectives would most likely never be met, unless the riparian zones are restored or rehabilitated.

Wood debris density
Where fine sediments make up the stream bed, wood debris can form a large proportion of the available in-stream habitat. Systems where wood debris has been removed have lower diversity. Removing wood debris can lead to increased erosion of the bed and banks, so may have an indirect impact on other important habitats.

As SEPP does not include the fauna of wood debris (only edge and riffle habitats are included), historic removal of wood may have had an indirect impact on edge habitats. The importance of this indirect impact cannot be assessed separately from other impacts on edge habitats. Natural recruitment of new wood may be a long process, relying on the death of riparian trees which fall into the river channel.

Water quality
Macroinvertebrates are sensitive to changes in water quality parameters such as salinity, water temperature, turbidity, nutrients and dissolved oxygen.

Short flushing flows to dilute or remove stratified saline groundwater are likely to only have a temporary effect, as inflows of saline groundwater will quickly re-establish pre-flush conditions. Such flows would need to be very frequent, or followed up by sufficient baseflow to prevent the return of adverse conditions. Suitable flows depend greatly on the physical nature of the stream channel (e.g. depth of pools). An approximation of the turbulent power of flowing water is the Reynolds number (Re). Reynolds number is used to check whether the flow is laminar or turbulent, with turbulent flow more likely to disrupt pool stratification. An approximate Reynolds Threshold of 45,000 has been adopted in previous FLOWS studies to delineate between laminar and turbulent flow (Alluvium 2010). Re is calculated from the formula:

$$Re= pwuH/n$$

where pw is the density of water, u is the average water velocity, H is the depth of water and n the absolute viscosity. For this study, Re was simply calculated as the average cross section velocity x depth x 1,000,000 at different flows.

3.7 Healthy platypus communities

The environmental objective relating to platypus for the Wimmera system is to 'maintain platypus populations'.

Description
A survey of 17 sites in the upper Wimmera catchment during 2008 (Mitrovski 2008) identified platypus in the MacKenzie River only. No platypuses were found in the Wimmera River and only a single platypus was found in the MacKenzie River. While platypus had previously been recorded in the upper Wimmera, because of the effects of drought, it had been suggested that "the MacKenzie River may contain the sole surviving platypus population in the upper Wimmera Catchment" (Mitrovski 2008, p. 1). Anecdotal evidence (video recording) since then has proven that platypus still do occur in the upper Wimmera River, however the very infrequent sightings of platypuses indicates that the population numbers are very low.

Relevant reaches
The environmental objectives relating to platypus apply to the MacKenzie River (reaches 1, 2 and 3) only given there is an existing population to maintain.

Flow objectives
Of the channel characteristics that are affected by flows, only maximum channel depth has shown a significant relationship with the presence of platypus. In Running Creek, north of Melbourne, Serena et al. (2001) found animals located in areas with an average depth of 0.8 m, but were absent from areas with average depths of 1.4 m, suggesting a preference for shallower waters. Davies and Cook (2001) suggest that foraging is optimal

at depths < 2 m and velocities less than 1 m/sec are optimal. On the other hand, Scott and Grant (1997) suggest that ideal habitat for platypus consists of “a series of distinct pools of less than 5 m depth, with little sand accumulation separated by cobbled riffle areas.” The depth limitation is probably related to diving ability – in Tasmania, mean dive depth was 1.28 m with a maximum of 8.77 m (Bethge 2002).

Platypus breeding occurs in spring. The eggs hatch after 7-10 days and platypus remain in the burrows for 3-4 months (Museum of Victoria website). Based on information in, juveniles emerge from burrows between January to March and can be found “for a number of months” in the home range, then decline in abundance, and that “most have left their home area by the end of their first year of life” Grant (2007).

Dispersal requirements for platypus are unknown, but depth criterion has been based on that for large bodied fish. This is assumed to also provide sufficient width of flowing water that reduces the potential for predation of moving juveniles.

The flow requirements to achieve the platypus environmental objectives for the MacKenzie River are summarised in Table 12.

Table 12. Flow requirements for platypus

Flow objective	Flow component	Season	Frequency & duration
Provide for instream habitat availability	Low Flow	All year	Continuous
Provision of access to food supply	Low Flow	All year	Continuous
Connectivity between habitats	High Flow	June-December	Depth in riffles > 50 cm

System limitations

Maintaining healthy platypus populations in the Wimmera catchment cannot be achieved through the provision of the recommended environmental flow regime alone. Other threats can limit the achievement of objectives in parts of Wimmera system. These limitations are described below.

Riparian vegetation quality

The main riparian zone influence on platypus is through the stabilisation of banks, important for maintaining burrows, as well as the impact on macroinvertebrate populations (the major food source for platypus). Vegetation clearing and grazing reduces these influences, making in-stream habitats less suitable for platypus (through less stable banks for burrows).

It is unlikely that flow alone could overcome the limitations to bankside burrows, so the objectives would most likely never be met, unless the riparian zones are restored or rehabilitated.

Water quality

Platypus are less sensitive to water quality changes than other in-stream fauna, and are often found in poor quality areas.

Sand slugs

Excess sand reduces the depth of available pools. Very shallow pools are less suitable for platypus foraging.

Predation

Predation of platypus by foxes has been reported, but there is little evidence to support that this is a major impact on populations.

There may be an opportunity for increased predation of juvenile platypus when migrating along a river, through shallow areas, but the importance is unclear.

3.8 Geomorphic processes

The environmental objectives relating to geomorphology for the Wimmera system are:

- Maintain structural integrity of stream bed and channel and prevent loss of channel capacity
- Provide sufficient bank inundation to reduce salt scolding from saline groundwater seepage
- Prevent excessive stream-bed colonisation by terrestrial species
- Prevent loss of channel diversity through lack of flow variability

Geomorphology of the Wimmera system

Fluvial geomorphology describes the size, shape and diversity of the river channel. The geomorphology (or 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.

The Wimmera River, its catchment and its flow regime have been substantially modified during the last 100 years through vegetation clearing, drainage works, channelisation and flow regulation (including the construction of on stream and offstream dams. These modifications have led to significant geomorphic disturbance in the last 100 years:

- Upper reaches of Wimmera River and tributaries are dominated by low gradient and discontinuous alluvial stream type
- Channel incision is generally confined to the upper reaches of the Wimmera.
- Human disturbance (clearing and drainage) has led to destabilisation of many of these systems, leading to instream, gully and sheet erosion in the upper tributaries
- There are a number of connected gully systems in the Upper Wimmera River systems that can deliver sediment to the Wimmera River. However most of the sediment derived from gully erosion in the upper catchment is not delivered to the river; rather it is stored in long-term deposits before it reaches the main stem of the Wimmera River (ID&A 2001)
- Middle reaches of the system have limited sediment transport capacity, further limited by presence of numerous weirs
- The lower reaches of Wimmera system are subject to significant sedimentation and channel aggradation. The source of sediment is not material transported from erosion in the headwaters—which is common in many south-eastern Australian systems—but rather Tertiary and Quaternary deposits: the Parilla Sands and aeolian (wind-blown) sands transported from the Lowan Foundation that overlies the Parilla Sands (ID&A 2001)
- Sedimentation in the lower reaches is driven by a combination of ready local supply of sand, low longitudinal bed slope and a reduction in flows from upstream from flow regulation
- Sedimentation is likely to continue (slowly) under current management arrangements, leading to contraction of the channel. Channel contraction is accelerated by vegetation encroachment into the channel, which reduces near bank flow velocities and promotes further sedimentation.
- In addition to excessive sedimentation and channel contraction, in some areas of the lower system there is active bank erosion and anabranch development

Relevant reaches

The environmental objectives relating to geomorphology apply to different reaches in the Wimmera system as shown in Table 13.

Table 13. Relevant reaches for geomorphic objectives

	Wimmera River	MacKenzie River	Mt William Creek	Burnt Creek	Bungalally Creek	Yarriambiack Creek
Maintain structural integrity of stream bed and channel and prevent loss of channel capacity	■	■	■	■	■	
Prevent excessive stream-bed colonisation by terrestrial species	■	■	■	■	■	■
Prevent loss of channel diversity through lack of flow variability			■	Upper only		
Provide sufficient bank inundation to reduce salt scolding from saline groundwater seepage	Reach 4 only					

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 or increases in the sediment supply from upstream (Petts & Gurnell 2005).

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. Bankfull flows are also important for mobilising sediment trapped in marginal vegetation communities that drive channel contraction.

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 in-channel features (bankfull flow)
- Bench maintenance flow (1 m depth over benches) where benches exist
- Sediment mobilisation flow (flow that generates shear stress of 1.1 N/m^2 to mobilise coarse sand that accumulates in pools)

The flow components to achieve these flow processes are freshes, bankfull and overbank flows. These requirements are summarised in Table 14.

The intent of the environmental objective to 'provide sufficient bank inundation to reduce salt scolding from saline groundwater seepage' relates to the prevention or reduction of bank weakness resulting from saline groundwater discharge on the banks of the lower Wimmera. The achievement of this objective could be met through provision of sufficient freshwater river flow to equalise the hydraulic gradient across the banks. This would prevent saline extrusion and provide dilution. However, there are a number of issues with this strategy: the timing, rate and level (in the bank) of groundwater extrusion is currently unknown, so estimating the flow requirement is not realistic; there is the potential for unintended consequences of meeting the objective through flow—in particular if long periods of near bankfull flow is required—accelerated bank erosion through long duration high flows, and mortality of existing bank vegetation that cannot withstand the duration of inundation. Instead, a targeting the revegetation of these banks with salt tolerant vegetation would be a more realistic and effective strategy. A discussion of the plant species suitable for this is presented in Section 3.5.

Table 14. Flow requirements to achieve geomorphic objectives

Environmental objective	Flow objective	Flow component	Season	Frequency and duration
Maintain structural integrity of stream bed and channel and prevent loss of channel capacity	Maintain channel capacity through provision of channel-forming flow (assumed to be equivalent to bankfull flow in absence of other data).	Bankfull	Any time	Frequency & duration as per unimpacted flow regime
Prevent excessive stream-bed colonisation by terrestrial species	Provide sufficient depth and duration of inundation of channel bed to prevent encroachment of terrestrial vegetation	Low flow	Refer section 3.5	
Prevent loss of channel diversity through lack of flow variability	Provide out of bank or floodplain flows for maintenance of floodplain features (where present)	Overbank	Any time	Frequency & duration as per unimpacted flow regime
	Maintain channel capacity through provision of channel-forming flow (assumed to be equivalent to bankfull flow in absence of other data).	Bankfull	Any time	Frequency & duration as per unimpacted flow regime
	Provide critical flows for maintenance of pools and benches with – ▪ shear stress of 1.1 N/m^2 to mobilise coarse sand, and ▪ Depth of flow of 1 m over benches.	Bankfull	Any time	Frequency & duration as per unimpacted flow regime
		Fresh	Any time	Frequency & duration as per unimpacted flow regime
Provide sufficient bank inundation to reduce salt scolding from saline groundwater seepage	Vegetation management option recommended to achieve this (refer discussion above)			

System limitations

Maintaining geomorphic processes in the Wimmera catchment cannot be achieved through the provision of the recommended environmental flow regime alone. Other threats and constraints can limit the achievement of objectives in parts of Wimmera system. These limitations are described below.

Riparian vegetation presence and structure

Geomorphic processes are strongly influenced by riparian vegetation. The root systems of trees increase the shear strength of the bank sediments, reducing the likelihood of mass failure. Ground covers 'shield' bank material from high shear stress and reduce hydraulic entrainment (removal) of sediment particles.

Stock exclusion is critical to a healthy, geomorphically effective riparian vegetation community.

Flow limiting infrastructure

The provision of environmental flows is constrained by the capacity of the available infrastructure to deliver water from storages (i.e. channels and gates) and flow capacity constraints in the system (e.g. weirs, levees and bridges). These constraints will have the largest effect on high environmental flow components.

3.9 Water quality

The environmental objectives relating to water quality for the Wimmera system are:

- Achieve State Environment Protection Policy (SEPP) compliant electrical conductivity
- Reduce ecological risks from the mobilisation of saline pools
- Reduce ecological risks from mixing and restratification of saline pools.

Description

Water quality issues identified in the Wimmera system as part of the original FLOWS study included low dissolved oxygen levels, high nutrient concentrations and high salinity levels (SKM 2002). The environmental objectives identified in this review exclusively relate to salinity, although in some cases may be inter-related. High salinity levels can threaten the survival of ecological values within the system (such as populations of fish, vegetation and macroinvertebrates).

There are a number of sites in the Wimmera catchment where salinity or electrical conductivity (EC) levels are monitored (Table 2).

Table 15. Salinity gauges in the Wimmera system

Reach	Gauge ID	Name	Period of record available
Wimmera 2/3	415200	Wimmera River @ Horsham	June 1992 to present
	415201	Wimmera River @ Glenorchy	September 1975 to June 2009
Wimmera 4	415246	Wimmera River @ Lochiel Railway Bridge	September 1984 to present
	415247	Wimmera River @ Tarranyurk	May 1993 to present
	415256	Wimmera River @ U/S Dimboola	June 1989 to present
MacKenzie 1	415202	MacKenzie River @ Wartook Reservoir	September 1975 to June 1988
MacKenzie 3	415251	MacKenzie River @ Mckenzie Creek	February 1993 to December 2003 September 2005 to November 2007
Mt William	415203	Mt William Ck @ Lake Lonsdale	September 1975 to June 2009

Analysis of the salinity data for the Wimmera River sites was undertaken as part of the FLOWS study and found:

- Localised intrusion of saline groundwater contributes significantly to the Wimmera River downstream of Antwerp (the lower part of Reach 4).
- Salinity levels frequently exceed 1,500µS/cm in the Wimmera River (33% of the time at Horsham and 58% of the time at Glenorchy and 92% of the time at Lochiel Railway Bridge).
- Seasonal variation of salinity levels is observed at Lochiel Railway Bridge and Glenorchy (Figure 17). At Lochiel Railway Bridge salinity levels are highest during summer and autumn. At Glenorchy salinity levels are highest during spring and summer.

- Saline pools exist upstream and downstream of Horsham although not all deep water sites in the Wimmera River are saline. The saline pools are believed to be a natural phenomenon exacerbated by land clearing and flow regulation.
- Saline pools are very stable but increased flow can reduce their abundance. Flow events large enough to disrupt saline pool formation usually occur once every winter during July and September hence the pools are probably present for nine months of the year. Under prolonged low flow conditions, groundwater becomes a major proportion of the water in the Wimmera River (SKM 2002).

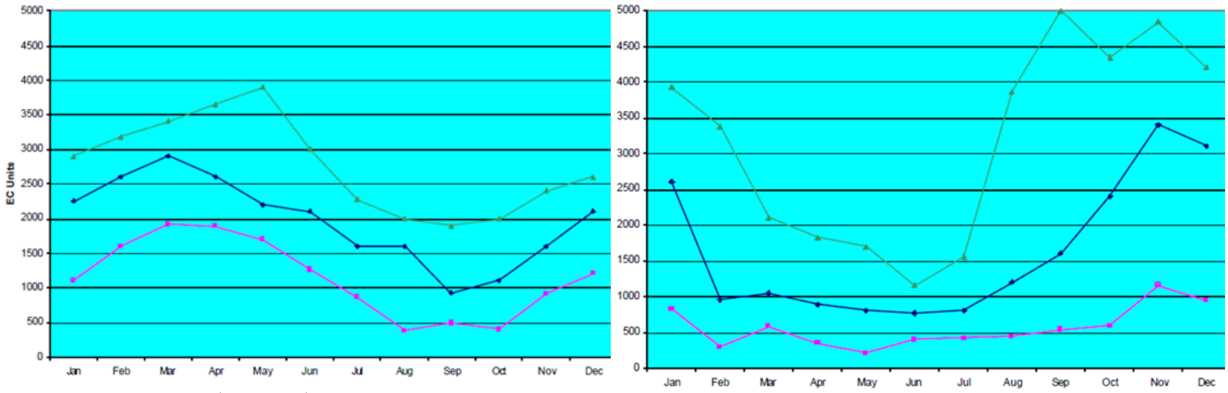


Figure 17. *Median, 10th and 90th percentile salinity levels recorded at Lochiel Railway Bridge (right) and Glenorchy (left)*

Relevant reaches
The objective to achieve SEPP compliant electrical conductivity applies to all reaches in this study except the lower Wimmera (Reach 4). High salinity levels in the lower Wimmera make SEPP compliant electrical conductivity unrealistic, so the objectives to reduce ecological risks associated with saline pools are more appropriate for Reach 4.

Flow objectives
Compliance with SEPP requires electrical conductivity at 25 °C to be less than 1500 µS/cm 75% of the time in the most parts of the Wimmera system (MacKenzie Reach 1, and some of Reach 2 is only required to be 500 µS/cm . The ecological risks associated with high salinity levels have been described separately for fish, vegetation, macroinvertebrates and mammals in Sections 3.4 to 3.7 of this report.

System limitations
The use of environmental flows to achieve salinity objectives in the Wimmera system needs to be done carefully, taking into account the ability of flow to dilute salt concentrations and reduce salinity, and also its ability to transport salt loads from upper to lower parts of the catchment.

Salinity monitoring shows that historically there has been low compliance in the Wimmera River with SEPP targets (SKM 2003). It is expected that achieving this salinity objective with environmental flows only is unlikely to be feasible. Salinity levels are a consequence of a number of influences within the catchment, so the ability to reduce salinity levels is dependent on land management practices, revegetation, the implementation of engineering options (such as groundwater pumping) and restoring areas already affected by salinity.

Notes on salinity units

A number of different units have been used in the literature to report the salinity of fresh waters. Unlike the case with ocean waters, where the Practical Salinity Unit (PSU) is the sole agreed reporting unit, freshwater studies can report salinity directly in terms of gravimetric units (such as mg/L or g/L, depending on salinity, and often called TDS or Total Dissolved Solids) or indirectly in terms of electrical conductivity. The latter approach is most often used, as it is simple and quick and the instrumentation readily available. Nevertheless, measurements of electrical conductivity remain only a surrogate for measurements of TDS and of 'bona fide' salinity. Measurements made in terms of electrical conductivity are cited most often in conductivity units of µS/cm or mS/cm (again, depending on salinity; the correct SI unit would be dS/m) or in EC ('Electrical Conductivity'); µS/cm is interchangeable with EC. Electrical conductivity can be used as a surrogate for salinity only for waters that have an ionic composition the same as ocean water, and over a limited salinity range, and at a given temperature (25^{o}C). They cannot be used for waters of a different ionic composition (e.g. calcium-dominated waters) or with highly saline samples (e.g. from salt lakes or other hypersaline waterbodies). Within these constraints, there are a number of slightly different equations that can be used to convert EC units to gravimetric units, but one used widely for the Murray River (and hence elsewhere in south-eastern Australia for freshwater streams and wetlands) is:

TDS (mg/L) = 0.6 EC (µS/cm @ 25^{o}C)

The values of <1,500 EC and <4,000 EC in the table above therefore correspond to salinities of <900 mg/Land <2,400 mg/L, respectively. Given the likely errors in measurement and conversion, plus the variability in biotic responses, these values are often rounded off to ~1 mg/L and ~2.5 mg/L, respectively.

4 Approach to environmental flow determination

The environmental flow recommendations for this study were determined using relevant hydraulic models and unimpacted hydrology data. The approach adopted to use these is described in the following sections

4.1 Hydraulic modelling

The flow magnitudes required to achieve the environmental objectives were determined using existing hydraulic models where available and, where no existing models were available, using new hydraulic models developed for this study.

Ten HEC-RAS models were used in this study (Table 16). These include four models created for the *Wimmera Glenelg Bulk Entitlement Conversion* report ('the 2003 Study'), four models created as part of the VEFMAP assessments in 2009 and two models created specifically for this study.

Table 16. Hydraulic models used in this study

Reach	Model	Model source
Wimmera 2/3	Gross Bridge	VEFMAP
Wimmera 4	Big Bend	VEFMAP
	Wundersitz	VEFMAP
MacKenzie 1 & 2	BE4 (downstream of the Mount Zero Channel offtake)	SKM study (2003b)
MacKenzie 3	Wonwondah	VEFMAP
Mt William Creek	BE1 (downstream of Lake Lonsdale)	SKM study (2003b)
Bungalally Creek	Bungalally Creek	Newly created
Upper Burnt Creek	BE29 (upstream of Toolondo Channel)	SKM study (2003b)
Lower Burnt Creek	BE52 (downstream of Toolondo Channel)	SKM study (2003b)
Yarriambiack Creek	Yarriambiack Creek	Newly created

No changes have been made to any of existing models for this study. The existing channel geometry, upstream and downstream boundary conditions and hydraulic roughness factors were assumed to be correct. However our review of the models identified varying degrees of suitability of the model for determining environmental flows. The limitations of each of the models used are outlined in the reach by reach section of this report. In general the VEFMAP 2009 models which were created for analysing a range of flows were well suited for use in this study, however the 2003 models were of a lower quality, often with inadequate extent and detail of survey data and questionable boundary conditions. Given the availability of these models no additional hydraulic modelling has been undertaken for these reaches. A future enhancement to this study would be to review and update the 2003 models to improve confidence in the flow recommendations for the relevant reaches.

The new hydraulic models were created for Bungalally Creek and Yarriambiack Creek. Since neither of these reaches have much permanent water, available LiDAR data was used to create the channel and floodplain in a one-dimensional HEC-RAS model. There were three primary variables used in the HEC-RAS model:

- Channel geometry (from LiDAR)
- Upstream and downstream boundary condition (from bed grade)
- Hydraulic roughness (Manning's *n*).

Table 17 lists the boundary conditions and hydraulic roughness adopted for each model. These parameters were adopted on the basis of field observations and aerial photography.

Table 17. Hydraulic parameters adopted in HEC-RAS

Hydraulic parameter	Bungalally Creek	Yarriambiack Creek
Manning's roughness - channel	0.07	0.07
Manning's roughness - floodplain	0.07	0.07
Downstream slope	0.008	0.00025
Upstream slope	0.008	0.00025

4.2 Seasonal frequency and durations

The determination of the number and duration of recommended flow events has been considered in this study for each of four prevailing climatic conditions; drought, dry, average and wet years. These climatic conditions align with those used by the Victorian Environmental Water Holder (VEWH) to prioritise environmental watering actions. The recommendations for wet years, when water resources are abundant, maximise recruitment and connectivity, and conversely the recommendations for drought years, when water is scarce, aim to avoid critical loss and maintain key refuges.

The four climatic conditions used in this study are represented by the four quartiles of the annual flow record. Figure 18 presents the four climatic conditions, demonstrating that wet years are when the total annual flow is exceeded in 25% of years, and drought years are when the total annual flow is exceeded in 75% of years.

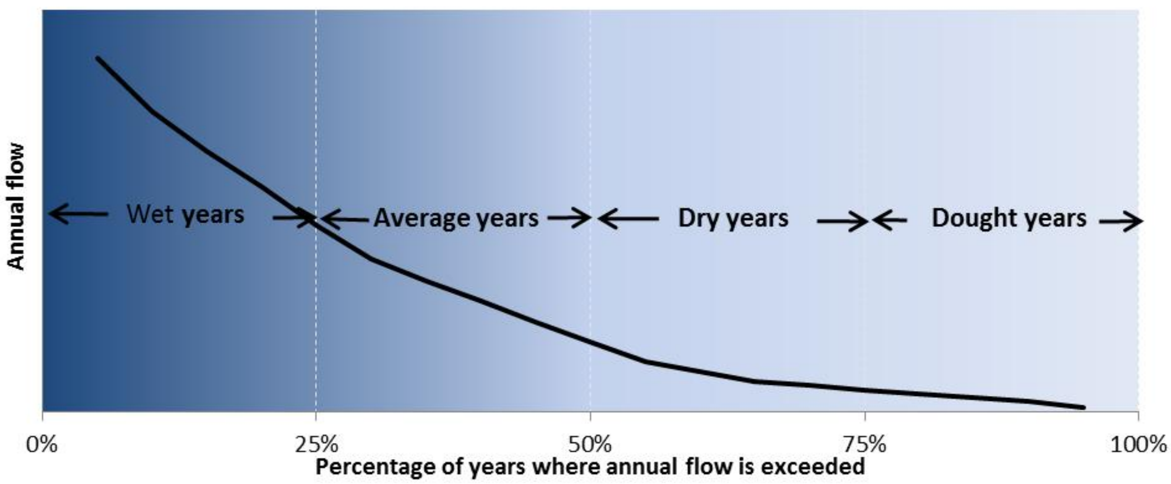


Figure 18. *Climatic conditions – wet, average, dry and drought years*

The climatic conditions were determined based on the 100 year (1903-2004) modelled unimpacted flow data (SKM 2005a). The modelled unimpacted sequence of flow was used as a basis for determining the prevailing climatic condition at three locations:

- Wimmera River at Glenorchy for Wimmera 2 & 3
- Inflows to Lake Wartook for MacKenzie 1 & 2
- Inflows to Lake Lonsdale for Mt William Creek

The annual flow totals used for determining the 'condition' were based on a water year starting on the first of April. This water year start relates to the minimum of the average six monthly moving average flow. In practice the operational water year starts on the first of July. Hence for the subsequent performance analysis the condition has been applied over a 1 July – 30 June year. Annual water totals reported here are also determined over the operational water year (1 July – 30 June).

For each flow recommendation, the number and duration of flow events which equalled or exceeded the recommended flow threshold in the relevant seasonal period was determined for the 100 year modelled unimpacted flow. These flow events were then sorted into each of the four condition years to provide a distribution of the duration and number of the event for each year type (condition). This distribution was used as the basis for determining recommended minimum number and duration of each event. Even within the eight categories (wet and dry season across each of four climatic conditions) there is a large range in the number and duration of many events (particularly small events). The basis of selecting the minimum from this reference distribution was to consider the 'average conditions' across the distribution, and because of the non-normal distribution, we based the selection on the median spell duration. The basis of determining the minimum recommended spell duration and number per season was:

- Spell duration = median duration of spell for the condition type
- Spell number = average number of spells of median length or more for the condition type

The resulting recommendation of total period in 'event' was around 20-30% of the total period in event under unimpacted conditions. This is because the spell length tended to be skewed through a few long events whereby mean spell duration was considerably larger than the median.

For some flow thresholds the direct application of the above approach would produce impractical flow recommendations such as many very short events, or multi-year carryover across years of a certain condition. For example, the median duration of the 'x' ML/d flow event in drought years may be two days in the wet season and four days in the dry season, and the average number of events of this size was four and 0.5 respectively. The direct application of these duration and frequencies requires delivering more but shorter events in the wet season, and a single but twice as long event every other drought year dry season. The spell duration and magnitude recommendations derived on the basis of the unimpacted flow regime were thus pragmatically revised to ensure the recommendations were more practical to deliver and to assess ongoing compliance. These revised spell duration and magnitude values were checked to ensure:

- they still achieved around 20-30% of the total period in event as per the above method
- that they were sufficient to achieve the environmental objective

It should be noted that it is very difficult to ascertain how well the environmental objectives are likely to be achieved hence the approach of using the unimpacted flow regime to estimate appropriate frequency and duration used here. The basis for selecting the median duration was expert judgement by the Technical Panel based on consideration of the known ecological response models in each of their areas of expertise. The resulting approach of applying duration and frequency values to achieve 20-30% of the unimpacted regime 'in event' should be considered expert judgement and may require local reinterpretation to suit conditions.

Since unimpacted daily streamflow data is only available (for a sufficient length) for flows at Glenorchy (Wimmera 2/3), Lake Wartook (MacKenzie 1) and Lake Lonsdale (Mt William Creek), the unimpacted frequency and duration for the other reaches could not be determined using a spells analysis. Instead it has been assumed that the frequency and duration for each flow component of the other reaches is equal to the frequency and duration of that flow component for the most appropriate reach where data is available. For example the frequency and duration recommendations for Wimmera 4 are based on the recommendations for Wimmera 2/3. The assumptions made in the recommendations are noted in the reach by reach sections of this report.

4.3 Rates of rise and fall

The rate of rise and fall relates to the increase and decrease, respectively, of flow between days. These fluctuations in the flow rate serve important ecological and geomorphic functions in a river system. For example, excessive rates of water-level fall can result in fish being stranded by falling waters or bank slumping. It is therefore important that the rate of rise and fall is not significantly altered from the unimpacted flows.

The recommended rates of rise and fall were determined from the modelled unimpacted daily flow data. Since this data is only available for three Wimmera system reaches (Wimmera 2 & 3, MacKenzie 1 and Mt William), rates specific to the other reaches could not be determined. Instead it is assumed that the recommended rates can be applied for equivalent flow components in other reaches. The rates for the lower Wimmera and MacKenzie Rivers can be based on the recommended rates for their upstream locations, noting that with shallower gradients downstream the natural rates of rise and fall are likely to be lower than their upper reaches. Rates for Burnt, Bungalally and Yarriambiack Creeks should be derived from modelled unimpacted hydrology in these reaches as their natural flow patterns are expected to be different from the Wimmera and MacKenzie Rivers and Mt William Creek. In the absence of any data, it is assumed that the rates of rise and fall recommended for the MacKenzie River Reach 1 would provide the most realistic representation of the flow variation in Burnt, Bungalally and Yarriambiack Creeks.

Rates of rise and fall are reported as the maximum rate of permissible rise/fall from one day to the next. For example, if the flow rate was 100 ML/d and the recommended rate of fall is 0.68, the flow on the following day should not be below 68 ML/d. Similarly, if the flow rate was 100 ML/d and the recommended rate of rise is 15.52, the flow on the following day should not exceed 1,552 ML/d.

The recommended maximum rate of rise has been defined as the 90th percentile of the unimpacted rates of rise. Correspondingly the recommended maximum rate of fall has been defined as the 10th percentile of all rates of fall (Table 18 to Table 20). These criteria have been used in many environmental flow studies throughout Victoria. It is important to remember when using the recommended rates of rise and fall that their reliability is limited by the quality of the modelled unimpacted flow data.

Table 18. Rates of rise and fall for the Wimmera River

Component	Flow range in Wimmera 2/3	Rise	Fall
Summer baseflow to low fresh	10-35ML/d	15.52	0.68
Summer low fresh to medium fresh Summer baseflow to winter baseflow	35-100 ML/d	16.63	0.66
Winter baseflow to low winter fresh	100-400 ML/d	18.34	0.65
Low winter fresh to medium winter fresh	400-1300ML/d	15.95	0.65
Medium winter fresh to high fresh	1300-2600 ML/d	20.02	0.65
Winter high fresh to bankfull	2600-4000 ML/d	16.05	0.64
Bankfull to overbank	4000-8000 ML/d	45.89	0.64

Table 19. Rates of rise and fall for MacKenzie River

Component	Flow range in MacKenzie 1	Rise	Fall
Summer baseflow to low fresh Summer baseflow to winter baseflow	2-27 ML/d	4.60	0.70
Summer low fresh to medium fresh Winter baseflow to winter low fresh	27 - 50 ML/d	5.49	0.65
Winter low fresh to high fresh	50-130 ML/d	4.93	0.63
Winter high fresh to bankfull	130-500 ML/d	6.50	0.60
Bankfull to overbank	500-900 ML/d	16.97	0.58

Table 20. Rates of rise and fall for Mt William Creek

Component	Flow range in Mt William	Rise	Fall
Baseflow to summer low fresh	5-20 ML/d	15.64	0.69
Summer low fresh to medium fresh	20-30 ML/d	28.13	0.74
Summer medium fresh to Winter low fresh	30-100 ML/d	44.56	0.55
Winter low fresh to high fresh	100-500 ML/d	10.99	0.41
Winter high fresh to bankfull	500-750 ML/d	10.75	0.30
Bankfull to overbank	750-1500 ML/d	12.05	0.39

4.4 The 'or natural' recommendation

Many of the environmental flow recommendations for each reach listed in Sections 5 and 6 include an 'or natural' requirement to the recommendation. The 'or natural' requirement can be applied to recommended flow magnitudes for baseflow, and to the frequency and/or duration of freshes, bankfull and overbank events.

In practical terms, achievement of the 'or natural' requirement means that in the absence of any upstream extraction/diversion (other than that resulting from land use change or farm dams) the recommendation may still be deemed to be met when the inflows are 'naturally' providing less than the recommended magnitude, frequency or duration. For example,

- if the baseflow recommendation is '10ML/d or natural' but unimpeded inflows are less than 10ML/d, compliance with the environmental flow recommendation is still achieved with a delivery of less than 10ML/d. If the natural baseflow is zero for more days than the recommended cease to flow duration some flow (typically a summer fresh) is still required to break the non-flow period.
- if the unimpeded flows only 'naturally' provide one bankfull per year, and the recommendation is for two to occur, then compliance is still achieved without forcing an additional event to be delivered.

However, if water extraction or diversion in the system prevents the recommended magnitudes, frequency or duration being achieved, then the recommendation is not met (i.e. non compliant).

5 Wimmera River - environmental flow recommendations

5.1 Reach 2 & 3 Wimmera River Huddleston's Weir to MacKenzie River

Summary Reach 2 & 3 characteristics

Flow through the reach is regulated by the operation of Huddleston's Weir which historically diverted most low-medium flows into the Wimmera Inlet Channel for supply to Pine and Taylors Lakes. The weir was recently upgraded to improve the passage of environmental flow releases downstream and Pine Lake is no longer required for water supply purposes. Extended cease to flow periods which occurred in the past, are now less frequent due to passing flow capability provided by infrastructure improvements, water savings from the Wimmera Mallee Pipeline and subsequent Bulk Entitlement rules. Water quality considerations have limited water harvesting at Huddleston's Weir since the Wimmera Mallee Pipeline was completed. The balance between water quality and quantity in Taylor's Lake as well as Bulk Entitlement passing flow rules will determine the extent its operation into the future.

