FINAL REPORT:

Glenelg River environmental flows study – mid and upper reaches

July 2013

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1 Introduction

A FLOWS study was undertaken for the Glenelg River in 2003 (SKM 2003a) as one of the earliest applications of the then newly developed FLOWS method to devise environmental flows in Victorian streams (NRE 2002). The recommendations from this study were incorporated with recommendations for the Wimmera and Avoca systems into the *Wimmera Glenelg Bulk Entitlement Conversion* report (SKM 2003b). This second report 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 considerable developments in environmental water management, including changes to governance and infrastructure, and advances in ecological knowledge about the flow-dependency of aquatic biota, as well as an update to the FLOWS method itself (DSE draft unpublished). To build on these developments, the Wimmera Catchment Management Authority (Wimmera CMA), in partnership with the Glenelg Hopkins Catchment Management Authority (Glenelg Hopkins CMA), 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. This report addresses specifically the Glenelg River, and an accompanying report addresses the Wimmera River system.

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 (Alluvium 2012) identified four reaches in the Glenelg catchment for update in this environmental flows study (Table 1, Figure 1). A description of each reach is provided in Section 4. Note that Reach 3 (Casterton to Nelson) was included in the original FLOWS study however is beyond the scope of this study.

Table 1. Study reaches

Waterway	Reach #	Description	Different to 2003 study?	Priority for update
Glenelg River	0	Moora Moora Reservoir to Rocklands Reservoir	No	Moderate
	1a	Rocklands Reservoir to Five Mile Outlet	Yes	High
	1b	Five Mile Outlet to Chetwynd River	Yes	High
	2	Chetwynd River to Wannon River	No	Moderate

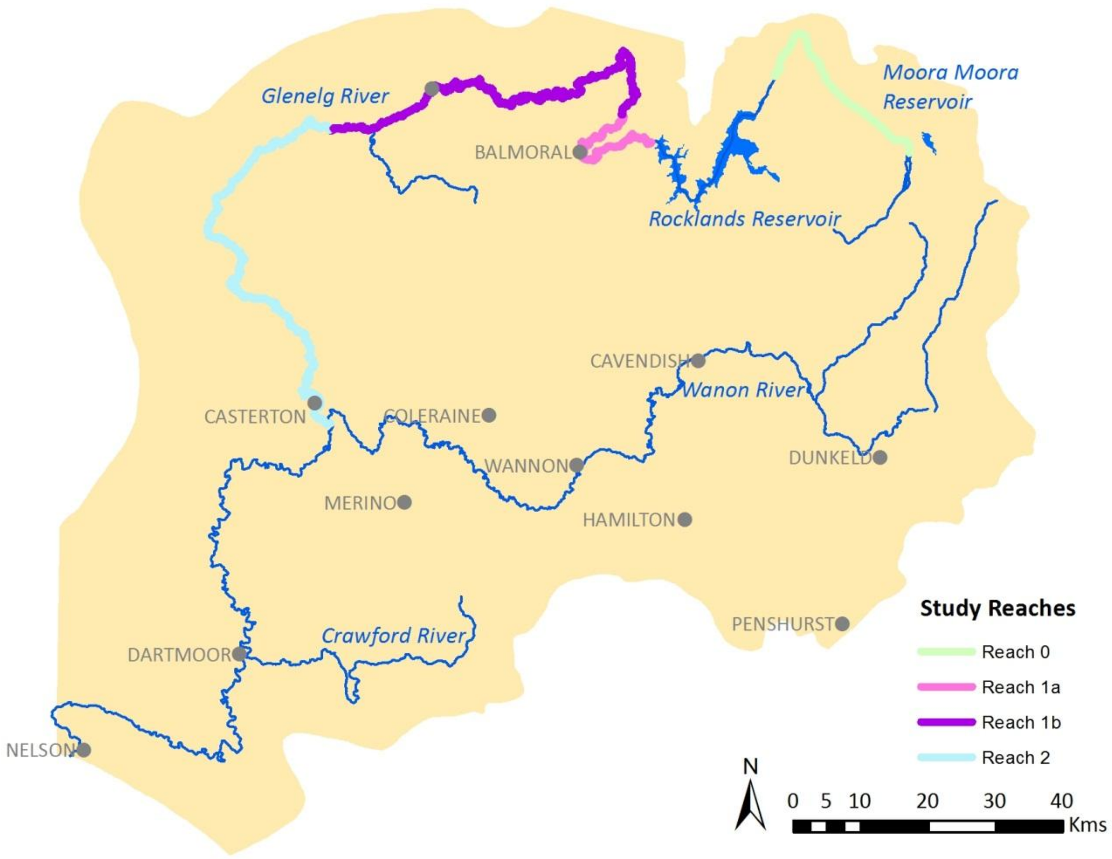


Figure 1. *Glenelg River catchment and study reaches*

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 '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 data was only available for inflows to Rocklands Reservoir. Consequently we have had to assume that the lower reaches of the Glenelg River experienced similar frequency and duration flow pattern under unimpacted conditions. This introduces some uncertainty in the validity of the recommended frequency and durations, but does not affect the flow magnitude, which is based on site by site hydraulic models. If and 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.

Hydraulic models have been used to identify the flow magnitude required to meet various ecological objectives. Each model represents a site on the Glenelg River of approximately 1-2 km length which are assumed to be representative of the reach and its environmental values. Initially no new models were to be developed for this study, so we have based our recommendations for most reaches on available HEC-RAS models. An exception to this was the development of a model (in XP SWMM) for a site in Reach 1a which was purpose built for this study. An evaluation of each model's suitability for determining recommendations is provided in the reach by reach sections 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 *Glenelg Environmental Flows Study- Mid and Upper Reaches,* provides an update to the 2003 FLOWS study for the Glenelg system. In particular, this report describes:

- an updated assessment of environmental values and threats in the Glenelg system,
- environmental objectives for flow-dependent environmental values
- reach–by-reach environmental flow requirements to meet the environmental objectives
- an assessment of the performance and risk in meeting these requirements associated with the current water management regime.

The information provided in this report can be used by environmental managers to make informed decisions about the best management of water for environmental benefit in the updated reaches. The report follows the first deliverable for this project, the *Review Report* (Alluvium 2012) 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 *Wimmera Environmental Flows Study*) has been prepared for the Wimmera system.

2 Water resource development in the Glenelg catchment

The Glenelg River drains a catchment area of 12,660 km^2 in south western Victoria. Its headwaters start in Grampians National Park, and traverse through the deeply dissected Dundas and Merino Tablelands, across basalt plains near Hamilton, before passing through one of Australia's longest estuarine lagoons near Nelson. The Wannon River is the largest tributary, which joins the river at Casterton.

Since 1837, two-thirds of the Glenelg catchment has been cleared for pasture to graze sheep and cattle. Remaining forested areas include Grampians National Park and the Lower Glenelg National Park. Extensive Blue Gum plantations exist across the catchment. The major urban areas are Hamilton, Casterton and Coleraine.

The major storages in the Glenelg catchment are Rocklands Reservoir (348 GL) and Moora Moora Reservoir (6.3 GL). Flow is diverted from the Glenelg River to the Wimmera system at Rocklands Reservoir via the Rocklands Toolondo Channel and from Moora Moora Reservoir via Moora Moora channel. Flow is also diverted from the headwaters of the Wannon River to Lake Bellfield. Licensed extractions also occur along the Glenelg River and its tributaries.

Seasonal flow patterns are greatly altered immediately downstream of Rocklands Reservoir but become more natural further downstream as unregulated tributaries enter the river (GHCMA & WCMA 2010). Cease to flow would occur under natural (i.e. pre-European conditions) at Balmoral between February and April. Water releases from Rocklands Reservoir to the Glenelg River can be made directly into the river downstream of the storage, or further down the river at the Five Mile and Twelve Mile outlets from the Rocklands-Toolondo Channel.

An important issue resulting from the changed land use and flow patterns in the Glenelg is the build-up of sediment in the system. The build-up of sand has smoothed the river bed and made it more shallow; the number of deep holes that provide habitat and refuges for aquatic biota have thus been diminished. In some locations sand slugs have effectively dammed the river creating backwater lakes or online wetlands. In some cases instream vegetation has been smothered by the excessive sand, further altering the condition of the channel. The 2004 Index of Stream Condition assessment (DSE 2005) categorised the regulated reaches of the Glenelg River as being in moderate condition (with some tributaries exhibiting poor and very poor condition). Other influences on river health from the regulation of flow at Rocklands Reservoir include increased salinity levels, increased frequency of blue-green algae outbreaks, and reduced fish and vegetation along the waterway.

Notable values of the river include diverse populations of native fish, birds, macroinvertebrates and mammals (including platypus) that live in and around the waterways. Many species indigenous to the Glenelg River are threatened, including the Glenelg Spiny Crayfish which is not found anywhere else in Victoria. The lower Glenelg is a Heritage Listed river reach due to the estuary's significant natural, landscape and recreation values.

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 the boxes below.

Table 2. Streamflow gauges in the Glenelg River

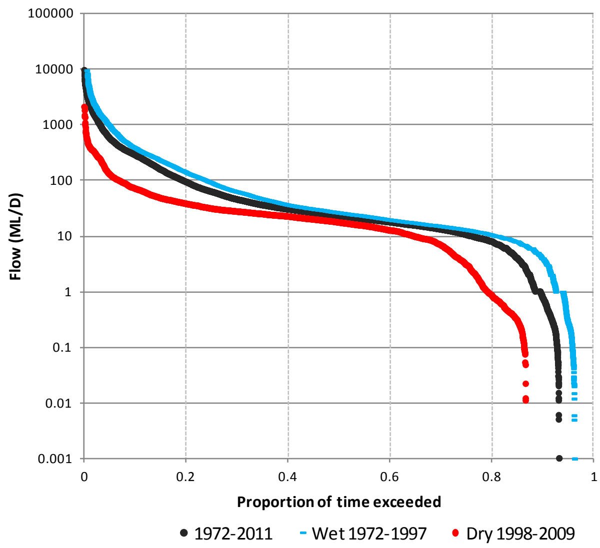
Gauge ID	Name	Status	Period of record available	Reach
238231	Glenelg River @ Big Cord	Active	24 Apr 1968 to present	0
238200	Glenelg River @ Moora Moora	Inactive	21 Apr 1889 to 1 Jan 1890	0
238201	Glenelg River @ Balmoral	Inactive	25 May 1889 to 1 Oct 1956	1a
238205	Glenelg River @ Rocklands Reservoir	Active	23 Mar 1941 to present	1a
238210	Glenelg River @ Harrow	Inactive	1 Dec 2001 to 26 Feb 2013	1b
238224	Glenelg River @ Fulham Bridge	Active	13 Jun 1964 to present	1b
238211	Glenelg River @ Dergholm	Active	14 Sep 2004 to present	2
238249	Glenelg River @ Burkes Bridge	Active	19 Apr 2001 to present	2
238212	Glenelg River @ Casterton	Inactive	2 Aug 1960 to 25 Mar 2002	2
238202	Glenelg River @ Sandford	Active	2 Jan 1908 to present	3
238206	Glenelg River @ Dartmoor	Active	9 Jun 1948 to present	3

Note: Gauge 238210 is flagged as inactive in the Victorian Water Resources Data Warehouse, however recent records suggest this may be an error and the gauge is still active.

Reach 1 (a and b)

*Relevant Gauge***:** 238224 (Glenelg @ Fulham Bridge)

The compliance point recommended for Reach 1 in the 2003 study is the Glenelg River at Harrow (Gauge 238210) (SKM 2003b). However, streamflow records have only been recorded at Harrow since 2001, resulting in a relatively small dataset for flow analysis. Fulham Bridge is located approximately 12 km upstream of Harrow and receives similar flow magnitudes and patterns. Analysis of the observed flows for Reach 1a and 1b has therefore been undertaken using the Fulham Bridge gauge (238224). A mean daily flow of 140 ML/d occurs under current observed conditions; however this is significantly lower during dry periods (38 ML/d).

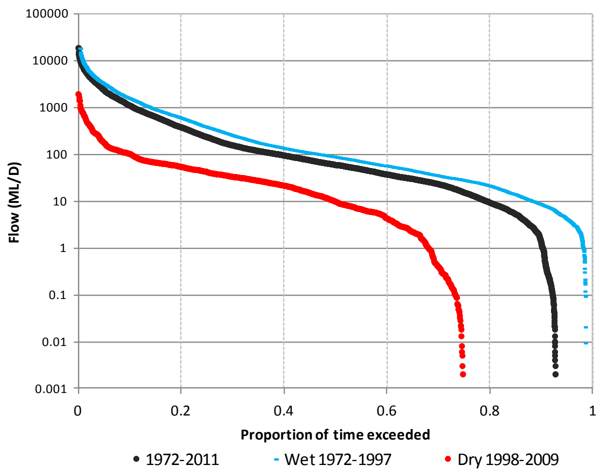


	Whole Period	Wet Period	Dry Period
Start	1/01/72	1/01/72	1/01/98
End	31/12/11	31/12/97	31/12/09
Mean	140.41	180.55	37.49
Median	23.26	26.32	17.56
Std deviation	491.84	574.57	97.72
CV	3.50	3.18	2.61
10th percentile	0.77	3.49	0.00
25th percentile	10.52	12.96	3.03
75th percentile	62.51	87.63	31.13
90th percentile	285.28	364.36	70.89

Current conditions flow duration curve at Fulham Bridge (Reach 1a and b)

Reach 2
Relevant Gauge: 238211 (Glenelg River@Dergholm)

Glenelg River at Dergholm is the intended reporting gauge, however the gauge was only commenced in 2004. In order to allow comparison of performance from wet and dry periods, Gauge 238212 (Glenelg River@ Casterton) has been used as it has data available from the start of the analysis period (1972) until 1988. For the Casterton gauge only instantaneous data was available for the analysis (this has been converted to represent daily average data by averaging the multiple readings per day, not by time weighted averaging). The following statistics represent direct reporting against 238212 for the period up to 1988 and for 238211 for the period from 2004.



	Whole Period	Wet Period	Dry Period
Start	1/01/1972	1/01/1972	14/09/2004
End	31/12/1988	31/12/1988	31/12/2009
Mean	454.14	585.06	47.33
Median	59.05	88.19	9.78
Std deviation	1297.22	1484.52	135.13
CV	2.86	2.54	2.85
10th percentile	1.29	8.38	0.00
25th percentile	15.23	28.00	0.00
75th percentile	232.70	378.17	41.66
90th percentile	1096.11	1540.76	102.19

Current conditions flow duration curve (Reach 2)

Modelled daily unimpacted inflows to Rocklands Reservoir are available for over 100 years (1 January 1903 to 30 June 2004). Unimpacted inflows 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 2005). Prior to this, the REALM model used monthly inputs including monthly unimpacted inflows to Rocklands Reservoir. The monthly time series was determined using a water balance for 1942 to 2004 and a hydrologic model for the years prior to 1942. The daily time series was determined by disaggregating the monthly data using the streamflow pattern recorded in the Glenelg River at Big Cord (gauge 238231). For the purposes of the REALM model the Rocklands Reservoir daily inflow series was divided into three subcatchments:

- 82% ROCK INFLOW – representing the inflow directly into Rocklands Reservoir
- 13% MOORA PICKUP – representing the inflow into the Moora Channel
- 5% MOORA INFLOW – representing the inflow into Moora Moora Reservoir

Another dataset of modelled unimpacted inflows to Rocklands Reservoir was provided by the Wimmera Catchment Management Authority for the period from 1989 to 1999. Given this was only available for 11 years, the analysis of unimpacted flows in the Glenelg 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 unimpacted 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 storms, but low baseflows still relatively common
- a ***high flow season***: higher baseflow with frequent, sometimes extended, periods of higher flows from larger and more widespread storms
- a ***transitional flow season from high to low***: lower flows becoming more common as rainfall events become smaller and more localised.

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).

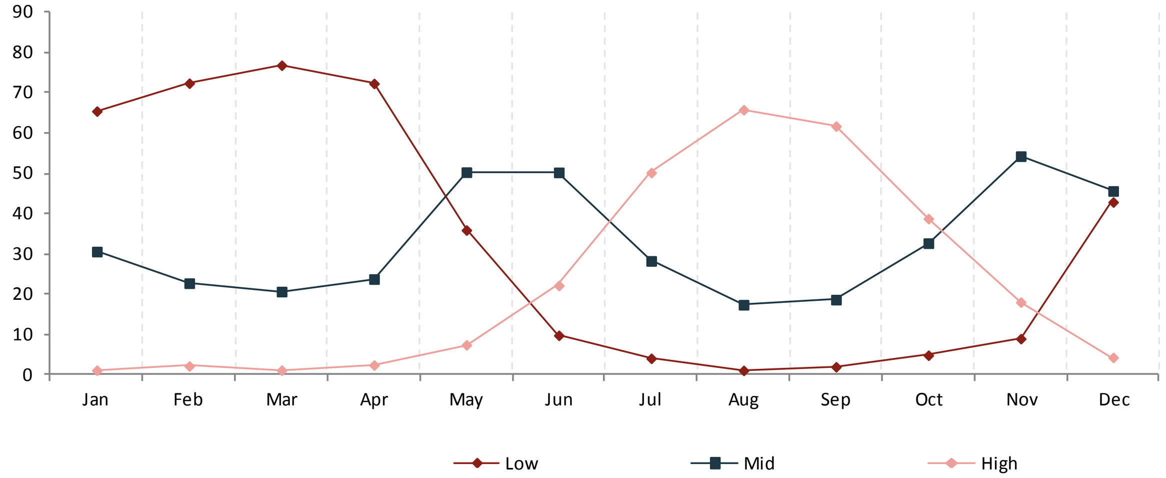


Figure 2. *Proportions of daily flows in the lower, mid and upper third percentiles in each month (Glenelg 1a and 1b).*

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

- January to April has a constant high proportion in the lower flow band (and constant proportions in the upper flow bands as well). These are clearly *low flow season* months.
- May is a typical early transitional month, with a relatively high proportion in the low flow band, but with more middle range flows.
- 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 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 (arguably could be a low flow month due to the increased proportion of low flows).

During different annual seasonal conditions (i.e. wet, average, dry and drought years), the start of flow seasons may differ during the transitional months. For example, during wet years there is a clear increase in flows in May, and the size of the increase is not reflected in the other season types. At the other end of the year, dry and drought years fall to low flow season levels in November, while the others do so in December.

Table 3. Flow seasons for the Glenelg 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 2003 FLOWS study (SKM 2003a) describes in detail the impact of development in the catchment on streamflow in the Glenelg River. Key points raised in the 2003 study include (SKM 2003a)

- The current level of development along the Glenelg River has resulted in a streamflow that is frequently considerably lower than under natural conditions.
- Streamflow upstream of Rocklands Reservoir is similar under natural and current conditions.
- Rocklands Reservoir has a significant impact on the seasonal flow pattern downstream of the reservoir between the dam wall and the confluence with the Chetwynd River. Downstream of Chetwynd River flows are generally continuous due to natural inflow from the catchment.
- Rocklands Reservoir has drastically reduced the frequency of large flows that under natural conditions occurred during late winter to September.
- Glenelg River, under natural conditions, commonly dried up at Balmoral over February to April, sometimes for months longer. Under current conditions flows at Balmoral are highly regulated by releases from Rocklands Reservoir so that periods without flow are often shorter than they would have been under natural conditions.