The Wimmera River through this reach consists of a primary channel with intermittent depositional features and numerous flood runners that would be engaged at higher flows. There are two major tributaries joining the Wimmera River in this reach; Mount William Creek (not far downstream of Huddleston's Weir) and Burnt Creek (a short distance upstream from the MacKenzie River). Between these two tributaries, is the distributary Yarriambiack Creek which naturally would have flowed periodically when the Wimmera River was experiencing high flows and under current conditions receives more frequent flow with the aid of a small concrete weir and offtake structure.

Figure 19. *Wimmera River at Faux's Bridge (W2&3) (July 2012)*

Significant environmental values in this reach include populations of freshwater catfish and golden perch. Golden perch and freshwater catfish are highly valued despite being non-endemic to the Wimmera, in Victoria they are recognised as vulnerable, with significantly reduced populations in their native streams.

In the past, bank erosion caused by seepage and unrestricted stock access was observed (SKM 2003). However more recent fencing has removed most stocked access and improvements in channel and riparian condition are occurring. Through the Barrabool Forest near the Mt William Creek confluence the river is in excellent condition.

Recreational values in this reach include Barabool Forest, 'Bigwater' near Longerenong and the weir pool at Horsham.

Environmental objectives
The environmental objectives for Wimmera River Reach 2&3 are:

- Maintain healthy and diverse mosaics of water-dependent vegetation
- Maintain endemic and recreational fish communities and self-sustaining freshwater catfish population
- Achieve SEPP compliant macroinvertebrate communities
- Maintain structural integrity of stream bed and channel and prevent loss of channel capacity
- Achieve SEPP compliant electrical conductivity

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

Environmental flow recommendations

Environmental flow recommendations to achieve the environmental objectives for Reach 2 & 3 of the Wimmera River are summarised in Table 21. Note that a 'cease to flow' component is not required to achieve any of the objectives, however it is recognised that under natural conditions cease to flow events would occur in this reach. Therefore the cease to flow recommendation below provides an upper limit of the total number of days in each year where it is acceptable for flow to cease in the reach.

Table 21. Environmental flow recommendations for Wimmera River Reach 2 & 3

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Cease to flow	Dec-May	0 ML/d	DROUGHT	As infrequently as possible	Less than 21 days in total	Ensure stress on environmental values is not exacerbated beyond natural. Cease to flow periods should be completed with fresh lasting at least 7 days duration.	Durations provide upper limit on the total number of days each year when cease is acceptable based on the number of zero flow days in the unimpacted Glenorchy flow data.
			DRY				
			AVERAGE		Less than 7 days in total		
Baseflow	Dec-May	10 ML/d or natural	ALL	Continuous	Continuous	Maintain edge habitats in deeper pools and runs, and shallow water habitat availability for **macroinvertebrates** and **endemic fish.** Maintains near-permanent inundated stream channel for riparian vegetation and to prevent excessive in stream terrestrial growth.	Riffles are uncommon in this reach, so the summer base flow aims to keep the bed wet and cover leaf packs. There is very little difference between 5 ML/d and 50 ML/d in terms of depth, except for the shallow xs52.64. 10 ML/d is preferable to 5 ML/d as it has some velocity to prevent water quality decline. 4cm depth at xs52.4 is deemed adequate due to the lack of riffles in this reach. If the natural baseflow is zero for more days than the recommended cease to flow duration some flow (typically a summer fresh) is still required to break the non-flow period.
	Jun-Nov	100 ML/d	ALL	Continuous	Continuous	Prevent terrestrialisation of the lower banks from invasive phragmites and provide increased flow and variability to support **fish** movement and diversity of **habitat**.	Wets lowest benches (Gross Bridge xs291 & xs204). 50 ML/d would increase by 100mm rather than 200mm and achieve some flow variability

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Freshes	Dec-May	35-40 ML/d	DROUGHT	2 per period	3 - 7 days	Periodically improving **water quality** by flushing pools during low flows.	The fresh duration must be at least 7 days following a cease to flow period. The unimpacted flow at Glenorchy suggests only one fresh occurs each year, however two are recommended to break cease to flow periods. In dry years, an alternative would be a single 100 ML/d fresh of 2-7 days.
			DRY				
	Dec-May	100 ML/d	AVERAGE	2 per period	2 - 7 days	Provide variable flow during low flow season for **macroinvertebrates (**over wood debris to increase biofilm abundance as a food source), **fish** movement and to maintain **water quality** and diversity of **habitat**.	The fresh duration must be at least 7 days following a cease to flow period. This fresh will increase the baseflow depth by approximately 200 mm.
			WET	3 per period			
	Jun-Nov	400 ML/d	DROUGHT	1 per period	1 day	Provide variable flow during high flow season for **fish** movement and to maintain **water quality** and diversity of **habitat**. Also flushes surface sediments from hard substrates for **macroinvertebrates**.	At least one fresh is required in November for flushing surface substrates. 400 ML/d achieves shear stress of 1.1 N/m^2 in pools (Gross Bridge xs117) and increases winter baseflow by approximately 200mm.
			DRY	3 per period	2 days		
			AVERAGE	5 per period	3 days		
			WET	5 per period	4 days		
	Jun-Nov	1,300 ML/d	DRY	1 per period	1 day	Wets benches, entraining organic debris and promoting diversity of **habitat**.	Gross Bridge xs19.7, xs31.47, xs162.68 and xs325.6 benches inundated
			AVERAGE	2 per period	2 days		
			WET	3 per period	3 days		
	May-Nov	2,600 ML/d	AVERAGE	1 per period	2 days	Disturbs algae/bacteria/organic biofilm present on rock or wood debris for **macroinvertebrates**. Wets higher benches, entraining organic debris and promoting diversity of **habitat**.	At least one fresh is required in May or June for disturbing algae, bacteria and organic biofilm. 2,600 ML/d achieves a velocity of 0.55m/s (xs242.6) to disturb algae and inundated high benches.
			WET	2 per period	3 days		
Bankfull	Any	4,000 ML/d	AVERAGE	1 per period, or natural	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	Refer to inundation extents shown in Figure 20. Bankfull is required 2-3 times per decade for River Red Gum and 2-5 times per decade for Ti Tree communities
			WET	1 per period			
Overbank	Aug-Nov	8,000 ML/d	WET	1 per period or natural	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	Refer to inundation extents shown in Figure 20. Overbank is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

Notes on environmental flow recommendations

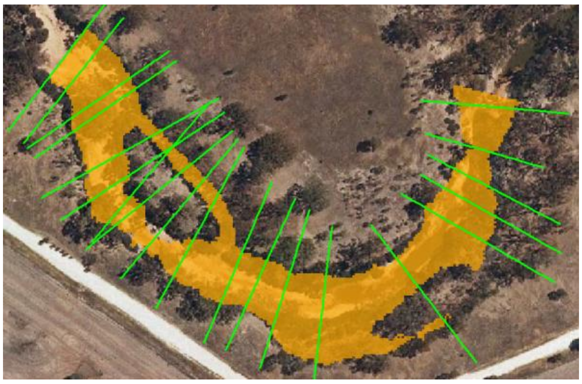
Hydraulic model quality

The Gross Bridge HEC-RAS model which was created as part of the VEFMAP assessments in 2009 was used to identify flow magnitudes for this reach. This model provided a considerably better representation of the reach than the five models created for the original FLOWs study which contain a limited number of surveyed cross sections (5-6 sections compared with 17 sections).

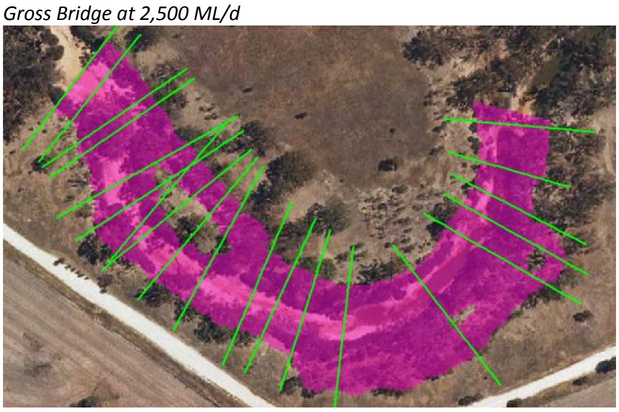
The Gross Bridge model is located in the lower section of this reach, downstream of the Mt William confluence and the Yarriambiack offtake. The reach has relatively homogeneous channel morphology and is predominantly single thread channel as represented in this model. Some sections of multi-section channel exist in the upper part of the reach have not been considered independently.

The model is georeferenced which allowed the results of the modelling to be analysed with respect to other geospatial information, including the LiDAR and aerial imagery. This allowed us to present the inundation extents for the higher magnitude flows as shown below in below.

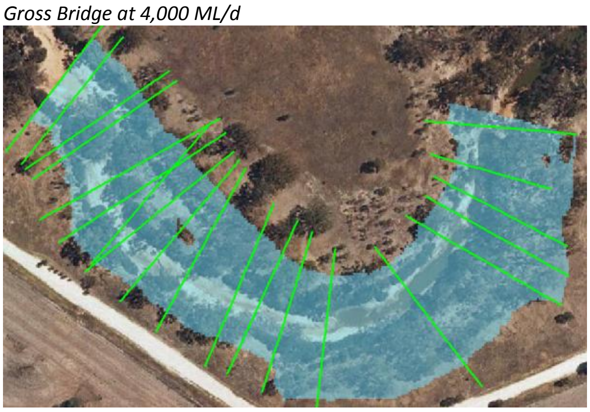
Gross Bridge at 2,500 ML/d



Gross Bridge at 4,000 ML/d



Gross Bridge at 8,000 ML/d



Gross Bridge at 15,000 ML/d

Figure 20. *Modelled inundation extents for Gross Bridge (Wimmera Reach 2/3)*

Compliance point

Proposed compliance point:	415200 Wimmera River at Horsham

The current compliance point for this reach is at Faux Bridge (gauge 415240). Faux Bridge is located mid-way between Huddleston's Weir and the confluence with Mt William Creek. Downstream of the Mt William Creek confluence (e.g. at the hydraulic model site of Gross Bridge or gauge 415239 at Drung Drung), the Wimmera - River flow differs due to:

- additional inflow from Mt William Creek and Burnt Creek
- diversions into Yarriambiack Creek
- losses due to evaporation and seepage

The Faux Bridge gauge has been inactive since 1987 therefore can no longer be used for compliance.

There are currently two active gauges within this reach; 415200 at Horsham and 415239 at Drung Drung.

The Drung Drung gauge represents flow in the Wimmera at a site very close to that used to determine the environmental flow magnitudes (Gross Bridge). The location of this gauge would therefore be appropriate for assessing compliance in this reach. However there are some known issues with the rating curve at Drung Drung which are unlikely to be resolved given the form of the river channel at this site.

The gauge at Horsham is located at the downstream end of the reach, approximately 3 kilometres downstream of a weir pool. In the absence of a reliable rating curve at Drung Drung, it is recommended to use this gauge to assess environmental flow compliance.

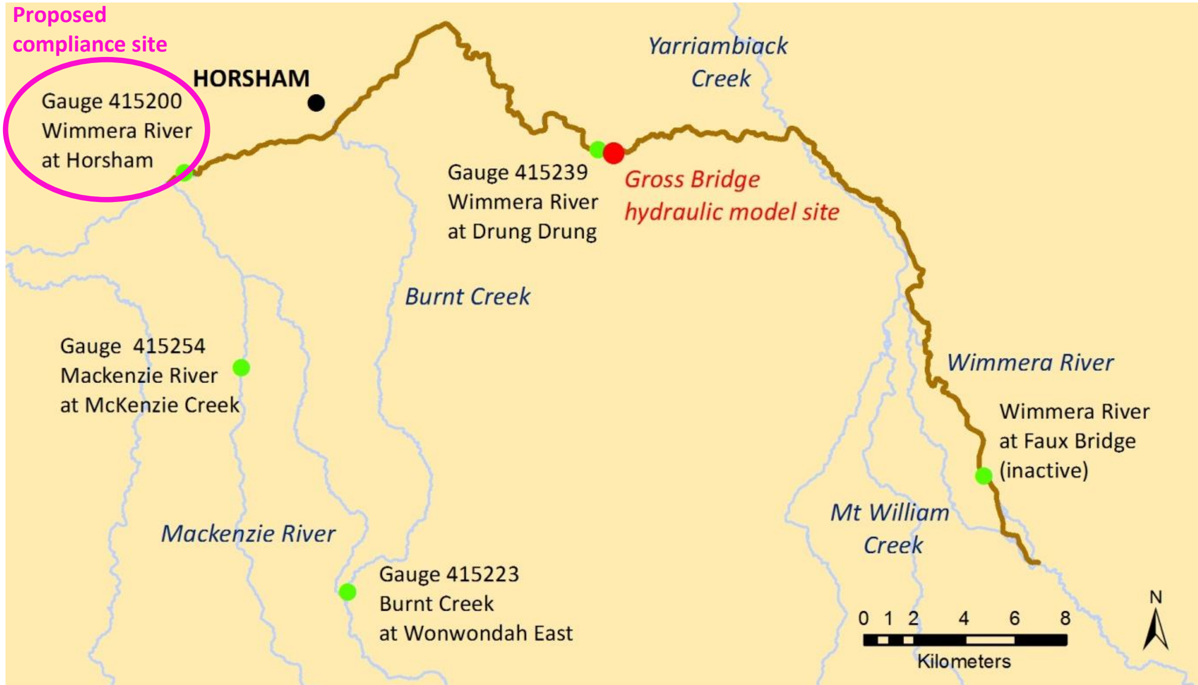


Figure 21. *Location of active flow gauges in Wimmera 2 & 3*

Performance assessment

Performance reporting point:

Gauge	415200
Name	Wimmera River @ Horsham
Status	Open / Active since Jan 1908
Start for assessment period	1 July 1972
End for assessment period	30 June 2011

For performance reporting (Table 22), the flow recommendations presented in Table 21 has been analysed using eFlow Predictor. The years have been sorted to allow grouping of drought, dry, average and wet years and the percentage compliance reflects duration of flow target achieved (baseflow) or the number of flow events achieved (freshes). Note that for this assessment each flow event (i.e. a fresh, bankfull or overbank) has been counted discretely (i.e. a single long event is only one event). No limit on the number of days between events was applied.

Table 22. Performance of environmental flow recommendations for Wimmera River Reach 2 & 3

				Flow Recommendation																	
	Years	Measured Flow (GL)	Shortfall (GL)	Summer Baseflow 10ML/d fo	Winter Baseflow 100 ML/d	Drought winter fresh 400M	Drought Dec-May 35ML x2 f	Dry jun-Nov 1300Mlx1 for	Dry winter fresh 400ML/d	Dry Dec-May 35MLx2 for se	Avg summer fresh 100 ML/d	Avg Jun-Nov fresh 2600ML/	Avg Jun-Nov 1300Ml/dx1 fo	Avg Bankfull 4000ML/d x1	Avg Overbank 8000ML/d x1	Avg june nov fresh 400ml/	wet Summer fresh 100 ML/d	wet winterfresh 400ML/d x	wet Jun-Nov 2600ML/d x 2	Wet Jun-Nov 1300ML/d x3 3	Wet Bankfull 4000ML/d x1
	median	10.0	14.7	35.0	7.0	0.0	100.0	0.0	0.0	0.0	50.0	100.0	100.0	100.0	0.0	30.0	33.0	20.0	100.0	67.0	100.0
	mean	80.5	14.9	42.8	21.2	13.3	53.3	40.0	20.0	40.0	43.8	87.5	87.5	62.5	37.5	32.5	27.3	20.0	72.7	66.7	81.8
Drought	1976	2.2	14.0	16	0	0	0														
	1977	0.7	15.3	0	0	0	0														
	1982	0.7	15.3	19	0	0	100														
	1994	1.6	14.7	66	1	0	100														
	1997	4.9	12.4	100	3	0	100														
	1998	7.7	11.9	100	5	100	100														
	1999	4.5	13.9	35	3	100	100														
	2001	5.6	12.7	68	7	0	100														
	2002	0.4	15.7	0	0	0	0														
	2003	1.8	15.0	34	1	0	100														
	2004	2.1	15.8	54	0	0	100														
	2005	0.3	15.7	0	0	0	0														
	2006	0.0	16.0	0	0	0	0														
	2007	0.2	15.8	0	0	0	0														
	2008	0.0	16.0	0	0	0	0														
Dry	1972	3.5	16.8	64	7			0	0	100											
	1985	0.6	19.1	4	0			0	0	0											
	1990	10.0	13.6	16	3			100	33	0											
	2000	0.8	18.8	25	0			0	0	100											
	2009	12.7	11.1	1	20			100	67	0											
Average	1978	8.4	33.4	19	6						50	0	0	0	0	20					
	1980	40.5	13.7	3	15						0	100	100	100	100	20					
	1984	88.0	13.7	14	29						50	100	100	0	0	20					
	1986	49.4	23.1	57	23						100	100	100	100	0	60					
	1987	22.5	13.8	54	19						100	100	100	100	100	40					
	1991	65.7	15.6	63	34						50	100	100	100	100	20					
	1993	73.5	7.1	93	45						0	100	100	0	0	40					
	1995	83.2	13.6	60	25						0	100	100	100	0	40					
Wet	1973	409.6	2.9	87	87												67	20	100	100	100
	1974	400.5	3.7	96	81												0	40	100	67	100
	1975	197.4	12.4	63	29												33	0	50	67	100
	1979	98.6	32.1	21	26												0	20	50	100	100
	1981	369.2	15.7	1	53												0	40	0	0	0
	1983	211.6	11.6	19	31												33	20	100	100	100
	1988	187.9	5.8	65	71												33	20	100	100	100
	1989	115.0	21.7	54	53												0	20	100	0	0
	1992	335.7	7.8	100	54												67	20	50	100	100
	1996	190.6	22.8	100	57												0	0	100	33	100
	2010	131.1	12.2	100	40												67	20	50	67	100

Colour coding: *occurs 0-10 % of the time; occurs 11-20 % of the time; occurs 21-30 % of the time; occurs 31-40 % of the time; occurs 41-50 % of the time; occurs 51-60 % of the time; occurs 61-70 % of the time; occurs 71-80 % of the time; occurs 81-90 % of the time; occurs 91-100 % of the time*

Eflow Predictor not only records the performance of each flow rule in year of the record, but generates a daily timeseries of the predicted flow regime that would be required to meet the flow recommendations. For each of the flow recommendations considered in this project, the eflow Predictor augmentation options have been set to 'extend' (i.e. if an event has commenced then augmented the flow until the duration requirement is achieved) and 'force' whereby a water release is forced to provide compliance of the flow recommendation. The resulting augmented flow time series quantifies how much additional water would have been required to be delivered over and above that which did pass the performance reporting point to achieve full compliance. This extra water we term 'shortfall' and has been summarised on an annual basis and is shown in Table 22. The flow recommendations vary by season and so too does the recommended environmental water. For the reporting period the mean annual flow was 80.5 GL and the mean shortfall was 14.9 GL. However the shortfall varied tremendously from as little as 2.9 GL in 1973 to 33.4 GL in 1978.

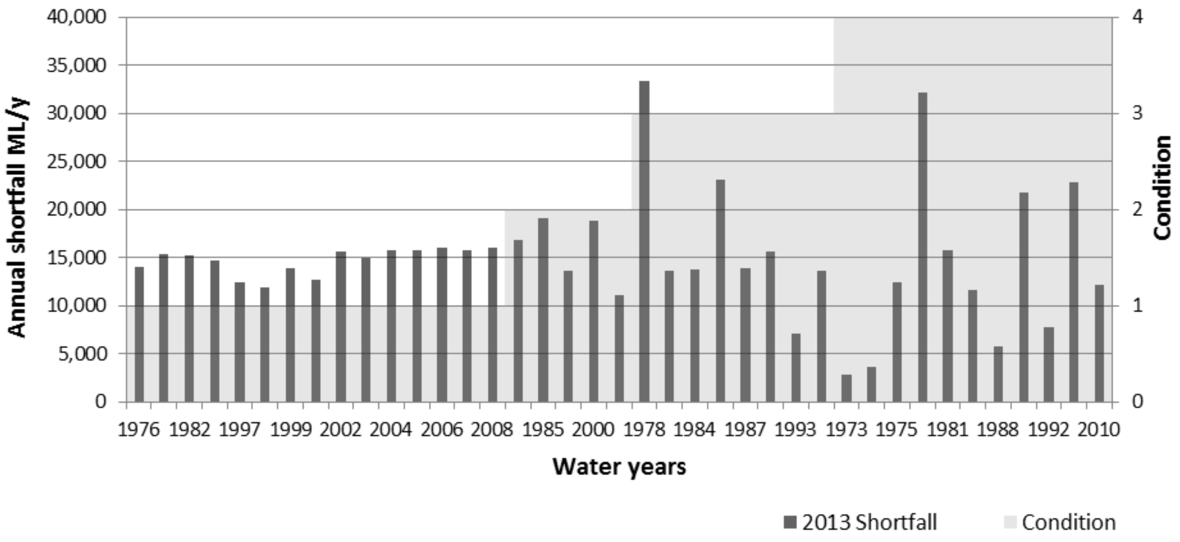


Figure 22. *Total Annual Shortfall across year types for Wimmera 2/3 (1=Drought, 2=Dry, 3=Average, 4=Wet)*

The implications of this shortfall analysis is that, if we assume the assessment period is typical of the current hydrology, then an additional 14.7 GL/yr of environmental water delivered to the compliance point (Drung Drung) will achieve compliance in 50% of all years (Figure 23). In drought years delivery of 15.3 GL would achieve compliance in 50% of years and in wet years delivery of 12.2 GL would achieve compliance in 50% of years.

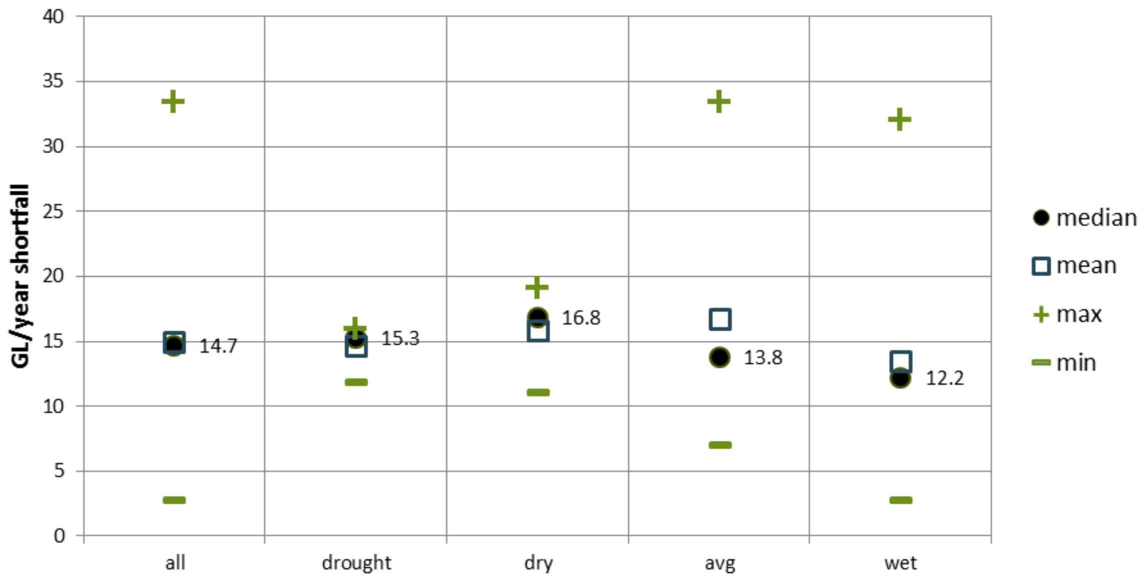


Figure 23. *Wimmera reach W2&3 shortfall summary by Climatic Condition (median values shown)*

This can also be presented in terms of the relative compliance likely to be achieved in any given year for any given environmental water availability (Figure 24). Say for example if 13GL of environmental water is available at the start of a given water year, depending on the prevailing environmental conditions this would be sufficient to achieve full compliance in around 30% of years, which ranges from only 12.5% of average years to around 65% in wet years. If 20GL was available, this would have achieved full compliance in all the drought and dry years, but only around 75% of average and wet years.

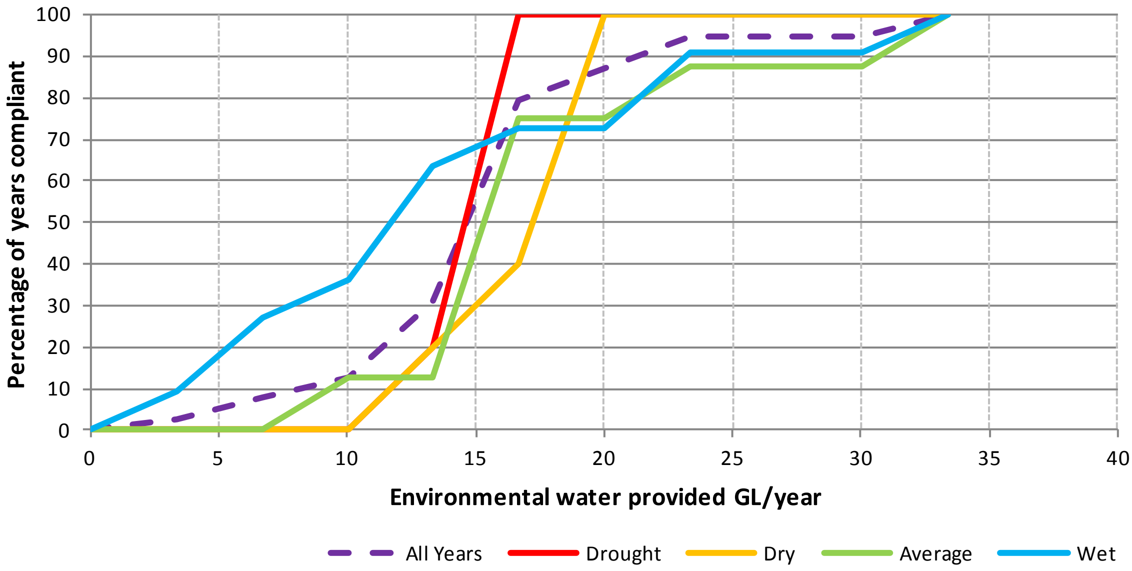


Figure 24. *Percentage of years compliant under different environmental water delivery – Wimmera Reach 2/3*

Summary of performance assessment

All flow conditions: The baseflow provisions apply under all climatic conditions. The mean performance of the summer baseflow was 43% (i.e. on average, 10ML/d was provided for only 40% of time recommended as the minimum allowable). Interestingly the summer baseflow were reasonably well achieved in the drought years of 1997 and 1998. These years followed average and wet years of 1995 and 1996, indicating a summer delivery of stored water from the wet years helped to achieve the summer baseflow requirement.

The winter baseflow had a lower overall performance (mean of 21% compliance), however the performance of the winter baseflow recommendation was more closely aligned to the seasonal conditions (more success in wet years than drought and dry years).

Drought conditions: There are two freshes specified for drought conditions (one summer fresh and one winter fresh) and for each only a single event of a single days length is required, hence compliance is simply a pass or fail. The summer freshes were achieved in about half the years, however the winter fresh was only achieved in 2 out of the 15 drought years assessed.

Dry conditions: There are three freshes specified for dry/drought conditions (one summer fresh and two winter freshes). The summer fresh was achieved in three out of the six dry years (50%), the winter freshes had a lower overall performance (22% and 33%).

Average conditions: Under average climatic conditions most flow recommendations were met in most years, even the bankfull and overbank flow requirements. The small (70ML/d) freshes had the poorest compliance, likely due to the number of events recommended.

Wet conditions: Under wet years there was at least partial compliance across almost all flow components in most years.

Comparison to 2003 study

The revised flow objectives outlined in Table 21 are considerably different from the recommendations provided in the 2003 study (Table 23). This is due to:

- Changes to environmental objectives (the 2003 flow objectives focussed on certain species of fish and vegetation and included flows to trigger spawning of cod and perch compared with the broader revised objectives to maintain healthy and diverse mosaics of water-dependent vegetation and endemic fish communities).
- Revised hydraulic modelling (a more appropriate HEC-RAS model at Gross Bridge was used to determine the magnitude of flows required).

- Introduction of different flow recommendations for wet, dry, drought and average years.

Table 23. 2003 study environmental flow recommendations for Wimmera River Reach 2 (SKM 2003)

Season	Magnitude	Frequency	Duration
December - May	0 ML/d	Annual	17 - 30 days
	6 ML/d	Annual	Continuous (except cease to flow periods)
	>16 ML/d	3 annually	7-15 days
July - November	60 ML/d	Annual	Continuous
	>164 ML/d	2-3 annually	Minimum 14 days
Any time	6,000 ML/d	Annual	Minimum 2 days

The key differences in the new recommendations are:

- The summer baseflow has increased from 6 ML/d to 10 ML/d to ensure there is some velocity passing the site to prevent water quality decline.
- The winter baseflow has also increased from 60 ML/d to 100 ML/d so that the low benches at the modelled site are inundated.
- A number of additional freshes are currently proposed. During dry summers, a fresh is included to flush pools to prevent water quality decline. In wet and average years, larger freshes are proposed to stimulate fish movement and provide a mosaic of spatially and temporally wetted areas of the channel for maintaining diverse channel habitat.
- In spring and winter, a suite of freshes are recommended to wet different benches and maintain channel diversity.
- The bankfull/overbank flow previously recommended (6,000 ML/d) is higher than the new bankfull (4,000 ML/d) and lower than the overbank (8,000 ML/d). Our confidence in these values is higher with the improved hydraulic modelling and the ability to present the results as inundations extents (Figure 20).

Comparison of performance assessment

The underlying method for identifying environmental objectives and the appropriate flow thresholds was similar in this study to the 2003 study. The volumetric changes summarised above are a result of revised environmental objectives and improved hydraulic modelling. The key structural difference between the risk based approach used in this flow study and that used for the 2003 study is in the consideration of the prevailing climatic conditions. For this study, the determination of the number and duration of recommended flow events has been considered for each of four prevailing climatic conditions; drought, dry, average and wet years.

The result of developing flow recommendations that are based on the prevailing flow conditions results in temporally varying flow requirements that are a closer reflection of unimpacted flow regimes (Figure 25) that will build ecosystem resilience in wetter periods and limit decline in dryer times. As a consequence the resulting flow regime is a closer reflection of a unimpacted flow regime, and also more closely reflects the water management environment whereby more water is available in wetter years than dry years.

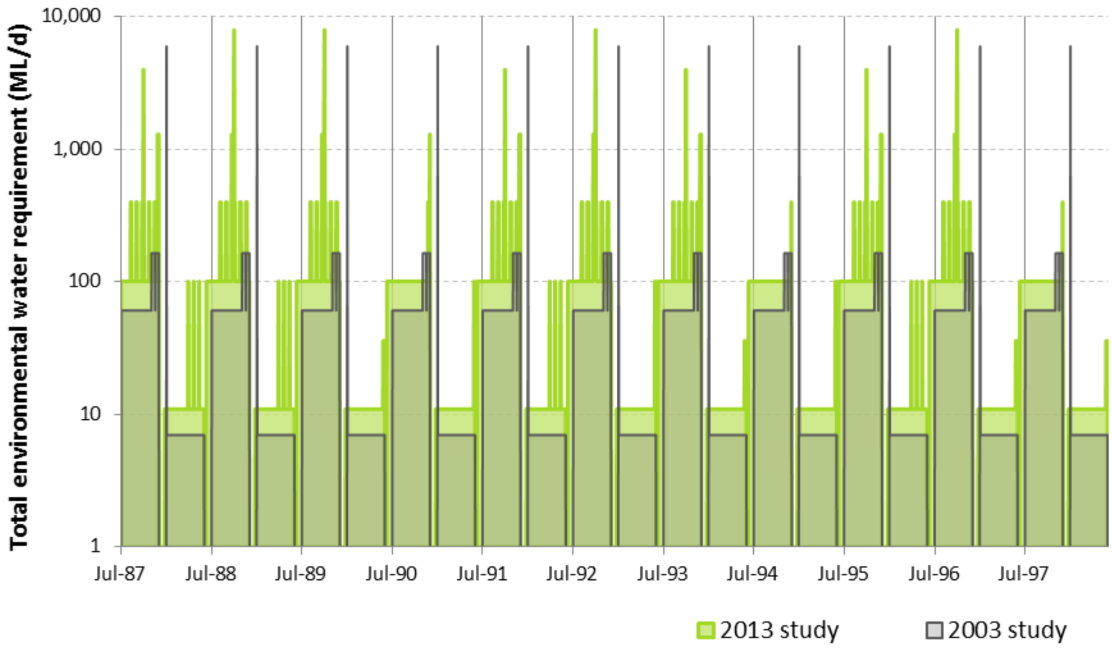


Figure 25. *Comparison of total environmental water recommendations for two studies*

The mean annual environmental water volume based on the recommendations from this study is approximately double the annual volume recommended in the 2003 study (Table 24, Figure 26). However the flow recommendations for this study are contingent on the prevailing weather conditions (drought, dry, average and wet conditions) such that the years of higher environmental water demand correspond with the years of higher water availability. The consequence of considering the prevailing weather conditions in the setting of flow recommendations has resulted in a similar overall mean and median shortfalls to the 2003 study but with less variation in shortfall in wet compared with drought years.

Note that the mean recorded flow at Horsham significantly exceeds the total environmental water recommendations from both studies (80.5 GL/y recorded compared with 18.2 GL/y and 19.6 GL/y), however there is still shortfall due to the timing of the recorded flows not meeting the individual components of the flow recommendations.