For this study, a plot of the unimpacted median flows at Rocklands Reservoir for each month of the year (Figure 3) 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 (Section 4).

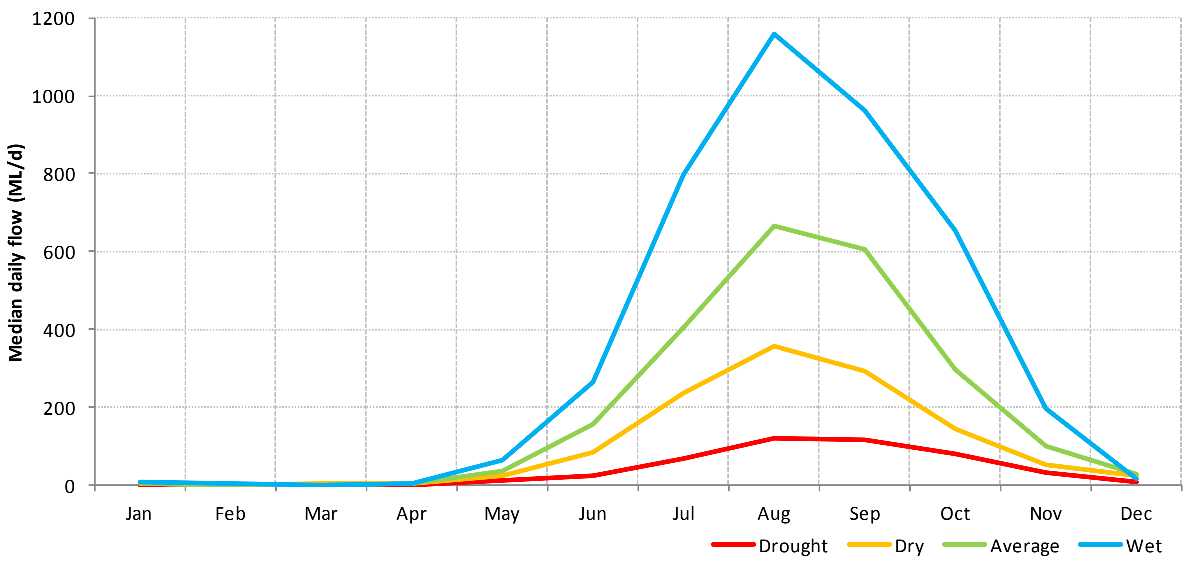
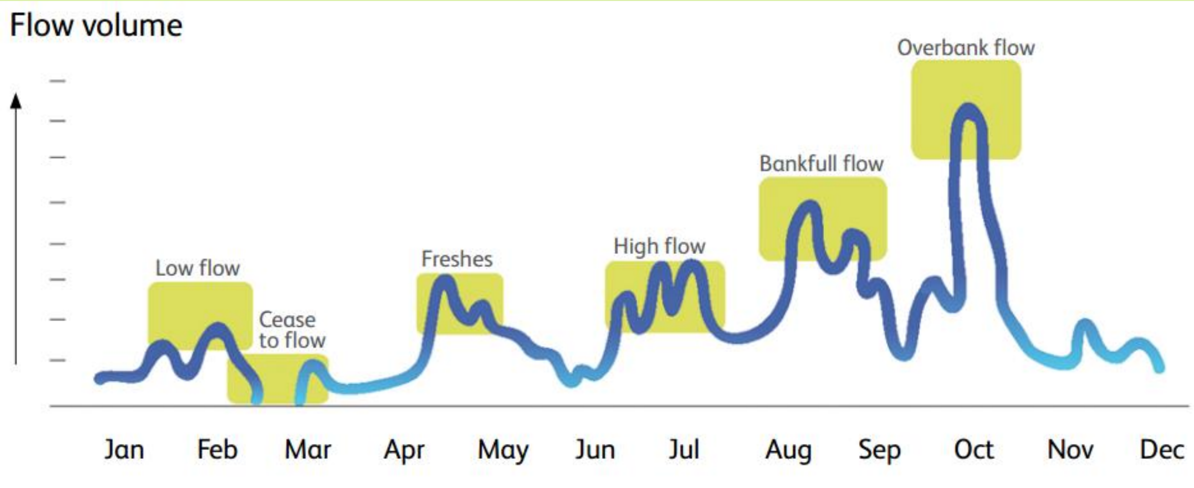


Figure 3. *Median` monthly flows under different seasonal conditions (unimpacted modelled daily data at Rocklands Reservoir)*

Further assessment of the hydrology of the Glenelg River system can be found in the previous FLOWS study (SKM 2003a).

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 4.



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

2.2 Groundwater

The Glenelg River catchment is geologically complex with three major groundwater provinces (SKM 2012):

- Uplands province – consisting of fractured rock systems in Cambrian to Palaeozoic rocks and contained alluvial valleys
- Gambier Embayment of the Otway Basin – containing Mesozoic and Tertiary sedimentary sequences
- Portland Trench of the Otway Basin – containing Mesozoic and Tertiary sedimentary sequences, overlain by basalts of the Newer Volcanics.

Depth to water table
The depth to water table (Figure 5) for the Glenelg River shows that there are only isolated connections between the water table and the river. This finding is consistent with previous studies that have identified isolated areas where saline groundwater discharges into deep pools in the river.

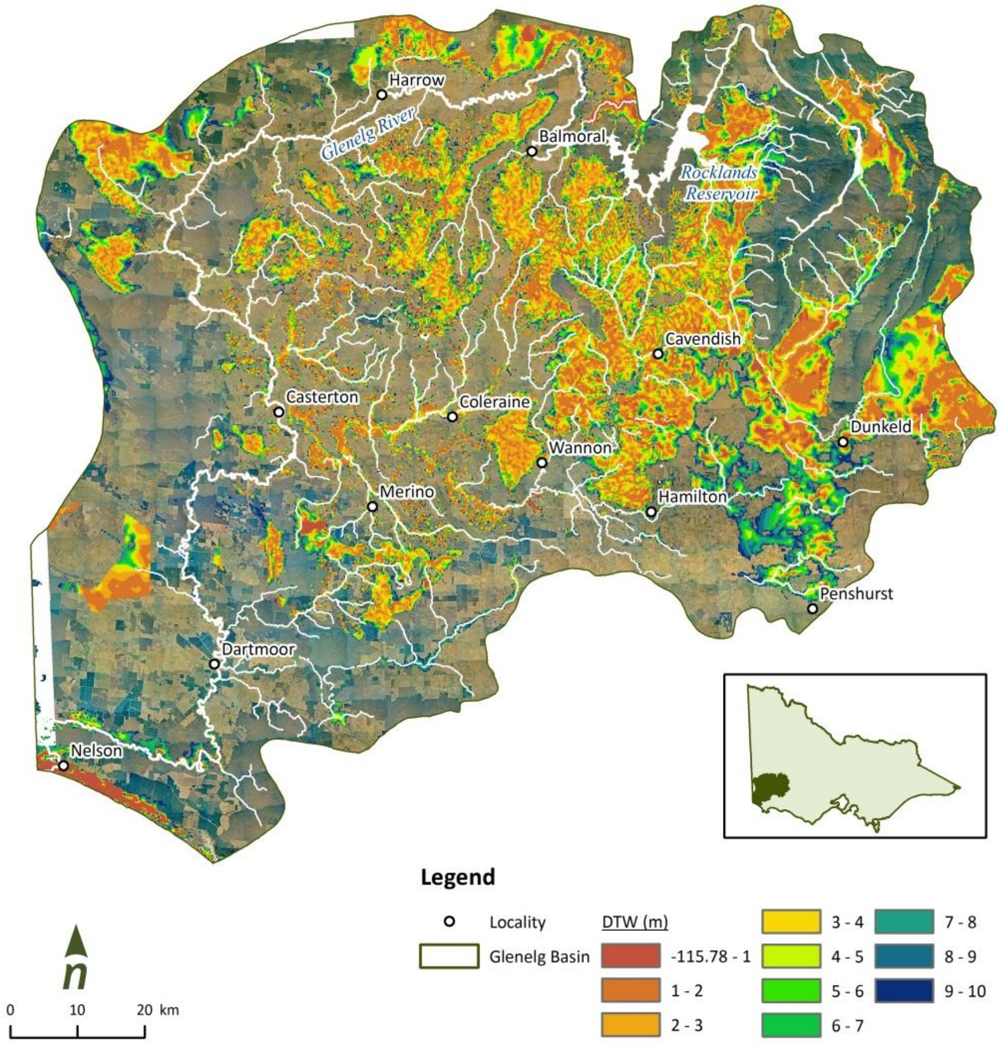


Figure 5. *Depth to water table – Glenelg catchment*

The depth to water table data is taken from the regional numerical groundwater models (200 metre grid) developed for the ecoMarkets project (SKM 2009; Hocking et al. 2010), for the following reasons:

- the distribution of spatial monitoring data was identified as inadequate for this purpose (SKM 2009)
- the unconfined water table occurs in a range of aquifer and lithology types, which involves a very complex analysis to establish a comprehensive data set from monitoring bores in different aquifers in different locations across the catchment – the groundwater model can provide this information very efficiently
- the results are plotted for the identified wet period year of 1992, which reflects the highest groundwater levels and thus the greatest potential contribution from groundwater.

Baseflow

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 Glenelg River. Nevertheless, the Lyne-Hollick filter was applied to the stream flow time series data for the selected sites, with the optimum alpha parameter identified as 0.99 for all stations. The analysis shows that there are significant periods of zero flow for the stations at Fulham Bridge, Dergholm and Sandford, indicating that groundwater flow contributions in these reaches are ephemeral. The Dartmoor data shows very low flows for only short periods, indicating that groundwater baseflow contributions may be important in this reach during low flow periods.

Potential effects of groundwater pumping on stream flows
The vast majority of bores in the Glenelg River catchment are used for stock and domestic purposes (2,708 bores, estimated to extract on average 2 ML per bore), with fewer licensed irrigation/industrial bores (150 bores) but extracting much higher volumes (about 6.4 GL for the 2008-09 year, or 18 ML/bore) (SKM 2012). Many of these irrigation bores are located on the western margins, well away from the Glenelg River.

A recent modelling study (SKM 2012) classified the Glenelg River and its adjoining aquifers as highly connected (streamflow depletion of greater than 90% of groundwater pumping occurring with a short time lags of less than 5 years). It is stressed that the SKM study was a risk-based modelling study rather than an empirical investigation. Nevertheless, the report does indicate that long term pumping at licensed rates is likely to deplete stream flow by 1% of mean annual flow under low–impact scenarios and up to 27% of annual low flow volume under a moderate impact scenario). These impacts are expected to be most significant during periods of low flow during the dry season, which may need to be considered when evaluating environmental flow options.

Saline pools
A number of previous studies have identified the occurrence of deep (2 – 8 metre) saline pools in the Glenelg River (Mitchell 1996; SKM 2003a), which are believed to be due to saline groundwater inflows. These pools are also believed to result in density-driven anoxic and/or temperature stratification, which creates considerable complexity when developing environmental flow strategies. 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 Glenelg River (SKM 2003a):

- **Low flow freshes -** low water levels prior to a sudden fresh may result in downstream mobilisation of a slug of highly saline water.
- **Low flows/high flows** – under moderate flows, saline flows from any deep holes may be carried downstream, with variable effects depending on dilution effects; the flows may not entirely flush the saline pool, and the groundwater flows subsequently replenish the saline pools (within about 3 months; SKM 2003a).
- **High flow freshes** – higher flows can be turbulent enough to disturb existing density-dependent stratification and thus mobilise the entire salt load within the pool, with variable effects downstream depending on dilution.
- **Bankfull/overbank flows** - higher flows or floods can export a large amount of salt (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 exporting process for the system.

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

Monitoring is required to establish the occurrence and location of saline pools confirm any groundwater contribution (aquifer levels and chemistry), establish hypsographic relationships (water level-area-volume, and water quality attributes of salinity, oxygenation, temperature), 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

3.1 Catchment environmental values

Water dependent environmental values for the Glenelg Catchment were identified by Glenelg Hopkins CMA and Technical Panel through literature review and field assessment (details provided in the Review Report (Alluvium 2012)) and are summarised in Figure 6. These represent the overarching values that are sought to be maintained and or improved through the management of water for environmental benefit.

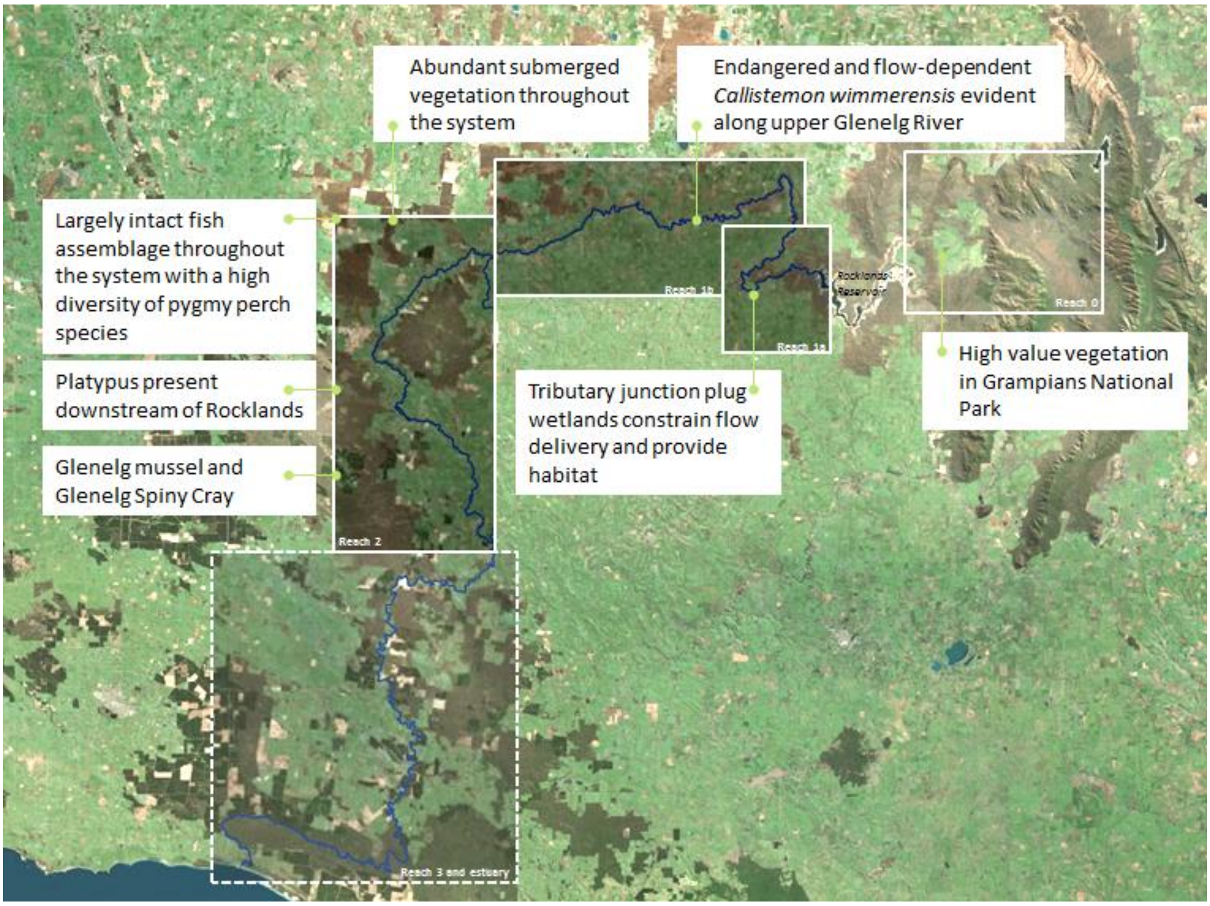


Figure 6. *Key water-dependent environmental values in the Glenelg River catchment. Note that the lower Glenelg and estuary are not included in the scope of this study.*

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

3.2 Catchment influences

The environmental condition of the Glenelg River is affected by a number of factors, including:

- **Flow regulation** (in particular Rocklands Reservoir and diversions to Moora Moora Reservoir and the Wimmera system) that has resulted in altered flood frequency, magnitude and duration of events, changed flow seasonality and diminished channel flushing (SKM 2003a). In addition, cold water pollution is associated with release from Rocklands Reservoir.
- **Sand slugs** that have led to loss of channel form, reduced the substrate diversity and instream habitat diversity.
- **Physical channel condition** is variable and influenced by bank erosion, stock access, riparian clearing and desnagging (SKM 2003a).

- **Altered water quality and increased salinity** leading to reduction in available habitat for aquatic fauna, stratification and deoxygenation of the water column, and inhibition of aquatic macrophyte growth (SKM 2003a)
- **Pest plant and animals**, in particular Spiny Rush *Juncus acutus* which is an aggressive exotic invader of the system and European Carp *Cyprinu carpio* which was first recorded in the Glenelg catchment in 2001 and has increased in abundance and distribution in recent years.

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

Environmental objectives were identified for each reach by the Glenelg Hopkins CMA in consultation with their River and Wetland Advisory Group. The objectives reflect the environmental values of the Glenelg system by the community. Objectives were determined in the context of the current water resource management, and social and economic values of the region. The overarching environmental objectives for the Glenelg system can be summarised as:

- Protect, maintain and where possible, enhance populations of native fish, including diadromous species.
- Maintain healthy and diverse mosaics of water-dependent vegetation
- Achieve SEPP compliant macroinvertebrate communities
- Maintain platypus populations
- Improve and maintain channel diversity using channel forming flow

These objectives are further detailed in the section below including for each objective a suite of sub-objectives identified by Glenelg Hopkins CMA. A full list of the environmental flow objectives and specific measureable criteria to meet each objective is provided in **Attachment A**.

3.4 Self-sustaining fish populations

The overarching environmental objectives relating to fish in the Glenelg system were to:

- Protect, maintain and where possible, enhance populations of diadromous native fish species ,
- Protect, maintain and where possible, enhance populations of non-diadromous native fish species,
- Expand self-sustaining populations of non-diadromous native fish species, and
- Limit recruitment of introduced fish species including translocated species native to Australia.

Fish populations in the Glenelg River

There have been numerous surveys of fish assemblages in the Glenelg river system since the 1980s, with a concentration since the VEFMAP commenced in 2006 (Table 4). A notable feature of the fish assemblages is the relatively high diversity of pygmy perches (*Nannoperca* spp.), with two of the three species (*N. obscura* and *N. variegata*) listed as under the Victorian Flora and Fauna Guarantee Act and the Federal Environmental Protection and Biodiversity Conservation Act (Table 4). *Nannoperca variegata* indigenous to only one other river system (Ewans and Piccaninnie Ponds systems, and the Eight-Mile Creek system in South Australia). Australian Grayling were once also recorded as present in the catchment in the late 1800s but are now presumed locally extinct (SKM 2003a). With the exception of Australian Grayling, the historic fish community is intact. Recent VEFMAP surveys (Ryan 2009; 2010; 2011; 2012) suggest there have been some recent declines in native fish abundances, which presumably reflect the impacts of drought initially concentrating fish in persistent refuges, while depleting overall numbers, but with the effects only becoming apparent once fish redistribute themselves under higher flow conditions (Ryan 2012). Despite the declines in abundance, broader distribution of native species does not seem to have been restricted by the drought. Despite the dominance of native species, there are also several introduced species in the system, including carp and redfin. Notably, *Cyprinus carpio*, which was first recorded in the Glenelg catchment in 2001 appears to have increased in abundance and distribution over the last few years (Ryan 2012). The presence of numerous migratory species is also important in terms of flow recommendations.

Table 4. Summary of fish species caught in the Glenelg River system 2000-2012 (Ryan 2012)

					Reach			
Category	**Family**	**Species name**	**Common name**	**Habitat**	**0**	**1**	**2**	**3**
Marine vagrant	Arripidae	*Arripis* spp.	Australian salmon	estuarine				■
	Mugilidae	*Aldrichetta forsteri*	Yelloweye Mullet	estuarine				■
	Percichthyidae	*Macquaria colonorum*	Estuary perch	estuarine			■	■
	Sparidae	*Acanthopagrus butcheri*	Black bream	estuarine				■
	Scinaenidae	*Argyrosomus hololepidotus*	Mulloway	estuarine				■
diadromous	Anguilidae	*Anguilla australis*	Short-finned eel	lowland/slopes		■	■	■
	Bovichtidae	*Pseudaphritis urvillii*	Tupong	lowland/slopes		■	■	■
	Galaxiidae	*Galaxias maculatus*	Common galaxias	lowland/slopes			■	■
	Geotriidae	*Geotria australis*	Pouched lamprey	lowland/slopes		■		
	Mordaciidae	*Mordacia mordax*	Short-headed lamprey	lowland/slopes		■		■
	Retropinnidae	*Retropinna semoni*	Australian smelt	lowland/slopes		■	■	■
Intermediate	Eleotridae	*Philypnodon grandiceps*	Flathead gudgeon	lowland		■	■	■
Non-migratory	Gadopsidae	*Gadopsis marmoratus*	River blackfish	slopes	■	■	■	■
	Galaxiidae	*Galaxias olidus*	Mountain galaxias	lowland/slopes	■	■	■	■
	Galaxiidae	*Galaxiella pusilla*	Dwarf galaxias	lowland	■	■		
	Nannopercidae	*Nannoperca australis*	Southern pygmy perch	lowland/slopes	■	■	■	■
	Nannopercidae	*Nannoperca obscura**	Yarra pygmy perch*	lowland/slopes	■	■	■	■
	Nannopercidae	*Nannoperca variegata**	Variegated pygmy perch*	lowland/slopes	■	■	■	■
Translocated	Eleotridae	*Hypseleotris spp.*	Carp Gudgeon^	lowland		■	■	■
	Percichthyidae	*Macquaria ambigua*	Golden perch	lowland		■		
	Percichthyidae	*Macquaria australasica*	Macquarie perch	lowland/slopes		■		
	Percichthyidae	*Macquaria novemaculeata*	Australian Bass	lowland/slopes		■	■	
Exotic	Cyprinidae	*Carassius auratus*	Goldfish	lowland/slopes	■	■	■	
	Cyprinidae	*Cyprinus carpio*	Common carp	Lowland/slopes	■	■	■	
	Cyprinidae	*Tinca tinca*	Tench	lowland	■	■	■	
	Percidae	*Perca fluviatilis*	Redfin perch	lowland	■	■	■	■
	Poeciliidae	*Gambusia holbrooki*	Mosquitofish	lowland		■	■	■
	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	slopes	■		■	
	Salmonidae	*Salmo trutta*	Brown trout	slopes	■		■	

* Conservation status: vulnerable (EPBC Act) and listed under the FFG Act, ^ likely accidental translocation from the Murray-Darling Basin.

Relevant reaches

The environmental objectives relating to self-sustaining fish populations apply to all reaches of the Glenelg River. Although estuarine species can extend their range some distance upstream from the estuary, they are not a specific target of the flow recommendations – the needs of these species are better considered as part of the estuarine flow requirements. Nevertheless, the presence of numerous diadromous species whose range extends from the upper reaches down to the estuary requires that the longitudinal continuity of flow events be protected, especially those relating to fish movement.

Table 5. Relevant reaches for fish objectives

Fish objective	Reach 0	Reach 1a	Reach 1b	Reach 2
Protect, maintain and where possible, enhance populations of diadromous native fish species		■	■	■
Protect, maintain and where possible enhance populations of non-diadromous native fish species	■	■	■	■
Expand self-sustaining populations of non-diadromous native fish species	■	■	■	■
Limit recruitment of introduced fish species including translocated species native to Australia	*no specific recommendations, refer flow objective text below*			

Flow objectives

Flow variability plays 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 (e.g. Crook et al, 2010)
- Maintaining productive food sources
- Regulating populations of some invasive species

The flow recommendations for native fish thus seek to address these five key areas, noting that the availability of suitable habitats and food resources will depend on some of the geomorphic, vegetation and macroinvertebrate objectives also being met.

Flows help maintain fish habitat both as channel forming flows (flow pulses and bankfull flows), which maintain channel features such as pools and riffles, and as the minimum flows required to maintain a sufficient diversity and area of specific hydraulic environments within the channel. Frequent high flows are particularly important in unstable sand-bed channels because fine sediments remain mobile even at very low flows, leading to gradual infilling of local-scour pools (Borg *et al.* 2005; Bond & Lake 2005). Because they are often associated with fallen timber local scour pools can be particularly important for species such as river blackfish, which have strong associations with in-stream structure (Bond & Lake 2003), and which are present in all reaches under investigation. The flow recommendations thus include channel-forming flows, which are linked to the geomorphic objectives, and also minimum baseflows, which have been based on an examination of the cross-sections in each reach and the range of habitat requirements for individual species.

A unique feature of the Glenelg River fish assemblage is the relatively high diversity of pygmy perches (Nannopercidae), with two of the three species listed as 'vulnerable' under state and federal legislation. Pygmy perches favour low velocity habitats with an abundance of aquatic macrophytes (Humphries 1995; Kuiter *et al.* 1996). As noted elsewhere in the report aquatic macrophytes were observed to be abundant at several of the sites visited during the field survey, especially in slackwater areas out of the main channel. A further aim of the flow recommendations is to ensure that these areas are maintained, and where possible expanded. For example in Reach 1a it is likely that extensive swampy areas provide breeding areas for Nannoperca and other small bodied fish such as mountain galaxias. The flows required to maintain aquatic macrophytes are identified under the vegetation objectives.

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, Crook et al. (2010) showed that movement of female tupong in the Glenelg River was frequently associated with flow pulses above the median daily flow. While flows can be associated with spawning (including pre-spawning movements), other factors such as temperature also play a critical role in determining the timing and success of spawning and subsequent recruitment (Humphries *et al.* 1999). In the Glenelg River fish species tend to spawn predominantly in spring or summer (Table 6). High flow freshes have thus been recommended for both of these periods. Recent surveys in the Glenelg suggest that several native species have declined in abundance since the 2010/11 floods (Ryan 2012). Certainly many native species are capable of surviving and breeding during drought conditions providing refuge habitats persist, but it is also possible that higher flows have allowed fish that were concentrated into small areas to disperse away from permanent refuges. Ryan (2012) proposed a reduction in high flows to prevent the scour of macrophytes from the main channel. While protecting macrophyte beds is clearly a priority, attempting to do so by excluding high flows could have other unintended consequences, and has not been adopted in the present study. Instead, flow regimes have been recommended that should enhance macrophyte growth within (and fish access to) off-channel habitats during wet periods, but allow them to contract into the main channel during dry periods. These recommendations should thus not be seen as being at odds with those of Ryan (2012), but will also require complementary actions, such as stock management, to prevent off-channel floodplain habitats from being degraded during periods of low flow.

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. Given that most species of fish in the Glenelg River prey on invertebrates (insects and crustaceans), these needs are largely covered under the invertebrate flow recommendations. It is however also 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. The nature of this relationship is however not well quantified for most river systems.

Table 6. Summary of approximate spawning times for each species (note: ■ denote estuarine, ■ diadromous, ■ intermediate, ■non-migratory, ■translocated and ■ introduced species).

Species name	Common name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Ref*
Arripis spp.	Australian salmon				■	■	■							*1.*
Aldrichetta forsteri	Yelloweye Mullet	■	■	■										*2.*
Macquaria colonorum	Estuary perch											■	■	*3.*
Argyrosomus hololepidotus	Mulloway	■	■								■	■	■	*4.*
Acanthopagrus butcheri	Black bream										■	■		*5.*
Anguilla australis	Short-finned eel						*limited data*							
Pseudaphritis urvillii	Tupong					■	■	■	■					*6.*
Galaxias maculatus	Common galaxias				■	■	■	■	■					*7.*
Geotria australis	Pouched lamprey							■	■	■	■	■	■	*8.*
Mordacia mordax	Short-headed lamprey							■	■	■	■	■		*8.*
Retropinna semoni	Australian smelt	■	■	■						■	■	■	■	*9.*
Philypnodon grandiceps	Flathead gudgeon	■	■	■							■	■	■	*8.*
Gadopsis marmoratus	River blackfish										■	■	■	*10.*
Galaxias olidus	Mountain galaxias							■	■	■				*11.*
Galaxiella pusilla	Dwarf galaxias							■	■	■				*8.*
Nannoperca australis	Southern pygmy perch								■	■	■			*12.*

Species name	Common name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Ref*
Nannoperca obscura	Yarra pygmy perch								■	■	■			*13.*
Nannoperca variegata	Variegated pygmy perch								■	■	■			*13.*
Hypseleotris spp.	Carp gudgeon	■	■	■								■	■	*8.*
Macquaria ambigua	Golden perch	■	■	■							■	■	■	*8.*
Macquaria australasica	Macquarie perch										■	■		*14.*
Macquaria novemaculeata	Australian Bass					■	■	■	■					*8.*
Carassius auratus	Goldfish	■									■	■	■	*8.*
Cyprinus carpio	Common carp	■								■	■	■	■	*8.*
Tinca tinca	Tench	■										■	■	*8.*
Perca fluviatilis	Redfin perch								■	■	■			*8.*
Gambusia holbrooki	Mosquitofish	■	■	■						■	■	■	■	*8.*
Oncorhynchus mykiss	Rainbow trout							■	■	■	■			*8.*
Salmo trutta	Brown trout					■	■	■	■					*8.*

References:
1. Gomon et al. (2008)
2. Thomson (1957)
3. McCarraher and McKenzie (1986)
4. SA DPI
5. Williams 2012
6. Crook et al. (2010)
7. Barbee et al (2011)
8. McDowall (1996)
9. Humphries et al. (2013)
10. Allen et al. 2002
11. O'Connor and Koehn (1991)
12. Llewyn (1974)
13. Koehn & O'Connor (1990)
14. Tonkin (2010)

Managing flows to limit the recruitment of invasive species

Ryan (2012) suggested that flows in the Glenelg be managed to reduce carp and goldfish populations in reach 1, noting that large congregations of carp and goldfish have been observed in shallow floodplains over the last three years near Balmoral and Harrow. He suggested a reduction in suitable spawning habitat could be achieved if water level could be managed below the shallow floodplains. Such approaches have been advocated as a strategy for limiting the success of carp spawning in other systems, either by reducing opportunities for spawning or stranding eggs and juveniles (Shields 1958; Stuart & Jones 2006). The advantage of stranding is that high flows can still be delivered during the spawning season (spring-early summer) to achieve other objectives, but with the goal being to limit the period of floodplain inundation. However, given carp eggs hatch after just 3-4 days, and natural floods will frequently inundate spawning habitats, the effectiveness of the approach may be extremely limited. For this reason no specific recommendations have been included in this study. If the approach is used experimentally in the future, appropriate monitoring of spawning success/failure is advised.

Table 7. Flows required for self-sustaining fish populations

Objective	Flow process/function	Flow components	Season	Frequency and duration
Protect, maintain and where possible, enhance populations of diadromous native fish species[2],[3]	Maintain area of pool habitat > 1.5m deep for large-bodied species	Low flow	All year	Continuous/near continuous
	Maintain shallow water littoral habitats for small bodied species (e.g. common galaxias)	Low flow	All year	Continuous/near continuous
	Provide stimulus and opportunity for downstream migration (e.g. Tupong)[4]	High flow fresh	Jun-Aug	Minimum 1 per year, 2-5 days[5]
	Provide stimulus and opportunity for upstream migration (e.g. G. maculatus YOY)[6]	High flow fresh	Oct-Nov	Minimum 1 per year (more in wet years)
Protect, maintain and where possible enhance populations of non-diadromous native fish species [7]	Maintain area of pool habitat > 1.5m deep for large-bodied species	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
	Maintain depth over shallow riffle areas[8]	Low flow	All year	Continuous/near continuous
	Provide opportunities for local movement and stimulus to recolonise following drought[9]	High flow fresh	Winter-Spring (wet and average years only)	Unimpacted median frequency and duration
Expand self-sustaining populations of non-diadromous native fish species[10]	Facilitate scour of pools in sand-bed reaches to restore pools and create habitat heterogeneity	Low flow fresh	Summer-Autumn (wet and average years only)	Unimpacted median frequency and duration
		High flow fresh	Winter – Spring (wet and average years only)	Unimpacted median frequency and duration
	Promote growth of macrophytes for habitat/spawning sites	(Refer vegetation requirements in Section 3.5)		
Limit recruitment of introduced fish species including translocated species native to Australia	No flow recommendation due to significance of management decisions in achieving this objective.			

System limitations

The achievement of a healthy and self-sustaining native fish assemblage will not be met through flow management alone. Key issues in the Glenelg include the legacies of broad-scale catchment clearing and erosion, which have created sand-slugs in sections of the river, which in turn greatly reduce available deep-water habitats and refuges. While some work is being done to try and restore habitats in heavily sanded sections of the river, the effectiveness of these interventions is likely to be limited, especially during droughts

2 Short-finned eel, spotted galaxias, climbing galaxias, common galaxias, pouched lamprey, short-headed lamprey, tupong, black bream, elongate hardyhead, small mouthed hardyhead, estuary perch
3 Australian grayling (lower priority than others because no confirmed sightings in the last 100 years
4 Rise to above median flows (Crook & Koster, 2010) with rates of rise and fall capped at the median natural rates.
5 Based on reported duration of movement in Crook & Koster, 2010
6 Requires a minimum depth over barriers of 0.1~0.2 m and rates of rise and fall capped at the median natural rates.
7 River blackfish, mountain galaxias, southern pygmy perch, flat-headed gudgeon, Australian smelt
8 Requires minimum cross-section depths ~ 0.1-0.2m
9 Rates of rise and fall capped at the median natural rates
10 Southern pygmy perch, dwarf galaxias, variegated pygmy perch

(Bond, 2005, Borg 2005). In the longer-term, habitat provisioning through sound riparian management will lead to improved instream habitat conditions. The other main issue is the occurrence of numerous migratory (diadromous) species, whose migration patterns can be disrupted by even small instream barriers. 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. To this end it is important that any such 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 vegetation in the Glenelg system is to:

- Maintain healthy and diverse mosaics of water-dependent vegetation

Water dependent vegetation of the Glenelg system

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

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

The Issues paper for the original Glenelg River FLOWS study (SKM 2001) used the presence of rare or threatened plant species to identify vegetation values and as the criterion for setting environmental objectives. It noted that there were 63 threatened species of plant in the Glenelg River catchment, of which 15 were deemed to be water-dependent (SKM 2001, page 24). Dyer and Roberts (2006) criticised the use of rare or threatened species as sole criteria for devising environmental flow recommendations, and this is a valid criticism that needs to be considered when setting making environmental-flow objectives and devising flow recommendations. Some information on in-stream, riparian and wetland vegetation is provided in SKM (2003, pages 31−36) but the environmental objectives (as listed on page 39 of that report) are merely two:

1. Sustainable River Swamp Wallaby Grass (maintenance; bankfull flows in spring); and
2. Sustainable River Red Gum community (maintenance; bankfull flows in winter/spring).

As noted in the introduction, the original Glenelg FLOWS study was among the first to be undertaken in Victoria using the then newly developed FLOWs method. Since the time of that study, a great deal of experience has been gained in applying the method and it would now be thought far preferable to base environmental flows on the hydrological requirements of dominant plant taxa or of generic vegetation groups (e.g. EVCs or broad functional groups) rather than on listed species. Making such assessments requires detailed and consistent information on the vegetation present in each study reach. Figure 22 shows the minimum type of information needed, using as an example the Glenelg River near Casterton − information on modelled 1750 EVCs and on current-day (2005) EVC types and distributions.