Table 24. Shortfall statistics for Wimmera 2/3 at Horsham 1972-2011 (GL/y)

Year type	Total environmental water recommendation		Shortfall in environmental water recommendation		Recorded flow
	2003 study	2013 study	2003 study	2013 study	
All years (mean)	18.2	31.1	11.4	14.9	80.5
All years (median)	18.2	19.6	14.6	14.7	10.0
Largest	18.2	51.9	18.1	33.4	409.6
Smallest	18.2	16.0	0.2	2.9	0.0
Drought (median)	18.2	16.0	17.4	15.3	1.6
Dry (median)	18.2	19.6	15.7	16.8	3.5
Average (median)	18.2	39.4	8.6	13.8	57.5
Wet (median)	18.2	51.9	4.1	12.2	197.4

In the 2003 study, 18.2 GL/y is recommended for every year type (Figure 26). This study recommends flows ranging from 16.0 GL/y in drought years to 51.9 GL/y in wet years, resulting in a mean total flow requirement of 31.1 GL/y across the reporting period. The overall environmental water recommendation for this reach is greater than that in the 2003 for all climatic conditions.

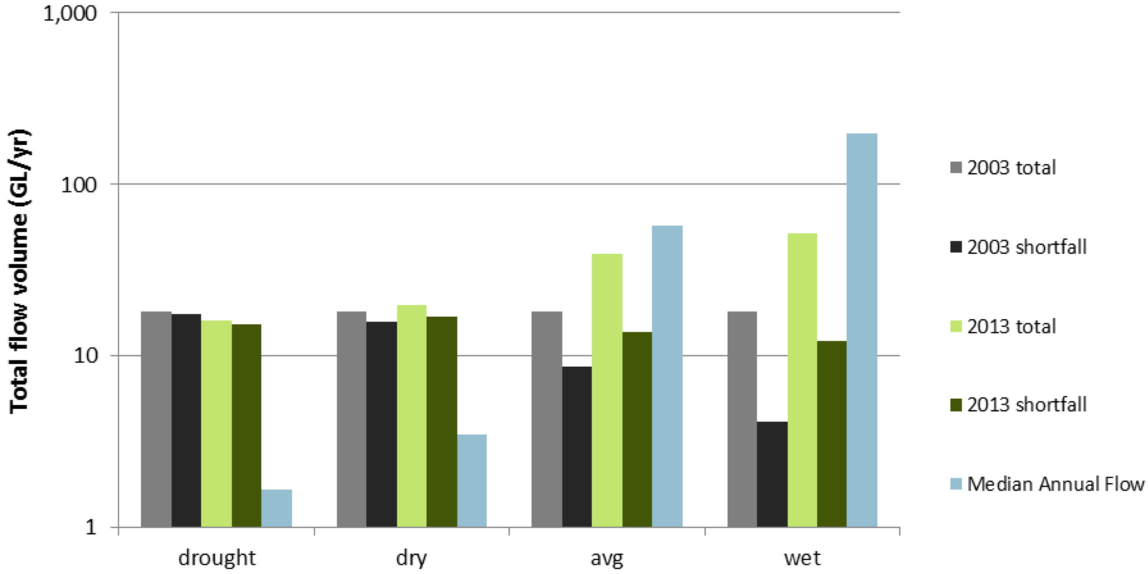


Figure 26. *Total environmental water recommendations by year type (note logarithmic Y axis makes values appear more similar)*

The shortfall in drought and dry years is fairly uniform and similar for the 2003 study and this study's recommendations (Figure 27). This study's recommendations will result in large shortfalls in average and wet years compared with the very small shortfalls under the 2003 study recommendations.

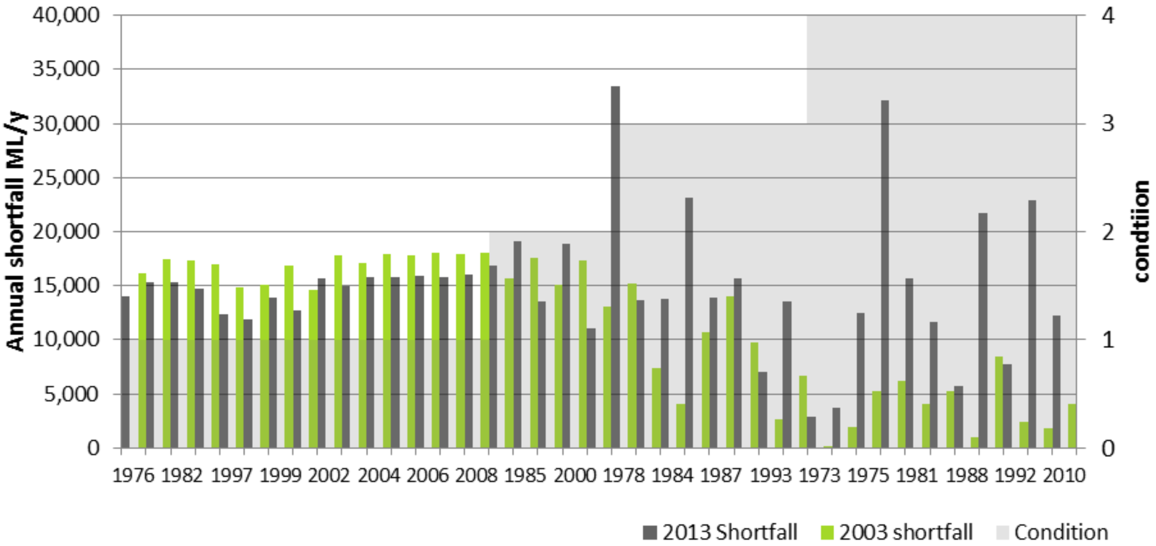


Figure 27. *Annual shortfall comparison – Wimmera 2/3 (1=Drought, 2=Dry, 3=Average, 4=Wet)*

5.2 Reach 4 Wimmera River MacKenzie River to Lake Hindmarsh

Summary Reach 4 characteristics

Downstream of the MacKenzie River confluence, the Wimmera River flows west for a short distance, then north, passing through Dimboola and Jeparit before discharging into Lake Hindmarsh. In wet periods, when Lake Hindmarsh fills, it spills into Outlet Creek which carries flow further north into Lake Albacutya. Exceptionally wet periods lead to Lake Albacutya overflowing into another reach of Outlet Creek and a series of lakes. The reach is characterised by sections with relatively wide shallow primary channel with large permanent pools and other sections of multi-thread channels.

There are some licensed diversions from this reach, although flow volumes are largely controlled by regulation in MacKenzie River, Mt William Creek and the management of Huddleston's Weir and Taylor's Lake. Norton Creek is the major unregulated tributary for this reach. Naturally flow is highly variable through this reach. Past operating conditions significantly altered the flow regime, particularly in dry periods when harvesting from Huddleston's weir would extend the duration of cease to flow events.


Figure 28. *Reach 4: Lake Hindmarsh (left) and Horseshoe Bend Dimboola (right). (July 2012)*

The section of this reach downstream of Polkemmet Bridge (a short distance north-west from Horsham) to the Wirrengren Plain (a terminal lake past Lake Albacutya) has been declared a 'heritage river' under the Victorian *Heritage Rivers Act 1992* for its biological, cultural and recreational values, particularly in association with the terminal lakes. Weir pools at Dimboola and Jeparit are of high social and recreational significance.

Lake Hindmarsh is Victoria's largest freshwater lake, and supports a number of environmentally significant values, including River Red Gum and Black Box communities. During extended dry periods, the lake dries out. Lake Albacutya is Ramsar listed wetland of international conservation significance. It fills only intermittently when Hindmarsh overflows. Both lakes support about 50 species of waterbird including the endangered Great Egret and Freckled Duck (SKM 2002).

In addition to the lakes, other important values in this reach include populations of freshwater catfish and endemic fish including Flathead Gudgeon and Australian Smelt and a stocked population of introduced, but vulnerable in Victoria, Golden Perch, Silver Perch and Freshwater Catfish. Upstream of Dimboola, this reach borders Little Desert National Park, where the uncleared bushland supports a floodplain and riparian zone in excellent condition (SKM 2002).

Large saline pools are located through this reach, resulting from saline groundwater inputs. During the drought, very high salinity levels have been recorded (up to 120,000 µS/cm). Monitoring of salinity profiles in these pools is underway and can be used to better understand the relationship between surface water flows and salinity levels in the pools. Whilst the natural flow regime in this reach would have seen very low summer flows including cease to flow periods, the previous FLOWS study recommended a summer dilution flow for this reach to minimise salt build up in the pools (SKM 2002).

Vegetation and geomorphic condition through this reach is well protected due to much of the riparian zone being crown land (including parks) and investment in freehold land areas. Dieback of native trees from rising saline groundwater levels was exacerbated during the recent drought. In some cases regrowth is now being observed. The dry period also created conditions for phragmites to colonise the dried out channel, however now that is wet, they have been drowned out in a number of locations.

The most significant threat to the terminal lakes is the reduction in frequency and extent of natural flood events from a drying climate.

Figure 29. *Reach 4 at Jeparit (left) and Tarranyurk gauge (right). (July 2012)*

Environmental objectives
The environmental objectives for Wimmera River Reach 4 are:

- Maintain healthy and diverse mosaics of water-dependent vegetation
- Maintain endemic and recreational fish communities and self-sustaining freshwater catfish population
- Achieve SEPP compliant macroinvertebrate communities
- Maintain structural integrity of stream bed and channel and prevent loss of channel capacity
- Provide sufficient bank inundation to reduce salt scolding from saline groundwater seepage
- Reduce ecological risks from the mobilisation of saline pools and mixing and restratification of saline pools

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

Environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for the lower Wimmera River (Reach 4) are summarised in Table 25.

Note that a 'cease to flow' component is not required to achieve any of the objectives, however it is recognised that under natural conditions cease to flow events would occur in this reach. Therefore the cease to flow recommendation below provides an upper limit of the total number of days in each year where it is acceptable for flow to cease in the reach.

Note: Unimpacted modelled hydrology was not available for this reach, therefore the seasonal frequency and durations have been derived from the unimpacted Wimmera River flow data at Glenorchy (Reach 2/3 of the Wimmera).   If/when unimpacted modelled flow data becomes available it is recommended that spells analysis is undertaken to update the recommended frequencies and durations for seasonal conditions.

Table 25. Environmental flow recommendations for Wimmera River Reach 4

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Cease to flow	Dec-May	0 ML/d	DROUGHT	As infrequently as possible	Less than 21 days in total	Ensure stress on environmental values is not exacerbated beyond the point of no return. Cease to flow periods should be completed with fresh lasting at least 7 days duration.	Durations provide upper limit on the total number of days each year when cease is acceptable based on the number of zero flow days in the unimpacted Glenorchy flow data.
			DRY				
			AVERAGE		Less than 7 days in total		
Baseflow	Dec-May	15 ML/d or natural	ALL	Continuous	Continuous	Maintain edge habitats in deeper pools and runs, and shallow water habitat availability for **macroinvertebrates** and **endemic fish.** Maintains near-permanent inundated stream channel for riparian vegetation and to prevent excessive in stream terrestrial species growth.	15 ML/d is adequate for shallow water habitat availability (at shallow section Wundersitz xs612) and depth is greater than 1.5m in main pools (Wundersitz xs101 & xs567, Big Bend xs414) provided there is continuous flow. If the natural baseflow is zero for more days than the recommended cease to flow duration some flow (typically a summer fresh) is still required to break the non-flow period.
	Jun-Nov	30 ML/d	ALL	Continuous	Continuous	Provides flow variability to maintain diversity of habitats.	Increases depth and edge wetting from summer baseflow, most significantly at Wundersitz xs249 and Big Bend xs243. Increases depth by 8-18cm.
Freshes	Dec-May	70 ML/d	DROUGHT	1 per period	2-7 days	Prevent **water quality** decline by flushing pools during low flows. Provide variable flow during low flow season for **macroinvertebrates (**over wood debris to increase biofilm abundance as a food source), **fish** movement and to maintain **water quality** and diversity of **habitat**.	The fresh duration must be at least 7 days following a cease to flow period. 40 ML/d would be sufficient to increases flow depth (from 15ML/d) by 11-25cm, however not sufficient for pool turnover. The recommended frequency and duration were derived from (unimpacted) 100 ML/d summer freshes at Glenorchy.
			DRY	2 per period			
			AVERAGE				
			WET	3 per period			
	Jun-Nov	70 ML/d	DROUGHT	1 per period	1 day	Increase the baseflow water depth by to provide stimulus for **fish movement** (not required in drought years, frequently required in wet years). Provide flow variability to maintain **water quality** and diversity of **fish habitats**.	Increases flow depth (from 30 ML/d) by 16-22cm. The recommended frequency and duration were derived from (unimpacted) 400 ML/d winter freshes at Glenorchy.
			DRY	3 per period	2 days		
			AVERAGE	5 per period	3 days		
			WET	5 per period	4 days		
	Jun–Nov	200 ML/d	DRY	1 per period	1 day	Wets lower benches, entraining organic debris and promoting diversity of **habitat**.	Inundates benches at Wundersitz (xs569 & xs352) and increases edge coverage at Big Bend. The recommended frequency and duration were derived from (unimpacted) 1,300 ML/d winter freshes at Glenorchy.
			AVERAGE	2 per period	2 days		
			WET	3 per period	3 days		

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Freshes	Jun–Nov	1300 ML/d	AVERAGE	1 per period	2 days	Flush surface sediments from hard substrates to support **macroinvertebrates**. Wets higher benches, entraining organic debris and promoting diversity of **habitat**.	At least one fresh required in November for flushing surface substrates. 1,300 ML/d achieves shear stress of 1.1N/m2 at Big Bend and approximately a third of the Wundersitz cross-sections (9,000 ML/d required to achieve at all sites is not realistic). Also inundates benches at Big Bend (e.g. xs636, xs515) and Wundersitz (xs567). The recommended frequency and duration were derived from (unimpacted) 2,600 ML/d winter freshes at Glenorchy.
			WET	2 per period	3 days		
Bankfull	Any	2,000 ML/d	AVERAGE	1 per period, or natural	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	Refer to inundation extents shown inFigure 20 Figure 30. Bankfull is required 2-3 times per decade for River Red Gum and 2-5 times per decade for Ti Tree communities
			WET	1 per period			
Overbank	Aug-Nov	6,000 ML/d	WET	1 per period or natural	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	Refer to inundation extents shown in Figure 30. Overbank is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

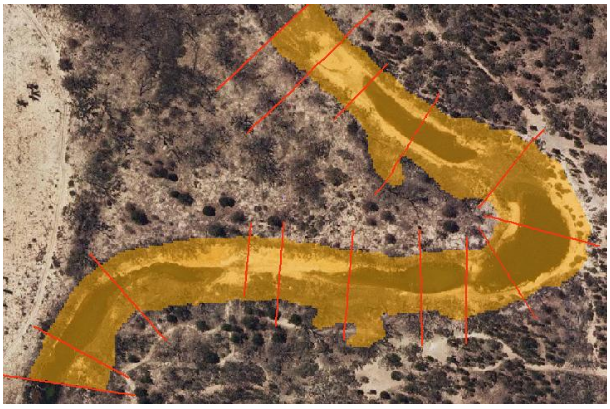
Notes on environmental flow recommendations

Hydraulic model quality

The flow magnitudes recommended for this reach were determined from two HEC-RAS models; Big Bend and Wundersitz. Both these models were created as part of the VEFMAP assessments in 2009. They are georeferenced, which allowed their results to be projected against aerial photography and LiDAR (Figure 10). They each contain an adequate number of surveyed cross sections to provide a good representation for determining environmental flows. The two other models used in the 2002 FLOWS study are not georeferenced, and contain only 6 cross sections, so were not used to revise the environmental flow recommendations.

The Big Bend model represents a section of single-thread channel similar to the sections of single-thread channel through the reach. It does represent one of the tighter meander bend leading to a more pronounced bench formation than exists elsewhere. The Wundersitz model represents a part of the reach with multiple channels and flood runners. Since the reach contains a mix of multi-channel and single-channel sections both models were considered when determining flow requirements.

Big Bend at 2,000 ML/d



Big Bend at 6,000 ML/d

Wundersitz at 2,000 ML/d

Wundersitz at 6,000 ML/d

Figure 30. *Modelled inundations on Wimmera Reach 4*

Hydrology
For this site the gauge used for assessment was 415246 (Wimmera River @ Lochiel Railway Bridge) which is an open gauge with continuous records available from February 1987. This period is dominated by the extended dry period in the 2000s and includes 12 drought years, four dry years, five average and five wet years. The limited length and dominance of below median conditions for the available flow record means that the reporting by climatic condition completed here doesn't necessarily demonstrate the full distribution of likely outcomes.

Compliance point

Proposed compliance point:	415246 Wimmera River at Lochiel

The compliance point proposed in the 2003 report for this reach the gauge at Dimboola (415243). However this gauge has been inactive for some years now and is influenced by its location within a weir pool. The active flow gauges within this reach are located upstream of Dimboola (415256), at Lochiel (415246) and Tarranyurk (415247) (Figure 31). System losses through this reach are considerable, and there are no significant inflows downstream of the MacKenzie River confluence, so that gauged flows in the lower part of this reach (i.e. at Tarranyurk) are often smaller than those upstream (i.e. at Lochiel). The recommended environmental flow magnitudes are based around the hydraulic modelling sites of Wundersitz and Big Bend, so a compliance point close to these would be appropriate. The gauge at Lochiel Railway Bridge (415246) would be most appropriate given its location a short distance upstream of the Wundersitz site. This is a fairly conservative approach for achieving flows at the hydraulic modelling sites given that if the flow magnitude is met at Lochiel it may be assumed that it was also achieved further upstream at the Big Bend site. However it will not provide much confidence around flows in the lower part of this reach (i.e. at Tarranyurk and Jeparit). It is understood that low flow deliveries at Lochiel will have minimal impact at Tarranyurk due to high losses through this part of the reach. If low flow objectives are to be achieved downstream of Wundersitz, the baseflow compliance will need to be higher than recommended in Table 25 at Lochiel.

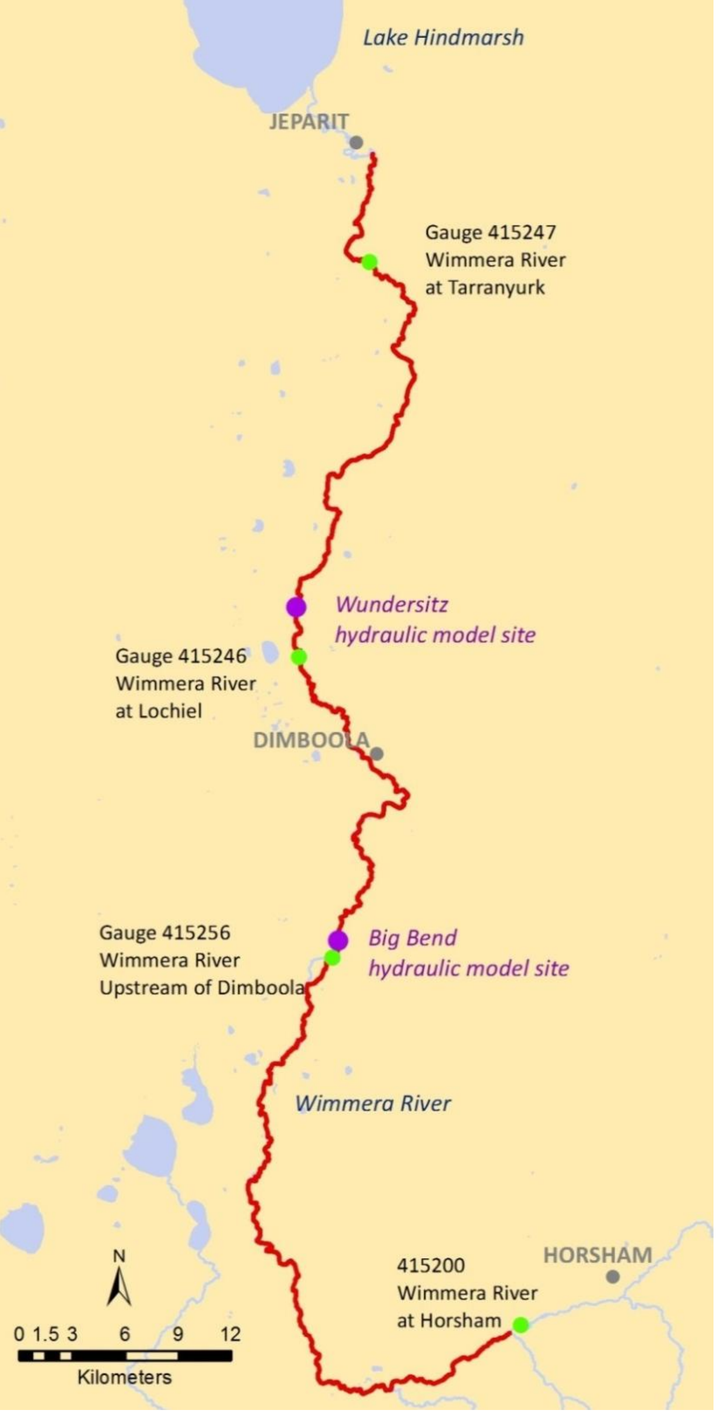


Figure 31. *Location of active flow gauges in Wimmera 4*

Performance assessment

Performance reporting point:

Gauge	415246
Name	Wimmera River @ Lochiel Railway Bridge
Status	Open / Active since 28 Feb 1987
Start for assessment period	1 July 1987
End for assessment period	30 June 2011

For performance reporting (Table 26), the flow recommendations presented in Table 25 has been analysed using eFlow Predictor. The years have been sorted to allow grouping of drought, dry, average and wet years and the percentage compliance reflects duration of flow target achieved (baseflow) or the number of flow events achieved (freshes). Note that for this assessment each flow event (i.e. a fresh, bankfull or overbank) has been counted discreetly (i.e. a single long event is only one event). No limit on the number of days between events was applied.

Table 26. Performance of environmental flow recommendations for Wimmera River Reach 4

				Flow Recommendation																	
		Mean annual flow (GL/y)	Shortfall (GL/y)	Summer Baseflow 15ML/d fo	Winter Baseflow 30 ML/d f	Drought summer fresh 70 M	Drought winter fresh 70ML	Dry Summer fresh 70ML/d x	Dry jun-Nov fresh 200ML/d	Dry winter fresh 70ML/d x	Avg Summer Fresh 70ML/d x	Avg Jun-Nov fresh 200ML/d	Avg Jun-Nov 1300Ml/dx1 fo	Avg Bankfull 2000ML/d x1	Avg Overbank 6000ML/d x1	Avg june nov fresh 70ml/d	wet Summer fresh 70 ML/d	wet winterfresh 70ML/d x	wet Jun-Nov 200ML/d x 3 f	Wet Jun-Nov 1300ML/d x2 3	Wet Bankfull 2000ML/d x1
median		6.2	3.5	17.0	20.5	0.0	0.0	0.0	100.0	67.0	25.0	100.0	100.0	100.0	100.0	30.0	67.0	20.0	67.0	100.0	100.0
mean		59.8	3.3	31.3	31.1	25.0	33.3	0.0	66.7	44.7	37.5	100.0	100.0	75.0	75.0	30.0	40.2	24.0	60.0	70.0	80.0
Drought	1994	1.2	3.5	51	0	0	0														
	1997	5.1	2.2	99	30	100	100														
	1998	7.2	2.1	79	49	0	100														
	1999	4.7	3.4	7	6	0	100														
	2001	4.0	4.2	51	7	100	100														
	2002	0.1	4.6	0	0	0	0														
	2003	0.2	4.4	5	0	100	0														
	2004	0.2	4.7	26	0	0	0														
	2005	0.0	4.7	0	0	0	0														
	2006	0.0	4.7	0	0	0	0														
	2007	0.0	4.7	0	0	0	0														
	2008	0.0	4.7	0	0	0	0														
Dry	1990	9.4	2.3	0	21			0	100	67											
	2000	1.0	4.2	14	4			0	0	0											
	2009	9.9	3.4	0	20			0	100	67											
Average	1987	32.9	2.0	39	51						100	100	100	100	100	20					
	1991	87.6	4.0	9	54						50	100	100	100	100	20					
	1993	82.2	2.6	52	71						0	100	100	0	0	40					
	1995	106.3	1.6	25	52						0	100	100	100	100	40					
Wet	1988	204.8	0.7	20	82												67	20	100	100	100
	1989	120.3	1.2	9	90												0	40	67	0	0
	1992	353.5	2.1	100	85												67	20	33	100	100
	1996	231.7	5.3	64	71												0	20	33	50	100
	2010	173.4	2.2	100	54												67	20	67	100	100

Colour coding: *occurs 0-10 % of the time; occurs 11-20 % of the time; occurs 21-30 % of the time; occurs 31-40 % of the time; occurs 41-50 % of the time; occurs 51-60 % of the time; occurs 61-70 % of the time; occurs 71-80 % of the time; occurs 81-90 % of the time; occurs 91-100 % of the time*

The 'short fall' (i.e. how much extra water would have been required to be delivered over and above that which did pass the compliance point to achieve full compliance) has been summarised on an annual basis (Table 26, Figure 32). The flow recommendations vary by season and so too does the recommended environmental water. For the reporting period the mean annual flow was 59.8 GL and the mean shortfall was 3.3 GL. However the shortfall varied tremendously from as little as 700 ML in 1988 to 5.63 GL in 1996.

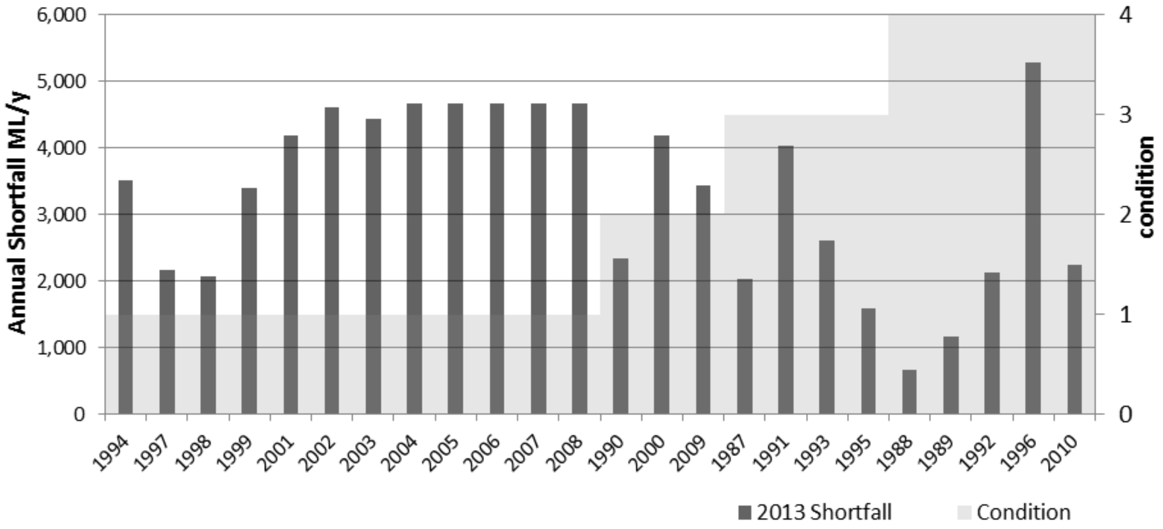


Figure 32. *Total Annual Shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet) (W4)*

The implications of this shortfall analysis is that, if we assume the assessment period is typical of the current hydrology, then an additional 3.5 GL/yr of environmental water delivered will achieve compliance in 50% of all years (Figure 33). In drought years delivery of 4.5 GL would achieve compliance in 50% of years and in wet years delivery of 2.1 GL would achieve compliance in 50% of years.

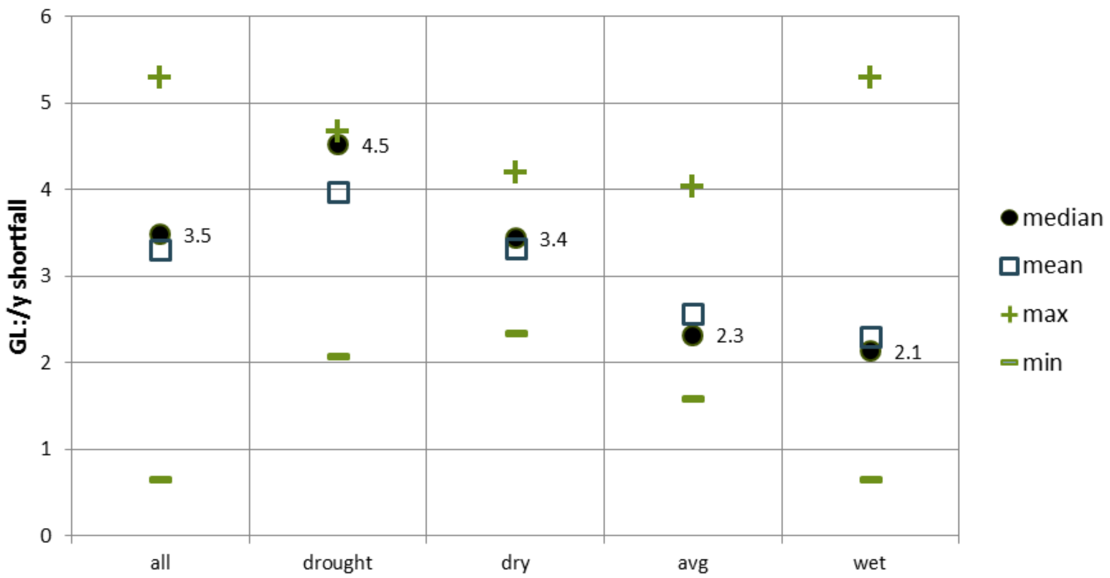


Figure 33. *Wimmera Reach 4 shortfall summary by climatic condition*

This can also be presented in terms of the relative compliance likely to be achieved in any given year for any given environmental water availability (Figure 34). Say for example if 3.5 GL of environmental water is available at the start of a given water year, depending on the prevailing environmental conditions this would be sufficient to achieve full compliance in around 40% of years, which ranges from only 17% of drought years to around 80% in wet years.

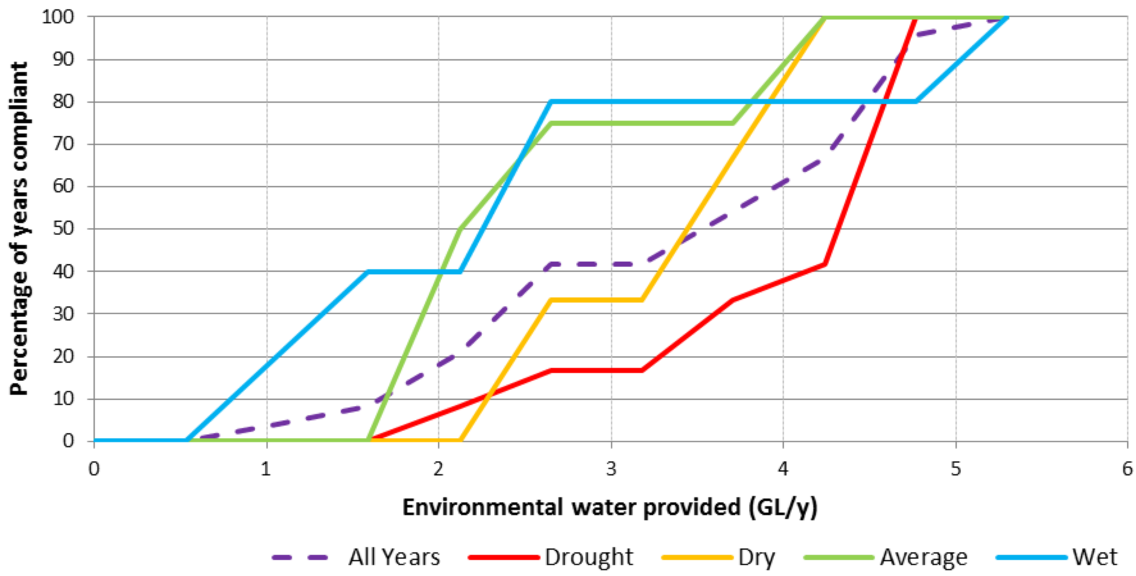


Figure 34. *Percentage of years compliant under different environmental water delivery (W4)*

Summary of performance [9]

All flow conditions: The baseflow provisions apply under all climatic conditions. The mean performance of the summer baseflow was 31% (i.e. on average, 15ML/d was provided for one third of time recommended as the minimum allowable). Interestingly the summer baseflow were reasonably well achieved in the drought years of 1997 and 1998. These years followed average and wet years of 1995 and 1996, indicating a summer delivery of stored water from the wet years helped to achieve the summer baseflow requirement. In these years summer was the only time that releases could take place, due to the channels being run at full capacity to deliver water during winter and spring.

The winter baseflow had a similar overall performance (mean of 31% compliance), however the performance of the winter baseflow recommendation was more closely aligned to the seasonal conditions (more success in wet years than drought and dry years).

Drought conditions: There are two freshes specified for drought conditions (one summer fresh and one winter fresh) and for each only a single event of a single days length is required, hence compliance is simply a pass or fail. These freshes were provided in 25-33% of years. The water requirements in drought years are relatively low compared to average and wet years.

Dry conditions: In dry years the poorest achieved flow recommendation was the summer freshes (70ML/d). Other flow recommendations (during winter and spring) were met across most dry years.

Average conditions: Under average climatic conditions most flow recommendations were met in most years, even the bankfull and overbank flow requirements. The small (70ML/d) freshes had the poorest compliance, likely due to the number of events recommended.

Wet conditions: Under wet years there was at least partial compliance across almost all flow components in most years.

Comparison to 2003 study

The revised flow objectives outlined in Table 25 are considerably different from the recommendations provided in the 2003 study (Table 27). This is due to:

[9] It is worth noting that compliance for this reach (Wimmera 4) is fairly high compared with the upstream reach (Wimmera 2/3). This is a consequence of the higher recommended winter flows in the upstream reach (e.g. baseflow is 100 ML/d compared with 30 ML/d and bankfull flow is 4,000 ML/d compared with 2,000 ML/d). The higher flow magnitudes are predominantly due to the different hydraulic conditions in the reaches rather than different objectives for the reaches.

- Changes to environmental objectives (the 2003 flow objectives focussed on certain species of fish and vegetation flows to trigger spawning of stocked species compared with the broader revised objectives to maintain healthy and diverse mosaics of water-dependent vegetation and endemic fish communities).
- Revised hydraulic modelling (more appropriate HEC-RAS models at Wundersitz and Big Bend were used to determine the magnitude of flows required).
- Introduction of different flow recommendations for wet, dry, drought and average years.

Table 27. 2003 study environmental flow recommendations for Wimmera River Reach 4 (SKM 2003)

Season	Magnitude	Frequency	Duration
December - May	0 ML/d	Annual	5-24 days
	>5 ML/d	Annual	Continuous (except cease to flow periods)
	>20 ML/d	4 annually	7-15 days
July - November	>34 ML/d	Annual	continuous
	>334 ML/d	5 annually	Minimum 14 days
Any time	3,000 ML/d	Annual	Minimum 2 days
	6,000 ML/d	Annual	3-5 days

The key differences in the new recommendations are:

- The summer baseflow magnitude is higher (15 ML/d compared to 5 ML/d) and the winter baseflow magnitude is slightly lower (30 ML/d).
- Higher summer freshes are included (70 ML/d compared with 20 ML/d), while the number of recommended freshes ranges from 1 to 3 per year depending on the prevailing climatic conditions.
- A mosaic of different winter freshes are included (ranging from 70 ML/d to 1,300 ML/d).
- A lower bankfull flow of 2,000 ML/d is included and only specified to occur in average and wet years.
- The overbank flow (6,000 ML/d) is recommended to occur only in wet years, and may occur for only one day.

Comparison of performance assessment
The result of developing flow recommendations that are based on the prevailing flow conditions results in temporally varying flow requirements that are a closer reflection of unimpacted flow regimes (Figure 35) that will build ecosystem resilience in wetter periods and limit decline in dryer times. As a consequence the resulting flow regime is a closer reflection of an unimpacted flow regime, and also more closely reflects the water management environment whereby more water is available in wetter years than dry years.

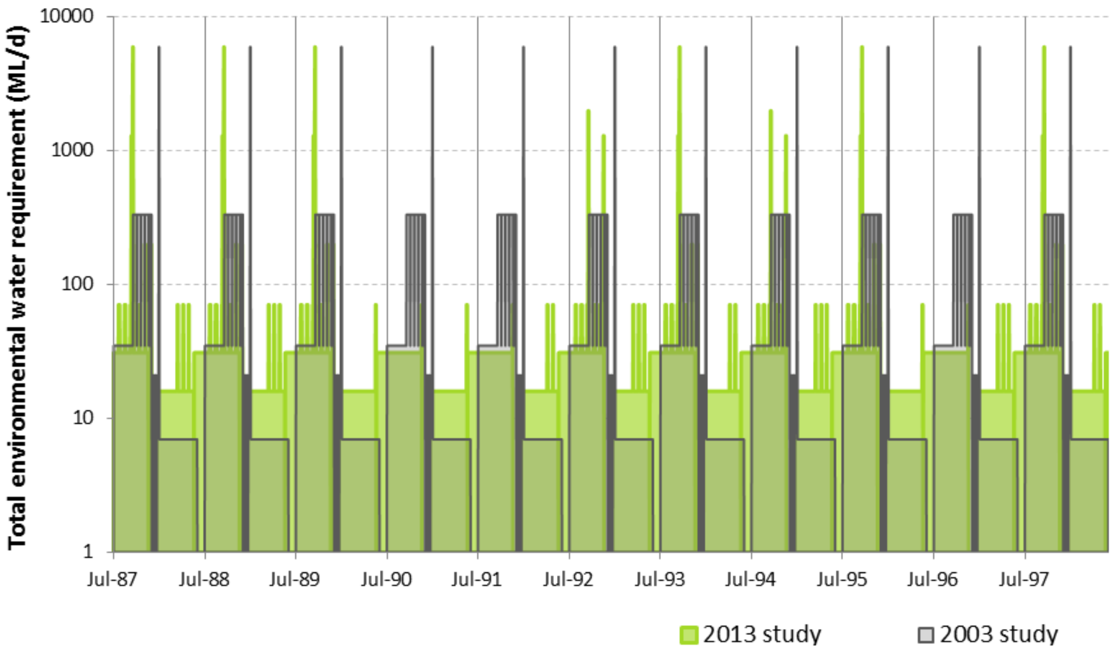


Figure 35. *Comparison of total environmental water recommendations for two studies (W4)*

The volumes required given the overall total environmental water recommendations as part of this study are around 31% less than those recommended as part of the 2003 project flow recommendations (Table 28, Figure 36). However the flow recommendations for this study are contingent on the prevailing weather conditions (drought, dry, average and wet conditions) such that the years of higher environmental water demand correspond with the years of higher water availability. The consequence of considering the prevailing weather conditions in the setting of flow recommendations has resulted in an overall reduction in the flow shortfall of around 90%.

Note that the mean recorded flow at Lochiel Railway significantly exceeds the total environmental water recommendations from this study (59.8 GL/y recorded compared with 10.8 GL/y), however there is still some shortfall due to the timing of the recorded flows not meeting the individual components of the flow recommendations.

Table 28. Shortfall statistics for Wimmera 4 at Lochiel Railway 1987 – 2010 (GL/y)

Year type	Total environmental water recommendation		Shortfall in environmental water recommendation		Recorded flow
	2003 study	2013 study	2003 study	2013 study	
All years (mean)	43.5	10.8	34.0	3.3	59.8
All years (median)	43.5	5.2	41.2	3.5	6.2
Largest	43.5	26.2	44.2	5.3	353.5
Smallest	43.5	4.7	1.9	0.7	0.0
Drought (median)	43.5	4.7	44.1	4.5	0.2
Dry (median)	43.5	5.2	41.7	3.4	9.4
Average (median)	43.5	15.7	27.3	2.3	84.9
Wet (median)	43.5	26.2	12.1	2.1	204.8

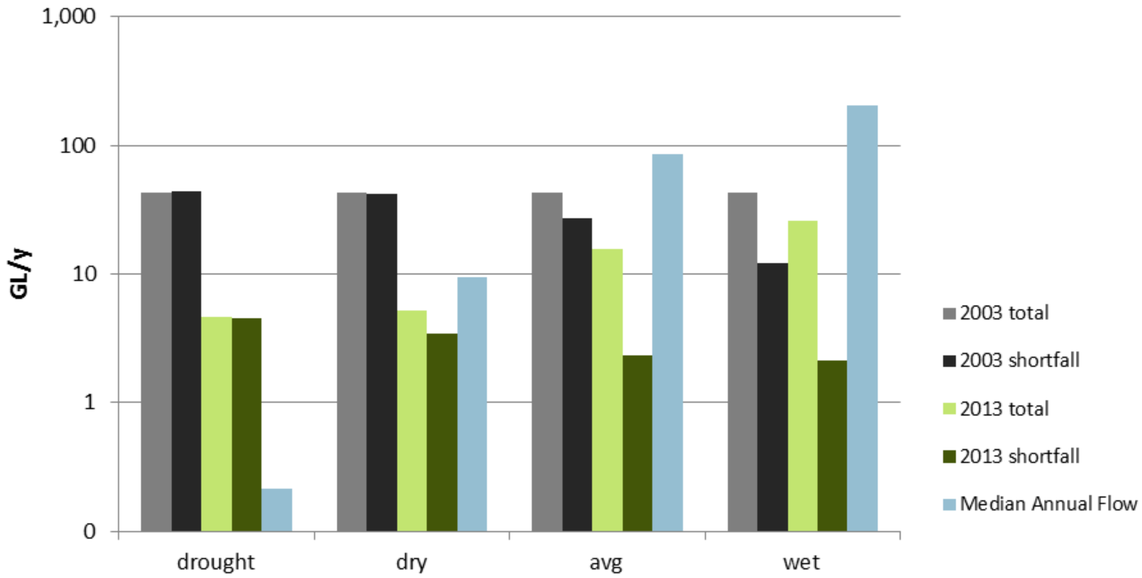


Figure 36. *Total environmental water recommendations by year type (note logarithmic Y axis makes values appear more similar).*

For the 2003 study, 43.5 GL/y is recommended in every year (Figure 36). This study recommends flows ranging from 4.7 GL/y in drought years to 26.2 GL/y in wet years, resulting in a mean total flow requirement of 10.8 GL/y across the reporting period. The overall environmental water recommendation for this reach is less than for previous studies. However, because the flow recommendations vary between the prevailing year types, the relative shortfall (difference between flow recommendation and actual water delivered) is much lower again for this study.

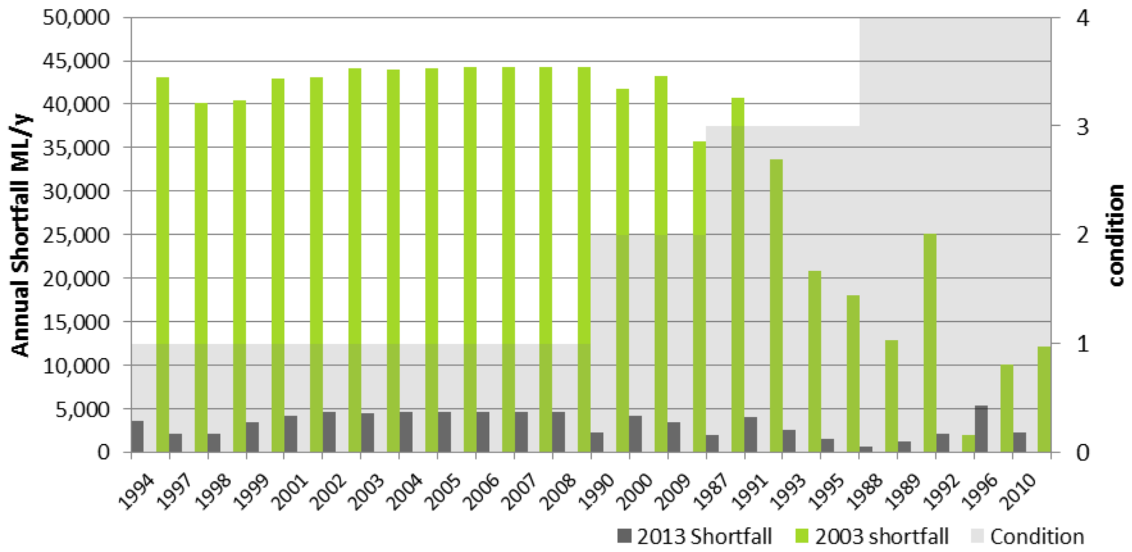


Figure 37. *Annual shortfall comparison – Wimmera 4 (1=Drought, 2=Dry, 3=Average, 4=Wet)*

6 Tributaries of the Wimmera River – environmental flow recommendations

6.1 Reach 1&2 Mackenzie River - Lake Wartook to Distribution Heads Weir

Reach 1 Lake Wartook to Dad and Dave Weir
This reach commences in the Grampians National Park where the oldest storage in the catchment, Lake Wartook is located. Downstream of the lake, the MacKenzie River Gorge is a rocky, highly stable section of river including the MacKenzie Falls. Further downstream the terrain flattens out, although the channel remains partly confined by the rocky terrain.

Releases from Lake Wartook into the MacKenzie River are predominantly for urban supply to Horsham (flood target curve releases, water transfers to Distribution Heads and environmental water releases are also made). However in general fairly uniform flows are released from Wartook, resulting in a loss of flow variability compared with unimpacted conditions through this reach.

The environmental value of this section of the MacKenzie River is amongst the highest of the regulated Wimmera waterways [WCMA 2006]. A diverse endemic fish assemblage exists, including River Blackfish, Mountain Galaxias and Southern Pygmy Perch. Blackfish in the Wimmera catchment are genetically distinct from other Victorian populations, and therefore may be more significant. Southern Pygmy Perch populations are restricted to the upper reaches of the Wimmera catchment, including the MacKenzie River (SKM 2003). The only confirmed platypus population in the Wimmera systems exists in this reach and reach 2 (i.e. the MacKenzie River upstream of Distribution Heads). Glenelg Spiny Crayfish have also been observed in this reach.

Reach 2 Dad and Dave Weir to Distribution Heads Weir
Releases into the MacKenzie River from Lake Wartook are mostly diverted at Dad and Dave Weir into Mount Zero Channel for supply to Horsham. The Mount Zero Channel has a capacity of about 30 ML/day allowing all flows released from the lake to be diverted into the channel. In summer and autumn the flows in the reach are typically environmental water releases apart from brief periods of transfers of water to a pipeline holding storage near Distribution Heads, and in the wetter months these are supplemented by local catchment runoff and flood pre-releases being transferred to Distribution Heads (and ultimately Taylor's Lake if required).

The MacKenzie River has been largely carp-free however downstream of Dad and Dave Weir large populations of carp arrived during the January 2011 floods, and the fishway is not currently in operation at the weir to limit their spread upstream. During recent dry years the majority of reach 2 has dried out apart from a few large deep pools, resulting in loss of fish and platypus (GHCMA and WCMA 2010). In recent years there has been improved fish diversity as fish have moved from upstream into this reach again (GHCMA and WCMA 2010) and migration of platypuses back into this reach has also occurred.

Environmental objectives
The environmental objectives for MacKenzie River Reach 1&2 are:

- Maintain healthy and diverse mosaics of water-dependent vegetation
- Maintain endemic fish communities
- Achieve SEPP compliant macroinvertebrate communities
- Maintain platypus populations
- Maintain structural integrity of stream bed and channel and prevent loss of channel capacity
- Achieve SEPP compliant electrical conductivity

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

Environmental flow recommendations

Environmental flow recommendations to achieve the environmental objectives for MacKenzie River reaches 1 & 2 are summarised in Table 29. Note that a 'cease to flow' component is not required to achieve any of the objectives, however it is recognised that under natural conditions cease to flow events would occur in this reach. When cease to flows occur they contribute to the flow variability in the reach. Therefore the cease to flow recommendation below provides an upper limit of the total number of days in each year where it is acceptable for flow to cease in the reach.

Table 29. Environmental flow recommendations for MacKenzie River Reach 1 & 2

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Cease to flow	Dec-May	0 ML/d	DROUGHT	As infrequently as possible	Less than 80 days in total	Ensure stress on environmental values is not exacerbated beyond natural. Cease to flow periods should be completed with fresh lasting at least 7 days duration.	Durations provide upper limit on the total number of days each year when cease is acceptable based on the number of zero flow days in the unimpacted Wartook flow data.
			DRY AVERAGE		Less than 30 days in total		
Baseflow	Dec-May	2 ML/d or natural	ALL	Continuous	Continuous	Maintain edge habitats in deeper pools and runs, and shallow water habitat availability for **macroinvertebrates** and **endemic fish.** Maintains near-permanent inundated stream channel to prevent excessive in stream terrestrial species growth.	Depth change is minimal between 2 ML/d and 10 ML/d due to model limitations. 2 ML/d was recommended in the 2003 Study, and it is difficult to justify changing this flow without a better model. Depths between 0.5m and 2m required for vegetation. If the natural baseflow is zero for more days than the recommended cease to flow duration some flow (typically a summer fresh) is still required to break the non-flow period.
	Jun-Nov	27 ML/d	ALL	Continuous	Continuous	Facilitate annual dispersal of juvenile platypus into the Wimmera River. Provides flow variability to maintain diversity of habitat.	Platypus require depth greater than 50cm over riffles, however the hydraulic model is not adequate to determine this (no riffles, and restrictive downstream rating table). A flow greater than 2 ML/d would be expected to achieve this. Unable to justify a flow magnitude, therefore propose keeping the 27 ML/d recommended in the 2003 study.
Freshes	Dec-May	5 ML/d	DROUGHT	3 per period	4 -7 days	Prevent **water quality** decline by flushing pools during low flows.	The fresh duration must be at least 7 days following a cease to flow period.
			DRY	4 per period	4 -7 days		
	Dec-May	50 ML/d	AVERAGE	2 per period	2 -7 days	Provide variable flow during low flow season for **macroinvertebrates (**over wood debris to increase biofilm abundance as a food source), **fish** movement and to maintain **water quality** and diversity of **habitat**.	50 ML/d recommended because it occurs with the same frequency as the 100 ML/d fresh in Wimmera 2 & 3 (and the hydraulic model did not provide sufficient confidence). Review if improved hydraulic model becomes available.
			WET	3 per period	2 - 7days		

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Freshes	Jun-Nov	55 ML/d	DROUGHT	5 per period	2 days	Flush surface sediments from hard substrates to support **macroinvertebrates**.	At least one fresh is required in November. 55 ML/d achieves shear stress of 1.1 N/m^2 at critical section (xs5). Magnitude should be reviewed if improved hydraulic model becomes available.
			DRY	5 per period	4 days		
			AVERAGE	5 per period	5 days		
			WET	5 per period	7 days		
	Jun-Nov	130 ML/d	DROUGHT	1 per period	1 day	Increase the baseflow water depth by to provide stimulus for **fish movement** (not required in drought years, frequently required in wet years). Provide flow variability to maintain **water quality** and diversity of **fish habitats**.	130 ML/d recommended because it occurs with the same frequency as the 400 ML/d fresh in Wimmera 2 & 3 (and the hydraulic model did not provide sufficient confidence). Review if improved hydraulic model becomes available.
			DRY	3 per period	2 days		
			AVERAGE	5 per period	3 days		
			WET	5 per period	4 days		
Bankfull	Any	500 ML/d	AVERAGE	1 per period	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	500 ML/d recommended because it occurs with the same frequency as the bankfull event in Wimmera 2 & 3 (and the hydraulic model did not provide sufficient confidence). Review if improved hydraulic model becomes available. Bankfull is required 2-3 times per decade for River Red Gum and 2-5 times per decade for Ti Tree communities
			WET	1 per period	2 days		
Overbank	Aug-Nov	900 ML/d	WET	1 per period	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	900 ML/d recommended because it occurs with the same frequency as the bankfull event in Wimmera 2 & 3 (and the hydraulic model did not provide sufficient confidence). Review if improved hydraulic model becomes available. Overbank is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

Notes on environmental flow recommendations

Hydraulic model quality

The recommended flows for reach 1 and 2 of the MacKenzie River were determined using the HEC-RAS model BE4 which was developed for the 2003 Study. This model covers only a very short length of the river upstream of the Mount Zero Channel offtake which is largely homogeneous. The model contains only 5 surveyed cross sections and does not include any pools or riffles, resulting in it offering a very limited representation of the reach and its values. No alternative models were available for assessing the flows through this reach, so the existing model has been used for this review. However all the flow components are affected by the quality of the model, and the ability to revise flow recommendations using this model was severely limited.

Hydrology

Modelled unimpacted inflows to Lake Wartook from 1 January 1903 to 30 June 2004 were used.

Compliance point

Proposed compliance point:	New site as shown on Figure 38

There was no compliance point recommended in the 2003 study due to no available flow gauges. A gauge on the MacKenzie River is located downstream of Lake Wartook which effectively records releases from the storage into the river (Figure 38). This gauge is not considered suitable for environmental flow compliance for MacKenzie 2 due to the large proportion of flow that is diverted into the supply system at Dad and Dave Weir. A gauge located on the MacKenzie River between Dad and Dave Weir and Distribution Heads Weir, preferably closer to Distribution Heads, would be a more appropriate site for measuring compliance in MacKenzie 2. It is recommended that a compliance gauge be commissioned at, or near, the proposed compliance site shown in Figure 38. As an interim arrangement, the existing regulators at Dad and Dave Weir can be used to measure flow through the reach. This is considered a secondary, but adequate option given that the reach is relatively short and the hydraulic model used to identify the flows is located near to Dad and Dave Weir.

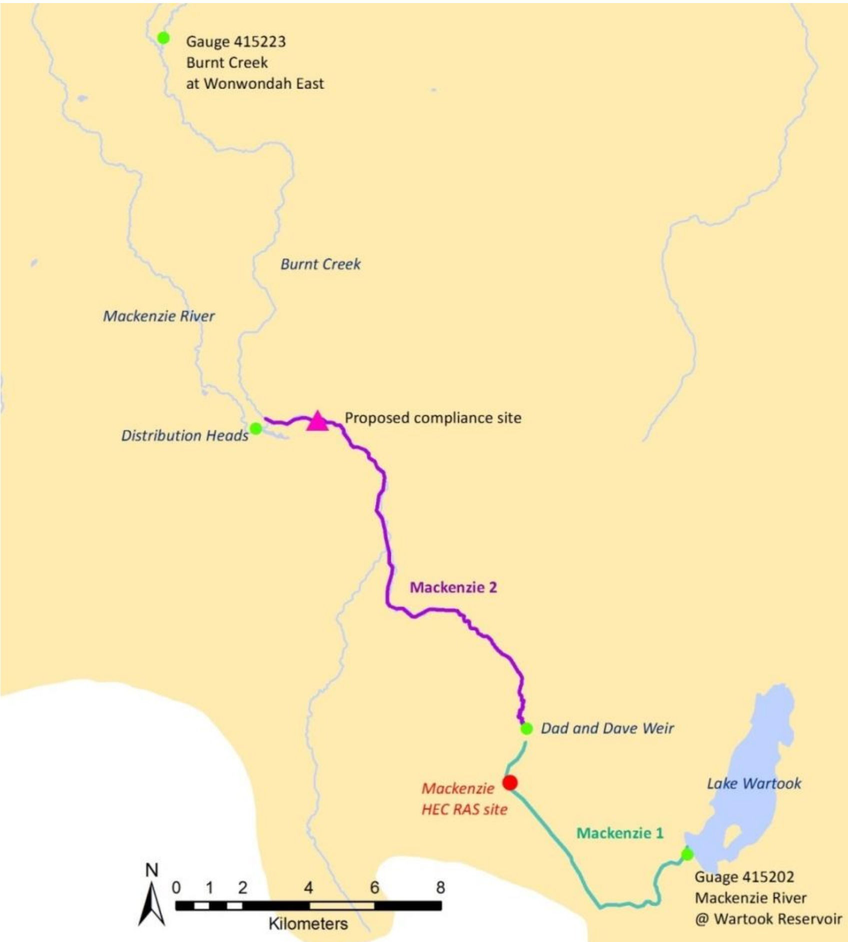


Figure 38. *Location of active flow gauges and hydraulic models in MacKenzie River 1 & 2*

Performance assessment

Performance reporting point:

Gauge	415202
Name	MacKenzie River below Lake Wartook
Status	Open / Active since 28 May 1975
Start for assessment period	1 July 1976
End for assessment period	30 June 2011

For performance reporting (Table 30), the flow recommendations presented in Table 29 has been analysed using eFlow Predictor. The years have been sorted to allow grouping of drought, dry, average and wet years and the percentage compliance reflects duration of flow target achieved (baseflow) or the number of flow events achieved (freshes). Note that for this assessment each flow event (i.e. a fresh, bankfull or overbank) has been counted discreetly (i.e. a single long event is only one event). No limit on the number of days between events was applied.

Table 30. Performance of environmental flow recommendations for Mackenzie River Reach 1 &2

				Flow Recommendations																
	Years	annual flow (GL)	Annual shortfall (no overbank) (GL)	Summer Baseflow 2 ML/d	Winter Baseflow 27 ML/d	Drought summer fresh 5 ML/d x3	Drought jun-nov fresh 55ML/d x5	Drought winter fresh 130ML/d x1	Dry Summer fresh 5ML/d x4	Dry jun-Nov fresh 55ML/d x5	Dry winter fresh 130ML/d x 3	Avg Summer Fresh 50ML/d x 2	Avg Jun-Nov fresh 55ML/d x 5	Avg Bankfull 500ML/d x1	Avg june nov fresh 130 ML/d x5	wet Summer fresh 50 ML/d x3	wet winterfresh 130ML/d x 5	wet Jun-Nov 55ML/d x 5	Wet Bankfull 500ML/d x1	Wet Overbank 900ML/d x1
	median	7.3	2.4	100.0	30.0	67.0	20.0	0.0	25.0	0.0	0.0	50.0	40.0	0.0	40.0	33.0	20.0	20.0	100.0	0.0
	mean	10.4	2.6	100.0	35.1	61.5	16.9	23.1	22.2	22.2	29.7	62.5	50.0	37.5	30.0	33.2	20.0	20.0	60.0	20.0
Drought	1976	2.9	2.4	100	5	100	0	0												
	1977	11.2	0.2	100	74	33	40	100												
	1982	4.9	1.7	100	13	100	40	0												
	1985	7.3	1.6	100	15	67	20	100												
	1994	4.9	1.2	100	16	33	0	0												
	1997	3.6	2.5	100	7	67	20	100												
	1999	2.1	2.9	100	1	33	0	0												
	2002	3.3	2.4	100	16	33	20	0												
	2004	6.8	0.6	100	89	33	20	0												
	2005	8.2	0.7	100	84	33	40	0												
	2006	2.6	2.8	100	37	100	0	0												
	2007	5.6	1.7	100	42	100	20	0												
	2008	1.3	3.6	100	0	67	0	0												
Dry	1978	2.2	3.8	100	5				25	0	0									
	1979	14.3	1.1	100	47				25	80	67									
	1984	20.0	0.6	100	65				25	40	100									
	1987	2.1	4.0	100	8				0	0	0									
	1990	4.1	2.9	100	18				25	0	0									
	1998	6.7	2.2	100	21				25	40	67									
	2000	1.4	4.5	100	0				25	0	0									
	2003	8.0	1.2	100	69				25	40	33									
	2009	1.3	4.3	100	5				25	0	0									
Average	1980	15.6	2.9	100	62							100	40	100	40					
	1983	10.6	4.3	100	18							50	20	100	20					
	1986	31.5	1.3	100	62							100	60	0	40					
	1989	17.3	2.0	100	46							50	100	0	40					
	1991	9.5	4.9	100	36							50	40	100	20					
	1993	16.7	1.9	100	78							50	100	0	40					
	1995	19.4	3.6	100	30							100	40	0	40					
	2001	1.5	7.2	100	0							0	0	0	0					
Wet	1981	28.5	1.3	100	66											33	20	20	0	0
	1988	15.3	3.0	100	52											33	20	20	100	0
	1992	36.9	1.2	100	58											33	20	20	100	100
	1996	27.4	1.5	100	66											0	20	20	100	0
	2010	10.5	5.2	100	18											67	20	20	0	0

Colour coding: *occurs 0-10 % of the time; occurs 11-20 % of the time; occurs 21-30 % of the time; occurs 31-40 % of the time; occurs 41-50 % of the time; occurs 51-60 % of the time; occurs 61-70 % of the time; occurs 71-80 % of the time; occurs 81-90 % of the time; occurs 91-100 % of the time*

The 'short fall' (i.e. how much extra water would have been required to be delivered over and above that which did pass the compliance point to achieve full compliance) has been summarised on an annual basis (Table 30, Figure 39). The flow recommendations vary by season and so too does the recommended environmental water. For the reporting period the mean annual flow was 10.4GL and the mean shortfall was 2.7GL. However the shortfall varied tremendously from as little as 244ML in 1977 to 7.2GL in 2001. If the overbank flow requirement is not considered as one that would normally be delivered as part of the operational environmental water delivery then the overall shortfall drops from 2.7GL/y to 2.6GL/y (mean).

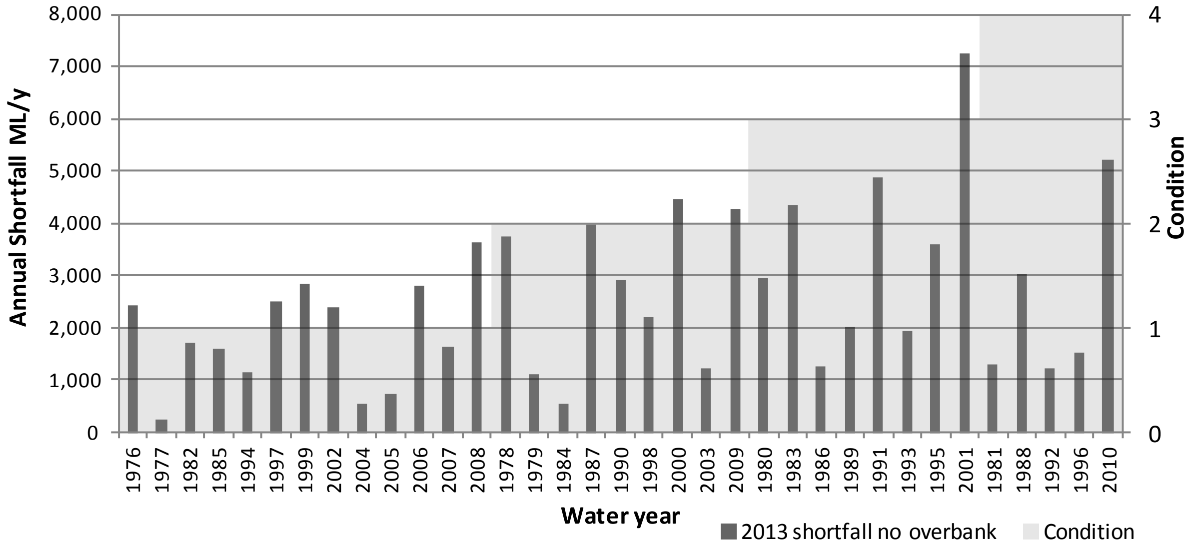


Figure 39. *Total annual shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet) – MacKenzie River Reach 1&2*

The implications of this shortfall analysis in terms of risk assessment are that if we assume the assessment period is typical, then delivery of 2.4 GL/y to the compliance point can achieve compliance in 50% of all years (Figure 40) (note that additional water may be required to be released from storages to achieve the required flows at the assessment site). In drought years delivery of 1.7 GL would achieve compliance in 50% of years and in wet years delivery of 1.5 GL would achieve compliance in 50% of years.

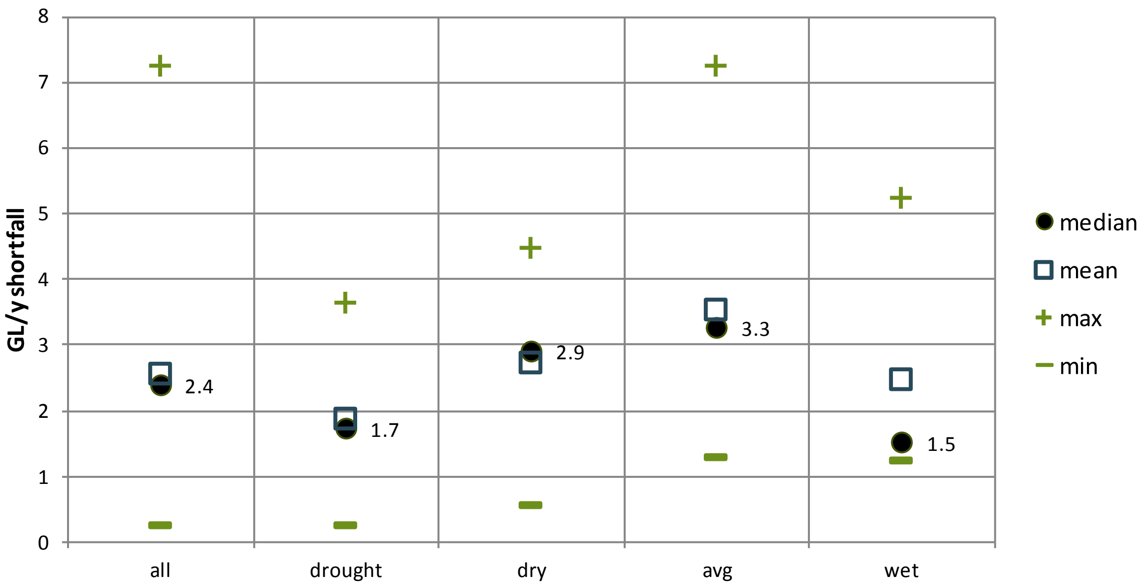


Figure 40. *MacKenzie River Reach 1&2 shortfall summary by seasonal condition (median values shown)*

This can also be presented in terms of the relative compliance likely to be achieved in any given year for any given environmental water availability (Figure 41). Say for example if 2 GL of environmental water is available at the start of a given water year, depending on the prevailing environmental conditions this would be sufficient to achieve full compliance in around 40% of years, which ranges from only 30% of average years to around 55% in wet years.

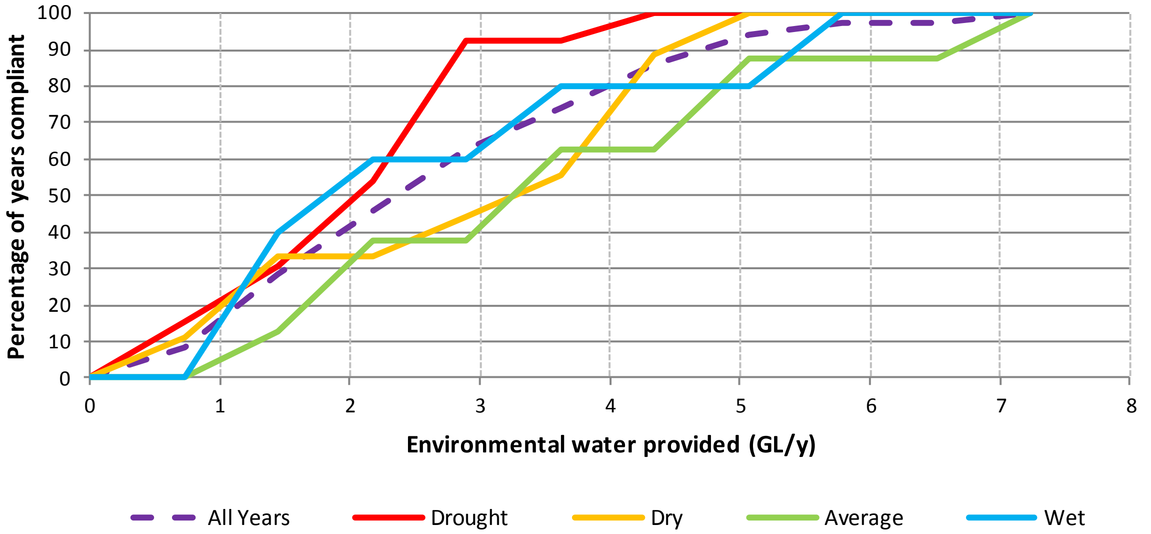


Figure 41. *Percentage of years compliant under different environmental water delivery – MacKenzie River Reach 1&2*

Summary of performance

All flow conditions: The baseflow provisions apply under all climatic conditions and were at least partially met in all years.