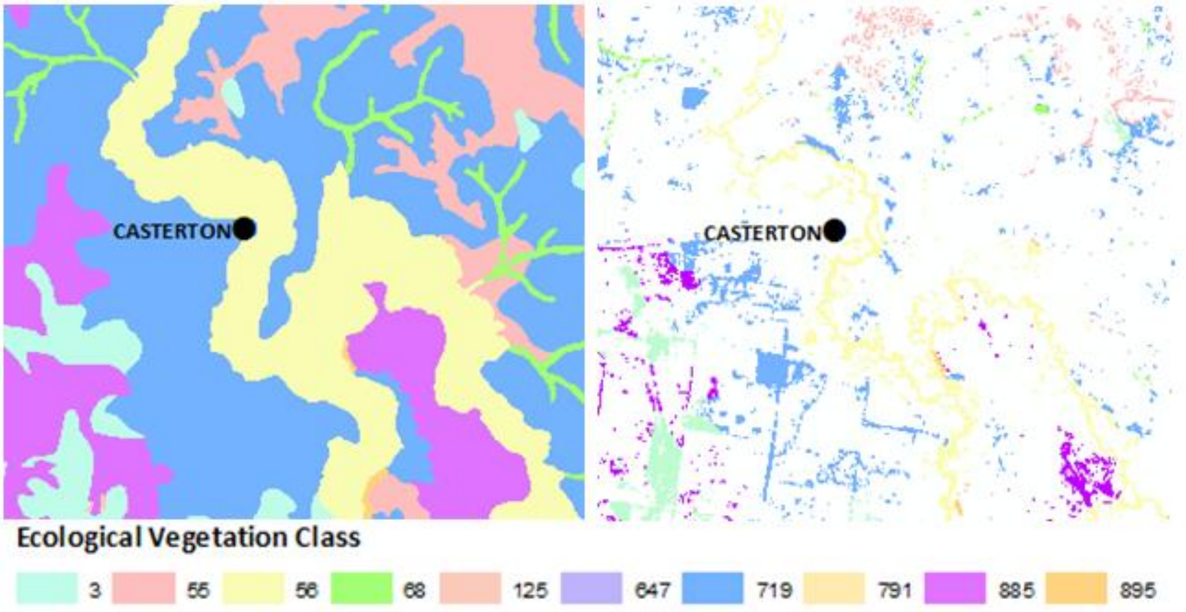


Figure 7. *Vegetation of the Glenelg River near Casterton (left shows modelled 1750 EVCs, right shows EVCs mapped in 2005). Source: DSE interactive biodiversity mapsite.*

VEFMAP vegetation surveys undertaken in 2009 at File Mile Outlet, Fulhams Bridge, Dergholm and Warrock Road found (Alluvium 2010). Some important conclusions from this investigation were:

- 157 native species and 68 exotic weed species were recorded
- Species richness aquatic and amphibious species was rather limited.
- Dominant species for each vegetation zone (zones defined as per VEFMAP protocols) were:
    - Zone A (mid channel to stream margin): *Phragmites australis* and *Typha domingensis* in shallow water; *Triglochin procera* in slightly deeper water
    - Zone B (stream margin to mid-way up bank): *Cotula coronopifolia* under a canopy of *Eucalyptus camaldulensis*.
    - Zone C (mid-way up bank to top of bank): greatest species richness but no plants were universal apart from *Eucalyptus camaldulensis* and a number of the exotic weed species, including *Bromus diandrus* and *Avena fatua*. Commonly observed native plants recorded in Zone C included *Poa labillardierii*, *Acaena echinata*, *Austrodanthonia caespitosa* and *Ficinia nodosa*.
- Notable reduction in the shrub layer, and increase in exotic vegetation from Reach 1 to Reach 2.
- Threatened species identified were *Callistemon wimmerensis*, nationally vulnerable Clover Glycine *Glycine latrobeana*, as well as numerous orchids and species documented as regionally uncommon to rare.

The Wimmera Bottlebrush (*Callistemon wimmerensis*) is a newly recognized species of small tree in the family Myrtaceae. It was discovered in 2004 in the Wimmera system (see Marriot 2006a, 2006b, 2010) and was originally thought to have a very limited distribution in the region Although it has since 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 listed as critically endangered under the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) 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]…'. These flooding requirements will have to be taken into account when revisions are made to past flow recommendations.

The field inspection of early March 2013 allowed a more comprehensive overview to be gained of water-dependent vegetation in the Glenelg River system. At all sites visited during this inspection (i.e. Burkes Bridge, Morree Bridge, Harrow and Five Mile), the presence of submerged and semi-emergent aquatic plants was noteworthy. The most common taxon was Water Ribbons *Triglochin procera*: Figure 12 shows an example of this plant, at the Weaver property in Reach 1a. The abundance of submerged and semi-emergent macrophytes in the river may be a function of the relatively low densities of carp, as this introduced species is well known to cause the loss of submerged plants in other inland waters in south-eastern Australia (Koehn et al. 2000). Riparian and floodplain vegetation at the study site on Reach 1a included a species-rich and apparently healthy mosaic of canopy-layer trees, mostly River Red Gum *Eucalyptus camaldulensis*, a shrub-layer that included Wimmera Bottlebrush, and a ground-layer of native grasses, herbs and forbs.

Figure 8. *Water Ribbons, Triglochin procera, in Reach 1a of the Glenelg River.*

Relevant reaches

The overarching environmental objective for vegetation in the Glenelg 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 vegetation values and hydrological conditions in each of the reaches. Table 8 below identifies the vegetation sub-objectives relevant for each reach of the Glenelg River.

Table 8. Relevant reaches for vegetation objectives

Vegetation objective	Reach 0	Reach 1a	Reach 1b	Reach 2
Improve condition, extent and diversity of instream native vegetation	■	■	■	■
Maintain and improve condition, extent and diversity of emergent native vegetation	Maintain only	Improve & maintain	Maintain only	Maintain only
Maintain, protect and enhance condition and extent of flow dependent species within River Red Gum woodland communities		■	■	■
Maintain, protect and enhance condition and extent of flow dependent species within Tea-tree communities	■	■	■	■
Maintain, protect and enhance condition and extent of flow dependent species within Black Box woodland	■	■		
Maintain, protect and enhance condition and extent of flow dependent *Callistemon wimmerensis*	■	■	■	■

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 create 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, below, 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 too in stabilizing stream banks and protecting them from erosion, and in accumulating sediments on benches and other low-lying features in the channel. As noted below under the section on limiting factors, large, tough emergent macrophytes have a role to play in stabilising accumulations of sand on in-stream benches throughout the Glenelg River system.

Submerged vegetation, especially Water Ribbons, was a feature of all sites examined during the field inspection. Such a great abundance of in-stream vegetation is unusual in many streams in south-eastern Australia, probably because of the interactive effects of the presence of carp (which uproot the plants and muddy the water) and of poor land-use practices in the catchment, which facilitates excessive sedimentation as well as increasing turbidity in the water column and thus further limiting the growth of in-stream vegetation.

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. 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.

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

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. Water Ribbons) or else are mostly emergent reeds, rushes and sedges (e.g. Common Reed)

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.

Table 9. Flows required for healthy and diverse water dependent vegetation

Environmental objective	Flow objective	Flow component	Season	Frequency and duration
Improve condition, extent and diversity of instream native vegetation	Maintain adequate depth of permanent water in channel (greater than 50cm depth) to permit long-term survival and recruitment of submerged plant taxa. Ensure a maximum water depth of about 2 m for obligately submerged taxa.[11]	Low flow	All year	Continuous/near continuous
Maintain and improve condition, extent and diversity of emergent native vegetation	Maintain adequate depth of permanent water in stream channel (greater than 50cm depth) to limit terrestrial encroachment into aquatic habitats.	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[12]
		High flow fresh	Autumn – winter	
Maintain, protect and enhance condition and extent of flow dependent species within ▪ River Red Gum woodland ▪ Tea-tree ▪ Black Box woodland ▪ *Callistemon wimmerensis*	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[13]
		Overbank	Autumn – winter	

System limitations

Maintaining healthy and diverse vegetation along the focus reaches of the Glenelg River cannot be achieved through the provision of the recommended environmental flow regime alone. Other threats can limit the achievement of objectives in parts of Glenelg system. 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.

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.

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). The absence of substantial populations of carp, and especially the absence of very large specimens of adult fish, probably contributes to the healthy beds of submerged and

[11] Freshes may be required to maintain suitable water quality (see below for related objectives).
[12] If this information is not available, 2-4 times in each period
[13] If this information is not available, 2-3 times per decade for River Red Gum woodland, 3-5 times per decade for Tea-tree and 1-3 times per decade for Black Box woodland. 3-5 times per decade will provide for River Red Gum forest and 1-3 times per year will provide for Tangled Lignum dominated systems if desired. If the natural frequency is not available inundate annually and monitor outcomes.

semi-emergent vegetation observed in all study sites of the river. Ongoing control of carp infestations should be a priority for river managers.

Finally, 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 (refer Section 3.8). Sand slugs have developed (Figure 9) 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. These sand depositions, however, provide excellent substrata on which emergent macrophytes such as Common Reed can establish, as shown in the photograph below. 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.

Figure 9. *Sand build-up in the Glenelg River at Burkes Bridge.*

3.6 Diverse and abundant macroinvertebrates

The environmental objective relating to macroinvertebrates for the Glenelg system is to achieve SEPP compliant macroinvertebrate communities. This includes maintaining self-sustaining populations of Glenelg Spiny Cray and Glenelg Mussel.

Description

The Victorian EPA sampled macroinvertebrate communities at eight sites in Glenelg River between Rocklands Reservoir and Casterton between 1997 and 2005 as part of a state-wide biological monitoring program (Table 10). Mitchell (2001) and Lind *et al.* (2007) surveyed macroinvertebrate communities in the Glenelg River at Balmoral, Fulham's Bridge and Harrow (between Rocklands Reservoir and Chetwynd River) each summer from 1997/98 to 2001/02 to assess responses to summer sustaining environmental flow releases.

Table 10. Macroinvertebrate monitoring sites in the Glenelg River

Site name	1997	2000	2001	2003/04	2004/05	1997-2002*
Balmoral						■
Rocklands Road				■		
Fulham Bridge			■			■
Harrow						■
Dergholm	■	■		■	■	
Warrock Rd, Roseneath					■	
Downstream of Casterton	■				■	

*Sampled by Lind *et al* (2005).

According to the 2004 ISC results, the macroinvertebrate fauna in the Glenelg River below Rocklands Reservoir (Reach 1a) was in good condition (SIGNAL score rating of 3 out of 4, AUSRIVAS score rating of 4 out of 4). Further downstream, in Reach 1b, the condition of the community had deteriorated, with a SIGNAL score rating of 3 out of 4, AUSRIVAS score rating of only 1 out of 4 (suggesting the loss of species or families that would have been expected to occur there. This relatively poor condition is maintained in Reach 2, where the 2004 ratings were 3 out of 4 for SIGNAL, and 2 out of 4 for AUSRIVAS.

Even though SKM (2007), in their design of the VEFMAP monitoring program, rated macroinvertebrate sampling as a low priority, providing adequate flows to promote macroinvertebrate diversity and abundance is important as they form the basis of the food chain, particularly for fish and platypus.

Relevant reaches
The environmental objectives relating to macroinvertebrates apply to all reaches of the Glenelg.

Flows objectives
The flows required to achieve the macroinvertebrate objectives are founded in the conceptual model described below and summarised in Table 11.

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 and mobilise sediments.

In many lowland streams where elevated turbidity reduces instream 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 disturb the algae/bacteria/organic biofilm present on in-stream surfaces. This 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), 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.

Table 11. Flows required for diverse and abundant macroinvertebrates

Environmental objective	Flow objective	Flow component	Season	Frequency and duration
Achieve SEPP compliant macroinvertebrate communities[14]	Maintain edge habitat availability	Low Flow	All year	Continuous
	Maintain shallow water habitat availability[15]	Low Flow	Summer - Autumn	Continuous
		Low Flow	Winter – Spring	Continuous
	Increase biofilm abundance on wood debris as a food source	Low Flow	All year	Continuous
		Low Flow Fresh	Spring-Summer	3-4 per year, or natural to introduce variability in wetting
	Flush surface sediments from hard substrates (riffles, wood, fringing roots and vegetation)[16]	(Low Flow) Fresh	Lead up to summer (late high flow season - Nov)	1 per year, or natural
	Prevent water quality decline in pools during low flows[17]	Low Flow & Low Flow Fresh	As required	As required
	Disturb the algae/bacteria/organic biofilm present on rocks or wood debris	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	Winter – Spring	1 per year
		Bankfull	Anytime	1 per year
		Overbank	Anytime	1 per year
Maintain self-sustaining population of Glenelg mussel	Maintain shallow water habitat availability[18]	Low Flow	All year	Continuous
Maintain self-sustaining population of Glenelg Spiny Cray	Maintain habitat availability	Low Flow	All year	Continuous
	Provide suitable salinity during moulting	Low Flow, High Flow & Low Flow Fresh	All year (juveniles) Summer (adults)	As required

[14] Not monitored in VEFMAP
[15] Flow sufficient to keep the bed wet and cover leaf packs
[16] A shear stress at least 1.1 N/m^2 is required to mobilise coarse sand
[17] A 7-14 day pool turnover time is recommended
[18] Mussels are found in firm, coarse sandy sediments in shallow (between 20 and 48 cm with a mean depth of 28 cm), narrow (2-5 m), flowing (mean velocity mean 0.1m/s) sections of the Crawford River.

System limitations

Maintaining diverse and abundant macroinvertebrate populations in the Glenelg 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 Glenelg 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).

  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 slow process, relying on the death of riparian trees which fall into the river channel.

- **Sand slugs**: Excess sand covers available habitat. Smothering habitats reduces the diversity and abundance of macroinvertebrates. In areas with stable sand slugs, macrophyte growth may provide habitat for macroinvertebrates, but in unstable areas the macroinvertebrate community is likely to be in poor condition.

- **Water quality**: Macroinvertebrates are sensitive to changes in water quality parameters such as salinity, water temperature, turbidity, nutrients and dissolved oxygen. A suitable low flow regime can reduce the impact of saline groundwater. Short flushing flows to dilute or remove any stratified saline groundwater may need to be frequent, depending on the level of saline inputs.

3.7 Healthy platypus communities

The environmental objectives relating to platypus for the Glenelg system is to maintain the existing platypus population.

Description

Although there appears to be no formal widespread survey of platypus in the Glenelg River, the species is well established and appears to be present along the length of the river.

Relevant reaches

The environmental objective to maintain the existing platypus population applies to all reaches of the Glenelg.

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 less than 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).

Table 12. Flows required for healthy platypus communities

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

System limitations
Maintaining healthy platypus populations in the Glenelg 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 Glenelg 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. 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.

- **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 Glenelg system are:

- Improve and maintain channel diversity using channel forming flow
- Maintain hydraulic capacity at tributary junction plugs

Geomorphology of the Glenelg system
The Glenelg River rises in the Grampians at an elevation of approximately 600 m and drains an area of 12,700 km^2 before discharging to the Southern Ocean at Nelson. From its source, the Glenelg flows north for a short distance through the flat Victoria Valley before heading west, passing across an uplifted, highly erodible palaeoplain (the Dundas Tablelands) that is dissected by a radial drainage network comprising the major upper tributaries of the Glenelg. At the town of Casterton, the river meets its major tributary the Wannon River (4,000 km^2). In its downstream reaches the Glenelg is unconfined by valleysides or hillslopes, and meanders across broad coastal plains before reaching the head of its estuary, which is a 65 km long limestone gorge. Rocklands Reservoir, the major storage on the system, captures flow from the upper 1,355 km^2 of the catchment area.

Sand slugs
Like many streams in south-eastern Australia, the Glenelg has been significant affected by slugs of sand generated by sheet and gully erosion of hillslopes and tributaries in granitic areas of the catchment. Approximately 6,000,000 m^3 of sand has entered the stream network in the last 100 years (Rutherfurd 2001). The major source of sand to the Glenelg River have moved from hillslope sources to transient storage zones in

the lower reaches of the major left bank tributaries, which have aggraded by between 1 and 5 m (Ruthefurd 2001).

The elevated supply of sediment to the main stem of the Glenelg is a geomorphic process common to many streams in south-eastern Australia that have been disturbed by anthropogenic activities such as mining, clearing vegetation for agriculture and artificial drainage. The large-scale, episodic injections of sediment create 'sand slugs' that persist in the stream for decades or centuries.

Sand slugs have significant geomorphic impacts: it effectively dams the river in some locations, creating 'tributary junction plugs' (TJPs) that become backwater lakes or online wetlands, infills the previously deep pools and generally causes aggradation (sedimentation) of the channel that generates largely featureless sheets of sand.

Upstream of Rocklands Reservoir the channel of the Glenelg River is mostly an ill-defined, heavily vegetated channel that is not affected by sand slug. Yarramyljup Creek, which joins the Glenelg River immediately downstream of Rocklands Reservoir, is the first major source of sand. From this point to approximately 25 km upstream of the estuary there are substantial deposits of sand in the bed of the Glenelg.

At the confluences with the Yarramyljup Creek, Mathers Creek, Deep Creek, Pigeon Ponds Creek and the Chetwynd and Wando Rivers the channel of the Glenelg is blocked, creating TJPs. Where TJPs are close together the sand slugs downstream of the confluence reaches the upstream extent of the next TJP downstream, creating a single continuous sheet of sand. Where the distance between confluences is larger, the sand slug breaks down into what Rutherfurd (2001) termed 'slugettes': localised aggradation of sand on existing riffles, without pool infilling.

The current rate of sediment transport in the main stem of the Glenelg was estimated to be low (between 10,000 and 30,000 m^3/year), which means the residence time is likely to be more than a century (and possibly longer). The attenuation effect of Rocklands Reservoir on catchment hydrology reduces flood frequency, which reduces the sediment transport rate.

Rutherfurd (2001) developed a conceptual model of sand movement in the Glenelg, which suggested the future trajectory for sand movement through the Glenelg system was likely to be:

- A reduction over time in supply from tributaries to main stem as land use practices improve, Glenelg Hopkins CMA works are implemented, and the erosion and transport processes naturally reduce in intensity
- Net erosion of sediment from TJPs as supply from tributaries reduces and sediment transport capacity in the main stem remains constant
- A single, continuous sheet of sand will form from upstream of Harrow to Burkes Bridge, and continuing supply of sand to maintain the downstream slugettes.

Relevant reaches

The environmental objective to 'improve and maintain channel diversity using channel forming flow' applies to all reaches of the Glenelg River downstream of Rocklands Reservoir (Reach 1a, 1b and 2). The objective to maintain hydraulic capacity at tributary junction plugs is relevant only to reach 1a (where Frasers Swamp is located).

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), and the sediment inflow regime. If any of these factors are altered, over time the geomorphic processes and form will change, for example changes in the flow regime through regulation (Gregory, Benito & Downs 2008), removal of riparian vegetation (Simon & Collison 2002) and interruptions in the sediment supply from upstream (Petts & Gurnell 2005).

As discussed above, the primary geomorphic processes in the Glenelg system relate to the oversupply of sand from tributary streams draining erodible granite catchments. The interactions between flow, vegetation and sediment transport in the Glenelg are largely driven by sand dynamics, so flow objectives need to influence sand storage and transport in a way that works towards the overall environmental objectives.

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 considers 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. In the Glenelg River, the persistence of large pools will primarily be governed by sand slug movement, so for reaches where sand slugs dominate geomorphic processes the effect of flow on pool formation is likely to be localised.

The flow processes required to meet the environmental objective are:

- Maintenance of gross channel physical form and inchannel features (bankfull flow)
- Sediment mobilisation flow (flow that generates shear stress of 1.1 N/m^2 to mobile coarse sand that accumulates in pools)
- The flow components to achieve these flow processes are bankfull and fresh flows. These requirements for each of these components are summarised in Table 13.

Maintaining the hydraulic capacity of TJPs is dependent on two factors: the rate at which sediment is transported from the TJPs downstream during flow events, and the rate of supply of sand from the tributaries. The risk to the hydraulic capacity of the TJPs is that insufficient flow is provided to move sediment downstream. Given system constraints, it is unlikely that flows of a sufficient magnitude will be released to increase the rate of erosion of sediment from the TJPs, so it is recommended that other management options (such as vegetation establishment) be investigated to reduce the rate of sediment supply from the tributaries contributing large sediment loads and large natural events (bankfull and overbank) be preserved to maximise sediment transport opportunities. There may also be options to directly intervene in the TJPs to reduce the water usage these systems have (although this must be balanced with the values they provide).

Table 13. Flow requirements to achieve geomorphic objectives

Environmental objective	Flow objective	Flow component	Season	Frequency and duration
Improve in channel habitat diversity and condition	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.	Fresh	Any time	Frequency & duration as per unimpacted flow regime
Maintain deep pools for in-channel habitat	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
Maintain hydraulic capacity at tributary junction plugs	Flows not recommended to achieve this objective (refer discussion above).			

System limitations

Maintaining geomorphic processes in the Glenelg 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 Glenelg system. These limitations are described below.

- Limitation in the bedload transport capacity releases from Rocklands Reservoir can produce due to outlet capacity constraints.
- Continuing supply of sediment (in the medium-term) to the TJPs from main tributaries
- Ongoing large-scale, long-term movement of sand slugs through the system.

4 Approach to updating environmental flow recommendations

The underlying method for identifying environmental objectives and the appropriate flow thresholds was similar in this study to the 2003 study. The environmental flow recommendations have changed due to updated environmental objectives described above, improved hydraulic models, and more extensive hydrological data and consideration of the climatic conditions. The following sections describe how the available hydraulic modelling and hydrology data has been used to determine the revised recommendations.

4.1 Hydraulic modelling

The flow magnitudes required to achieve the environmental objectives were determined using existing hydraulic models where available and for Reach 1a, where no existing model was available, the objectives were determine using a new hydraulic model developed for this study.

Existing hydraulic models

Six of the eight HEC-RAS models created as part of the VEFMAP assessments in 2009 were adopted for this study. These models were created to assess a range of low and high flows similar to what is required for determining environmental flow recommendations. Three models are located in Reach 1b and three in Reach 2:

Reach 1b

- Five Mile Outlet
- Dick Roberts
- Harrow

Reach 2

- Burkes Bridge
- Warrock Road
- Section Road

Another HEC-RAS model located at Yat Nat Hole in Reach 1a was deemed unsuitable due to it featuring a single steep drop that is not representative of the reach itself.

No changes have been made to the existing models for this study. The existing channel geometry, upstream and downstream boundary conditions and hydraulic roughness factors were assumed to be correct. Some notes on the appropriateness of each of the models for determining environmental flow for their reach are included below the environmental flow recommendations in Sections 4.4 to 5.4.

New hydraulic model

A new hydraulic model was developed to determine the flow magnitudes required in Reach 1a. This reach transitions between sections of multi and single thread channel and includes a number of flood-out features and backswamps. Cross sectional survey was undertaken at a site identified by the Technical Panel. The site is located a few kilometres downstream of Frasers Swamp and comprises a section of multi-channel floodplain and a section of single defined channel. The survey focussed on the in-channel detail and this was integrated with the existing LiDAR data to provide the floodplain detail.

The combined survey and LiDAR data was used to generate a two-dimensional hydraulic model in XPSWMM. It was decided to use a two-dimensional model (rather than the traditional one-dimensional HEC-RAS model) because it provides:

- Detailed representation of the multi-channel floodplain.
- Better representation of the hydrodynamic interactions across the floodplain, assesses flow in multiple directions across the floodplain compared to a one-dimensional models like HEC-RAS which can only assess flow in a single defined channel and require the modeller to define any flow splits.
- No issues with selection of cross section locations as the model uses a grid covering the entire channel and floodplain and produces results on that scale.

- Better distribution of shear stress, velocity and even water depth (assumption of having horizontal water surface is not true in most cases especially when water flows over the floodplain) over the sections.

There were three primary variables used in the XPSWMM model:

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

As no streamflow gauging stations are present adjacent to the survey site, an upstream and downstream slope was used for boundary conditions, as calculated from the longitudinal profile. Table 14 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 14. Hydraulic parameters adopted in XPSWMM model

Hydraulic parameter	Value
Manning's roughness - channel	0.045
Manning's roughness - floodplain (from bare soil to dense trees)	0.03 to 0.065
Downstream slope	0.001
Upstream slope	0.001

4.2 Inter-annual variability (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 10 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.

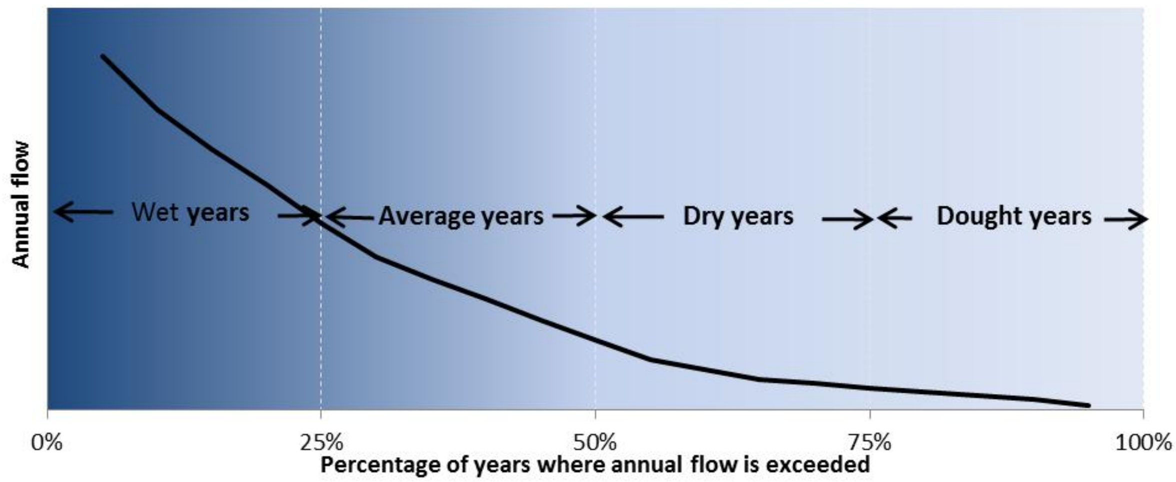


Figure 10. *Climatic conditions – wet, average, dry and drought years*

The climatic conditions were determined based on the 100 year (1903-2004) modelled unimpacted flow sequence (SKM 2005). The modelled unimpacted sequence of inflow to Rocklands Reservoir was used as the basis for determining the prevailing climatic condition for Glenelg Reach 1a. 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:

a. Spell duration = median duration of spell for the condition type.
b. 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 multiyear 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 4 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;

a. they still achieved around 20-30% of the total period in event as per the above method, and
b. 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. Hence the resulting approach of applying duration and frequency values to achieve 20-30% of the unimpacted regime 'in event' should be considered an arbitrary starting point that may require local reinterpretation to suit conditions.

Since a modelled 'unimpacted' streamflow sequence was only available for inflows to Rocklands Reservoir (Reach 1a), the frequency and duration for the downstream reaches (Reach 1b and Reach 2) could not be determined using the same methodology. Instead it has been assumed that the frequency and duration for each flow component of the downstream reaches is equal to the frequency and duration of that flow component in Reach 1a.

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 inflows to Rocklands Reservoir (Reach 1a), rates specific to the lower reaches could not be determined. Instead it is assumed that the recommended rates for Reach 1a be applied for the equivalent flow components to Reach 1b and 2.

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 0.87, the flow on the following day should not be below 87 ML/d. Similarly, if the flow rate was 100 ML/d and the recommended rate of rise is 2.21, the flow on the following day should not exceed 221 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 15). These criteria have been used in many environmental flow studies throughout Victoria.

Table 15. Rates of rise and fall for the Glenelg River

Component	Flow range in reach 1a	Rise	Fall
Summer baseflow to fresh or Summer baseflow to winter baseflow	10-60ML/d	2.21	0.87
Winter baseflow to winter fresh	60-550ML/d	1.87	0.87
Winter fresh to bankfull	550-1400 ML/d	2.60	0.77
Bankfull to overbank	1400-4000ML/d	4.69	0.67

4.4 The 'or natural' recommendation

Many of the environmental flow recommendations for each reach listed in Section 5 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 '10 ML/d or natural' but unimpeded inflows are less than 10 ML/d, compliance with the environmental flow recommendation is still achieved with a delivery of less than 10 ML/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 Environmental flow recommendations

5.1 Reach 0 Glenelg River upstream of Rocklands Reservoir

Located in Grampians National Park, this reach is relatively undisturbed. An ill-defined channel flows through a swampy valley with high-value riparian habitat. Water can be diverted from the Glenelg to Moora Moora Reservoir and subsequently diverted to the Wimmera catchment via the Moora Moora Channel. The Moora Moora channel also collects large amounts of surface runoff. All non-diverted flows continue flowing into Rocklands Reservoir at downstream end of reach.

There is no evidence of sand slugs in this reach, which is due to the relatively low level of catchment disturbance and erosion, and consequently limited change in sediment delivery to the Glenelg from pre-European settlement.

The reach is well vegetated with a eucalyptus forest over-story and tea tree understorey (Figure 11). Six native fish species are present including the protected dwarf galaxias (SKM 2003a). Healthy macroinvertebrate communities are also expected to exist. The presence of fire dams within the catchment reduce flows in this reach, as does flow picked up by Moora Moora Reservoir and the Moora Moora Channel.

Figure 11. *Glenelg Reach 0*

Environmental objectives

Reach 0 is recognised in particular for the high value vegetation in Grampians National Park. The environmental objectives for this reach relate to vegetation, native fish, macroinvertebrates and platypus:

- Protect, maintain and where possible, enhance populations of native fish
- Maintain healthy and diverse mosaics of water-dependent vegetation
- Achieve SEPP compliant macroinvertebrate communities
- Maintain existing platypus population

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

Environmental flow recommendations
No environmental flow recommendations have been quantified for Reach 0 due to:

- Lack of existing hydraulic model within the reach
- Lack of modelled current and unimpacted hydrology within the reach
- Higher priority to determine environmental flow recommendations for Reach 1a

The flows required to meet each of the environmental objectives for this reach are described qualitatively in Section 3.

The flow components required to achieve the environmental objectives are outlined in Table 16. If a suitable hydraulic model becomes available for this reach the magnitude of flow could be determined for each component. The frequency, duration and seasonality required for each flow could be determined using the identified magnitude and unimpacted hydrology.

Note that a cease to flow is not required to achieve any of the objectives

Table 16. Environmental flow components required for Glenelg River Reach 0

Flow component	Period	Objectives achieved	Notes on frequency/duration/condition
Baseflow	Dec – May	Maintain edge habitats, pools and shallow water habitat availability for **platypus, macroinvertebrates** and **fish**. Also maintain a near-permanent inundated stream channel to **prevent excessive instream terrestrial species** growth and promote instream aquatic vegetation.	A continuous baseflow would achieve the objectives. No cease to flow period is necessary, however flow is understood to cease under natural, or unimpacted conditions. Maximum tolerable periods of cease to flow could be derived from available hydrology.
	Jun – Nov	Maintain shallow water habitat availability for **macroinvertebrate**s and facilitate annual dispersal **of juvenile platypus.** Improves **habitat diversity** by increasing wetted area from summer period.	
Freshes	Dec – May	Provide variable flow during low flow season for supporting **macroinvertebrates** (over wood debris to increase biofilm abundance as a food source), diverse **habitats** and **water quality**. Facilitate scour of sand for **fish habitat**. Maintain condition of **emergent vegetation** by wetting benches/lower banks.	
	Jun – Nov	Facilitate scour of sand for **fish habitat**. Provide stimulus and opportunity for **fish migration**. Maintain and improve condition of **emergent vegetation** by wetting benches/lower banks.	At least one fresh is required in October – November.
Bankfull	Any	Inundate **riparian vegetation** to maintain condition and facilitate recruitment.	Tea-tree requires inundation 2-5 times per decade.
Overbank	Aug – Nov	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment.	Tea-tree requires inundation 2-5 times per decade. Black box requires inundation 1-3 times per decade.

5.2 Reach 1a Glenelg River between Rocklands Reservoir to Five Mile outlet

There are variations in channel form in this reach; it transitions between sections of well-defined single thread channel, which can vary in width, to floodout features with ill-defined channel form to sections with a complex network of channels, island and backswamps (Figure 12).

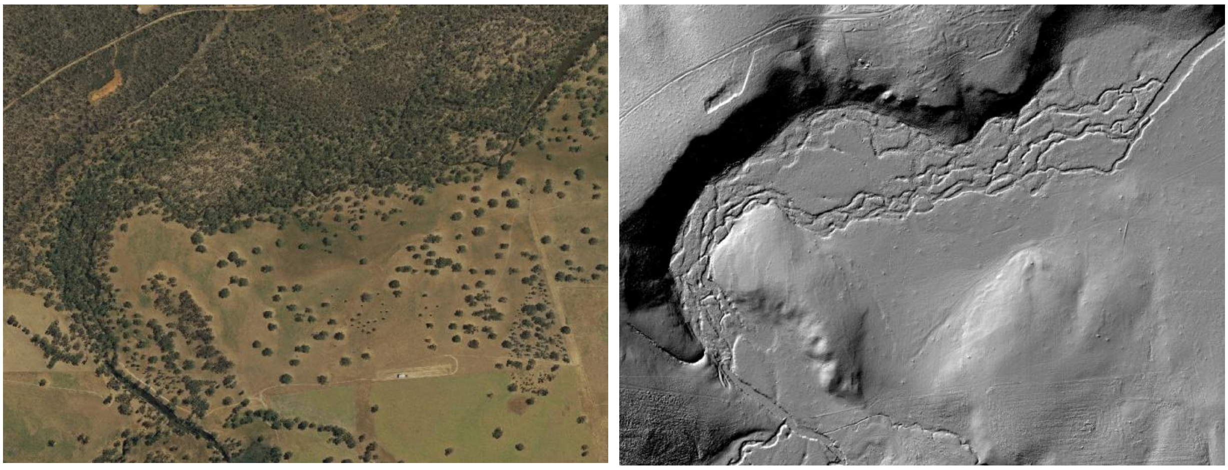


Figure 12. *A section of Reach 1a approximately 4 km upstream from Balmoral (flow direction right to left)*

Regulated flows can be delivered to this reach directly from Rocklands Reservoir; however releases from the Reservoir may also by-pass this reach and instead be delivered directly to Reach 1b of the Glenelg River at Five Mile outlet.

Important values through this reach include Frasers Swamp (a TJP) (Figure 13) and an associated Growling Grass Frog population. This build-up of sand at Frasers Swamp restricts the channel capacity and limits environmental flow delivery without flooding private property. This reach is also recognised as being a source of salt, with high levels of salinity observed and impacting on the habitat quality.

Figure 13. *Glenelg Reach 1a (immediately downstream of Frasers Swamp)*

Environmental objectives

The environmental objectives for Reach 1a relate to native fish, vegetation, macroinvertebrates, platypus and geomorphic values:

- Protect, maintain and where possible, enhance populations of native fish, including diadromous species.
- Maintain healthy and diverse mosaics of water-dependent vegetation
- Achieve SEPP compliant macroinvertebrate communities
- Maintain existing platypus population
- Maintain hydraulic capacity at tributary junction plugs
- Improve and maintain channel diversity using channel forming flow

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

Environmental flow recommendations

Environmental flow recommendations to achieve the environmental objectives for Reach 1a are summarised in Table 17.

Table 17. Environmental flow recommendations for Glenelg River Reach 1a

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendations
Cease to flow	Dec-May	0 ML/d	DROUGHT	As infrequently as possible	< 145 days	None of the environmental objectives require a cease to flow. This recommendation acknowledges that cease to flows naturally occur and provides guidance to ensure that stress on the environmental values is not exacerbated beyond the point of no return.	The total cease to flow duration in each period should not exceed the number of days recommended in this table. These durations are based on cease to flow periods in the unimpacted hydrology. Refer note below this table about cease to flow periods for further detail.
			DRY		< 125 days		
			AVERAGE		< 110 days		
			WET				
	Jun- Nov	0 ML/d	DROUGHT	As infrequently as possible	< 110 days		
			DRY		< 55 days		
			AVERAGE		<35 days		
			WET				
Baseflow	Dec-May	10 ML/d or natural	ALL	Continuous		Maintain edge habitats, pools and shallow water habitat availability for **platypus, macroinvertebrates** and **fish**. Also maintain a near-permanent inundated stream channel to prevent excessive instream terrestrial species growth and promote instream vegetation.	
	Jun- Nov	60 ML/d or natural	ALL	Continuous		Maintain shallow water habitat availability for **macroinvertebrate**s and facilitate annual dispersal of **juvenile platypus.** Improves habitat diversity by increasing wetted area from summer period.	
Freshes	Dec-May	60 ML/d	DROUGHT	2 per period	2 days	Provide variable flow during low flow season for supporting **macroinvertebrates** (over wood debris to increase biofilm abundance as a food source), diverse **habitats** and **water quality**. Facilitate scour of sand for **fish habitat**. Maintain condition of **emergent vegetation** by wetting lower banks. Wetting high flow channels	
			DRY		3 days		
			AVERAGE		3 days		
			WET		3 days		
	Jun-Nov	550 ML/d	DROUGHT	1 per period	1 day	Facilitate scour of sand for **fish habitat**. Provide stimulus and opportunity for upstream and downstream **fish migration** Maintain pools and inundate benches to improve **in-channel diversity.**	At least one fresh is required in October - November for fish migration.
			DRY	2 per period	3 days		
			AVERAGE	3 per period	5 days		
			WET	5 per period	5 days		
Bankfull	Any	1,400 ML/d	DRY	1 per year or natural	1 day	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	Only required 2-3 times per decade for River Red Gum and 2-5 times per decade for Tea-tree communities
			AVERAGE		3 days		
			WET		5 days		
Overbank	Aug-Nov	4,000 ML/d	WET	1 per period or natural	2 days	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	Only 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 Tea-tree.

Notes on environmental flow recommendations

Cease to flow periods

Periods without flow are a distinctive feature of the hydrology of the Glenelg River both prior to and since regulation. Cease to flow periods can play a number of important ecological roles in rivers, especially in the breakdown and cycling of organic matter, and can also favour native taxa over introduced species such as trout, carp and redfin due to differences in tolerances and breeding requirements (McNeil & Closs 2007; McNeil *et al.* 2009). Cease to flow periods nevertheless pose a risk to native fish populations, especially since sand sedimentation has greatly reduced the size and depth of refuge pools. For this reason, while it is acknowledged that cease to flow spells will continue to occur in the Glenelg River, especially during drought periods, they have not been recommended as a flow component. Instead, the recommendation is that cease to flow spells not be extended in duration above that expected to occur naturally during any particular event. In addition, during extended drought periods it may be necessary to periodically release water to replenish refuge pools. However, the volumes required are hard to estimate and thus no specific recommendation has been made around such releases and should be guided by real time monitoring.

Hydraulic model quality

The hydraulic model used to determine these flows was developed specifically for this project following discussions with Glenelg Hopkins CMA and the Technical Panel. The site provides a good representation of the reach, including single and multi-channel sections allowing flow magnitudes to be identified which achieve objectives in both types of channel.

The model was created using the two-dimensional hydraulic model in XPSWMM which offers a number of advantages over a one-dimensional HEC-RAS model. In particular, the two-dimensional model allows for the better representation of flow through the multi-channel section. The two dimensional model is much slower to run than a HEC-RAS model, so less flow magnitudes were run in the model than would typically be done. After the initial set of results subsequent flows were selected and run where gaps were identified.