Drought conditions: There are three freshes specified for drought conditions (one summer fresh and two winter freshes). The low summer fresh of 5ML/d (3 events) was at least partially met in most years. The two winter freshes (five events of 55ML/d and one of 130ML/d) were met at a lower frequency.

Dry conditions: In dry years the poorest achieved flow recommendation was the winter freshes.

Average conditions: Under average climatic conditions the smaller freshes were at least partially met in most years. However bankfull of 500ML/d was only met in about half of years.

Wet conditions: Under wet years there was at least partial compliance across almost all flow components in most years. The overbank requirement was only met in one of the wet years.

Comparison to 2003 study

The revised flow objectives outlined in Table 29 are different from the recommendations provided in the 2003 study (Table 31). This is due to:

- Changes to environmental objectives (the 2003 flow objectives focussed on certain species of fish and vegetation and included native bird objectives compared with the broader revised objectives to maintain healthy and diverse mosaics of water-dependent vegetation and endemic fish communities).
- Introduction of different flow recommendations for wet, dry, drought and average years.

Note that due to the limitations of the hydraulic model for this reach the recommended baseflow magnitudes (for summer and winter seasons) have not changed from the 2003 study.

Table 31. 2003 study environmental flow recommendations for MacKenzie River Reach 1 & 2 (SKM 2003)

Season	Magnitude	Frequency	Duration
Summer	0 ML/d	Maximum 5 annually	Maximum 7 days each
	2 ML/d	Annual	Continuous (except cease to flow periods)
	>5 ML/d	5 annually	5 days
Winter	27 ML/d	Daily	Continuous (July – November)
	>75 ML/d	Minimum 3 annually	Minimum 7 days
Any time	1,700 ML/d	1 in 4-5 years	Minimum 1 day

The key differences in the new recommendations are:

- Summer freshes of different magnitudes are included for drought, dry and average years only
- A mosaic of different winter freshes are included providing greater flow variation (ranging from 55 ML/d to 550 ML/d)
- The highest flows (bankfull at 500 ML/d and overbank at 900 ML/d) are considerably lower than the 1,700 ML/d previously recommended. Note that the new flow magnitude recommendations were determined from the modelled unimpacted hydrology rather than the hydraulic model used in the previous study due to limitations identified in the hydraulic model.

Comparison of performance assessment

The result of developing flow recommendations that are based on the prevailing flow conditions results in temporally varying flow requirements that are a closer reflection of natural flow regimes (Figure 42) that will build ecosystem resilience in wetter periods and limit decline in dryer times. As a consequence the resulting flow regime is a closer reflection of a unimpacted flow regime, and also more closely reflects the water management environment whereby more water is available in wetter years than dry years.

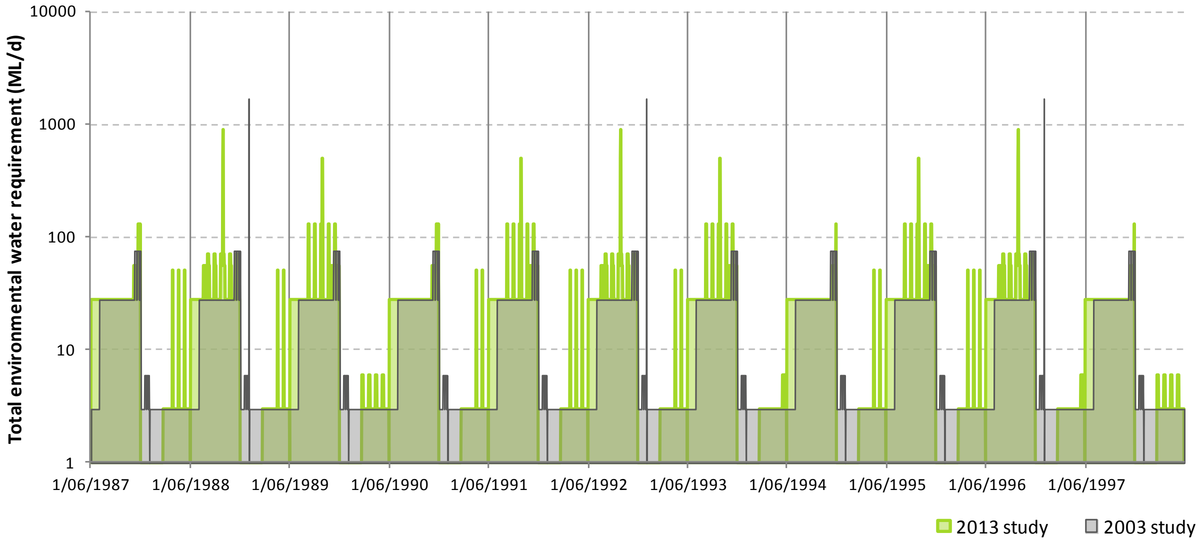


Figure 42. *Comparison of total environmental water recommendations for two studies – MacKenzie River Reach 1&2*

The overall total environmental water recommendations as part of this study are around 3.2GL/y more than those recommended as part of the 2003 project flow recommendations (Table 32, Figure 43). However the flow recommendations for this study are contingent on the prevailing weather conditions (drought, dry, average and wet conditions) such that the years of higher environmental water demand correspond with the years of higher water availability. The consequence of considering the prevailing weather conditions in the setting of flow recommendations has resulted in an overall increase in the water shortfall from 2003 of 900 ML/y (excluding overbank requirements).

Table 32. Shortfall statistics for Mackenzie River Reach 1 & 2 at Lake Wartook 1976 – 2010 (GL/y)

Year type	Total environmental water recommendation		Shortfall in environmental water recommendation			Recorded flow
	2003 study	2013 study	2003 study	2013 study	2013 study (no overbank)	
All years (mean)	5.6	6.2	2.4	2.7	2.6	10.4
All years (median)	5.1	5.3	2.5	2.4	2.4	7.3
Largest	6.8	8.4	5.5	7.2	7.2	36.9
Smallest	5.1	4.6	0.0	0.2	0.2	1.3
Drought (median)	5.1	4.6	2.8	1.7	1.7	4.9
Dry (median)	5.1	5.3	2.9	2.9	2.9	4.1
Average (median)	5.1	8.4	1.9	3.3	3.3	16.2
Wet (median)	6.8	8.3	0.9	3.0	1.5	27.4

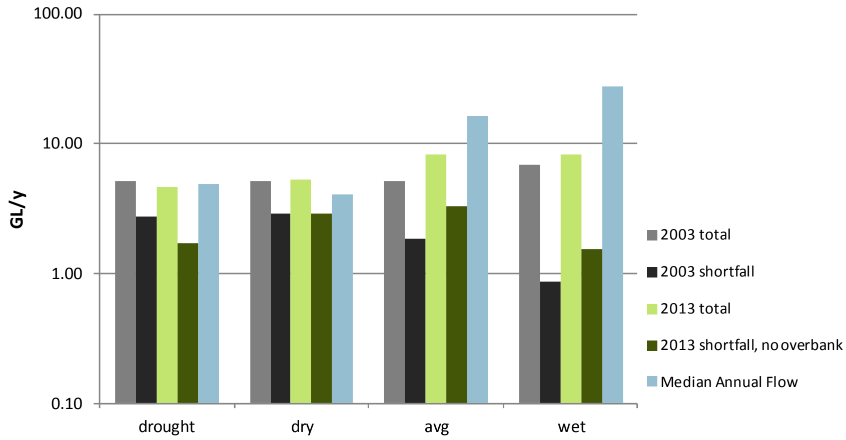


Figure 43. *Total environmental water recommendations by year type (note logarithmic Y axis makes values appear more similar) – MacKenzie River Reach 1&2*

In the 2003 study, 5.1 GL/y is recommended every year with an additional 1.7 GL recommended every 4-5 years (i.e. in wet years) (Figure 43). This study recommends flows ranging from 4.6 GL/y in drought years to 8.4 GL/y in average and wet years, resulting in a mean total flow requirement of 6.2 GL/y across the reporting period. The overall environmental water recommendation for this reach is more than for the 2003 study. However, because the flow recommendations vary between the prevailing year types, the relative shortfall (difference between flow recommendation and actual water delivered) is similar (median 2.4 compared to 2.5 GL/y). If the requirement for overbank is removed, the mean shortfall in wet years would be halved (reduced from 3.0 GL/yr to 1.5 GL/yr).

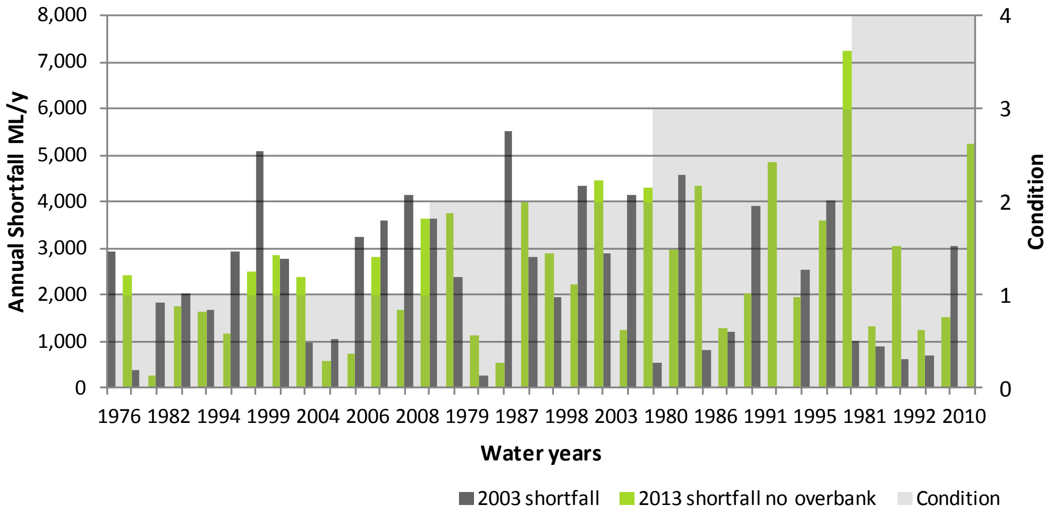


Figure 44. *Annual shortfall comparison – Mackenzie 1 & 2 (1=Drought, 2=Dry, 3=Average, 4=Wet)*

6.2 Reach 3 Mackenzie River – Distribution Heads Weir to Wimmera River

This section of the MacKenzie River is a discontinuous anabranching chain of ponds. Intact geomorphic form and continuous vegetation make this a rare stream type in south-eastern Australia. Most waterways in the region with this sort of channel form have cleared riparian zones and undergone significant degradation (Earth Tech 2003). Flows into the reach are received from the MacKenzie River upstream and from Moora Moora Reservoir via the Moora Channel which discharges into the river at Distribution Heads. Distribution Heads provides a small storage and transfers flows to Taylor's Lake down Burnt Creek, so that the downstream MacKenzie River experiences much lower flows than under natural conditions.

Vegetation and channel form are in good condition through this entirety of this reach, and the high water quality provides an injection of fresh water into the more saline Wimmera River at Horsham. The recently discovered and critically endangered *Callistemon Wimmerensis* in this reach is of particularly high value. Environmental flows have been found to markedly improve condition and trigger recruitment of *Callistemon Wimmerensis* (Marriot 2006a).

Environmental objectives
The environmental objectives for Reach 3 are:

- Maintain healthy and diverse mosaics of water-dependent vegetation
- Facilitate dispersal and establishment of endemic fish species
- Achieve SEPP compliant macroinvertebrate communities
- Maintain structural integrity of stream bed and channel and prevent loss of channel capacity
- Achieve SEPP compliant electrical conductivity

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

Environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for the lower MacKenzie River (Reach 3) are summarised in Table 33.

Note that a 'cease to flow' component is not required to achieve any of the objectives, however it is recognised that under natural conditions cease to flow events would occur in this reach. Therefore the cease to flow recommendation below provides an upper limit of the total number of days in each year where it is acceptable for flow to cease in the reach.

Note: Unimpacted modelled hydrology was not available for this reach therefore the seasonal frequency and durations have been derived from the unimpacted hydrology for surrounding reaches, including upstream reaches. If/when unimpacted modelled flow data becomes available it is recommended that spells analysis is undertaken to update the recommended frequencies and durations for seasonal conditions.

Table 33. Environmental flow recommendations for MacKenzie River Reach 3

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Cease to flow	Dec-May	0 ML/d	DROUGHT	As infrequently as possible	Less than 80 days in total	Ensure stress on environmental values is not exacerbated beyond the point of no return. Cease to flow periods should be completed with fresh lasting at least 7 days duration.	Durations provide upper limit on the total number of days each year when cease is acceptable based on the number of zero flow days in the unimpacted Wartook flow data.
			DRY		Less than 30 days in total		
			AVERAGE				
Baseflow	Any	10ML/d or natural	Continuous	Continuous	Continuous	Maintain edge habitats in deeper pools and runs, and shallow water habitat availability for **macroinvertebrates** and **endemic fish.** Maintains near-permanent inundated stream channel for riparian vegetation and to prevent excessive in stream terrestrial species growth.	At 7 ML/d 3 out of 7 riffles have 10cm inundation xs227, xs555 and xs670. 10 ML/d achieves better width of bed coverage and permanently inundates edges at pools (xs90 and xs670). 85 ML/d is required to achieve pool depths of 1.5m which was deemed impractical. If the natural baseflow is zero for more days than the recommended cease to flow duration some flow (typically a summer fresh) is still required to break the non-flow period.
Freshes	Dec-May	35ML/d	DROUGHT	3 per period	2 - 7 days	Provide variable flow during low flow season for **macroinvertebrates** (over wood debris to increase biofilm abundance as a food source), **fish** movement and to maintain **water quality** and diversity of **habitat**.	35 ML/d increases depth from 10 ML/d by 200mm at 18 out of 21 sections. (Refer xs616, xs610 and xs555). Frequency and duration recommendations have been based on low flow fresh frequencies for Mt William Creek of 30 ML/d.
			DRY	3 per period	3 -7 days		
			AVERAGE	4 per period	3 - 7 days		
			WET	4 per period	3 - 7 days		
	Jun-Nov	35ML/d	DROUGHT	5 per period	2 days	Stimulate **fish** movement and maintain **water quality** and diversity of **habitat**.	35 ML/d increases depth from 10 ML/d by 200mm at most sections (e.g. xs616, xs610 and xs555). Frequency and duration recommendations have been based on unimpacted occurrence of 55 ML/d in Mackenzie 1.
			DRY		4 days		
			AVERAGE		5 days		
			WET		7 days		
	Jun-Nov	190 ML/d	AVERAGE	1 per period	1 day	Flush surface sediments from hard substrates to support **macroinvertebrates**. Wets higher benches, entraining organic debris and promoting diversity of **habitat**.	At least one fresh required in November for flushing surface substrates. 190 ML/d achieves shear stress of 1.1 N/m^2 at most sections. Frequency and duration recommendations have been based on unimpacted occurrence of 550 ML/d in Mackenzie 1.
			WET	1 per period	2 days		
Bankfull	Any	500 ML/d	WET	1 per period, or natural	1 day	Inundate **riparian vegetation** to maintain condition and facilitate recruitment (including Callistemon Wimmerensis). Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	500 ML/d recommended based hydraulic model at xs555. Bankfull is required 2-3 times per decade for River Red Gum and 2-5 times per decade for Ti Tree communities.

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Overbank	Aug-Nov	1,000 ML/d	WET	1 per period, or natural	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment (including Callistemon Wimmerensis). Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	Overbank is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

Notes on environmental flow recommendations

Hydraulic model quality

The recommended flows for the MacKenzie River Reach 3 were determined using the MacKenzie HEC-RAS model developed for the 2009 VEFMAP assessments. This model covers a 700 metre long site in the mid-section of reach 3 and includes 21 surveyed cross sections.

The model appears generally representative of the pool riffle sequence through this reach. Another HEC-RAS model (BE28) created for the 2003 Study was not used due to its small extent, limited number of surveyed sections and lack of pools and riffles.

Hydrology

No unimpacted hydrology was available for this reach. Assumptions based on modelled unimpacted inflows to Lake Wartook (where applicable) and Mt William Creek for others.

Compliance point

Proposed compliance point:	415251 at McKenzie Creek

There is no compliance point currently recommended for this reach. A streamflow gauge (415251) located in the bottom third of the reach, upstream of the confluence with Bungalally Creek offers an appropriate site to assess compliance with the environmental flow recommendations for MacKenzie Reach 3 (Figure 45).

Figure 45. *Location of active flow gauges and hydraulic models in MacKenzie River 3*

Performance assessment

Performance reporting point:

Gauge	415251
Name	MacKenzie River @ Mckenzie Creek
Status	Open/Active since 25 August 1988
Start for assessment period	1 July 1989
End for assessment period	30 June 2011

For performance reporting (Table 34), the flow recommendations presented in Table 33 has been analysed using eFlow Predictor. The years have been sorted to allow grouping of drought, dry, average and wet years and the percentage compliance reflects duration of flow target achieved (baseflow) or the number of flow events achieved (freshes). Note that for this assessment each flow event (i.e. a fresh, bankfull or overbank) has been counted discreetly (i.e. a single long event is only one event). No limit on the number of days between events was applied.

Table 34. Performance of environmental flow recommendations for MacKenzie River Reach 3

				Flow Recommendations												
	Years	annual flow (GL)	annual shortfall (GL)	Baseflow 10ML/d	Drought summer fresh 35 M	Drought winter fresh 35ML	Dry Summer fresh 35ML/d x	Dry winter fresh 35ML/d x	Avg Summer Fresh 35ML/d x	Avg Jun-Nov fresh 190ML/d	Avg june nov fresh 35ml/d	wet Summer fresh 35 ML/d	wet winterfresh 35ML/d x	wet Jun-Nov 190ML/d x 1 f	Wet Bankfull 500ML/d x1 O	Wet Overbank 1000ML/d x1
	median	0.3	1.3	28.0	0.0	0.0	0.0	0.0	0.0	100.0	20.0	25.0	20.0	100.0	100.0	100.0
Condition	mean	3.5	1.2	35.0	0.0	2.2	0.0	10.0	6.3	100.0	15.0	31.3	20.0	100.0	75.0	75.0
Drought	1994	0.4	0.4	100	0	0										
	1997	0.2	1.1	0	0	0										
	1999	0.0	1.3	0	0	0										
	2002	0.0	1.1	1	0	0										
	2004	0.0	1.3	0	0	0										
	2005	0.3	1.2	6	0	20										
	2006	0.0	1.3	0	0	0										
	2007	0.6	1.3	26	0	0										
	2008	0.0	1.1	1	0	0										
Dry	1990	0.0	1.4	54			0	0								
	1998	0.0	1.7	0			0	0								
	2000	0.0	1.7	0			0	0								
	2003	0.0	1.6	0			0	0								
	2009	0.5	1.6	57			0	0								
	2011	4.2	0.9	32			0	60								
Average	1989	3.7	0.8	29					0	100	20					
	1991	10.4	0.4	48					0	100	0					
	1993	13.3	0.6	86					0	100	20					
	1995	0.4	2.1	100					25	100	20					
Wet	1988			37								0	0	100	0	0
	1992	19.7	0.9	100								50	20	100	100	100
	1996	14.2	1.1	28								0	20	100	100	100
	2010	10.1	1.3	100								75	40	100	100	100

Colour coding: *occurs 0-10 % of the time; occurs 11-20 % of the time; occurs 21-30 % of the time; occurs 31-40 % of the time; occurs 41-50 % of the time; occurs 51-60 % of the time; occurs 61-70 % of the time; occurs 71-80 % of the time; occurs 81-90 % of the time; occurs 91-100 % of the time*

The ‘short fall’ (i.e. how much extra water would have been required to be delivered over and above that which did pass the compliance point to achieve full compliance) has been summarised on an annual basis

(Table 34, Figure 46). The flow recommendations vary by season and so too does the recommended environmental water. For the reporting period the mean annual flow was 3.5GL and the mean shortfall was 1.3GL. However the shortfall varied tremendously from as little as 411ML in 1994 to 3.2GL in 2010. If the overbank flow requirement are not considered as one that would normally be delivered as part of the operational environmental water delivery then the overall shortfall drops from 1.3GL/y to 1.2GL/y (mean).

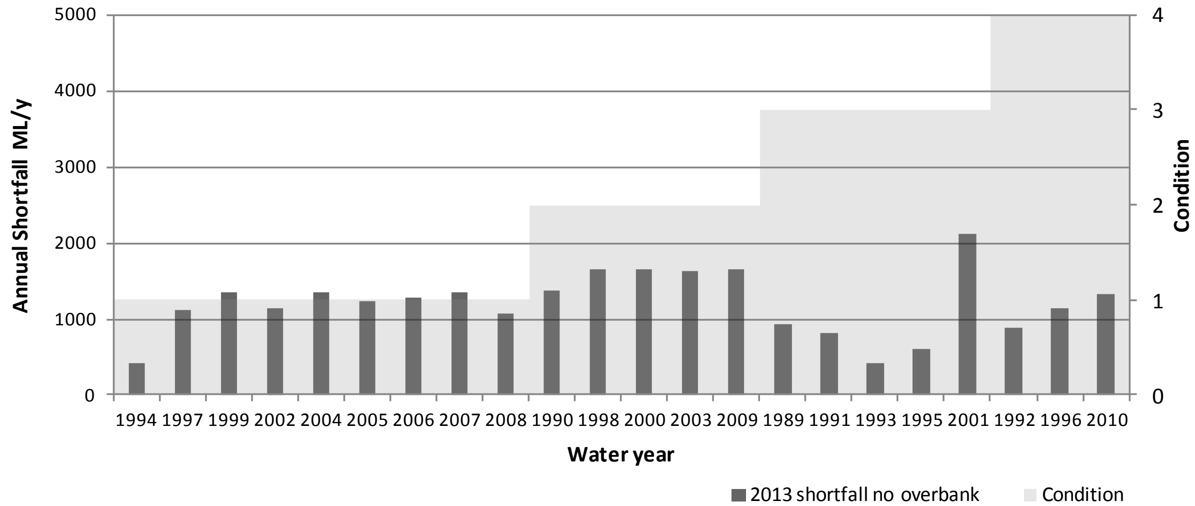


Figure 46. *Total annual shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet) – MacKenzie River Reach 3*

The implications of this shortfall analysis in terms of risk assessment are that if we assume the assessment period is typical, then delivery of 1.3 GL/y can achieve compliance in 50% of all years (Figure 47) (note that additional water may be required to be released from storages to achieve the required flows at the assessment site). In drought years delivery of 1.2 GL would achieve compliance in 50% of years and in wet years delivery of 1.1 GL would achieve compliance in 50% of years.

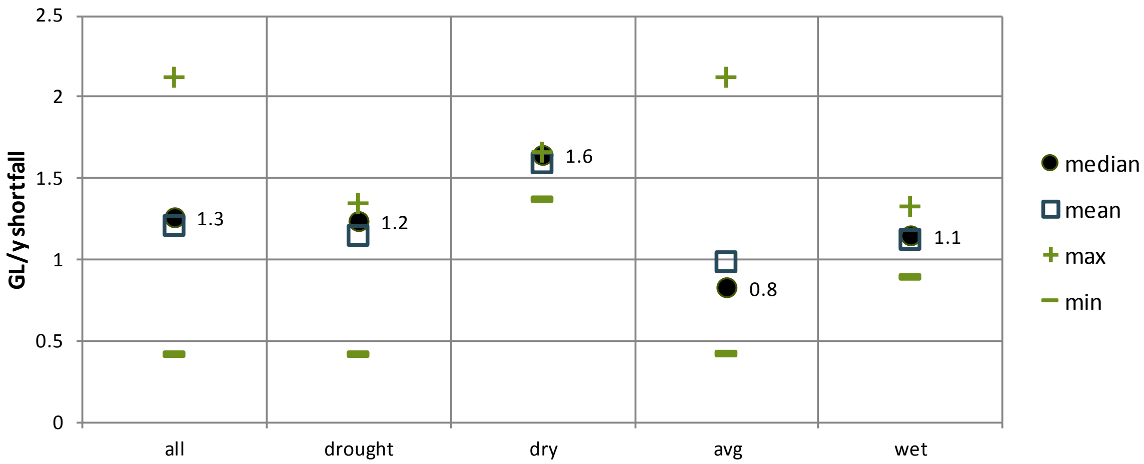


Figure 47. *MacKenzie River Reach 3 shortfall summary by seasonal condition (median values shown)*

This can also be presented in terms of the relative compliance likely to be achieved in any given year for any given environmental water availability (Figure 48). Say for example if 1 GL of environmental water is available at the start of a given water year, depending on the prevailing environmental conditions this would be sufficient to achieve full compliance in around 25% of years, which ranges from only 0% of dry years to around 75% in average years.

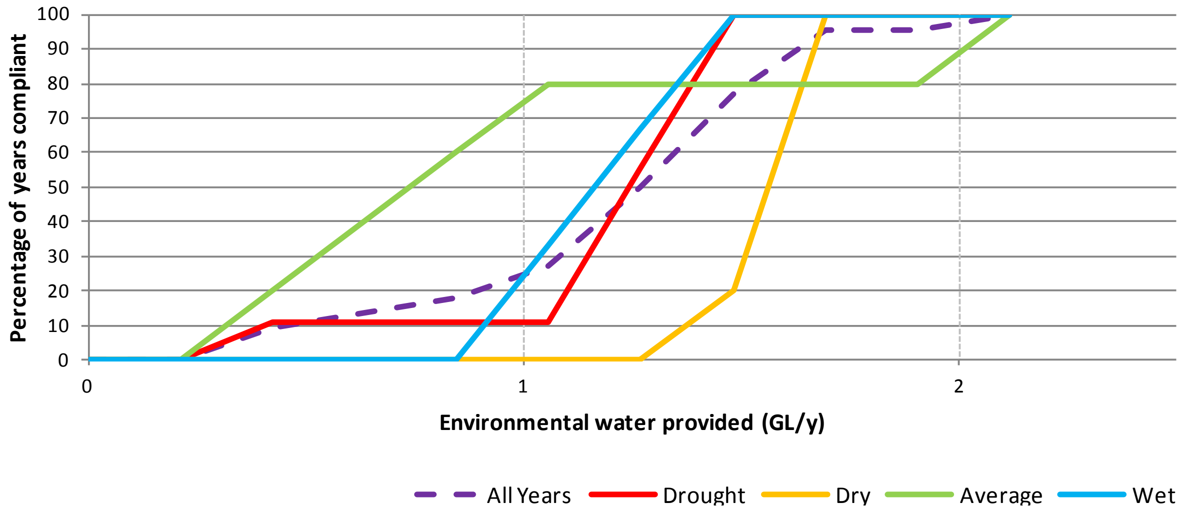


Figure 48. *Percentage of years compliant under different environmental water delivery (excludes overbank flow recommendation) – MacKenzie River Reach 3*

Summary of performance

All flow conditions: The baseflow provisions apply under all climatic conditions and were at least partially met in most years (i.e. achieved for some proportion of the year)

Drought conditions: There is a summer and winter fresh recommended in drought years. These were rarely met in the test period.

Dry conditions: Similar freshes to the drought were recommended for the dry, these were rarely met.

Average conditions: Summer freshes were rarely met under the average conditions, but winter freshes were at least partially met in most years.

Wet conditions: Most wet year flow conditions were met in most years.

Comparison to 2003 study

The revised flow objectives outlined in Table 33 are considerably different from the recommendations provided in the 2003 study (Table 35). This is due to:

- Changes to environmental objectives (the 2003 flow objectives included maintaining self-sustaining native bird and fish populations compared with the revised objective to facilitate dispersal of endemic fish species, and focussed on the maintenance of certain species of vegetation compared with the revised priority to maintain mosaics of floodplain and riparian water-dependent vegetation).
- Revised hydraulic modelling (an improved HEC-RAS model at North-East Wonwondah Road was used to determine the magnitude of flows required).
- Introduction of different flow recommendations for wet, dry, drought and average years.

Table 35. 2003 study environmental flow recommendations for MacKenzie River Reach 3 (SKM 2003)

Season	Magnitude	Frequency	Duration
Summer	0 ML/d	Maximum 5 annually	Maximum 7 days each
	2 ML/d	Annual	Continuous (except cease to flow periods)
	>5 ML/d	5 annually	7 days
Winter	37 ML/d	Daily	Continuous (July – November)
	>100 ML/d	Minimum 3 annually	Minimum 7 days
Any time	1,700 ML/d	1 in 4-5 years	Minimum 1 day

The key differences in the new recommendations are:

- A higher summer baseflow is included (10 ML/d compared to 2 ML/d) and cease to flows are specified to occur as infrequently as possible)
- A lower winter baseflow equal to the summer baseflow is included (10 ML/d compared with 37 ML/d)
- A range of different freshes are included (higher summer freshes, and lower and higher winter freshes) with different frequencies depending on the climatic condition of the year (i.e. drought, dry, average or wet)
- The highest flows (bankfull at 500 ML/d and overbank at 1,000 ML/d) are considerably lower than the 1,700 ML/d previously recommended.

Comparison of performance assessment

The result of developing flow recommendations that are based on the prevailing flow conditions results in temporally varying flow requirements that are a closer reflection of unimpacted flow regimes (Figure 35). As a consequence the resulting flow regime is a closer reflection of a unimpacted flow regime, and also more closely reflects the water management environment whereby more water is available in wetter years than dry years.

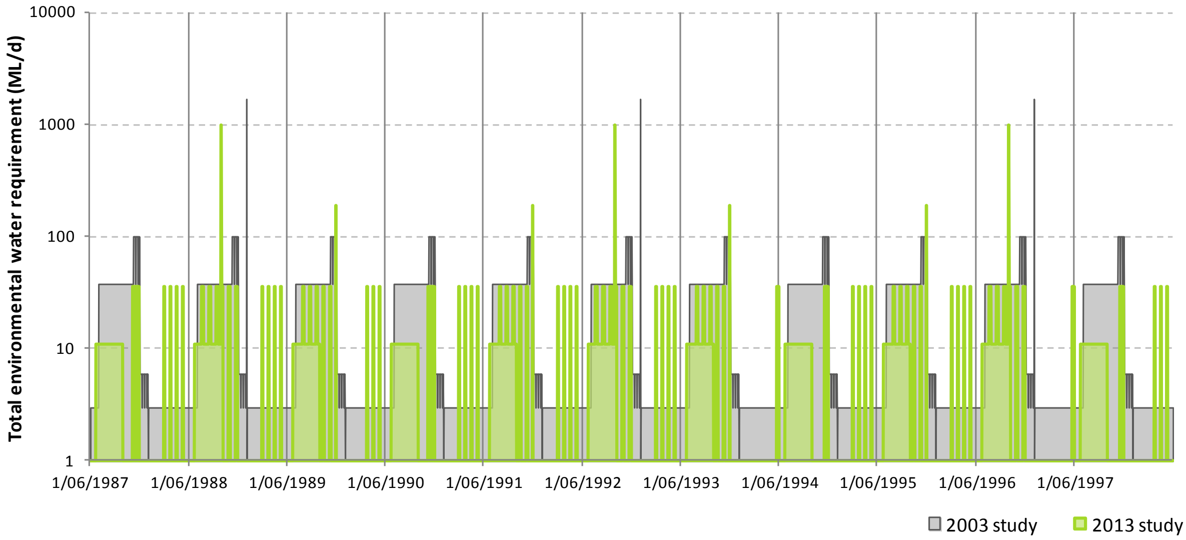


Figure 49. *Comparison of total environmental water recommendations for two studies – MacKenzie River Reach 3*

The mean annual environmental water volume based on the recommendations from this study is considerably less than the annual volume recommended in the 2003 study (2.0 GL/y compared with 7.4 GL/y – Table 36, Figure 50). However the flow recommendations for this study are contingent on the prevailing weather conditions (drought, dry, average and wet conditions) such that the years of higher environmental water demand correspond with the years of higher water availability. The consequence of considering the prevailing weather conditions in the setting of flow recommendations has resulted in an overall decrease in mean annual shortfall from 6.4 GL/y for the 2003 study to 1.4 GL/y.

Note that the mean recorded flow in Mackenzie River at Mckenzie Creek exceeds the total environmental water recommendations from this study (3.5 GL/y compared with 2.0 GL/y), however there is still shortfall due to the timing of the recorded flows not meeting the individual components of the flow recommendations.

Table 36. Shortfall statistics for Mackenzie River Reach 3 at Mckenzie Creek 1989 – 2010 (GL/y)

Year type	Total environmental water recommendation		Shortfall in environmental water recommendation			Recorded flow
	2003 study	2013 study	2003 study	2013 study	2013 study (no overbank)	
All years (mean)	7.4	2.0	6.4	1.4	1.2	3.5
All years (median)	7.0	1.7	7.0	1.3	1.3	0.3
Largest	8.7	4.4	8.5	3.3	2.1	19.7
Smallest	7.0	1.3	2.7	0.4	0.4	0.0
Drought (median)	7.0	1.3	7.0	1.2	1.2	0.0
Dry (median)	7.0	1.7	7.0	1.6	1.6	0.0
Average (median)	7.0	2.2	5.3	0.8	0.8	4.2
Wet (median)	8.7	4.4	4.1	2.1	1.1	14.2

In the 2003 study, 7.0 GL/y is recommended every year, with an additional 1.7 GL every 4-5 years (i.e. wet years) (Figure 50). This study recommends flows ranging from 1.3 GL/y in drought years to 4.4 GL/y in wet years, resulting in a mean total flow requirement of 2.0 GL/y across the reporting period. The overall environmental water recommendation for this reach is less for all climatic conditions than the 2003 recommendations.

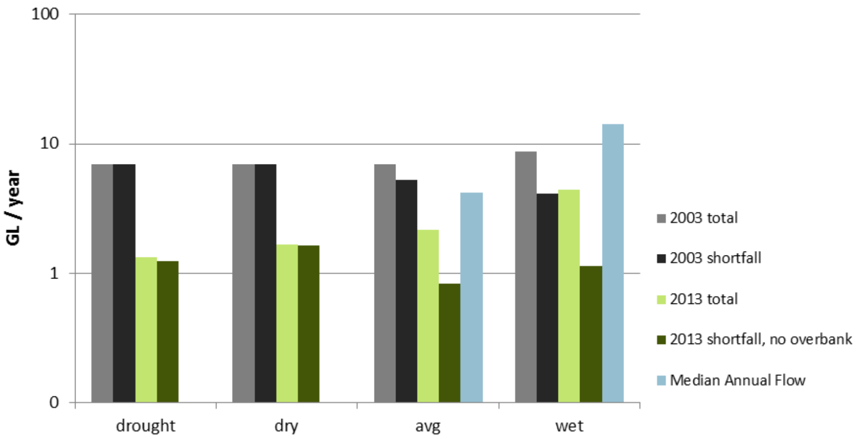


Figure 50. *Total environmental water recommendations by year type (note logarithmic Y axis makes values appear more similar) – MacKenzie River Reach 3*

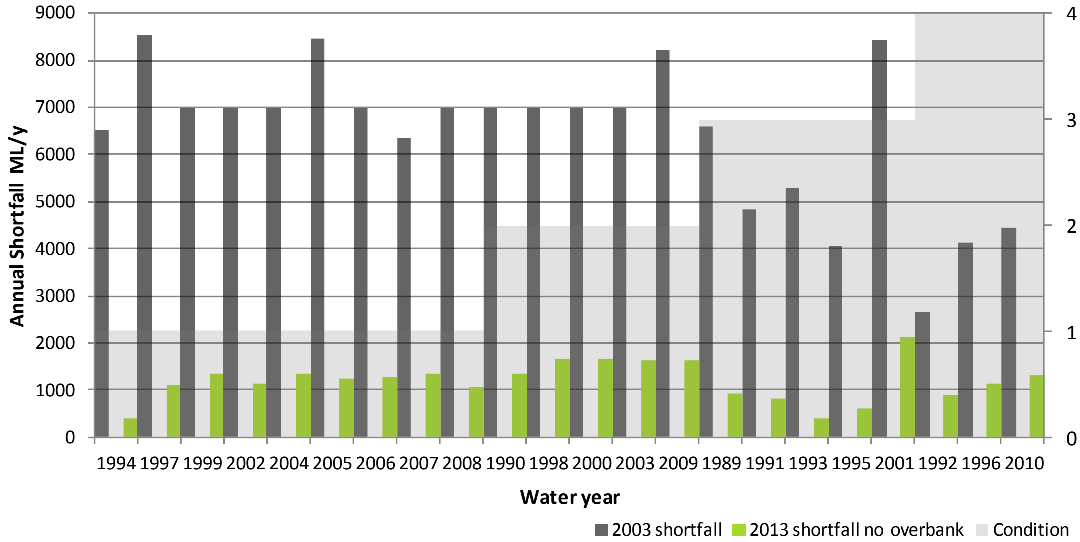


Figure 51. *Annual shortfall comparison – Mackenzie 3 (1=Drought, 2=Dry, 3=Average, 4=Wet)*

6.3 Mt William Creek

Lake Lonsdale to Wimmera River

This reach comprises Mt William Creek downstream of Lake Lonsdale to its confluence with the Wimmera River. Prior to the completion of the Wimmera Mallee Pipeline, releases from Lake Lonsdale were made to meet domestic and stock and urban demands via the Main Central Channel and occasionally via the lower Mt William Creek. Lower than unimpacted flows were consistently received in this reach, resulting a ranking of the third most flow-stressed waterway in Victoria (SKM 2005b). Lake Lonsdale is no longer essential for consumptive water supply, so that releases are now made largely for flood management and environmental use. Consequently the flow regime has now changed considerably. Flows to Mt William Creek are typically over-delivered. These flows are larger than recommended due to the use of Lake Lonsdale to meet Wimmera River Reach 4 objectives at the compliance point far downstream (Lochiel). The Wimmera Reach 4 flow recommendations comprise higher volumes and have high en-route losses, including to Yarriambiack Creek.

The channel and floodplain morphology of this reach is complex. There are a number of minor tributaries, and a number of flood runners heading across the floodplain and connecting with the Wimmera River. A large assemblage of native species exists including Mountain Galaxias and the 'vulnerable' Southern Pygmy Perch. Good refuge holes downstream of Lake Lonsdale would have helped support these populations during dry periods. The channel bed is predominantly sand, with good in-stream vegetation provided by emergent macrophytes. The riparian vegetation is in reasonable to good condition particularly in the upper reaches when it borders the Grampians National Park.


Figure 52. *Lake Lonsdale (left) and Mt William Creek at Roses Gap Rd (right). (July 2012)*

Environmental objectives

The environmental objectives for Mt William Creek are:

- Maintain healthy and diverse mosaics of water-dependent vegetation
- Maintain endemic fish communities
- Achieve SEPP compliant macroinvertebrate communities
- Maintain structural integrity of stream bed and channel and prevent loss of channel capacity
- Achieve SEPP compliant electrical conductivity

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

Environmental flow recommendations

Environmental flow recommendations to achieve the environmental objectives for Mt William Creek are summarised in Table 37. Note that a 'cease to flow' component is not required to achieve any of the objectives, however it is recognised that under natural conditions cease to flow events would occur in this reach. Therefore the cease to flow recommendation below provides an upper limit of the total number of days in each year where it is acceptable for flow to cease in the reach.

Table 37. Environmental flow recommendations for Mt William Creek

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Cease to flow	Dec-May	0 ML/d	DROUGHT	As infrequently as possible	Less than 90 days in total	Ensure stress on environmental values is not exacerbated beyond the point of no return. Cease to flow periods should be concluded with fresh lasting at least 7 days duration.	Durations provide upper limit on the total number of days each year when cease is acceptable based on the number of zero flow days in the unimpacted Lonsdale flow data.
			DRY		Less than 30 days in total		
			AVERAGE				
Baseflow	Any	5 ML/d or natural	ALL	Continuous	Continuous	Maintain edge habitats and shallow water habitat availability for **macroinvertebrates** and **endemic fish** and near-permanent inundated stream channel for riparian vegetation and prevents excessive instream terrestrial species growth.	Overbank is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree. If the natural baseflow is zero for more days than the recommended cease to flow duration some flow (typically a summer fresh) is still required to break the non-flow period.
Freshes	Dec-May	20 ML/d	DROUGHT	3 per period	2-7 days	Prevent **water quality** decline by flushing pools during low flows.	Freshes following cease to flow should last for at least 7 days. In dry years, an alternative would be two 30ML/d freshes of 3 days each.
			DRY	3 per period	4-7 days		
	Dec-May	30 ML/d	AVERAGE	3 per period	2-7 days	Provide variable flow during low flow season for **macroinvertebrates (**over wood debris to increase biofilm abundance as a food source), **fish** movement and to maintain **water quality** and diversity of **habitat**.	Increases flow depth (from 5 ML/d) by 16-19cm, and inundates benches (xs2)
			WET	3 per period	3-7 days		
	Jun-Nov	100 ML/d	DROUGHT	1 per period	3 days	Wets benches, entraining organic debris and promoting diversity of habitat. Flush surface sediments from hard substrates to support **macroinvertebrates**. Wets low benches, entraining organic debris and promoting diversity of **habitat.**	100 ML/d and 500 ML/d inundate a number of benches in the hydraulic model.
			DRY	3 per period	3 days		
			AVERAGE	5 per period	5 days		
			WET	5 per period	7 days		
	Jun-Nov	500 ML/d	DRY	1 per period	1 days	Wets highest benches, entraining organic debris and promoting diversity of habitat	
			AVERAGE	2 per period	2 days		
			WET	3 per period	3 days		
Bankfull	Any	750 ML/d	AVERAGE	1 per year or natural	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	750 ML/d is based on xs4. Bankfull is required 2-3 times per decade for River Red Gum and 2-5 times per decade for Ti Tree communities.
			WET	1 per year	4 days		
Overbank	Aug-Nov	1,500 ML/d	WET	1 per year	1 days	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	Overbank is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

Notes on environmental flow recommendations

Hydraulic model quality: VERY POOR

The flow recommendations for Mt William Creek have been determined using the HEC-RAS model BE1 which was created for the 2003 Study. The model represents a site downstream of Lake Lonsdale (and downstream of Sheepwash Weir and Trudgeons Weir). The site has been described as having complex morphology where the alluvial surface is occasionally higher than the floodplain and terrace (SKM 2003).

The HEC-RAS model itself is limited by only containing a small number of surveyed cross sections (6) covering only 130m stretch of the Mt William Creek. The survey clearly shows benches for inundation, it does not identify any pools or riffles with variation in channel invert being minimal along the 130 m long reach.

Compliance point

Proposed compliance point:	415203 at Lake Lonsdale

Releases from Lake Lonsdale into Mt William Creek (gauge 415203) have been recorded since 1910. This gauge was not previously recommended for environmental flow compliance, due to it including flows diverted from Mt William Creek a short distance downstream of Lake Lonsdale into the Main Central Channel. Since the completion of the Wimmera Mallee Pipeline, these diversions no longer occur, so the releases from the lake provide a better indication of the flow in Mt William Creek. Ideally a gauge downstream of the hydraulic model site (Figure 53) would be used to assess whether the required flows are passing the site at which they were determined. However, given the relatively small distance between the existing gauge and site of the hydraulic model, it is practical and sufficient to assume there is negligible difference in flow at these two sites and use the existing gauge for compliance.

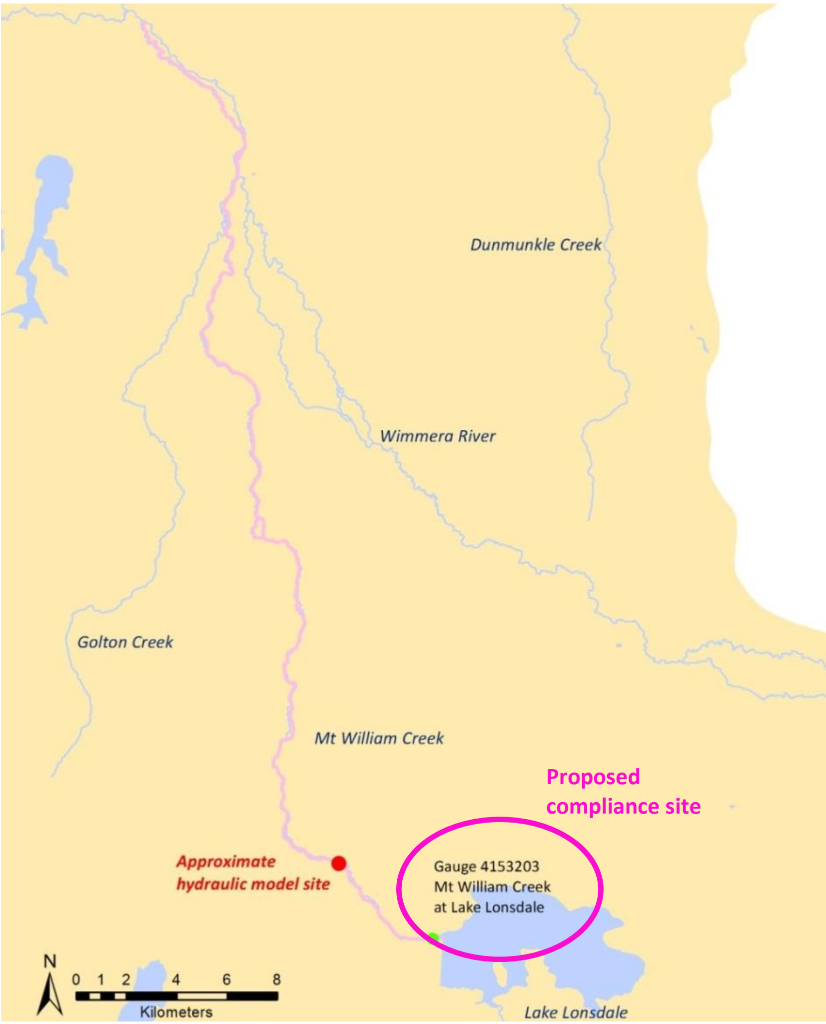


Figure 53. *Location of active flow gauges and hydraulic models in Mt William Creek*

Performance assessment
No suitable point for assessing historical compliance exists due to the substantial diversions which have occurred out of Mt William Creek downstream of the Lake Lonsdale gauge. The performance and comparison with previous studies was therefore not able to be completed.

Comparison to 2003 study
The revised flow objectives outlined in Table 37 are considerably different from the recommendations provided in the 2003 study (Table 38). This is due to:

- Changes to environmental objectives (the 2003 flow objectives focussed on certain species of fish and vegetation and included native bird objectives compared with the broader revised objectives to maintain healthy and diverse mosaics of water-dependent vegetation and endemic fish communities).
- Introduction of different flow recommendations for wet, dry, drought and average years

Table 38. 2003 study environmental flow recommendations for Mt William Creek (SKM 2003)

Season	Magnitude	Frequency	Duration
Summer	0 ML/d	Annually	Maximum 48 days
	>5 ML/d	3 annually	5 days
Winter	29 ML/d	Daily	Continuous (June – November)
	>143 ML/d	2 annually	Minimum 7 days (July – October)

The key differences in the new recommendations are:

- A summer baseflow is included (and cease to flows are specified to occur as infrequently as possible)
- The winter baseflow is substantially lower (5 ML/d compared with 29 ML/d)
- Freshes are substantially higher and recommended at different frequencies depending on the climatic condition of the year (i.e. drought, dry, average or wet)
- A bankfull flow of 750 ML/d is included for average and wet years, and an overbank flow of 1,500 ML/d is included in wet years.

6.4 Bungalally Creek - Toolondo Channel to MacKenzie River

Bungalally Creek is a high flow effluent channel from Burnt Creek which discharges into the MacKenzie River. Under current conditions, flows are diverted into Bungalally Creek via Burnt Creek and the Toolondo Channel. Historically, given its role as a water transfer channel most flows were diverted to Bungalally South Channel (with some into Bungalally West Channel also), resulting in diminished in stream habitat (SKM 2003).

The channel is narrow with mild sinuosity. The surrounding floodplain has been extensively cleared for grazing and the riparian and in stream vegetation and habitat has been significantly degraded in some sections (SKM 2003), and moderately degraded in others.

Environmental objectives
The environmental objective for Bungalally Creek is to maintain mosaics of water-dependent vegetation. Information regarding the important flow characteristics to achieve each of environmental objectives is provided in Sections 3-8.

Environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for Bungalally Creek are summarised in Table 39.

Note: Unimpacted modelled hydrology was not available for Bungalally Creek. Therefore the frequency and duration recommended for the bankfull and overbank flows have been derived from the unimpacted hydrology at Glenorchy (Wimmera 2/3). If/when unimpacted modelled flow data becomes available for Bungalally Creek it is recommended that spells analysis is undertaken to update the recommended frequencies and durations for seasonal conditions.

Table 39. Environmental flow recommendations for Bungalally Creek

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved
Bankfull	Any	60 ML/d	AVERAGE WET	1 per period or natural [10]	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Maintain **structural integrity of channel.** (Refer Figure 54).
Overbank	Aug-Nov	150 ML/d	WET	1 per period or natural	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Maintains **floodplain geomorphic features**. (Refer Figure 54).

Notes on environmental flow recommendations

Hydraulic model quality

The flow recommendations for Bungalally creek were determined using a new HEC-RAS model created specifically for this review. The model was based on available LiDAR data which was flown when no water was in the creek. The high resolution of LiDAR resulted in detailed cross-sectional data being incorporated in the model, which covered a substantial section of the reach. The model represents the 2 kilometre section of the creek north of Excells Road.

The HEC RAS model was geospatially referenced, allowing the higher flow inundations to be mapped against other geospatial data. The modelled inundation extents for flows in Bungalally Creek of 60 ML/d, 150 ML/d and 200 ML/d are presented in Figure 54.

Figure 54. *Bungalally expected inundation - 60 ML/d (blue), 150 ML/d (green) and 200 ML/d (yellow)*

[10] Inundation is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

Compliance point

Proposed compliance point:	New site as shown on Figure 55

There are no active flow gauges in Bungalally Creek. In order to assess compliance with the environmental flow recommendations for Bungalally Creek a gauge is required. The gauge is only required to measure the two flow components recommended in Table 39; bankfull and overbank and therefore may be quite simple. The gauge should be located on the downstream side of the hydraulic model site, potentially at the site of the inactive gauge shown in Figure 55.

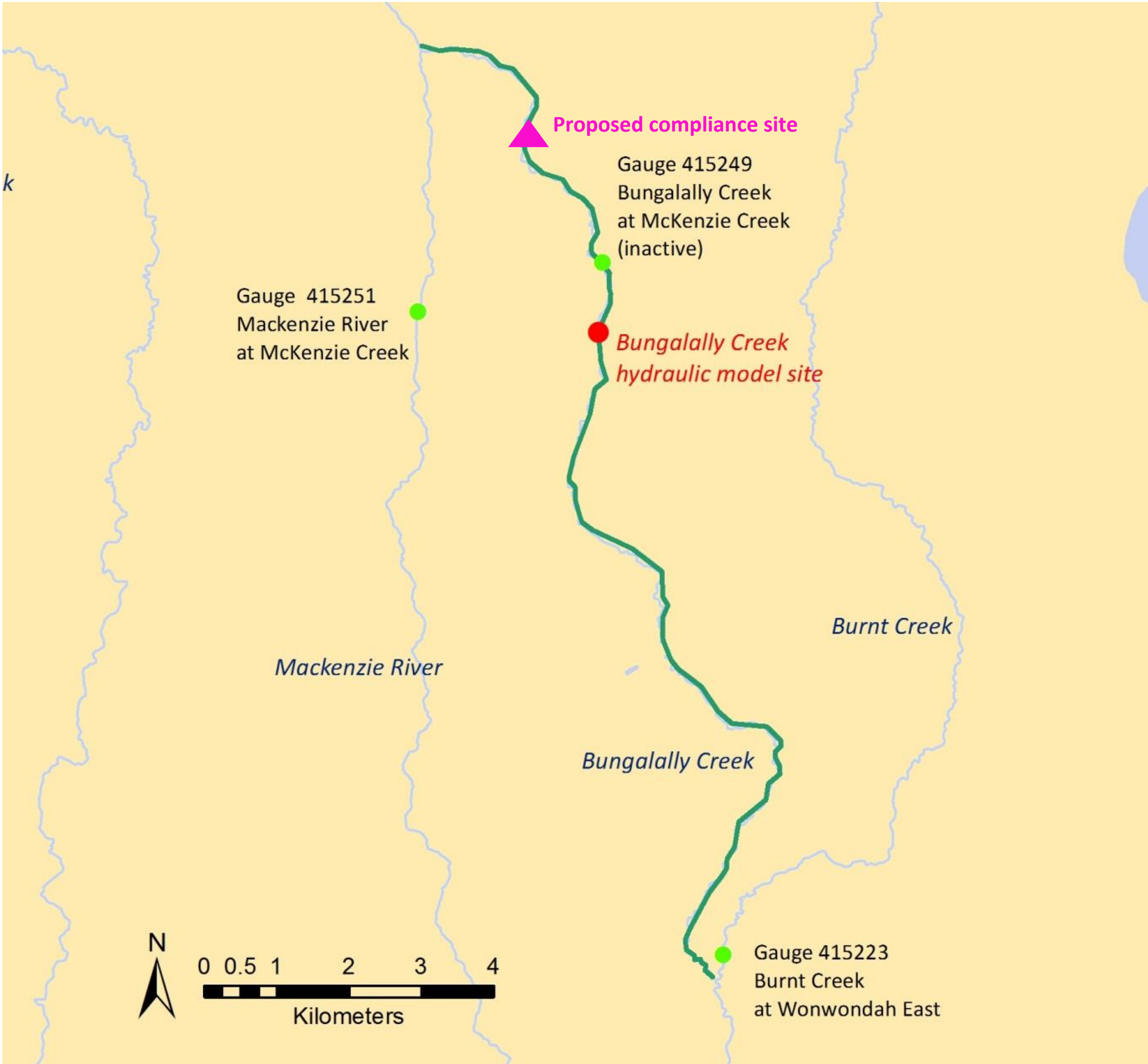


Figure 55. *Location of hydraulic model in Bungalally Creek*

Performance assessment

Compliance point: no suitable compliance point exists, performance of the flow recommendation over recent history and comparison with previous studies cannot be completed.

Comparison to 2003 study

The flow recommendations for Bungalally Creek in the 2003 study were largely qualitative due to a lack of hydraulic and hydrologic data. It was recommended to remove summer diversions to address the impacts on low flows while allowing for high flows, in particular winter freshes, to improve conditions of instream fauna and fish recruitment (SKM 2003). A winter baseflow of 2 ML/d was suggested and the first two winter freshes permitted to pass.

The revised flow objectives outlined in Table 39 are considerably different from the 2003 study recommendations due to:

- Changes to environmental objectives (the 2003 flow objectives included maintaining self-sustaining fish and native bird populations and maintenance of certain species of vegetation compared with the revised single priority to maintain mosaics of floodplain and riparian water-dependent vegetation).
- Use of a hydraulic model to determine flow magnitudes (A HEC-RAS model for a site in the lower section of Bungalally Creek was developed as part of this project to identify the flow requirements.)
- Introduction of different flow recommendations for wet, dry, drought and average years (flows now only recommended in wet and average years).

6.5 Upper Burnt Creek - Distribution Heads Weir to Toolondo Channel

This reach covers Burnt Creek from Distribution Heads to Toolondo Channel. Distribution Heads is a wetland that has been modified to harvest all water conveyed into the MacKenzie River and transfers from Moora Moora Reservoir. Under natural conditions Burnt Creek may have been a flood distributary channel from the MacKenzie River (SKM 2003).

The current flow regime in this reach is highly regulated. During winter and spring and depending on water availability relatively uniform flows may be released from Distribution Heads into the creek for transfer to Taylors Lake via the Toolondo Channel. In summer and autumn releases from Distribution Heads cease and the reach is dry.

The channel form is mostly narrow, with steep but stable banks with some ill-defined sections including Boggy Corner. It supports a healthy riparian zone and floodplain, surrounded by cleared agricultural land. In stream habitat and vegetation is reduced in quality by the lack of variability in the flow pattern (SKM 2003).

The complete assemblage of endemic fish species for the Wimmera system have been observed/recorded in the Burnt Creek downstream of Distribution Heads weir, including river blackfish and mountain galaxias (SKM 2003, Biosis 2013). Based on the consistent flows recorded in the river, it is likely that a diverse macroinvertebrate community exists. Western Swamp Crayfish (listed under the *Flora and Fauna Guarantee Act 1988*) are known to exist in this reach.

Environmental objectives
The environmental objectives for the upper Burnt Creek are:

- Maintain healthy and diverse mosaics of water-dependent vegetation
- Facilitate dispersal and establishment of endemic fish species
- Achieve SEPP compliant macroinvertebrate communities
- Maintain structural integrity of stream bed and channel and prevent loss of channel capacity
- Achieve SEPP compliant electrical conductivity

Information regarding the important flow characteristics to achieve each of environmental objectives is provided in Sections 3-8.

Environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for the Upper Burnt Creek are summarised in Table 40.

Note that a 'cease to flow' component is not required to achieve any of the objectives, however it is recognised that under natural conditions cease to flow events would occur in this reach. Therefore the cease to flow recommendation below provides an upper limit of the total number of days in each year where it is acceptable for flow to cease in the reach.

Note also that unimpacted modelled hydrology was not available for Upper Burnt Creek. The seasonal frequency and duration for each flow component was therefore determined from the Mt William Creek recommendations for an equivalent component. If and when a suitable unimpacted flow dataset becomes available for this reach, the recommended seasonal frequencies and durations should be reviewed with a spells analysis.

Table 40. Environmental flow recommendations for Upper Burnt Creek

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Cease to flow	Dec - May	0 ML/d	DROUGHT	As infrequently as possible	Less than 90 days in total	Ensure stress on environmental values is not exacerbated beyond the point of no return. Cease to flow periods should be concluded with fresh lasting at least 7 days duration.	Durations provide upper limit on the total number of days each year when cease is acceptable based on the number of zero flow days in the unimpacted Lonsdale flow data.
			DRY AVERAGE		Less than 30 days in total		
Baseflow	All year	1 ML/d or natural	ALL	Continuous	Continuous	Maintain edge habitats and shallow water habitat availability for **fish** and **macroinvertebrates** and inundated stream channel for **riparian vegetation** and **prevents excessive instream terrestrial growth**.	Hydraulic model shows minimal depth change between 1 ML/d and 15 ML/d (driven by downstream boundary condition). Unable to justify changing the baseflow recommendation of 1 ML/d from the 2003 study. If the natural baseflow is zero for more days than the recommended cease to flow duration some flow (typically a summer fresh) is still required to break the non-flow period.
Freshes	Dec-May	30 ML/d	DROUGHT	3 per period	2-7 days	Prevent **water quality** decline by flushing pools during low flows.	The fresh duration must be at least 7 days following a cease to flow period. The recommended frequency and duration were derived from (unimpacted) 30 ML/d summer freshes for Mt William Creek.
			DRY	3 per period	4-7 days		
			AVERAGE	3 per period	2-7 days		
			WET	3 per period	3-7 days		
	Jun – Nov	55 ML/d	DROUGHT	1 per period	3 days	Provide variable flow for **fish** movement and diversity of **habitat**. Also flushes surface sediments from hard substrates for **macroinvertebrates**.	At least one fresh required in November for flushing surface sediments.55 ML/d achieves shear stress of 1.1 N/m^2 for most sections, and increases depth by 200 mm. The frequency and duration were derived from (unimpacted) 100 ML/d winter freshes for Mt William Creek.
			DRY	3 per period	3 days		
			AVERAGE	5 per period	5 days		
			WET	5 per period	7 days		
	May - Jun	160 ML/d	DRY	1 per period	1 day	Disturb the algae/bacteria/organic biofilm present on rock or wood debris to support **macroinvertebrate** communities.	160 ML/d achieves velocities of 0.55m/s (xs2). The recommended frequency and duration were derived from (unimpacted) 500 ML/d winter freshes for Mt William Creek.
			AVERAGE	2 per period	2 days		
			WET	3 per period	3 days		
Bankfull	Any	400 ML/d	AVERAGE WET	1 per year or natural	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	The frequency and duration were derived from (unimpacted) bankfull at Glenorchy. Bankfull is required 2-3 times per decade for River Red Gum and 2-5 times per decade for Ti Tree communities.
Overbank	Aug-Nov	1,000 ML/d	WET	1 per year	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	The frequency and duration were derived from (unimpacted) overbank at Glenorchy. Overbank is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

Notes on environmental flow recommendations

Hydraulic model quality: VERY POOR
The flow recommendations for the Upper Burnt Creek have been determined using the HEC-RAS model BE29 which created for the 2003 study. This model represents a site upstream of Toolondo Channel and downstream of the gauge weir (M. Toomey pers. comm. 4 December 2012). (Despite including labels which incorrectly suggest it is downstream.) The site has been described as comprising a small channel with relatively steep but cohesive banks, and a small anabranch (SKM 2003).

The quality of the HEC-RAS model is limited by a number of factors including:

- Few surveyed cross sections (only seven),
- Insufficient number of points in each surveyed section (including no evidence of an anabranch)
- A relatively short length of the river covered (only 180 metres),
- Minimal bed diversity (no pools or riffles identified and a constant slope between 5 sections), and
- A downstream boundary condition (rating table) that corresponds to minimal change in water elevation at flows less than 100 ML/d (and does not represent flows greater than 950ML/d).

The model is also not georeferenced, making it not possible to compare its data and results with other geospatial data.

Compliance point

Proposed compliance point:	415223 Burnt Creek at Wonwondah East

The 2003 report did not suggest any compliance points for this reach. An existing gauge at Wonwondah East (415223) is located in the downstream end of the reach (Figure 56). This gauge is an appropriate place to measure environmental flow compliance given its proximity to the lower end of the reach, and its possible location close to the hydraulic model. Note that the location of the hydraulic model is understood to be a short distance upstream of the existing gauge although is not georeferenced so was not able to be confirmed.

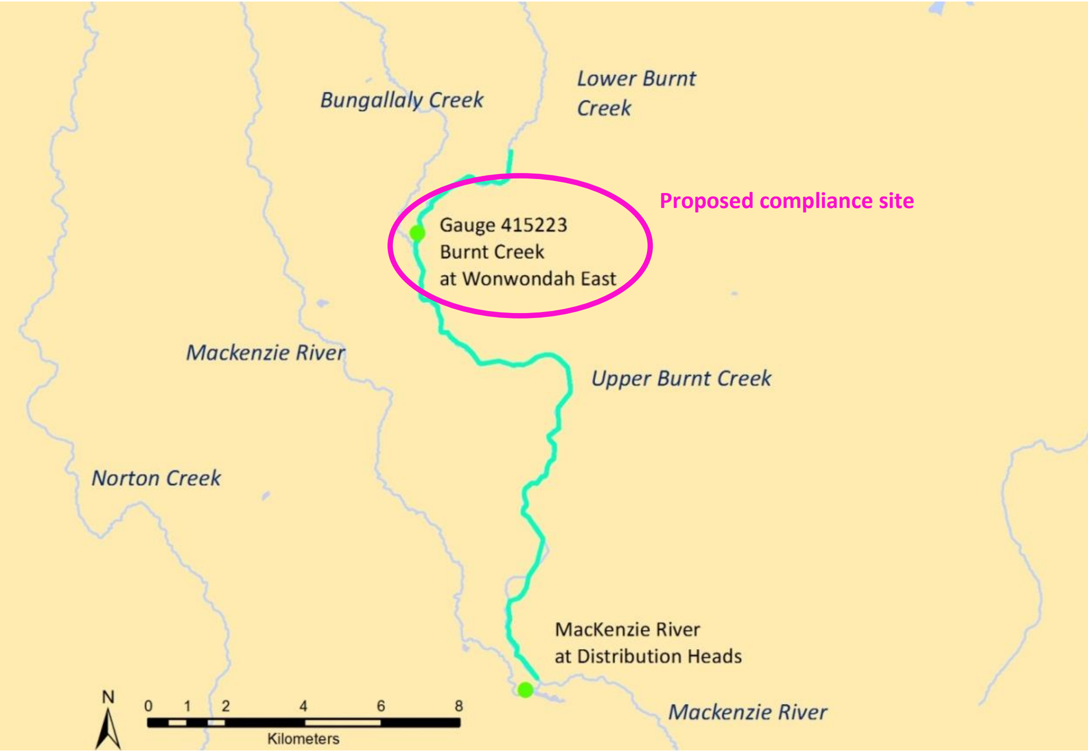


Figure 56. *Location of active flow gauges in Upper Burnt Creek*

Performance assessment

Performance reporting point:

Gauge	415223
Name	Burnt Creek @ Wonwondah East
Status	Open / Active
Start for assessment period	1 July 1972
End for assessment period	30 June 2010

For performance reporting (Table 41), the flow recommendations presented in Table 40 has been analysed using eFlow Predictor. The years have been sorted to allow grouping of drought, dry, average and wet years and the percentage compliance reflects duration of flow target achieved (baseflow) or the number of flow events achieved (freshes). Note that for this assessment each flow event (i.e. a fresh, bankfull or overbank) has been counted discreetly (i.e. a single long event is only one event). No limit on the number of days between events was applied.

The 'short fall' (i.e. how much extra water would have been required to be delivered over and above that which did pass the compliance point to achieve full compliance) has been summarised on an annual basis (Table 41, Figure 57).

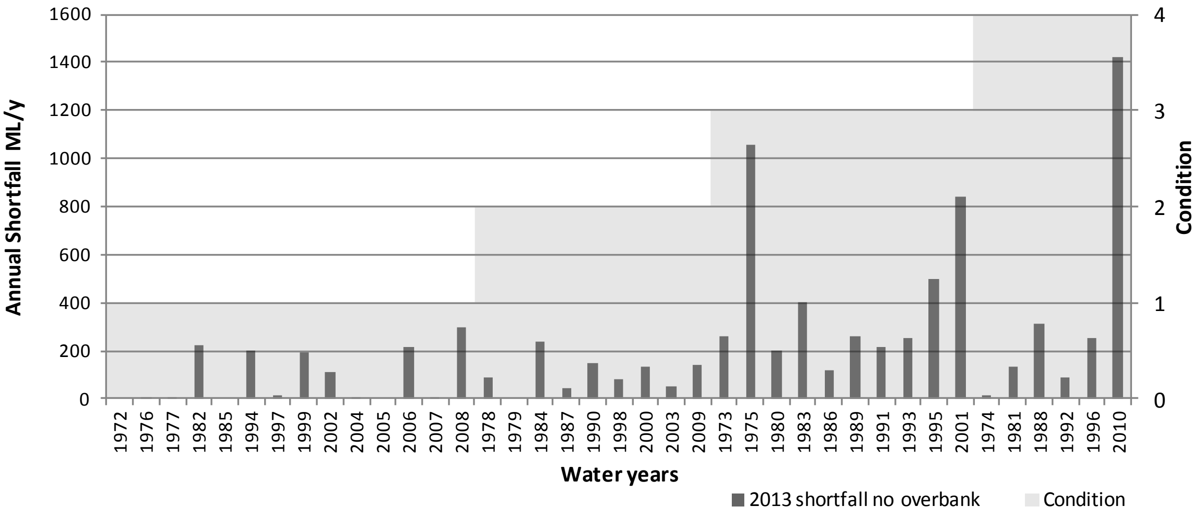


Figure 57. *Total Annual Shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet) – Upper Burnt Creek*

For the reporting period the mean annual flow was 18.1 GL and the mean shortfall was 0.3 GL. However the shortfall varied tremendously from as little as 0 ML in several years to 3.3 GL in 2010. If the overbank flow requirement is not considered as one that would normally be delivered as part of the operational environmental water delivery then the overall shortfall drops from 0.3 GL/y to 0.2 GL/y (mean).