Results of the two-dimensional hydraulic modelling are presented as georeferenced aerial inundations (for example Figure 14). Results were also analysed at a number of cross sections to identify flow depth, velocity and shear stress. Figure 14 shows the inundation extents predicted for a 10 ML/d flow (the summer baseflow) and a flow of 550 ML/d (winter fresh).

Figure 14. *Modelled inundations on Reach 1a at 10 ML/d (left) and 550 ML/d (right).*

Compliance point
The current compliance point for Reach 1 is at the township of Harrow (gauge 238 210). Harrow is located approximately 80 km downstream from the hydraulic modelling site for Reach 1a (as shown in Figure 15). Flows passing the gauge at Harrow are typically much higher from those in Reach 1a due to the considerable additional catchment between the two sites (including tributaries discharging into the Glenelg). The flow is also likely to be higher as flows from Rocklands Reservoir are delivered to Five Mile Outlet via the channel (shown below).

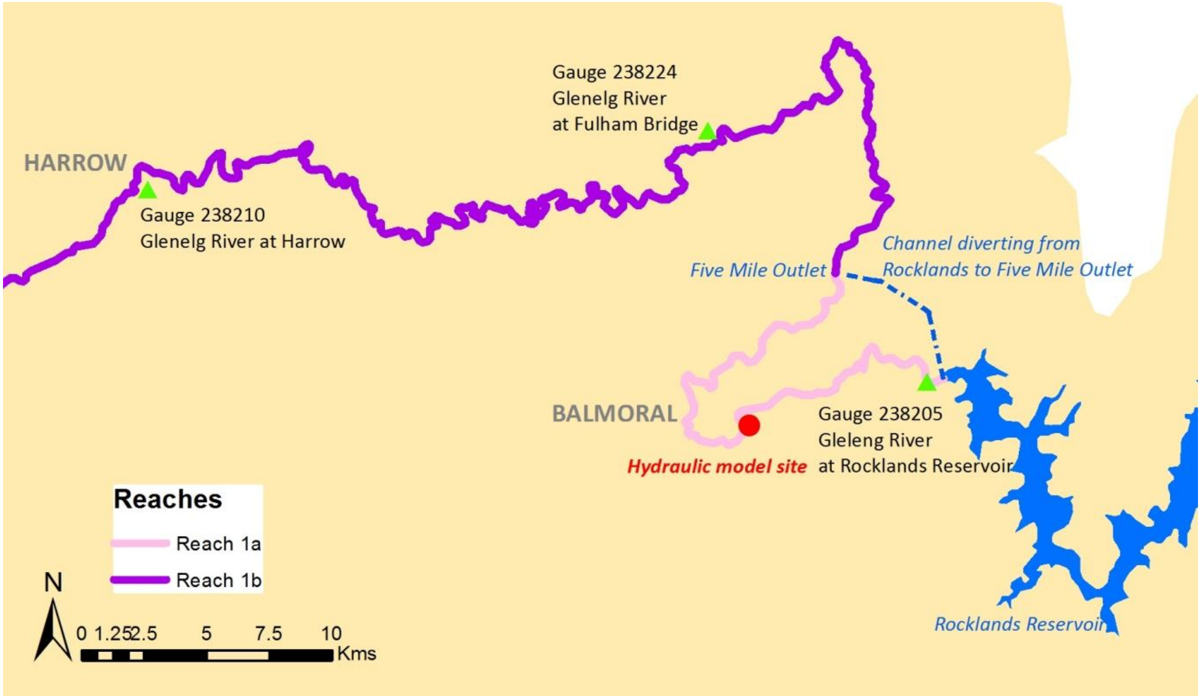


Figure 15. *Location of current Reach 1 compliance point and hydraulic model site for Reach 1a*

Another active gauge located within Reach 1b at Fulham Bridge (gauge 238 224) would provide a slightly better compliance point than Harrow due to it being closer to Reach 1a, however it could still carry significantly different flows than Reach 1a due to the capacity to deliver directly to Reach 1b at Five Mile Outlet.

Compliance for this reach should be located within Reach 1a, preferably as close to the hydraulic modelling site as possible. Releases into the Glenelg River at Rocklands Reservoir (gauge 238 205) may provide a better representation of flow at the site, however due to the expected losses along the reach (particularly at Frasers Swamp) these flows would be considerably higher than what would be present at the model site. Consequently, the Rocklands Reservoir gauge does not provide an appropriate place to measure compliance. It is recommended that a new streamflow gauge be created at, or downstream of the hydraulic model site to provide an adequate mechanism for measuring compliance in Reach 1a.

Performance and risk assessment
Performance assessment point for Reach 1a:

Gauge	238 224
Name	Glenelg @ Fulham Bridge
Status	Open / active
Start for assessment period	1 July 1972
End for assessment period	30 June 2010

For performance reporting (Table 18) the flow recommendations presented in Table 17 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).

Table 18. Performance of environmental flow recommendations for Glenelg Reach 1a (% compliance)

				Flow recommendation																		
	Years	annual total (GL)	annual shortfall (GL)	Drought summer fresh 60 M	Drought winter fresh 550M	Drought summer baseflow 1	Drought Winter baseflow 6	Dry Summer fresh 60ML/d x	Dry winter fresh 550ML/d	Dry bankfull 1400Ml/d for	Dry Sumemr Baseflow 10Ml/	Dry Winter Baseflow 60Ml/	Avg Summer Fresh 60ML/d x	Avg june nov fresh 550ml/	Avg bankfull 1400Ml/d x1	Avg Summer baseflow 10Ml/	Wet Overbank 4000ML/d x1	wet Summer fresh 60 ML/d	wet winterfresh 550ML/d x	Wet Bankfull 1400ML/d x1	wet summer baseflow 10ML/	Wet Winter Baseflow 60ML/
	median	27.35	5.20	0	0	100	15	50	50	100	100	61	50	0	0	100	0	50	20	0	100	83
	mean	45.21	7.01	8	17	67	28	29	36	57	91	68	50	11	44	95	33	58	17	42	97	82
	1972	10.0	0.9	100	100	100	67															
	1982	2.4	4.6	0	0	100	0															
	1994	5.5	3.2	0	0	100	21															
	1997	8.3	2.5	0	0	100	51															
	1999	4.4	3.7	0	0	100	11															
	2000	7.7	1.7	0	0	100	51															
	2002	2.9	4.2	0	0	0	15															
	2004	23.8	0.0	0	100	100	100															
	2005	4.7	3.2	0	0	100	11															
	2006	1.0	5.2	0	0	0	0															
	2007	3.6	4.3	0	0	0	14															
Drought	2008	1.2	4.9	0	0	0	0															
	1976	17.2	3.0					50	0	0	100	66										
	1977	9.8	8.4					50	0	100	100	52										
	1990	22.6	5.1					0	0	100	100	87										
	1998	16.1	3.5					50	50	0	100	57										
	2003	17.5	4.7					0	50	100	78	53										
	2009							0	50	100	100	61										
Dry	2011	28.4	4.1					50	100	0	57	100										
	1978	34.0	6.9										50	0	0	71						
	1979	52.9	9.0										100	0	100	92						
	1980	51.5	7.4										100	33	100	90						
	1985	18.3	13.2										0	0	0	100						
	1987	27.4	8.9										100	33	100	100						
	1988	114.1	3.3										0	33	0	100						
	1989	47.6	6.2										0	0	0	100						
	1991	65.3	7.9										0	0	100	100						
Average	2001	20.9	9.7										100	0	0	100						
	1973	69.6	12.6														0	100	40	100	100	100
	1974	180.6	1.2														0	50	20	100	64	95
	1975	187.7	4.6														100	100	0	100	100	94
	1981	102.6	14.9														0	50	0	0	100	70
	1983	66.8	16.6														0	50	0	0	100	75
	1984	43.4	12.4														0	0	20	0	100	60
	1986	50.1	14.1														0	100	40	0	100	88
	1992	210.9	6.2														100	50	20	100	100	100
	1993	30.6	12.4														0	50	0	0	100	78
	1995	52.0	13.4														0	0	20	0	100	75
	1996	76.4	9.4														100	50	0	0	100	90
Wet	2010	73.6	15.8														100	100	40	100	100	53

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 Figure 16.

The flow recommendations vary by season and so too does the recommended environmental water. For the reporting period the mean annual flow was 45.2GL and the mean shortfall was 8.3GL (including overbank flows). However the shortfall varied tremendously from as little as 23ML in 2004 to 24GL in 1995. If we don't consider the overbank flow requirement as one that would normally be delivered as part of the operational environmental water delivery then the overall shortfall drops from 8.3GL/y to 7.0GL/y (Mean).

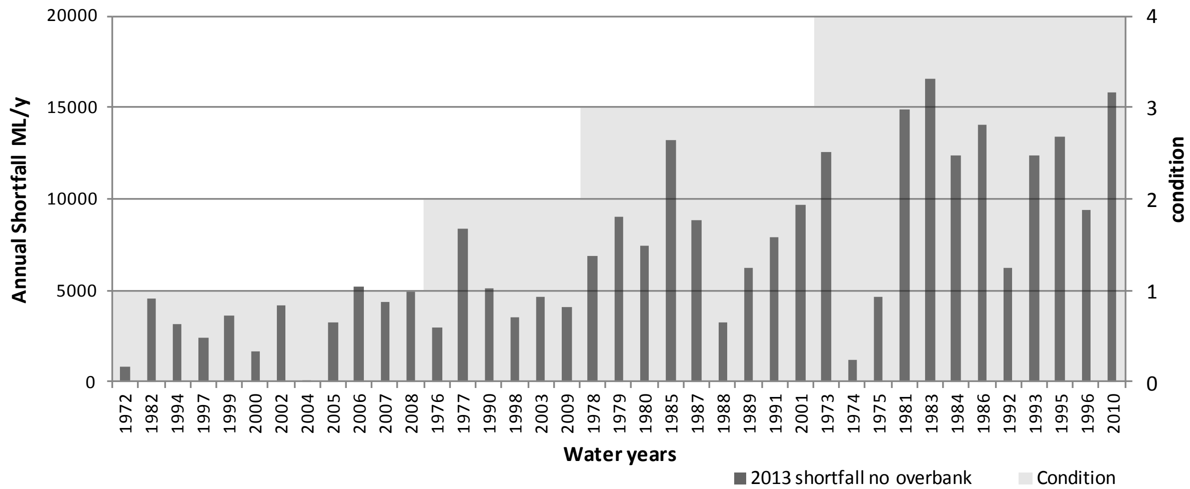


Figure 16. *Total Annual Shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet) (G1a)*

The implications of this shortfall analysis is that, if we assume the assessment period is typical of the current hydrology, then an additional 5.2GL/yr of environmental water releases will achieve compliance in 50% of all years (Figure 17). Considering drought years; if 5.2 GL was provided on a drought year, one could expect that full compliance would be achieved in half of years, or to consider this another way, full compliance would be achieved on a typical (median) drought year if 5.2 GL of additional water was effectively delivered.

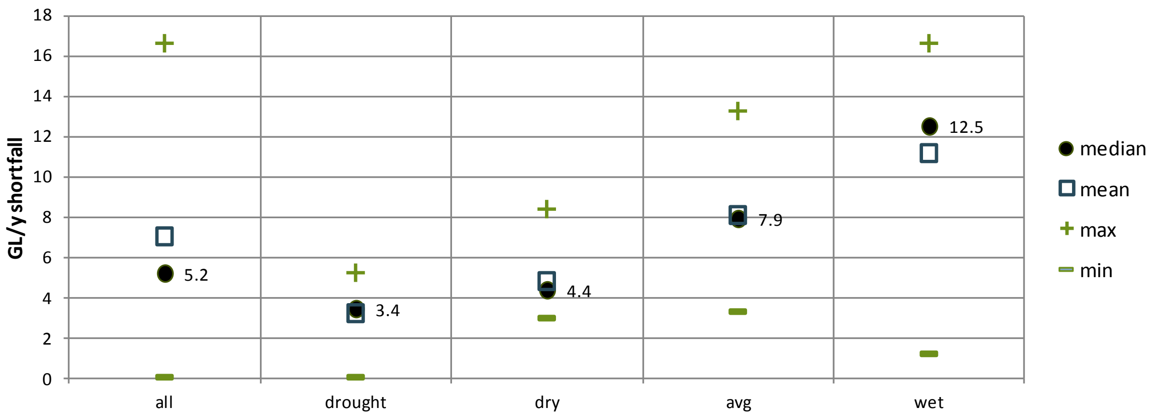


Figure 17. *Glenelg River reach 1a shortfall summary by climatic condition (median values shown)*

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 18). Say for example if 4 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 30% of all years, which ranges from only 11% of average years to almost 70% in drought years.

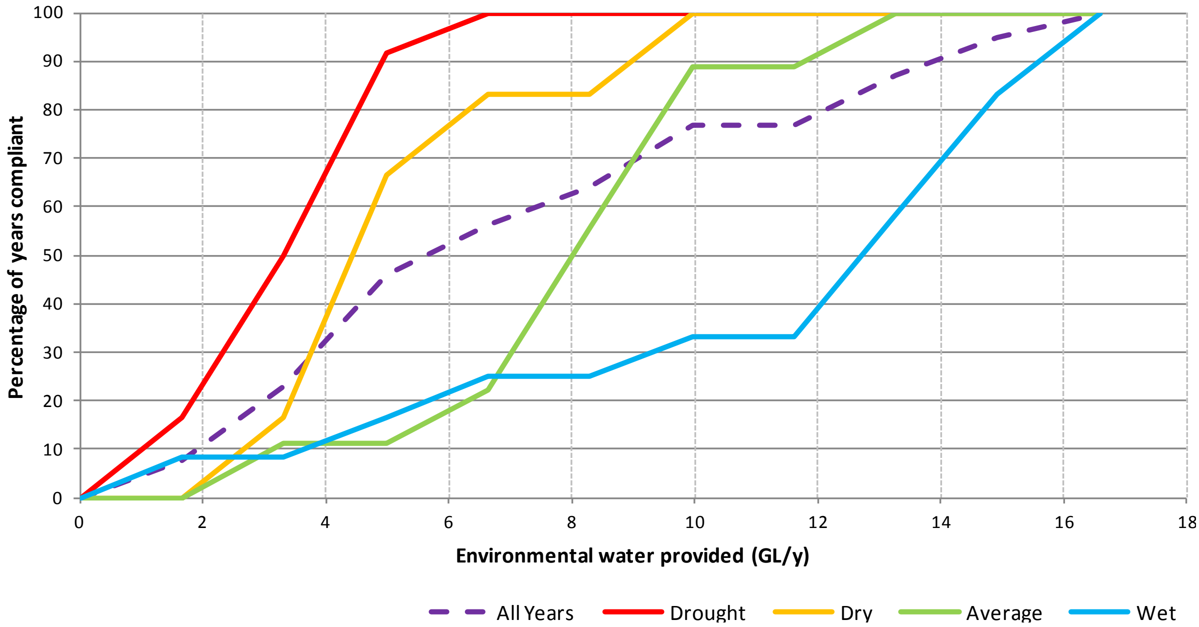


Figure 18. *Percentage of years compliant under different environmental water delivery (excludes overbank flow recommendation).*

Summary of performance:

Drought Conditions: Under drought conditions, the baseflow requirements were at least partially met in most years. The drought based summer and winter freshes were rarely met under the recorded flow.

Dry Conditions: Similar to drought conditions, the baseflow requirements in dry years were at least partially met in all years, however the freshes requirement (both summer and winter) each had several years where there was no partial success. Interestingly, the requirement for a short bankfull event in dry years was met in most years.

Average conditions: Baseflow conditions were met in most average years, however 550ML/d winter freshes were the poorest performing flow recommendation for these years.

Wet conditions: The performance in wet years was similar to average years (good baseflow performance, moderate fresh performance).

Comparison to 2003 study

In the *Wimmera Glenelg Bulk Entitlement Conversion* report (the 2003 study) recommendations were made for a longer reach from Rocklands Reservoir to Chetwynd River (effectively Reach 1a and Reach 1b). The recommendations for this longer reach are provided in Table 19. These are different from the current recommendations due to revised environmental objectives, an improved hydraulic model and consideration of varying climatic conditions between years. They compare with the current Reach 1a recommendations as follows:

- Summer baseflows and freshes have similar magnitudes (10 ML/d and 60 ML/d compared with 11 ML/d and 64 ML/d respectively). However the recommended frequency and duration of the freshes to reflect the median frequency and duration of these flows occurring during summer based on the available unimpacted hydrology.
- Winter baseflows have been reduced from 100 ML/d to 60 ML/d. 60 ML/d was considered sufficient to increase the flow depth above the summer baseflow.
- Winter freshes of 1,400 ML/d (three times per year) have been replaced with smaller 550 ML/d recommended between one and five times per year depending on the seasonal conditions. The spring freshes of 130 Ml/d and 450 ML/d which were previously recommended are no longer required. 550 ML/d will provide sufficient flow variability for fish, vegetation and macroinvertebrate objectives.

- Bankfull flows of 1,400 ML/d are now recommended once per year (except in drought conditions). This flow matches the winter fresh flow previously recommended.
- An overbank flow of 4,000 ML/d is now recommended in wet years.

The 2003 study had no consideration for variation in seasonal conditions (i.e. different requirements in drought, dry, average and wet years).

Table 19. 2003 flow recommendations for Glenelg River from Rocklands to Chetwynd River (SKM 2003b)

Season	Magnitude	Frequency	Duration
Dec – May	Min 11ML/day	Annual	Continuous
	>64ML/day	5 times annually	Min 6 days
Jun	100ML/day	Annual	Continuous
Jul – Oct	Minimum flow 150ML/day	Annual	Continuous
	>1400ML/day	3 times annually	3 days
Nov	130 ML/day	Annual	Continuous
Jul – Nov	>450 ML/day	2 times annually	10 days

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.

Since the flow recommendations include temporally varying flow based on flow conditions, they provide a closer reflection of unimpacted flow regimes (Figure 19) than the 2003 study. 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.