The implications of this shortfall analysis in terms of risk assessment are that if we assume the assessment period is typical, then delivery of 0.14 GL/y can achieve compliance in 50% of all years (Figure 58). Note that additional water may be required to be released from storages to achieve the required flows as the assessed site.

Table 41. Performance of environmental flow recommendations for Upper Burnt Creek

				Flow recommendation																		
	Years	annual flow total (GL)	annual Shortfall (GL)	Baseflow summer 1Mld for	Baseflow winter 1ML/d for	Drought summer fresh 30 M	Drought winter fresh 55ML	Dry Summer fresh 30ML/d x	Dry May-Jun 160ML/d x 1 f	Dry winter fresh 55ML/d x	Avg Summer Fresh 30ML/d x	Avg May-Jun fresh 160ML/d	Avg june nov fresh 55ml/d	Avg bankfull 400Ml/d x1 f	Wet Overbank 1000ML/d x1	wet Summer fresh 30 ML/d	wet winterfresh 55ML/d x	wet May-Jun 160ML/d x 3 f	Wet Bankfull 400ML/d x1 O
	median	11.03	0.14	100	100	0	100	0	0	100	33	0	20	100	50	33	20	0	100
	mean	18.14	0.22	77	97	29	57	17	20	80	40	15	20	80	50	28	17	11	83
	1972	25.2	0.0	100	100	67	100												
	1976	9.2	0.0	100	100	67	100												
	1977	14.2	0.0	100	100	0	100												
	1982	1.7	0.2	67	100	0	0												
	1985	7.7	0.0	100	100	100	100												
	1994	2.4	0.2	100	100	33	0												
	1997	3.6	0.0	83	100	0	100												
	1999	1.7	0.2	10	100	0	0												
	2002	1.8	0.1	22	100	0	0												
	2004	7.8	0.0	35	100	67	100												
	2005	8.3	0.0	70	100	67	100												
	2006	4.1	0.2	3	100	0	0												
	2007	6.3	0.0	0	100	0	100												
Drought	2008	1.9	0.3	28	45	0	0												
	1978	13.6	0.1	100	100			33	0	100									
	1979	25.4	0.0	100	100			67	100	100									
	1984	26.6	0.2	100	100			0	0	33									
	1987	10.5	0.0	100	100			33	100	100									
	1990	6.8	0.1	100	100			33	0	33									
	1998	6.6	0.1	100	100			0	0	100									
	2000	4.1	0.1	39	84			0	0	67									
	2003	9.5	0.0	23	100			0	0	100									
	2009	3.2	0.1	0	79			0	0	67									
Dry	2011			7	97			0	0	100									
	1973	23.1	0.3	100	100						0	100	20	100					
	1975	41.3	1.1	100	100						67	0	20	100					
	1980	31.1	0.2	100	100						33	0	20	100					
	1983	24.2	0.4	100	100						33	0	20	100					
	1986	51.4	0.1	100	100						33	0	20	100					
	1989	25.2	0.3	100	100						100	0	20	100					
	1991	23.2	0.2	100	100						0	0	20	100					
	1993	18.6	0.3	100	100						33	0	0	0					
	1995	27.6	0.5	100	100						67	50	40	100					
Average	2001	8.4	0.8	100	86						33	0	20	0					
	1974	41.0	0.0	100	100										0	33	20	33	100
	1981	55.6	0.1	100	100										0	0	20	33	0
	1988	27.8	0.3	100	100										0	33	20	0	100
	1992	54.6	0.1	100	100										100	33	0	0	100
	1996	41.4	0.3	100	100										100	0	20	0	100
Wet	2010	11.0	1.4	86	79										100	67	20	0	100

Colour coding: *occurs 0-10 % of the time; occurs 11-20 % of the time; occurs 21-30 % of the time; occurs 31-40 % of the time; occurs 41-50 % of the time; occurs 51-60 % of the time; occurs 61-70 % of the time; occurs 71-80 % of the time; occurs 81-90 % of the time; occurs 91-100 % of the time*

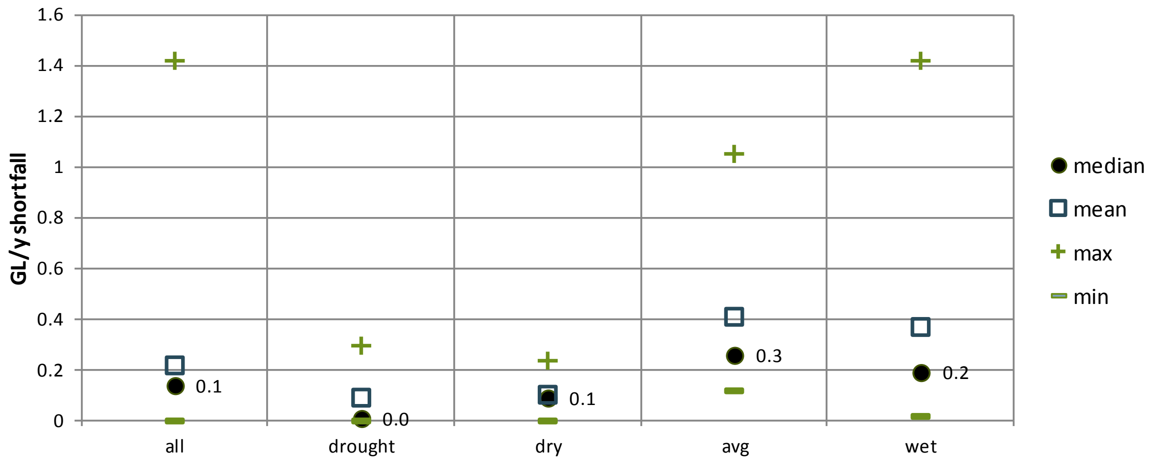


Figure 58. *Upper Burnt Creek shortfall summary by seasonal condition*

This can also be presented in terms of the relative compliance likely to be achieved in any given year for any given environmental water availability (Figure 59). For example if 200ML of environmental water is available at the start of a given water year, depending on the prevailing environmental conditions this would be sufficient to achieve full compliance in around 60% of years, which ranges from only 15% of wet years to around 70% in drought years.

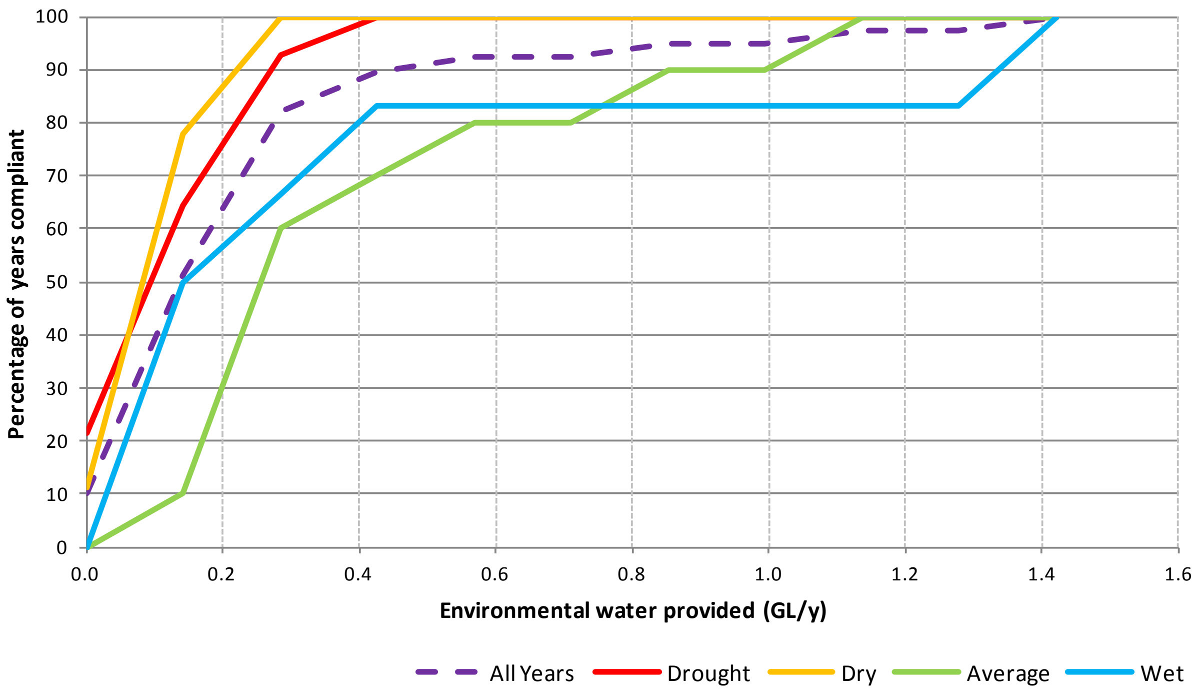


Figure 59. *Percentage of years compliant under different environmental water delivery (excludes overbank flow recommendation) – Upper Burnt Creek*

Summary of performance:

All flow conditions: The baseflow provisions apply under all climatic conditions and were at least partially met in most years (i.e. achieved for some proportion of the year)

Drought conditions: The winter fresh requirement is met in approximately half the drought years. The requirement for three summer freshes is rarely met, with most years not receiving even one summer fresh).

Dry conditions: Similar freshes to the drought were recommended for the dry. The winter freshes were also met in approximately half the dry years and the summer freshes were rarely met.

Average conditions: Summer freshes were rarely met under the average conditions, but winter freshes were at least partially met in most years. A bankfull event was achieved in most years.

Wet conditions: The summer and winter fresh requirements were not met completely in any wet years, however were partially met in most years. The overbank and bankfull conditions were achieved in most wet years.

Comparison to 2003 study

The revised flow objectives outlined in Table 40 are considerably different from the recommendations provided in the 2003 study (Table 42). This is due to:

- Changes to environmental objectives (the 2003 flow objectives included maintaining self-sustaining native bird and fish populations compared with the revised objective to facilitate dispersal of endemic fish species, and focussed on the maintenance of certain species of vegetation compared with the revised priority to maintain mosaics of floodplain and riparian water-dependent vegetation).
- Introduction of different flow recommendations for wet, dry, drought and average years.

Table 42. 2003 study environmental flow recommendations for Upper Burnt Creek (SKM 2003)

Season	Magnitude	Frequency	Duration
Summer	0 ML/d	Annually	4 months
	>45 ML/d	1 in 2 years	Minimum 1 day
Winter	1 ML/d	Daily	Continuous (May – December)
	>2 ML/d	2 annually	Minimum 5 days (June – October)
Annual	45 ML/d	3 annually	Minimum 2 days

Key differences with the new recommendations are:

- A baseflow is included in summer (and winter) and a maximum cease to flow period which can be tolerated is specified. This change is due to a difference in the environmental objectives applied in the two studies and improvements to the understanding of flow-ecology response models since 2003.
- Summer freshes are included every year.
- Winter freshes are higher in magnitude (however are recommended for review with an improved hydraulic model).
- In average and wet years a bankfull flow of 400 ML/d is included, and in wet years an overbank flow of 1,000 ML/d is included (these flow magnitudes are recommended for further review with an improved hydraulic model).

Comparison of performance assessment

The result of developing flow recommendations that are based on the prevailing flow conditions results in temporally varying flow requirements that are a closer reflection of unimpacted flow regimes (Figure 60). As a consequence the resulting flow regime is a closer reflection of a unimpacted flow regime, and also more closely reflects the water management environment whereby more water is available in wetter years than dry years.

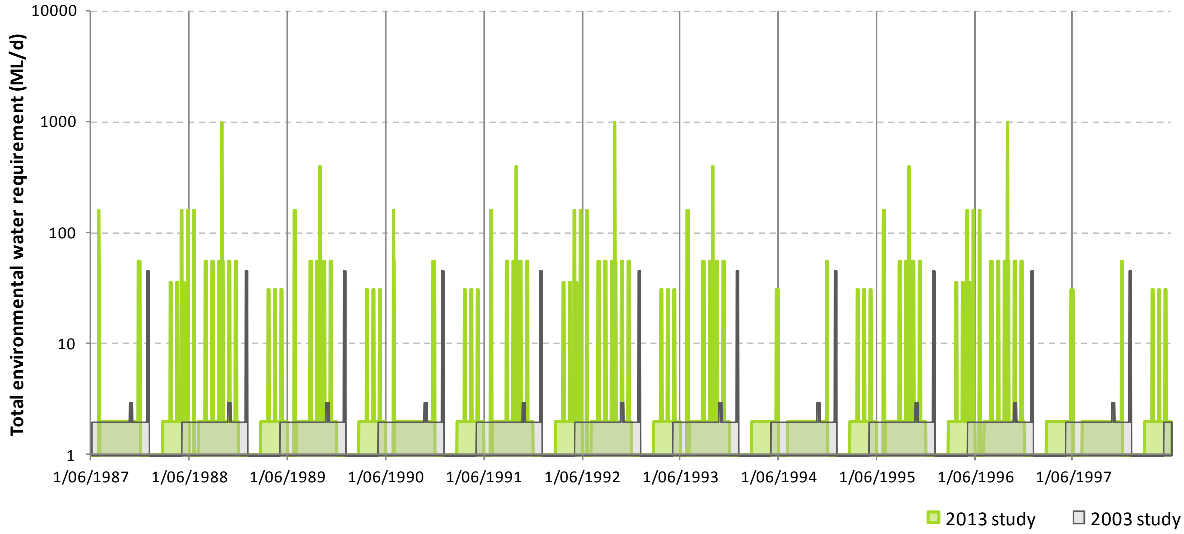


Figure 60. *Comparison of total environmental water recommendations for two studies – Upper Burnt Creek*

The overall total environmental water recommendations as part of this study are around 1.1 GL/y more than those recommended as part of the 2003 project flow recommendations (Table 43, Figure 61). However the flow recommendations for this study are contingent on the prevailing weather conditions (drought, dry, average and wet conditions) such that the years of higher environmental water demand correspond with the years of higher water availability. The new recommendations resulted in an overall increase in the water shortfall from 2003 of 1.3 GL/y (excluding overbank requirements).

Table 43. Shortfall statistics for Upper Burnt Creek at Wonwondah East 1972 – 2010 (GL/y)

Year type	Total environmental water recommendation		Shortfall in environmental water recommendation			Recorded flow
	2003 study	2013 study	2003 study	2013 study	2013 study (no overbank)	
All years (mean)	0.50	1.63	0.09	0.33	0.22	18.14
All years (median)	0.50	0.64	0.02	0.14	0.14	11.03
Largest	0.50	4.38	0.37	3.30	1.42	55.63
Smallest	0.50	0.37	0.00	0.00	0.00	1.67
Drought (median)	0.50	0.37	0.16	0.01	0.01	5.19
Dry (median)	0.50	0.64	0.02	0.09	0.09	9.47
Average (median)	0.50	2.64	0.00	0.26	0.26	24.70
Wet (median)	0.50	4.38	0.02	0.48	0.19	41.17

In the 2003 study, 0.5 GL/y is recommended for every year type (Figure 26Figure 61). This study recommends flows ranging from 0.4 GL/y in drought years to 4.4 GL/y in wet years, resulting in a mean total flow requirement of 1.6 GL/y across the reporting period. The overall environmental water recommendation for this reach is greater than that in the 2003 for all climatic conditions.

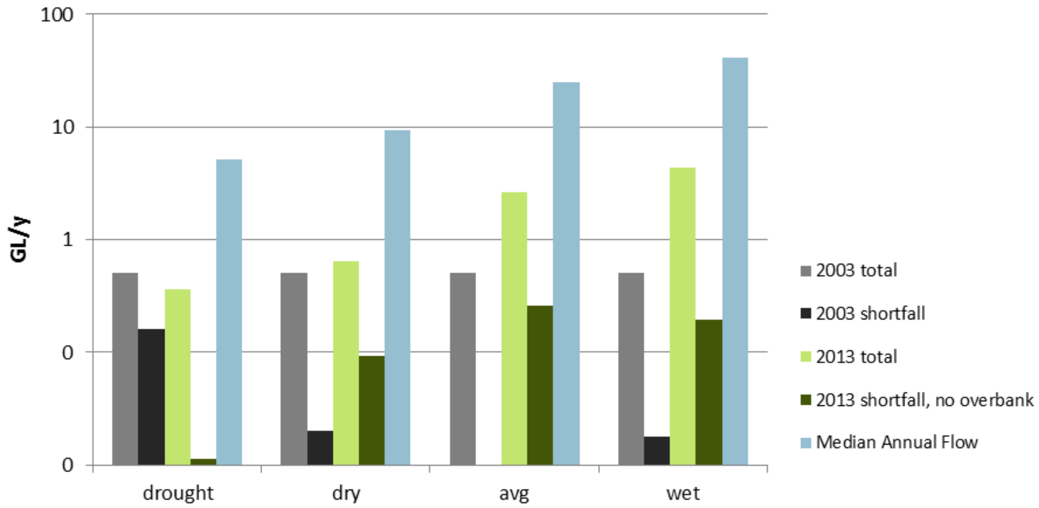


Figure 61. *Total environmental water recommendations by year type (note logarithmic Y axis makes values appear more similar) –Upper Burnt Creek*

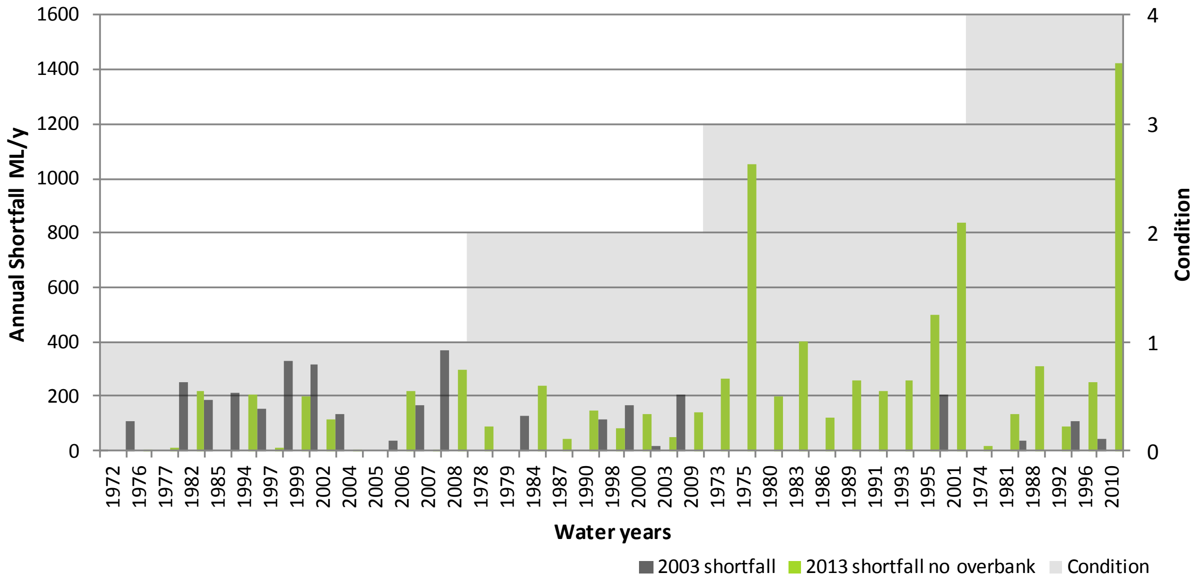


Figure 62. *Annual shortfall comparison – Upper Burnt (1=Drought, 2=Dry, 3=Average, 4=Wet)*

6.6 Lower Burnt Creek - Toolondo Channel to Wimmera River

Flow in this reach is significantly reduced from what would have occurred under natural conditions. Most flow in Burnt Creek at Toolondo Channel is diverted to Taylors Lake, so Burnt Creek only flows downstream in the highest flow events or when specific environmental releases are made.

The channel section is small and sinuous. The riparian zone provides a strip of trees passing though agricultural land cleared for grazing. The quality of vegetation is limited with very poor vegetation in the reach between Horsham and the Western Highway which has been cleared and straightened to improve drainage. During extended dry periods, organic material can build up on the channel bed, and may lead to black water issues when flows are received. The surrounding floodplain supports a Black Box community, and the riparian zone is characterised by a River Red Gum over-storey (SKM 2003).

Due to the ephemeral nature of this stream, there is relatively low diversity of fish species (SKM 2003) although historically there was a great abundance of Blackfish in the reach (Earth Tech 2005). Given the lower reaches of Burnt Creek are now subjected to extended periods of cease to flow and lacks suitable refuges (Biosis 2013), a decision has been made to forego any specific flow management to support fish in this reach.[11]

Environmental objectives
The environmental objective for the Lower Burnt Creek is to maintain mosaics of water-dependent vegetation (floodplain and riparian).

Information regarding the important flow characteristics to achieve each of environmental objectives is provided in Sections 3-8.

Environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for the Lower Burnt Creek are summarised in Table 44.

Note: Unimpacted modelled hydrology was not available for the Lower Burnt Creek. Therefore the recommended frequency and durations have been derived from the unimpacted Wimmera River hydrology at Glenorchy (Wimmera 2/3). If/when unimpacted modelled flow data becomes available it is recommended that spells analysis is undertaken to update the recommended frequencies and durations for seasonal conditions.

Table 44. Environmental flow recommendations for Lower Burnt Creek

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved
Bankfull	Any	45 ML/d	AVERAGE WET	1 per period or natural[12]	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.
Overbank	Aug-Nov	90 ML/d	WET	1 per period	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.

Notes on environmental flow recommendations

Hydraulic model quality: VERY POOR
The flow recommendations for the Lower Burnt Creek have been determined using the HEC-RAS model BE52 which was created for the 2003 Study. This model represents a relatively homogeneous section of the reach downstream of Toolondo Channel. However the reach is described in the conversion report as having 'a highly variable long profile' (SKM 2003). There are no bars or benches represented in the model, most likely due to the limited number of surveyed points in the model.

There are a number of factors impacting the quality of this model:

- Few surveyed cross sections (only 6)
- Insufficient number of points in each surveyed section
- Relatively short length of the river covered (only 65 metres)

[11] If circumstances change and flows are required to facilitate the dispersal and establishment of endemic fish species through Lower Burnt Creek, flow pulses would need to be provided to stimulate fish movement. Low flow freshes (December – May) and high flow freshes (June – November) would need to be provided to provide flow variability and ensure any instream barriers are inundate by at least 0.1 metres of water. The magnitude of these freshes would need to be determined using an improved hydraulic model (as no instream barriers are included in the current model). The frequency and duration of the flows could be based on the recommended frequency and duration for low and high flow freshes in Burnt Upper.
[12] Inundation is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

- Minimal bed diversity (no pools or riffles identified)
- A downstream boundary condition (rating table) that corresponds to minimal change in water elevation at flows less than 100 ML/d (and does not represent flows 1,300 ML/d).

The model is also not georeferenced, making it not possible to compare its data and results with other geospatial data. The flow recommendations should be reviewed if/when an improved hydraulic model becomes available.

Compliance point

Proposed compliance point: New gauge required at downstream end of reach

There are no active flow gauges in Lower Burnt Creek to measure compliance with the environmental flow recommendations. In order to assess compliance with the environmental flow recommendations for this reach a gauge is required. The gauge is only required to measure the two flow components recommended in Table 44; bankfull and overbank and therefore may be quite a simple gauge. It is understood that the hydraulic model site is near the top of this reach. However it is not georeferenced to be able to confirm the exact site location. It is proposed that a new gauge for environmental flow compliance be located towards the downstream end of the reach so that the flow recommendations are achieved for the full length of the reach, although not too close to the end of the reach that the flows would be impacted by backwater effects from the Wimmera River.

Performance assessment
Compliance point: no suitable compliance point exists, performance of the flow recommendation over recent history and comparison with previous studies cannot be completed.

Comparison to 2003 study
The revised flow objectives outlined in Table 40 are considerably different from the recommendations provided in the 2003 study (Table 45). This is due to:

- Changes to environmental objectives (the 2003 flow objectives included maintaining self-sustaining fish and native bird populations and maintenance of certain species of vegetation compared with the revised single priority to maintain mosaics of floodplain and riparian water-dependent vegetation).
- Introduction of different flow recommendations for wet, dry, drought and average years (flows now only recommended in wet and average years).

Table 45. 2003 study environmental flow recommendations for Lower Burnt Creek (SKM 2003)

Season	Magnitude	Frequency	Duration
Summer	0 ML/d	Annually	4 months
	>45 ML/d	1 in 2 years	Minimum 1 day
Winter	1 ML/d	Daily	Continuous (May – December)
	>2 ML/d	2 annually	Minimum 5 days (June – October)
Annual	45 ML/d	3 annually	Minimum 2 days

The key differences in the new recommendations are:

- No cease to flow is included (while it is expected this will occur there is no justification for recommending one)
- No freshes or winter baseflow are included (due to changes in the objectives)
- A bankfull flow of 45 ML/d is only recommended for average and wet years (compared to three times per year every year)
- An overbank flow of 90 ML/d is included in wet years.

6.7 Yarriambiack Creek - Downstream of the Wimmera River

Yarriambiack Creek is a distributary of the Wimmera River that flows north past the towns of Jung, Warracknabeal, Brim and Beulah and ends in a series of terminal lakes including Lake Corrong and Lake Lascelles. Under natural conditions the creek would flow only in high flows and floods, however the construction of a weir and offtake from the Wimmera River, ensures that flows are diverted from the Wimmera River at all levels. Following protracted debate during drought conditions in the 1960s, an agreement was reached to build a structure to divert a proportion of Wimmera River low flows into Yarriambiack Creek. During the 1850s the creek offtake was modified to direct increased flows from the river up the creek for stock and domestic purposes, illustrating the long history of flow modification in the region.

The creek channel is narrow and is surrounded by a complex floodplain which connects at various points into nearby Station and Corkers Creeks which are flood runners. Floodrunners also drain into Darlot Swamp and King Swamp which in only the highest flows overflow into Two Mile Creek and reconnect with the downstream Wimmera River. Downstream of the offtake structure the condition of River Red Gums in the riparian zone improved following enduring severe stress during the drought; these trees do not face the same salinity issues as River Red Gums on the lower Wimmera River. Progressing downstream, the riparian vegetation shifts away from River Red Gum to Black Box communities (refer Section 3.4).

Community values of the creek include recreational activities at the terminal lakes, and along the waterway at weir pools at Warracknabeal, Brim, Beulah and Jung. Water is also supplied to these weir pools (apart from Jung) via the Wimmera Mallee Pipeline. Key issues for the waterway include improving riparian vegetation.

Figure 63. *Yarriambiack Creek (July 2012)*

Environmental objectives

The environmental objective for Yarriambiack Creek is to maintain mosaics of water-dependent vegetation (floodplain and riparian). Information regarding the important flow characteristics to achieve each of environmental objectives is provided in Sections 3-8.

Environmental flow recommendations

Environmental flow recommendations to achieve the environmental objectives for Yarriambiack Creek are summarised in Table 46.

Note: Unimpacted modelled hydrology was not available for Yarriambiack Creek. Therefore the recommended frequency and durations for Yarriambiack Creek have been derived from the unimpacted hydrology for the Wimmera River at Glenorchy (Wimmera 2/3). If/when unimpacted modelled flow data becomes available it is recommended that spells analysis is undertaken to update the recommended frequencies and durations for seasonal conditions.

Table 46. Environmental flow recommendations for Yarriambiack Creek

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved
Bankfull	Any	40 ML/d	AVERAGE / WET	1 per period or natural [13]	2 days	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Maintain **structural integrity of channel**. Refer Figure 64.
Overbank	Aug-Nov	200 ML/d	WET	1 per period	1 day	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Maintains **floodplain geomorphic features**. Refer Figure 64.

Notes on environmental flow recommendations

Hydraulic model quality: GOOD

The flow recommendations for Yarriambiack Creek were determined using a new HEC-RAS model created specifically for this review. The model was based on available LiDAR data which was flown when virtually no water was in the creek. The high resolution of LiDAR resulted in detailed cross-sectional data being incorporated in the model, which covered a substantial section of the reach. The model represents the 2 kilometre section of the creek downstream of its offtake from the Wimmera.

Due to the complex nature of the Yarriambiack floodplain, including numerous tributaries and pooling areas, two-dimensional hydraulic modelling would provide a better representation of this reach. The HEC RAS model was geospatially referenced, allowing the higher flow inundations to be mapped against other geospatial data (Figure 64).

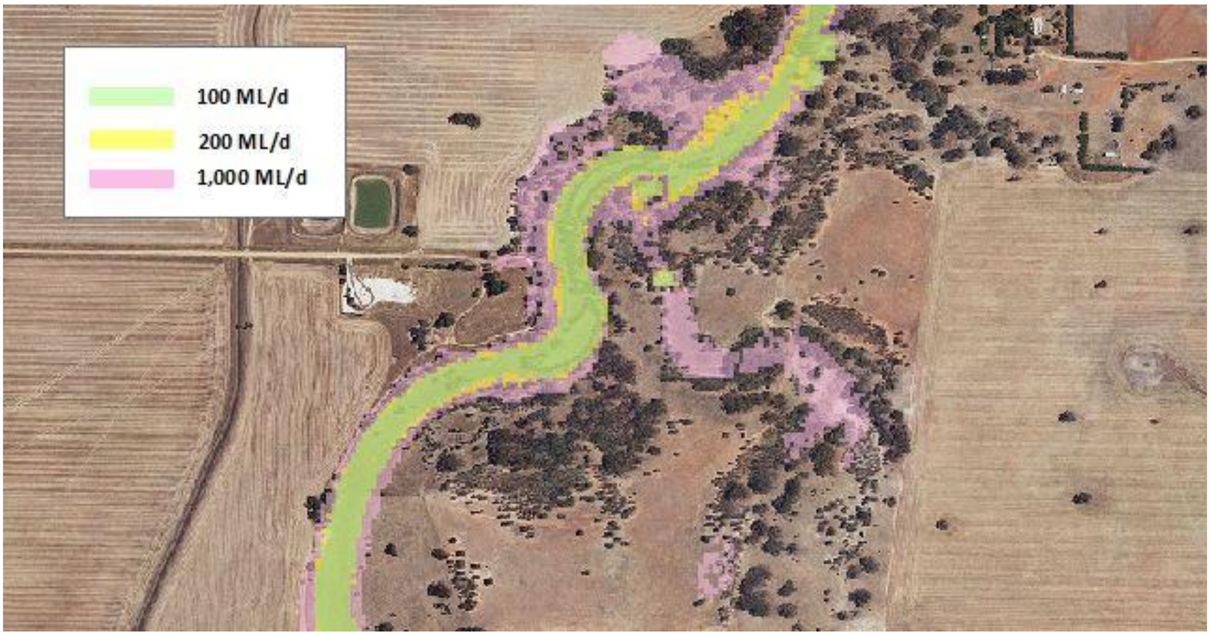


Figure 64. *Yarriambiack expected inundations*

Compliance point

Proposed compliance point:	415241 Yarriambiack Creek at Murtoa

No compliance point was proposed for Yarriambiack Creek in the 2003 study. However an existing gauge (415241) at Murtoa (downstream of the Wimmera Highway) is located within the reach. This site provides a suitable location for measuring flows to determine whether the environmental flow recommendations are achieved. Its proximity to the hydraulic modelling site is shown in Figure 65. It is worth noting that while

[13] Inundation is required 2-3 times per decade for River Red Gum, 1-3 times per decade for Black Box and 2-5 times per decade for Ti Tree.

compliance at Murtoa will ensure that the recommendations are met at the modelled site, this is located within the first 10-15 kilometres of a creek which extends more than 100 kilometres, and there is insufficient modelling data to determine whether the lower part of the creek is achieved with these same flows. It is recommended that during flow releases observations of the creek downstream be made to confirm whether bankfull and overbank flows are also achieved further downstream.

Figure 65. *Location of active flow gauges and hydraulic model in Yarriambiack Creek*

Performance assessment

Performance reporting point:

Gauge	415241
Name	Yarriambiack Creek @ Murtoa (Wimmera Highway)
Status	Open / Active
Start for assessment period	1 July 1978
End for assessment period	30 June 2010

For performance reporting (Table 47), the flow recommendations presented in Table 25 has been analysed using eFlow Predictor. The years have been sorted to allow grouping of Drought, Dry, Average and Wet Years and the percentage compliance reflects duration of flow target achieved (baseflow) or the number of flow events achieved (freshes). Note that for this assessment each flow event (i.e. a fresh, bankfull or overbank) has been counted discreetly (i.e. a single long event is only one event). No limit on the number of days between events was applied.