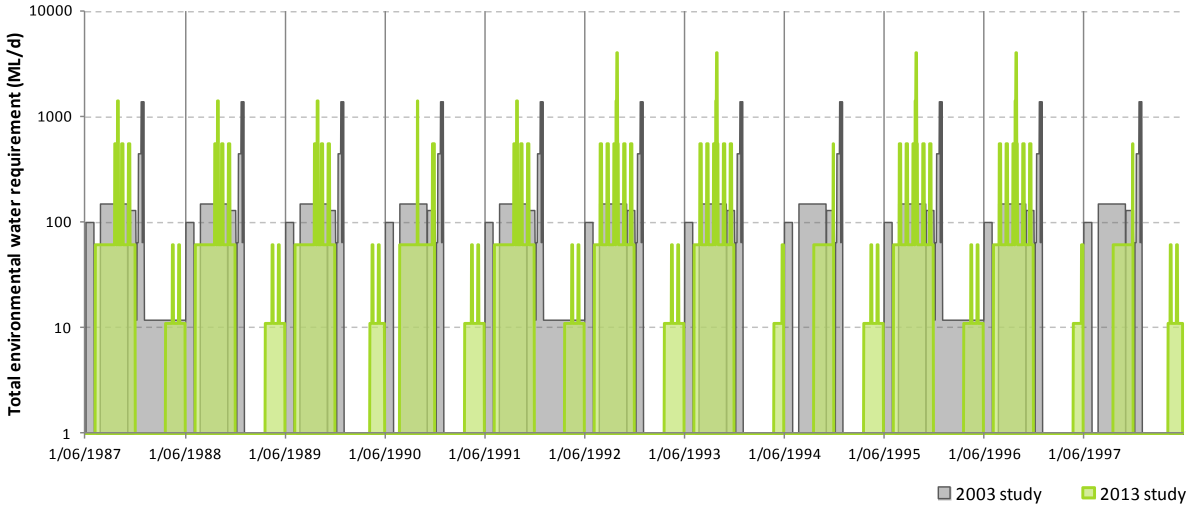


Figure 19. *Comparison of total environmental water recommendations for two studies (2003 and 2013) (G1a)*

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 20, Figure 20). 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 the water shortfall in the 2003 study from 21.9GL/y to 7.0GL/y (excluding overbank requirements).

Table 20. Headline figures for flow shortfall for period 1987-2011 (GL/y)

Year type	2003 study total environmental water recommendation	2013study total environmental water recommendation	2003 study shortfall environmental water recommendation	2013 study shortfall environmental water recommendation	2013 study shortfall, no overbank	Measured flow
All years (mean)	36.58	21.61	21.88	8.31	7.01	45.21
All years (median)	36.57	22.94	23.17	6.24	5.20	27.35
Largest	36.70	40.77	35.90	23.78	16.58	210.93
Smallest	36.57	5.36	0.61	0.02	0.02	1.00
Drought (median)	36.57	5.36	32.44	3.44	3.44	4.58
Dry (median)	36.57	13.79	25.57	4.37	4.37	17.34
Average (median)	36.57	22.94	19.42	7.91	7.91	47.55
Wet (median)	36.57	40.77	12.20	16.71	12.50	71.60

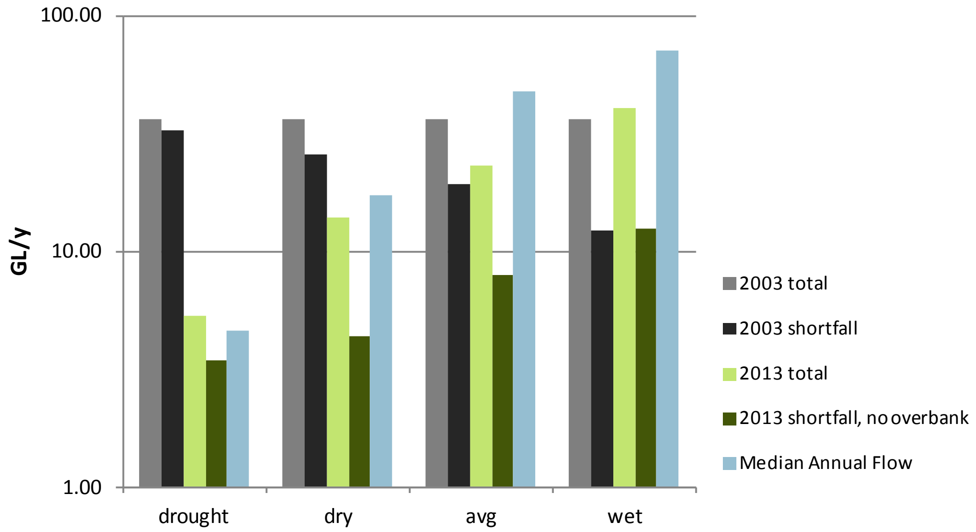


Figure 20. *Total environmental water recommendations by year type (note logarithmic Y axis makes vales appear more similar)*

For the 2003 study, the same 39,500ML/y is recommended across every year type (Figure 21). For this 2013 study the flow recommendations varies from 5,360ML/y in drought years to 40,770ML/y in wet years to give a mean total flow requirement of 21,610ML/y across the reporting period. The overall environmental water recommendation for this reach is much less than for the previous 2003 study. However, because the flow recommendations vary between the prevailing year types, the relative shortfall (difference between flow recommendation and actual water delivered) should be considered for the different prevailing climatic conditions.

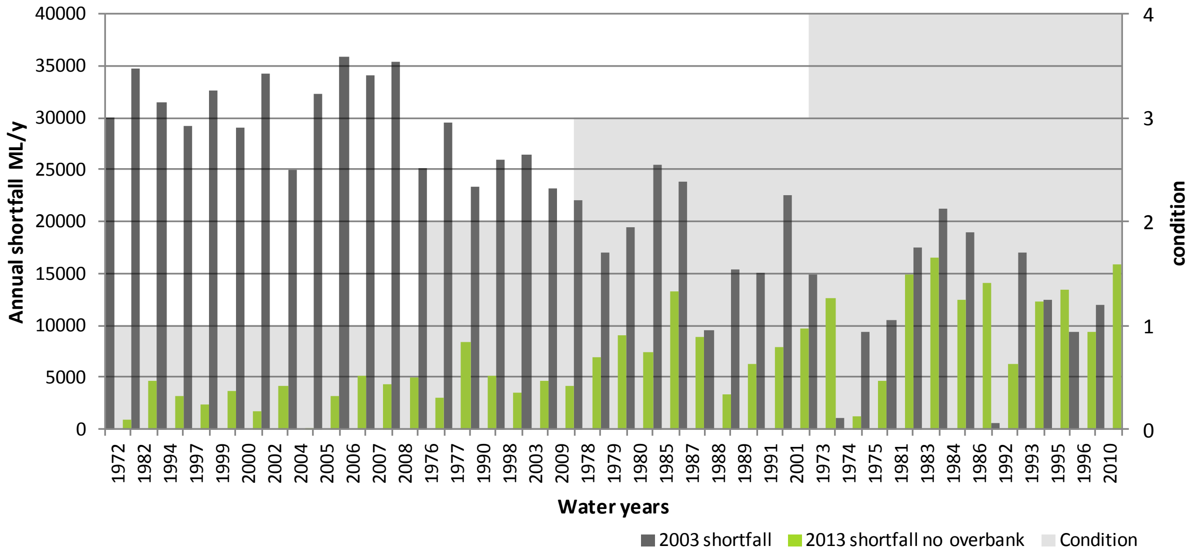


Figure 21. *Annual shortfall for different year types for the two studies*

5.3 Reach 1b Glenelg River between Five Mile Outlet to Chetwynd River

The system transitions between sections of well-defined single thread channel, to floodout features with ill-defined channel form to sections with a complex network of channels, island and backswamps (Figure 22). Moving downstream the system flows through a confined channel which has incised into the bedrock plains. Depositional features, including some small floodplain pockets, have formed along the valley margins (Figure 23).

Figure 22. *Upstream of Fulhams Bridge (flow right to left), Note the transition between a well-defined single thread channel, to multiple channels then a floodout feature with no defined channel before forming a single thread channel again*

Figure 23. *Section of reach 1b which has incised into the bedrock plains leading to valley confinement (flow direction right to left). Note the depositional features at the valley margins.*

Flows from Rocklands Reservoir can be delivered to this reach via Reach 1a of the Glenelg River or by the diversion channel at Five Mile and Twelve Mile Outlets.

This reach contains 13 species of native freshwater fish, eight of which have significant conservation value. Riparian and floodplain vegetation is comprised of Box and River Red Gums with Paperbark and Tea-Tree understorey. Aquatic vegetation includes Common Reed, Water Ribbons, Stonewort, Cumbungi and filamentous algae (SKM 2003a) (Figure 24). The Glenelg Spiny Cray is also found in the reach, although numbers are currently in decline and in 2011 it was recognised as an 'endangered' species under the *EPBC Act 1999.*

The deposition of sand and smothering of aquatic habitats is a major ecological threat in this reach. Alteration of unimpacted flow regime and degraded water quality, especially salinity are also of concern. Other threats include exotic fish, bank instability due to stock access, and channel constriction by vegetation (SKM 2003a).

Figure 24. *Glenelg River at Dick Roberts*

Environmental objectives
The environmental objectives for Reach 1b relate to native fish, vegetation, macroinvertebrates, platypus and geomorphic values:

- Protect, maintain and where possible, enhance populations of native fish, including diadromous species
- Maintain healthy and diverse mosaics of water-dependent vegetation
- Achieve SEPP compliant macroinvertebrate communities
- Maintain existing platypus population
- Improve and maintain channel diversity using channel forming flow

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

Environmental flow recommendations
Environmental flow recommendations to achieve the environmental objectives for Glenelg River (Reach 1b) are summarised in Table 21.

Table 21. Environmental flow recommendations for Glenelg River Reach 1b

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	< 145 days	None of the environmental objectives require a cease to flow. This recommendation acknowledges that cease to flows naturally occur and provides guidance to ensure that stress on the environmental values is not exacerbated beyond the point of no return.	The total cease to flow duration in each period should not exceed the number of days recommended in this table. These durations are based on cease to flow periods in the unimpacted hydrology at Rocklands Reservoir. Refer note below this table about cease to flow periods for further detail.
			DRY		< 125 days		
			AVERAGE		< 110 days		
			WET				
	Jun-Nov	0 ML/d	DROUGHT	As infrequently as possible	< 110 days		
			DRY		< 55 days		
			AVERAGE		<35 days		
			WET				
Baseflow	Dec-May	15 ML/d or natural	ALL	Continuous		Maintain edge habitats, pools and shallow water habitat availability for **platypus, macroinvertebrates** and **fish**. Also maintain a near-permanent inundated stream channel to prevent excessive instream terrestrial species growth and promote instream vegetation.	15 ML/d keeps the bed wet and covers leaf packs. Flows as low as 1 ML/d provide sufficient habitat for platypus and water rat. Baseflow should be less than 70 ML/d to ensure depths are less than 30cm for the Spiny Cray. Dick Roberts xs638 is the critical section (160 ML/d is needed for 50cm depth for small bodied fish).
	Jun-Nov	100 ML/d or natural	ALL	Continuous		Maintain shallow water habitat availability for **macroinvertebrate**s and facilitate annual dispersal **of juvenile platypus**	160 ML/d is required to achieve water depth of 50cm over all modelled riffles (Dick Roberts xs638 critical), however 100ML/d achieves this at all other sections and inundates low benches. Confidence in the 50cm requirement for platypus is not high enough to warrant recommending 160 ML/d.
Freshes	Dec-May	100 ML/d	DROUGHT	2 per period	2 days	Improve condition of **emergent vegetation** by wetting lower banks. Introduce wetting during summer to increase biofilm abundance on wood debris as a food source for macroinvertebrates.	Increases depth by 15-40cm and inundates lowest benches (Five Mile Outlet xs709). The frequency and durations are based on 60 ML/d unimpacted flow at Rocklands Reservoir
			DRY	2 per period	3 days		
			AVERAGE	2 per period	3 days		
			WET	2 per period	3 days		
	Jun-Nov	250 ML/d	DROUGHT	1 per period	1 day	Increase the baseflow water depth to provide stimulus for **fish movement** (not required in drought years, frequently required in wet years). Wet low benches and increased edge habitat to improve **diversity of habitat**.	Increases depth by 15-35cm (from 100 ML/d). Wets benches at Five Mile Outlet xs144, Dick Roberts xs403 and Harrow xs815. The frequency and durations are based on 550 ML/d unimpacted flows at Rocklands Reservoir. At least one fresh is required in October-November for fish migration.
			DRY	2 per period	3 days		
			AVERAGE	3 per period	5 days		
			WET	5 per period	5 days		
	Jun-Nov	550 ML/d	AVERAGE	1 per period	2 days	Flush surface sediments from hard substrates for **macroinvertebrates**. Wet higher benches and increased edge habitat to improve **diversity of habitats**.	Flows up to 5,500ML/d required to mobilise sand (Harrow, xs1195). 550 ML/d will mobilise sand at Harrow and two-thirds of Dick Roberts. Will also inundate additional benches. The frequency and durations are based on 2,600 ML/d unimpacted flows in the Wimmera River at Glenorchy. Note this was adopted as a last resort due to no comparable fresh in the Glenelg system with natural hydrology to analyse.
			WET	2 per period	3 days		

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendation
Bankfull	Any	1,000 ML/d	DRY	1 per year	1 day	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 durations are based on an unimpacted bankfull downstream of Rocklands Reservoir. River Red Gums require inundation 2-3 times per decade and Tea-trees require it 2-5 times per decade.
			AVERAGE	1 per year or natural	3 days		
			WET	1 per year	5 days		
Overbank	Aug-Nov	6,000 ML/d	WET	1 per period or natural	2 days	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 durations are based on an unimpacted overbank downstream of Rocklands Reservoir. River Red Gums require inundation 2-3 times per decade and Tea-trees require it 2-5 times per decade. Black box requires inundation 1-3 times per decade.

Notes on environmental flow recommendations

Cease to flow periods

Periods without flow are a distinctive feature of the hydrology of the Glenelg River both prior to and since regulation. Cease to flow periods can play a number of important ecological roles in rivers, especially in the breakdown and cycling of organic matter, and can also favour native taxa over introduced species such as trout, carp and redfin due to differences in tolerances and breeding requirements (McNeil & Closs 2007; McNeil *et al.* 2009). Cease to flow periods nevertheless pose a risk to native fish populations, especially since sand sedimentation has greatly reduced the size of refuge pools and historic land clearing is likely to have increased salt loads in groundwater. For this reason, while it is acknowledged that cease to flow spells will continue to occur in the Glenelg River, especially during drought periods, they have not been recommended as a flow component. Instead, the recommendations in Table 21 are that cease to flow spells not be extended in duration above that expected to occur naturally during any particular event. In addition, during extended drought periods it may be necessary to periodically release water to replenish refuge pools. However, the volumes required are hard to estimate and thus no specific recommendation has been made around such releases.

Hydraulic model quality

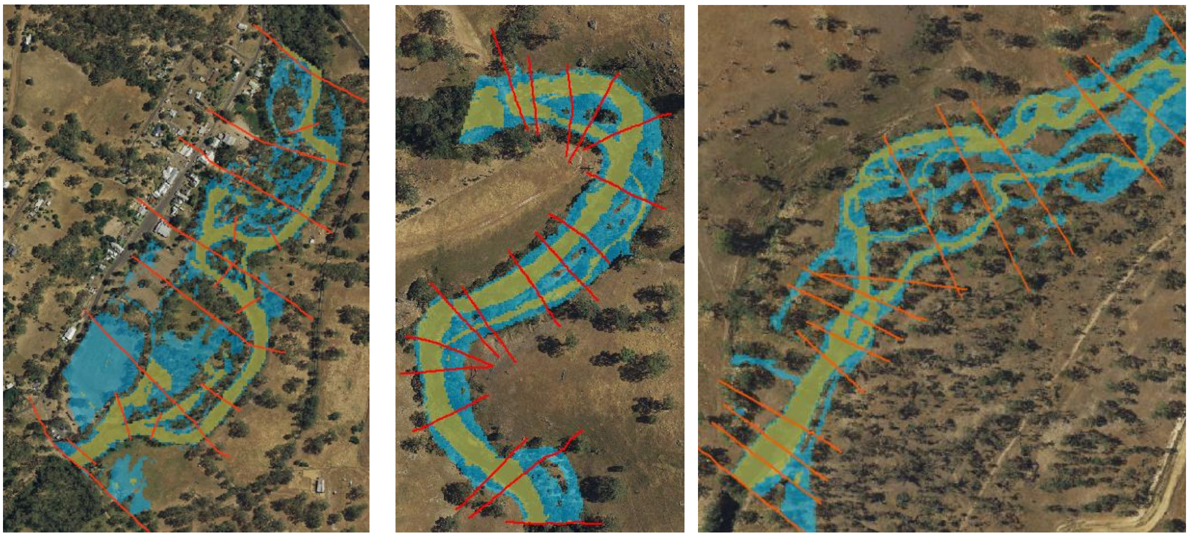
Three suitable HEC-RAS models were used in this review to determine the flow magnitudes required for this reach. The models were located at Five Mile Outlet (the upstream end of the reach), Dick Roberts' property (mid-way along the reach) and at the township of Harrow (approximately 20km upstream of Chetwynd River).

All three models were created as part of the VEFMAP assessments in 2009, and were based on adequate survey information covering reasonable spans of the reach. The sites cover a mix of the channel form characteristics displayed in this reach. For example, Five Mile Outlet represents a section with multiple channels due to flood runners, Dick Roberts represents a site with one flood runner and Harrow a site with a single thread channel (Table 22).

Table 22. Reach 1b hydraulic model characteristics

Model site	Model extent	Habitat features at the site	Characteristics
Five Mile Outlet	16 cross-sections covering approximately 1000 m	Two pool-riffle sequences exist in primary channel. Numerous secondary flood runner channels exist.	Sections of river which have multiple channels due to flood runners are common in the between sections of single thread channel.
Dick Roberts	17 cross-sections covering approximately 800 m	Two pool-riffle sequences exist in primary channel. A secondary flood runner channel exists. Some benches also exist. Limited floodplain habitat due to valley confinement.	The site is representative of the section of river that has incised into bedrock plains.
Harrow	16 cross-sections covering approximately 1300 m	All pools as the downstream cross-section is small concrete weir limiting riffle habitat. Some benches exist and flood runners exist.	The site is predominately single thread which is common in reach 1. Poor cross-section placement means over bank flow is likely to be inaccurate.

The models were all 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 (Figure 25). The overbank flow inundation extent (i.e. 6,000 ML/d) at Harrow should be used cautiously due to the short cross sections in the HEC-RAS model for this site not capturing the capacity of the floodplain completely.



Harrow *Dick Roberts* *Five Mile Outlet*

Figure 25. *Modelled inundations on Reach 1b for 1,000 ML/d (green) and 6,000 ML/d (blue)*

Hydrology

Modelled hydrology was not available for this reach of the Glenelg River so the recommended seasonal frequency and durations have been derived from the frequencies and durations recommended for Reach 1a. It is expected that under 'natural' conditions (i.e. prior to European settlement), when regulation did not allow diversions from Rocklands directly to Reach 1b and sand accumulation in the channel was less, Reach 1a and Reach 1b would have fairly similar patterns of freshes and high flows. Footnotes to Table 17 identify where the assumptions have been derived from. If natural or unimpacted modelled flow data becomes available it is recommended that spells analysis is undertaken to update the recommended frequencies and durations for seasonal conditions.