Table 47. Performance of environmental flow recommendations for Yarriambiack Creek

				flow recommendation		
	Years	annual flow total (GL)	annual Shortfall (GL)	Avg bankfull 40Ml/d x1 fo	Wet Overbank 200ML/d x1 O	Wet Bankfull 40ML/d x1 Oc
	median	0	0	0	0	50
	mean	1.85	0.03	44	38	50
	1982	3.1	0			
	1994	0.0	0			
	1997	0.0	0			
	1998	0.0	0			
	1999	0.0	0			
	2001	0.0	0			
	2002	0.0	0			
	2003	0.0	0			
	2004	0.0	0			
	2005	0.0	0			
	2006	0.0	0			
	2007	0.0	0			
Drought	2008	0.0	0			
	1985	0.0	0			
	1990	0.0	0			
	2000	0.0	0			
	2009	0.2	0			
Dry	2011	2.0	0			
	1978	1.7	0.01	100		
	1980	3.8	0	100		
	1984	7.8	0	100		
	1986	1.1	0	0		
	1987	0.0	0.1	0		
	1991	0.0	0.1	0		
	1993	0.0	0.1	0		
Average	1995	0.0	0.1	0		
	1979	6.7	0.0	100	100	100
	1981	17.2	0.0	100	0	100
	1983	14.6	0.0	100	100	100
	1988	0.0	0.1	0	0	0
	1989	0.0	0.1	0	0	0
	1992	0.0	0.1	0	0	0
	1996	0.0	0.1	0	0	0
Wet	2010	4.6	0	100	100	100

Colour coding: *occurs 0-10 % of the time;* *occurs 91-100 % of the time*

The 'short fall' (i.e. how much extra water would have been required to be delivered over and above that which did pass the compliance point to achieve full compliance) has been summarised on an annual basis (Table 47, Figure 66, Figure 67, Figure 68). The flow recommendations vary by season and so too does the recommended environmental water. For the reporting period the mean annual flow was 1.85GL and the mean shortfall was 73ML. If overbank flow requirement are not included as part of operational environmental water delivery then the overall shortfall drops from 73 ML/y to 29 ML/y (mean).

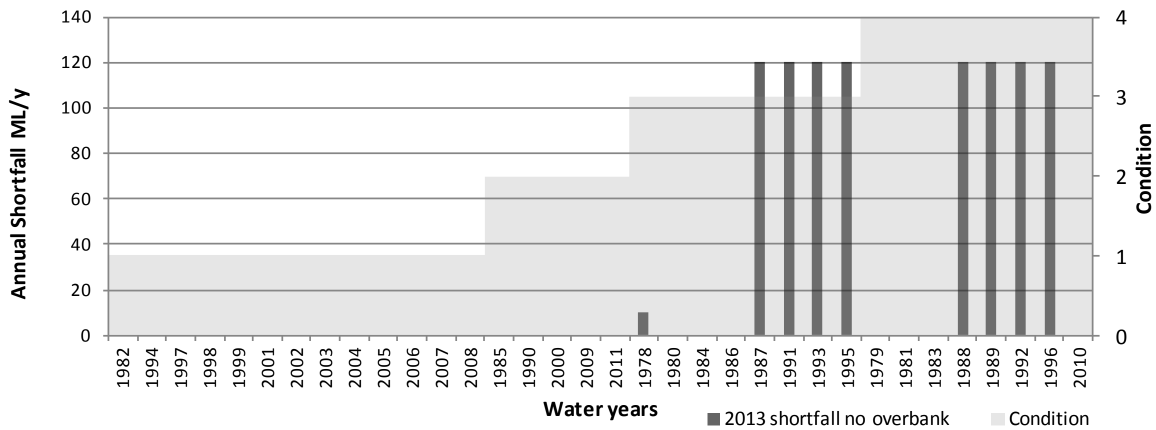


Figure 66. *Total Annual Shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet) (Yarriambiack)*

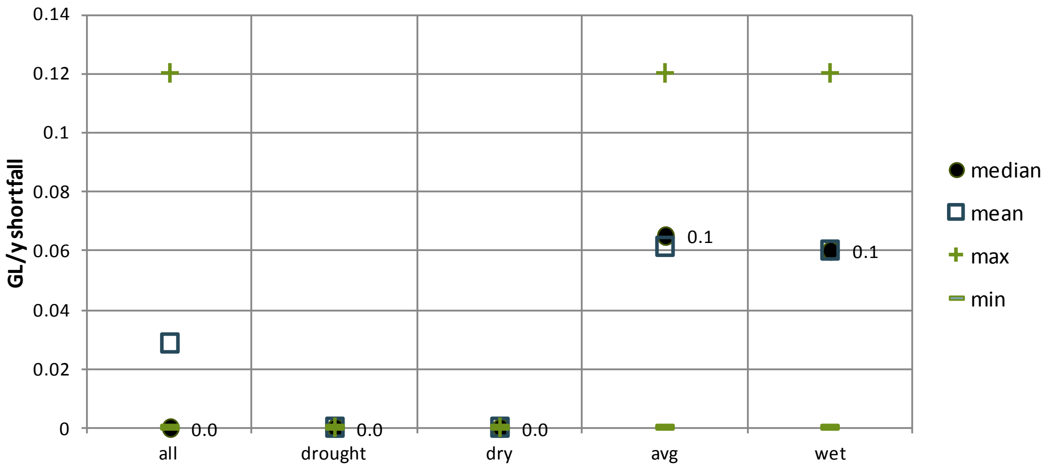


Figure 67. *Yarriambiack Creek shortfall summary by seasonal condition*

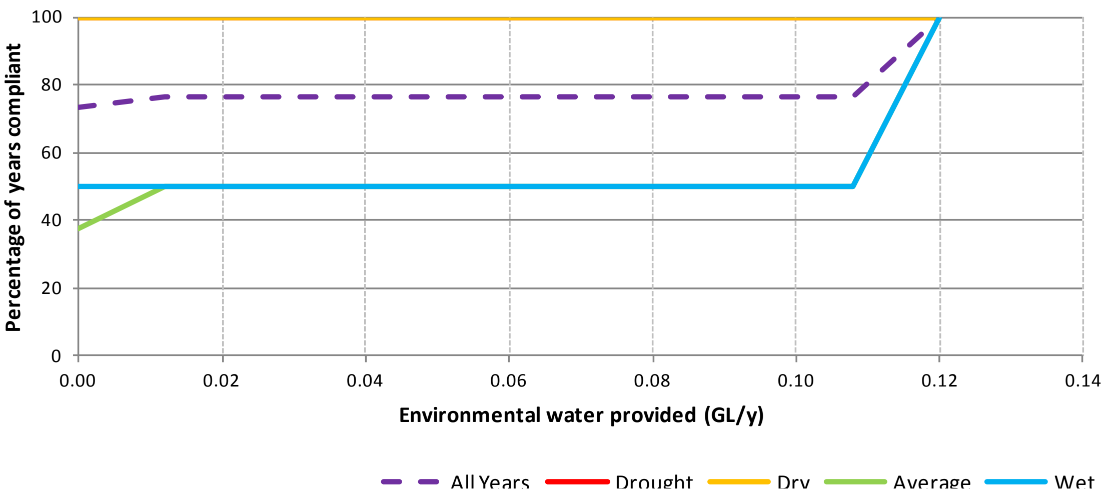


Figure 68. *Percentage of years compliant under different environmental water delivery (excludes overbank flow recommendation).*

Comparison to 2003 study

The revised flow objectives outlined in Table 46 are considerably different from the recommendations provided in the 2003 study (Table 48). This is due to:

- Changes to environmental objectives (the 2003 flow objectives included maintaining self-sustaining fish populations and concentrated on certain species of vegetation compared with the revised priority to maintain mosaics of floodplain and riparian water-dependent vegetation).
- Revised hydraulic modelling (a new HEC-RAS model was created using available LiDAR data).
- Introduction of different flow recommendations for wet, dry, drought and average years (flows now only recommended in wet and average years).

Table 48. 2003 study environmental flow recommendations for Yarriambiack Creek (SKM 2003)

Season	Magnitude	Frequency	Duration
Summer	0 ML/d	Annually	Maximum 365 days (or natural)
Winter	>80 ML/d	Annual	Minimum 3 days
	>400 ML/d	Annual	Minimum 1 day

The key differences in the new recommendations are:

- No cease to flow is included (while it is expected this will occur there is no justification for recommending one)
- Lower flow magnitudes (bankfull is 40 ML/d not 80 ML/d, and overbank of 200 ML/d not 400 ML/d)
- Flows are only recommended in wet and average years.

The overall total environmental water recommendations as part of this study are around 130ML/y (compared to 960ML/y from 2003 study). The relative shortfall over the analysis period was 70ML/y, and if overbank events are excluded, then this shortfall drops to 30ML/y with a similar requirement of 60-70ML/y in average and wet years (Table 49, Figure 69, Figure 70).

Table 49. Shortfall statistics for Yarriambiack Creek at Murtoa 1978 – 2010 (GL/y)

Year type	Total environmental water recommendation		Shortfall in environmental water recommendation			Recorded flow
	2003 study	2013 study	2003 study	2013 study	2013 study (no overbank)	
All years (mean)	0.96	0.13	0.85	0.07	0.03	1.85
All years (median)	0.96	0.00	0.96	0.00	0.00	0.00
Largest	0.96	0.44	0.96	0.44	0.12	17.17
Smallest	0.96	0.00	0.00	0.00	0.00	0.00
Drought (median)	0.96	0.00	0.96	0.00	0.00	0.00
Dry (median)	0.96	0.00	0.96	0.00	0.00	0.00
Average (median)	0.96	0.12	0.96	0.07	0.07	0.56
Wet (median)	0.96	0.44	0.86	0.33	0.06	2.31

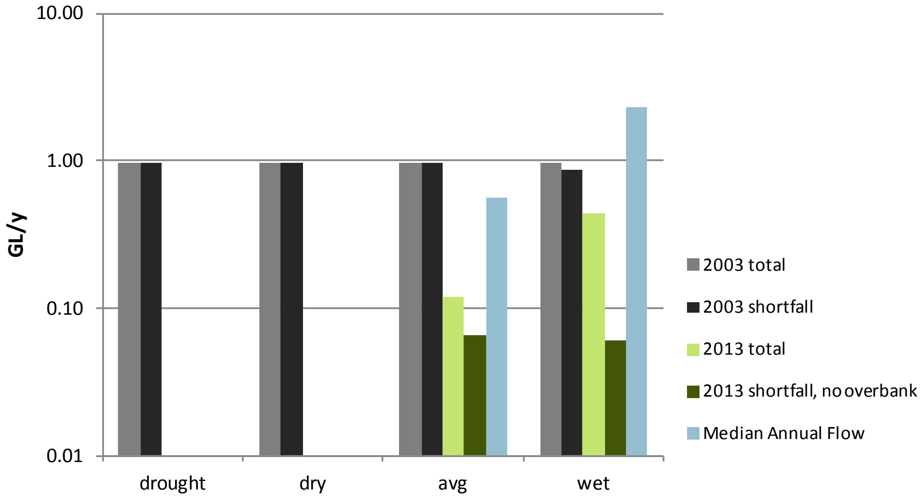


Figure 69. *Total environmental water recommendations by year type (note logarithmic Y axis makes values appear more similar)*

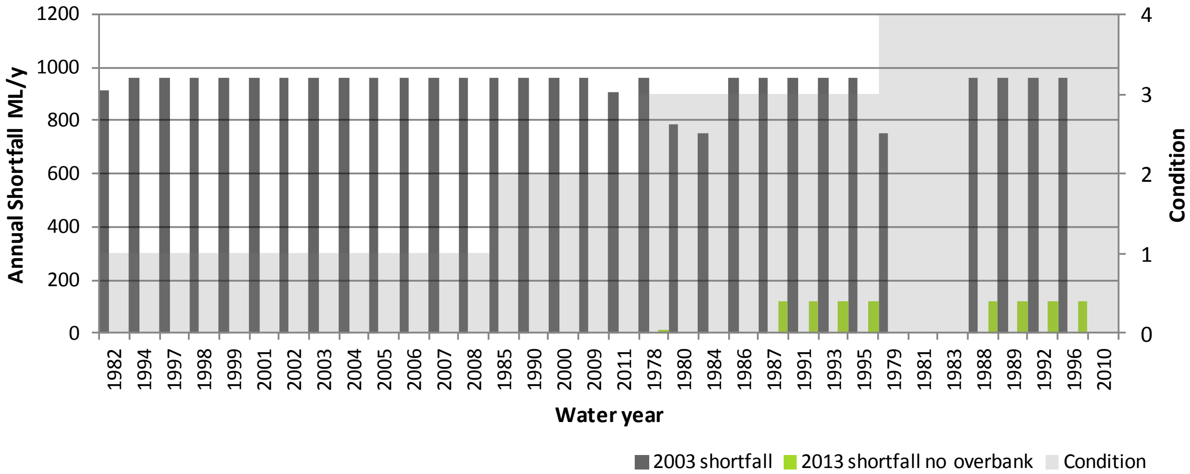


Figure 70. *Annual shortfall comparison – Yarriambiack (1=Drought, 2=Dry, 3=Average, 4=Wet)*

7 Conclusions and recommendations

The objective of this study was to improve the information used in decision making regarding the management of water and provision of environmental water in the Wimmera and Glenelg River systems. The scope and project tasks have been addressed as follows:

- *Compliance point specification and reach delineation*
  During the initial phase of the project (Alluvium 2012) the representativeness of the reaches specified in the 2003 study were reviewed. Recommended compliance points for all reaches have been specified in Section 5-6 of this report.

- *Review and revise flow dependent objectives*
  The Technical Panel has provided updated flow objectives to achieve the updated overarching environmental objectives determined by the Wimmera CMA in this project. Updated flow objectives are outlined in Section 3 of this report.

- *Improve understanding of temporal flow components*
  Recommended environmental flow components for all reaches have been described for four temporal conditions – wet, average, dry and drought (Section 5-6). To aid the understanding of how these temporal flow components are achieved under the observed flow regime a performance assessment against observed streamflow data is also documented in each section. The recommendations also include rates of flow change and information regarding occurrence thresholds between key flow components.

- *Improve information at 'b' sites*
  The 'b' site recommended for further assessment in the Wimmera catchment was Bungalally Creek. Environmental flow recommendations have been developed for Bungalally Creek and documented in Section 7.2.

- *Updated FLOWS study*
  This report documents the updated FLOWS study for the Wimmera River system. The report draws on information from the 2003 study and provides updated assessments where new information has become available. The updated study was undertaken through the application of the FLOWS method, however this study did not comprise the repeat of all tasks undertaken in the 2003 study. Rather, this project provides updated information identified and agreed in the Review Report (Alluvium 2012).

The project and related assessments have identified a number of items for consideration in the next steps in management of environmental water in the Wimmera River system. The following activities are recommended to achieve the optimum outcome from environmental water management:

- Install a permanent streamflow gauge to assess compliance of environmental flows in MacKenzie Reach 2 with the environmental flow requirements outlined in this report. Recommencement of gauging of flows at Bungalally Creek and installation of either a permanent or temporary gauge in Lower Burnt Creek is.

- Update the existing hydraulic models in Mt William Creek, MacKenzie 1&2 and Burnt Creek to include greater extent of the reaches and detail of instream habitat features to improve confidence in recommended environmental flows.

- Improve extent of modelled daily flow data. Unimpacted modelled hydrology data (daily time series) for the Wimmera system were only available for inflows at Glenorchy, Wartook and Lonsdale. If and when unimpacted modelled flow data becomes available it is recommended that spells analysis is undertaken to update the recommended frequencies and durations in all reaches for seasonal conditions.

- Continue to implement the monitoring and evaluation program to assess the effectiveness of environmental flow recommendations (i.e. VEFMAP) and operating decisions (i.e. compliance). Incorporate into the program advances that have been made in general approaches and specific field techniques for assessing the effect of drought and of environmental watering including on eucalypt condition.

- Identify complementary river health activities such as stock exclusion, revegetation and weed control; and implement in priority locations to ensure the river health outcomes sought from the environmental flow recommendations are achieved.

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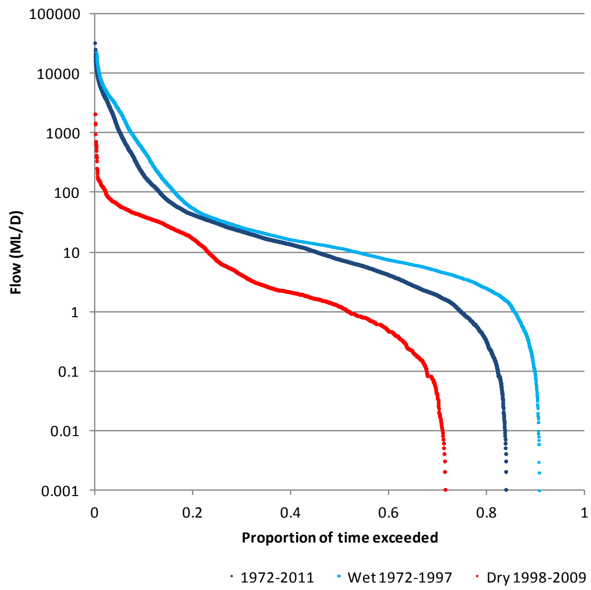
Attachment A
Summary of hydrologic gauge data

Wimmera River Reach 2/3

Relevant Gauge: 415200 (Wimmera River@ Horsham)

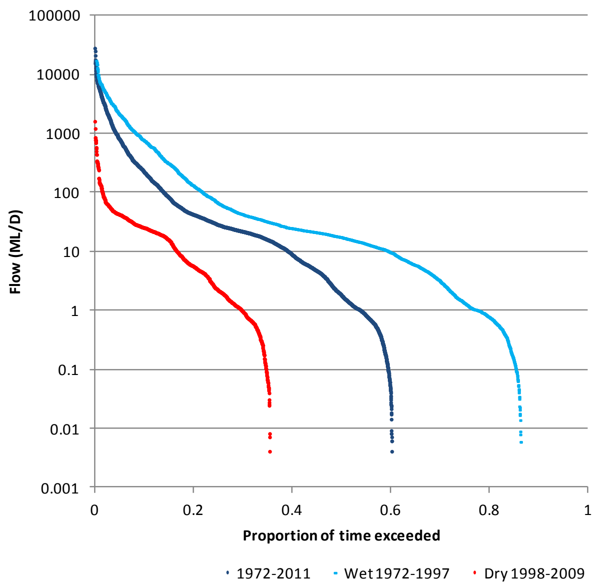


	Whole Period	Wet Period	Dry Period
Start	1/01/72	1/01/72	1/01/98
End	31/12/11	31/12/97	31/12/09
Mean	257.68	353.82	14.22
Median	7.37	11.75	1.19
Std deviation	1270.26	1447.31	65.98
CV	4.93	4.09	4.64
10th percentile	0.00	0.04	0.00
25th percentile	0.93	3.62	0.00
75th percentile	30.01	34.99	6.94
90th percentile	188.82	465.80	38.91

Current conditions flow duration curve – Wimmera River at Horsham

Wimmera River Reach 4

Relevant Gauge: 415246 (Wimmera River @ Lochiel Railway Bridge)

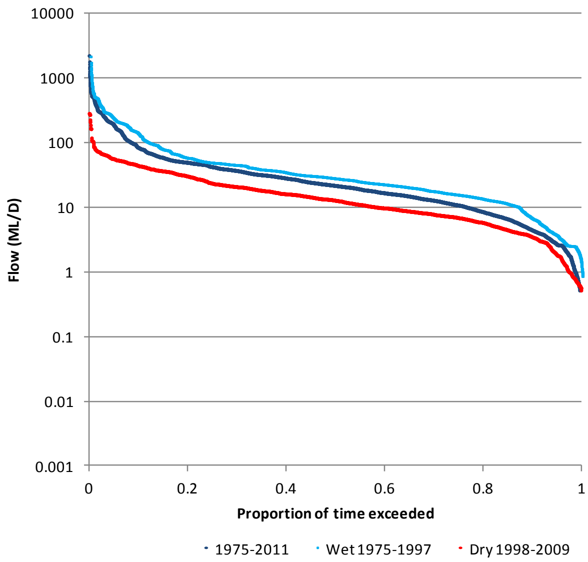


	Whole Period	Wet Period	Dry Period
Start	1/01/72	1/01/72	1/01/98
End	31/12/11	31/12/97	31/12/09
Mean	203.98	353.16	9.98
Median	1.79	17.44	0.00
Std deviation	1054.44	1263.64	52.20
CV	5.17	3.58	5.23
10th percentile	0.00	0.00	0.00
25th percentile	0.00	1.29	0.00
75th percentile	27.75	64.64	2.14
90th percentile	215.34	739.66	24.70

Current conditions flow duration curve – Wimmera River at Lochiel Railway Bridge

MacKenzie River Reach 1

Relevant Gauge: 415202 (MacKenzie River @ Wartook Reservoir)

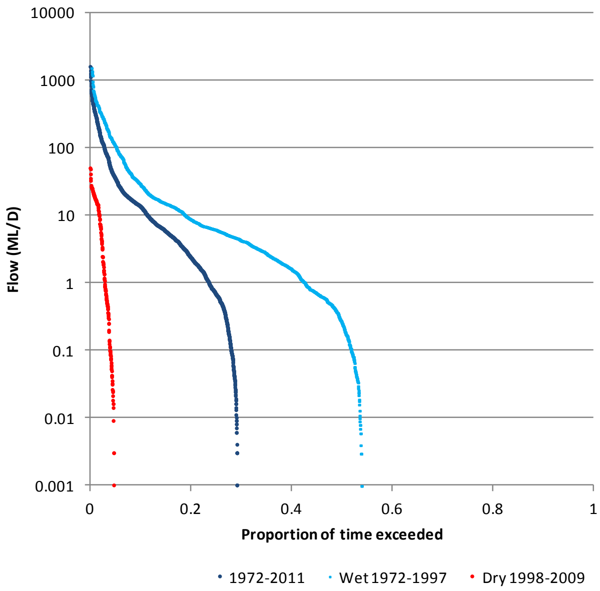


	Whole Period	Wet Period	Dry Period
Start	8/05/75	8/05/75	1/01/98
End	31/12/11	31/12/97	31/12/09
Mean	44.22	57.97	19.03
Median	21.37	28.37	12.60
Std deviation	87.00	105.16	21.24
CV	1.97	1.81	1.12
10th percentile	4.38	6.68	3.43
25th percentile	10.62	15.79	6.78
75th percentile	41.67	49.59	23.16
90th percentile	82.65	131.38	43.34

Current conditions flow duration curve – MacKenzie River at Wartook Reservoir

MacKenzie River Reach 3

Relevant Gauge: 415251 (MacKenzie River @ MacKenzie Creek)



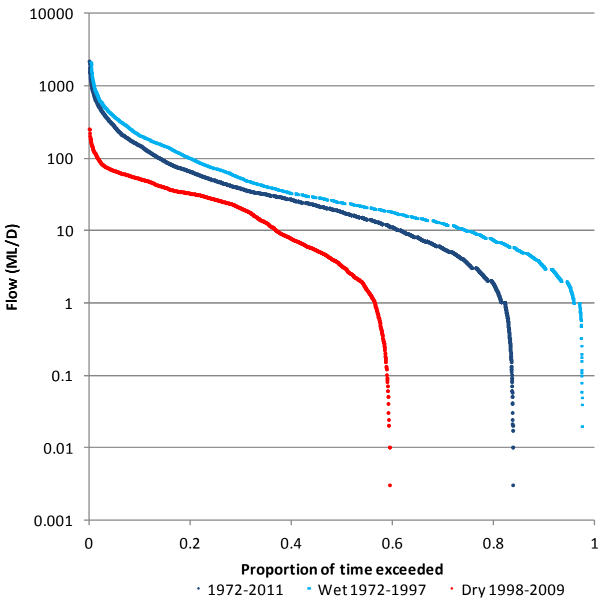
	Whole Period	Wet Period	Dry Period
Start	1/01/72	1/01/72	1/01/98
End	31/12/11	31/12/97	31/12/09
Mean	11.67	21.29	0.40
Median	0.00	0.23	0.00
Std deviation	67.06	90.92	2.82
CV	5.75	4.27	7.08
10th percentile	0.00	0.00	0.00
25th percentile	0.00	0.00	0.00
75th percentile	0.67	6.07	0.00
90th percentile	13.35	27.29	0.00

Current conditions flow duration curve – MacKenzie River at MacKenzie Creek

Note: No gauge data is available for Mt William Creek, Lower Burnt Creek, Bungalally

Upper Burnt Creek

Relevant Gauge: 415223 (Burnt Creek @ Wonwonda East)

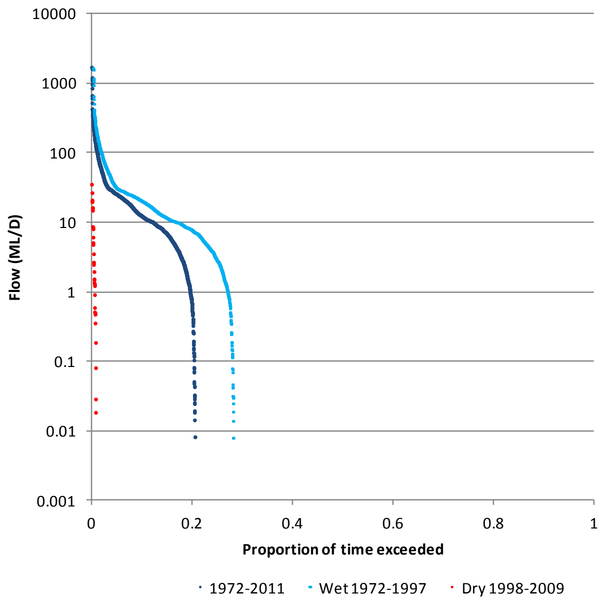


	Whole Period	Wet Period	Dry Period
Start	1/01/72	1/01/72	1/01/98
End	31/12/11	31/12/97	31/12/09
Mean	58.71	79.97	16.28
Median	17.90	24.20	3.14
Std deviation	137.10	161.36	26.09
CV	2.34	2.02	1.60
10th percentile	0.00	3.00	0.00
25th percentile	3.37	10.00	0.00
75th percentile	48.00	72.00	26.41
90th percentile	147.00	204.00	51.18

Current conditions flow duration curve – Burnt Creek at Wonwondah East

Yarriambiack

Relevant Gauge: 415241 (Yarriambiack Creek @ Murtoa (Wimmera Highway))



	Whole Period	Wet Period	Dry Period
Start	1/01/72	1/01/72	1/01/98
End	31/12/11	31/12/97	31/12/09
Mean	5.86	8.59	0.05
Median	0.00	0.00	0.00
Std deviation	38.39	47.52	0.97
CV	6.55	5.53	18.38
10th percentile	0.00	0.00	0.00
25th percentile	0.00	0.00	0.00
75th percentile	0.00	2.64	0.00
90th percentile	11.98	19.91	0.00

Current conditions flow duration curve – Yarriambiack Creek at Wimmera Highway

Attachment B
Environmental flow objectives

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
FISH	Maintain a self-sustaining freshwater catfish population in lower Wimmera River	Maintain sufficient area of pool habitat > 1.5m deep	Low flow	continuous	Pools >1.5 m deep Complex edge habitats (tree roots, logs sugmerged)
		Protect flows during the spawning/nesting	Low flow	Oct-Dec (nesting period)	Continuous flow to maintain flow during the nesting period
	Maintain intact endemic fish communities	Maintain sufficient area of deep habitats >1.5m deep	Low flow	continuous	Maintain sufficient area of deep habitats >1.5m deep
		Maintain shallow water littoral habitats for small bodied species (e.g. pygmy perch, flathead gudgeon)	Low flow	continuous	
	Provide adequate water quality/habitat for fish refuge locations in dry periods	Maintain oxygen and salinity levels within tolerances of native species	Low flow	All year	
		Flush salt from waterholes	High flow fresh	Jun - Nov	
		Limit artificial extension of unimpacted cease-to-flow spells	Cease to flow	All year	
	Facilitate dispersal and establishment of endemic fish species	Flow pulses to provide stimulus for fish movement	Low Flow fresh	Base on unimpacted hydrology	Flow increase of 0.1-0.2m (arbitrary). [Median unimpacted rise/fall rates for given volume] Also essential that it inundates any instream barriers by a minimum of 0.1-0.2m
			High Flow fresh	Jun - Nov	
	Restore endemic fish community diversity and abundance	Provide flow variability to maintain water quality and a diversity of habitats	Low Flow fresh	Base on unimpacted hydrology	Flow increase of 0.1-0.2m (arbitrary).
			High Flow fresh	Jun - Nov	
	Provide adequate water quality to maintain introduced recreational species	Prevent high salinities that exceed the tolerances of golden perch and river catfish	High flow fresh	As necessary based on real-time monitoring	Prevent salinities exceeding about 15,000 mg/L

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
VEGETATION	Adequate flows to protect and restore riparian/floodplain EVCs	Inundate riparian zone (bankfull) and floodplain (overbank) in order to maintain condition of adults and facilitate sexual recruitment Assumes also likely requirement for permanent or near-permanent low flows over whole year to maintain inundated stream channel.	Bankfull flow	Spring-summer	Bankfull flow and overbank flows as per unimpacted return interval (as determined, e.g., by spells analysis) or, if this information is not available, 2-5 times per decade for River Red Gum woodland/forest, and 1-3 times per decade for Black Box and Tangled Lignum dominated systems.
			Overbank flow	Spring-summer	
	Maintain submerged and emergent aquatic vegetation quality, diversity and extent for fish habitat	Maintain adequate depth of permanent water in stream channel (greater than 50cm depth) to limit terrestrial encroachment into aquatic habitats and permit long term survival and recruitment of submerged plant taxa (maximum water depth of about 2m for obligately submerged taxa).	Low flow	All year	Minimum instream water depth >0.5 m all year (maximum water depth of ~2 m for obligately submerged taxa).
		Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches and on lower banks. Variations in water depth of approximately 10-20 cm over low-flow levels in each of the two flow seasons.	Low flow fresh	Spring – Summer	Variations in water depth of ~10-20 cm over low-flow levels in each of the two flow seasons. Periodicity as per unimpacted return interval (as determined, e.g., by spells analysis) or, if this information is not available, 2-4 times per year in each of spring-summer and autumn-winter periods.
			High flow fresh	Autumn – winter	
	Maintain adequate surface water salinity to enable growth and reproduction of submerged aquatic macrophytes	Provide flows that will, where possible, limit surface water salinity to <4,000 EC and preferably <1,500 EC.	Freshes and bankfull flows	Summer-autumn	Flows sufficient to limit salinity to that of a freshwater regime. May not be possible to infer from FLOWS method and might need to be estimated from empirical trials.
	Maintain adequate surface water salinity for growth and reproduction of emergent vegetation	Provide flows that will, where possible, limit surface water salinity to <4,000 EC and preferably <1,500 EC.	Low flow fresh	Summer - autumn	Flows sufficient to limit salinity to freshwater regime. May not be possible to infer from FLOWS method and might need to be estimated from empirical trials.

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
MACRO-INVERTEBRATES	Achieve SEPP compliant macroinvertebrate communities	Maintain shallow water habitat availability	Low flow	All year	All riffles with at least 25% of width with depth >10 cm
		Maintain deep water habitat availability	Low flow	All year	Parts of edge habitats permanently inundated (fringing vegetation, exposed tree roots)
		Flush surface sediments from hard substrates (riffles, wood, fringing roots and vegetation)	Low Flow Freshes	Low Flow Season	Shear stress =>1.1 N/m^2 to mobilise coarse sand
		Increase biofilm abundance as a food source	Low Flow Low Flow Freshes	Low Flow Season	Variable flow over wood debris (no criterion about how much variation – taken from other criteria)
		Disturb the algae/bacteria/organic biofilm present on rocks or wood debris	High Flow Freshes		Velocity >0.55 m/s suitable to scour surface algae and biofilm (Ryder et al. 2006)
		Entrain organic debris from benches in the channel and from the floodplain	High Flow Freshes, Bankfull and Overbank Flows	High Flow Season	From hydraulic model
		Prevent water quality decline in pools during low flows	Low Flow Low Flow Freshes	Low Flow Season	7-14 day turnover time
MAMMALS	Maintain suitable habitat for platypus	Provide for in stream habitat availability	Low flow High flow	All year	Continuous flow to maintain area of pool water depths less than 5 m
	Appropriate timing of flows to facilitate annual dispersal of juvenile platypus into Wimmera River	Provision of access to food supply	Low flow High flow	All year	Parts of edge habitats permanently inundated (backwaters, fringing vegetation, exposed tree roots)
	Appropriate timing of flows to facilitate annual dispersal of juvenile platypus into Wimmera River	Connectivity between habitats	High Flow	June-December[14]	Depth in riffles > 50 cm[15]

[14] Juveniles emerge from burrows between January to March and can be found "for a number of months" in the home range, then decline in abundance, and that "most have left their home area by the end of their first year of life" (Grant 2007). Also, breeding in spring, eggs hatch after 7-10 days and platypus remain in the burrows for 3-4 months (Museum Victoria Discovery Centre 2012)
[15] Depth requirement unknown but based on criteria for large bodied fish, assume will also need adequate water width to avoid predation.

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
GEOMORPHOLOGY	Maintain structural integrity of stream bed and channel and prevent loss of channel capacity	Maintain channel capacity through provision of channel-forming flow (assumed to be equivalent to bankfull flow in absence of other data).	Bankfull	Any time	Bankfull flow defined morphologically. Frequency as per unimpacted flow regime
	Provide sufficient bank inundation to reduce salt scolding from saline groundwater seepage	Vegetation management option recommended to achieve this			
	Prevent excessive stream-bed colonisation by terrestrial species	Provide sufficient depth and duration of inundation of channel bed to prevent encroachment of terrestrial vegetation	Low flow	Dependent on vegetation species requirements	Sufficient depth and duration of channel inundation
	Prevent loss of channel diversity through lack of flow variability	Provide out of bank or floodplain flows for maintenance of floodplain features	Overbank flow	Any time	Flow inundating floodplain features in reaches where they are present. Frequency as per unimpacted flow regime.
		Provide critical flows for maintenance of inchannel diversity (i.e. pools and benches)	Bankfull flow	Any time	Bankfull flow defined morphologically. Frequency as per unimpacted flow regime.
			Fresh	Any time	Shear stress =>1.1 N/m^2 to mobilise coarse sand Depth of flow of 1 m over benches