Compliance points

The current compliance point for this reach is at the township of Harrow (gauge 238 210). Harrow is located midway along Reach 1b (Figure 26). Harrow is also the location of one of the three hydraulic models used in making our assessment. The other two hydraulic models are located at the upstream end of the reach (Five Mile Outlet) and between Harrow and Five Mile Outlet (Dick Roberts). Flows passing the gauge at Harrow should therefore provide a good representation of flows in Reach 1b.

An alternative gauge at Fulham Bridge (gauge 238224) could be considered however Harrow provides a better compliance point as losses between Fulham Bridge and Harrow may occur and the actual flows not be achieved at Harrow.

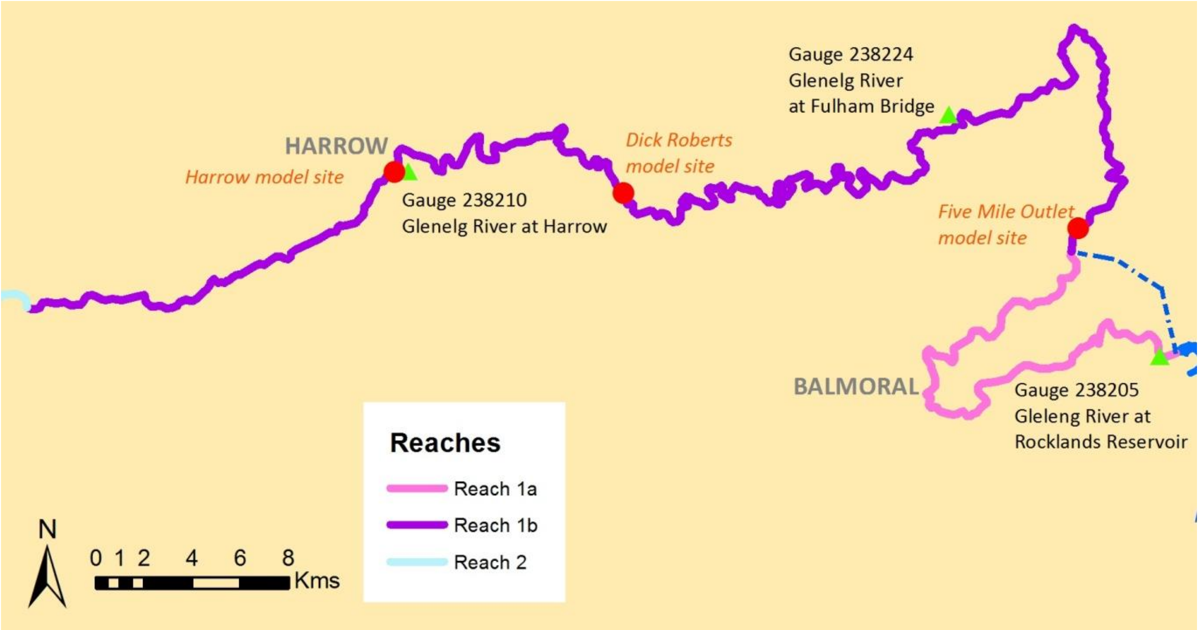


Figure 26. *Location of current compliance point and hydraulic model site for Reach 1b*

Performance and risk assessment

Performance assessment point for Reach 1b:

Gauge	238 224
Name	Glenelg @ Fulham Bridge
Status	Open / active
Start for assessment period	1 July 1972
End for assessment period	30 June 2010

For performance reporting (Table 23), 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).

Table 23. Performance of environmental flow recommendations for Glenelg Reach 1b (% compliance)

				Flow recommendation																					
	Years	annual total (GL)	annual shortfall (GL) no overbank	Drought summer fresh 100	Drought Winter baseflow 1	Drought jun-Nov 250ML/d x	Drought summer baseflow 1	Dry Summer fresh 100ML/d	Dry bankfull 1000Ml/d for	Dry Sumemr Baseflow 15Ml/	Dry Winter Baseflow 100Ml	Dry jun-Nov 250ML/d x 2 f	Avg Summer Fresh 100ML/d	Avg june nov fresh 550ml/	Avg bankfull 1000ML/d x1	Avg Summer baseflow 15Ml/	Avg Winter Baseflow 100ML	Avg jun-Nov 250Ml/d fresh	Wet Overbank 6000ML/d x1	wet Summer fresh 100 ML/d	wet winterfresh 550ML/d x	Wet Bankfull 1000ML/d x1	wet summer baseflow 15ML/	Wet Winter Baseflow 100ML	Wet june-Noc 250ML/d x 5
	median	27.35	4.82	0	2	0	100	0	100	100	32	100	50	100	100	100	57	100	0	50	50	100	85	72	60
	mean	45.21	5.10	4	14	33	67	21	71	88	45	93	33	89	78	85	60	81	8	58	50	67	82	71	60
	1972	10.0	4.6	50	25	100	100																		
	1982	2.4	6.8	0	0	0	100																		
	1994	5.5	5.3	0	3	0	100																		
	1997	8.3	3.6	0	22	100	100																		
	1999	4.4	6.1	0	0	0	100																		
	2000	7.7	2.8	0	19	100	100																		
	2002	2.9	6.9	0	0	0	0																		
	2004	23.8	0.1	0	93	100	100																		
	2005	4.7	5.7	0	3	0	100																		
	2006	1.0	7.4	0	0	0	0																		
	2007	3.6	7.0	0	0	0	0																		
Drought	2008	1.2	7.2	0	0	0	0																		
	1976	17.2	5.1					50	100	100	32	100													
	1977	9.8	6.7					50	100	91	23	100													
	1990	22.6	3.2					0	100	100	50	100													
	1998	16.1	5.0					0	0	100	20	50													
	2003	17.5	5.3					0	100	65	30	100													
	2009							0	100	100	57	100													
Dry	2011	28.4	3.8					50	0	57	100	100													
	1978	34.0	3.5										50	100	100	42	57	100							
	1979	52.9	6.3										100	0	100	82	55	100							
	1980	51.5	1.8										50	100	100	44	77	100							
	1985	18.3	9.4										0	100	100	100	29	33							
	1987	27.4	4.1										50	100	100	100	46	100							
	1988	114.1	0.7										0	100	100	99	90	100							
	1989	47.6	1.2										0	100	0	100	76	100							
	1991	65.3	4.8										0	100	100	100	62	33							
Average	2001	20.9	4.7										50	100	0	100	46	67							
	1973	69.6	4.7																0	100	100	100	88	77	100
	1974	180.6	2.1																0	50	50	100	51	90	20
	1975	187.7	2.3																100	100	0	100	81	91	80
	1981	102.6	10.5																0	50	50	0	57	62	40
	1983	66.8	8.7																0	50	0	100	79	61	60
	1984	43.4	8.7																0	0	50	0	47	43	40
	1986	50.1	4.8																0	100	100	100	100	77	100
	1992	210.9	1.7																0	50	50	100	100	95	20
	1993	30.6	4.1																0	50	50	0	100	67	60
	1995	52.0	7.7																0	0	50	100	76	53	60
	1996	76.4	4.8																0	50	0	0	100	82	100
Wet	2010	73.6	9.8																0	100	100	100	100	51	40

The flow recommendations for Reach 1b vary by season and so too does the recommended total environmental water (or 'shortfall'). For the reporting period the mean annual flow was 45.2GL and the mean shortfall was 9.1GL (including overbank flows). However the shortfall varied tremendously. If we don't consider the overbank flow requirement as one that would normally be delivered as part of the operational environmental water delivery then the overall shortfall drops from 9.1GL/y to 5.1GL/y (mean).

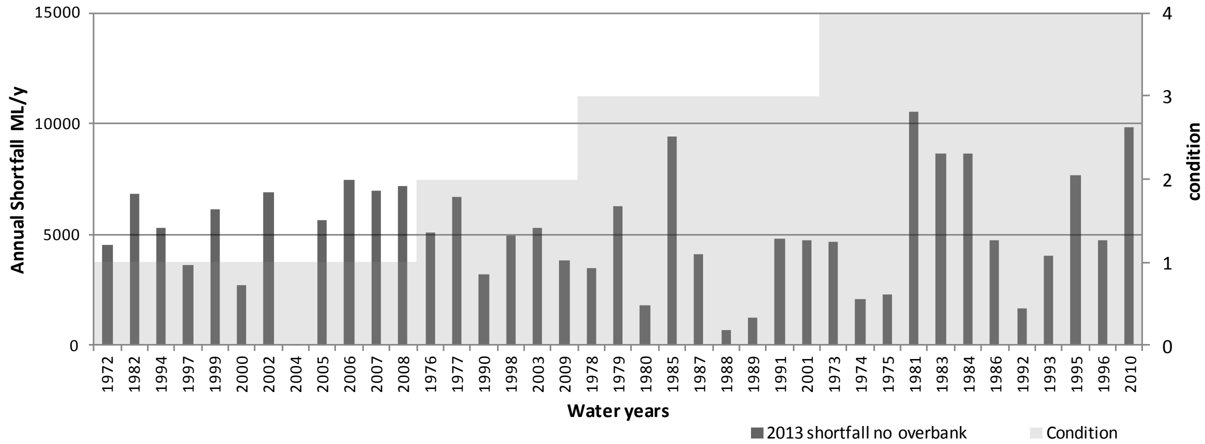


Figure 27. *Total Annual Shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet) for Glenelg Reach 1b*

The implications of this shortfall analysis is that, if we assume the assessment period is typical of the current hydrology, then an additional 4.8 GL/yr of environmental water releases will achieve compliance in 50% of all years (Figure 28). Considering drought years; if 4.8 GL was provided on a drought year, one could expect that full compliance would be achieved in half of years, or to consider this another way, full compliance would be achieved on a typical (median) average and wet year if 4.8 GL of additional water was effectively delivered.

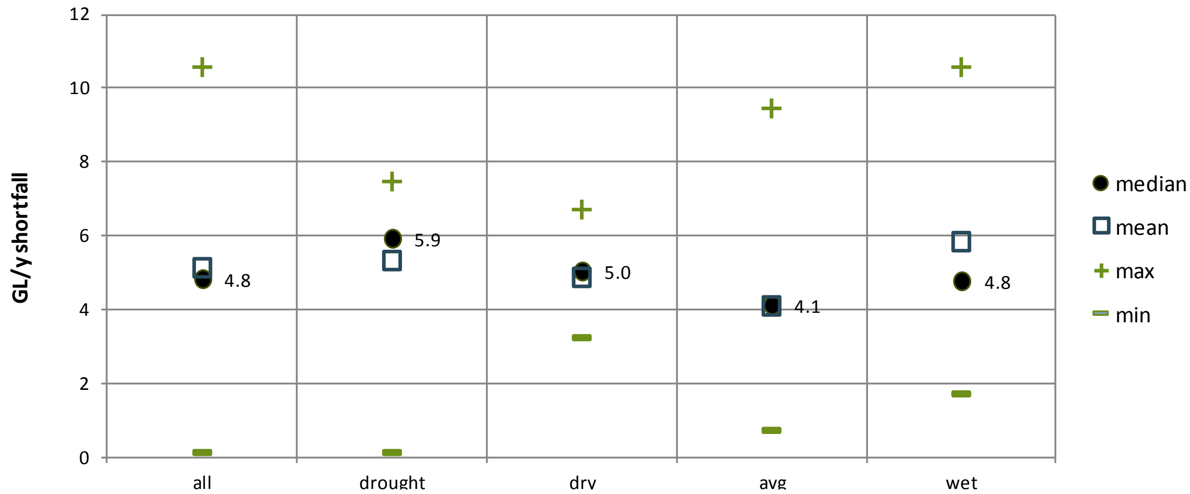


Figure 28. *Glenelg Reach 1b shortfall summary by seasonal climatic condition*

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 29). Say for example if 4 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 30% of years, which ranges from only 25% of dry and drought years to around 50% in average years.

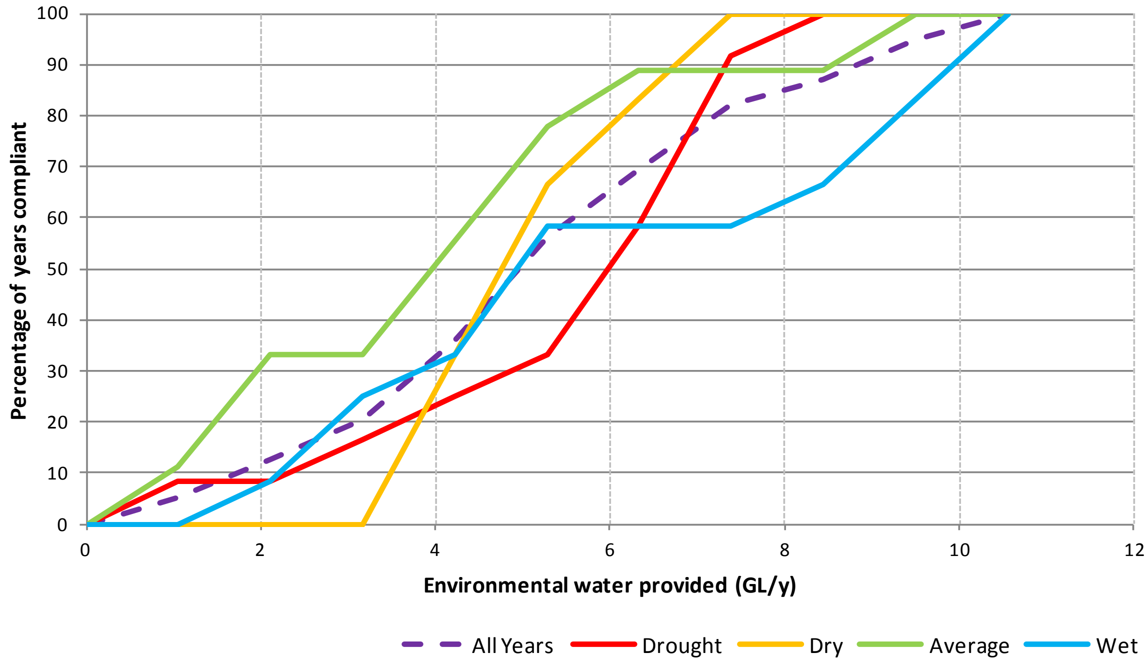


Figure 29. *Percentage of years compliant under different environmental water delivery in Glenelg Reach 1b (excludes overbank flow recommendation)*

Summary of performance:

Drought Conditions: Under drought conditions, the summer baseflow (15ML/d) was met in most years, however the winter baseflow of 100 ML/d was only met in one in three drought years. The summer and winter freshes were poorly met in drought years.

Dry Conditions: Most dry year flow requirements were at least partially met in most dry years. However the summer freshes (100ML/d) were poorly met.

Average conditions: Most flow recommendations were met in average years, the exception being summer freshes.

Wet conditions: The performance in wet years was similar to average years (good baseflow performance, moderate fresh performance). Overbank flows (6000ML/d) were only met in one year of the record (1974), implying that the overbank threshold may be too high. This is likely to be a result of current channel morphology at the hydraulic modelling section not reflecting the current hydrology.

Comparison to 2003 study

In the 2003 study recommendations were made for a longer reach from Rocklands Reservoir to Chetwynd River (effectively Reach 1a and Reach 1b). The recommendations for this longer reach are provided in Table 19. These are different from the current recommendations due to revised environmental objectives, an improved hydraulic model and consideration of varying climatic conditions between years. They compare with the current recommendations as follows:

- Summer baseflows have increased only slightly from 11 ML/d to 15 ML/d. 15 ML/d was identified as the flow required to keep the streambed wet and sufficiently cover leaf packs.
- Summer freshes have increased in magnitude (from 64 ML/d to 100 ML/d), however decreased in frequency (only two per year recommended now compared with five in the 2003 study).
- Winter baseflows remain the same at 100 ML/d.
- Winter freshes of 1,400 ML/d (three times per year) have been replaced with smaller freshes of 250 ML/d and 550 ML/d. The 250 ML/d fresh is recommended between one and five times per year, and the 550 ML/d fresh is only recommended in average and wet years). The spring freshes of

130 ML/d and 450 ML/d which were previously recommended have effectively been replaced by with the 250 ML/d and 550 ML/d freshes.

- Bankfull flows of 1,000 ML/d are now recommended once per year (except in drought conditions).
- An overbank flow of 6,000 ML/d is now recommended in wet years.

The 2003 study had no consideration for variation in seasonal conditions (i.e. different requirements in drought, dry, average and wet years).

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.

Since the flow recommendations include temporally varying flow based on flow conditions, they provide a closer reflection of unimpacted flow regimes (Figure 30) than the 2003 study. As a consequence the resulting flow regime more closely reflects the water management environment whereby more water is available in wetter years than dry years.

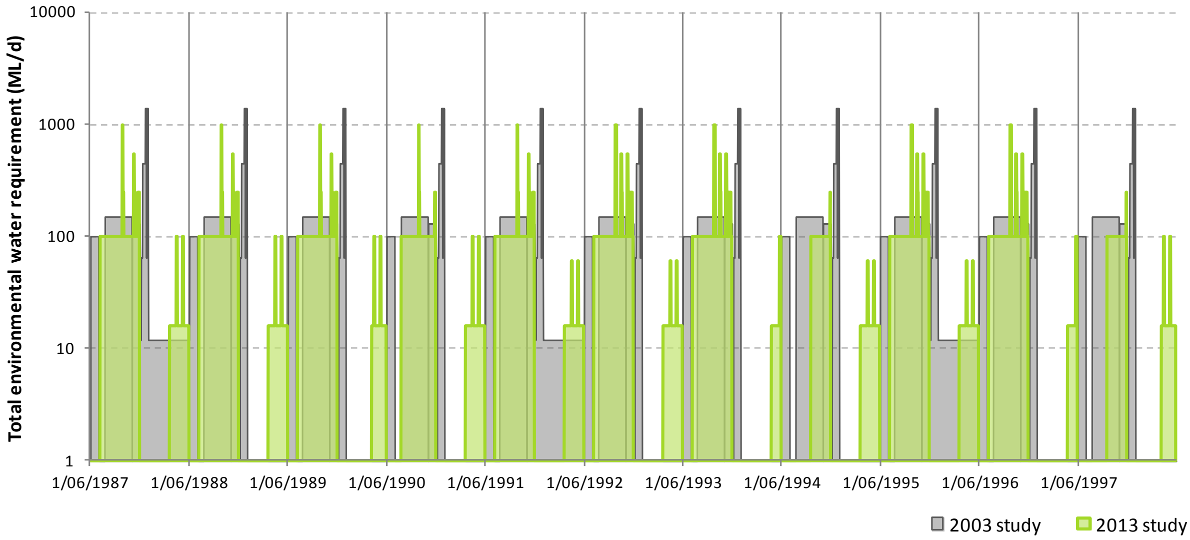


Figure 30. *Comparison of total environmental water recommendations for two studies (2003 and 2013) (G1b)*

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 24, Figure 31). 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 the water shortfall from 2003 from 21.8GL/y to 5.1GL/y (excluding overbank requirements).

Table 24. Headline figures for flow shortfall for period 1987-2011 (GL/y)

Year type	2003 study total environmental water recommendation	2013study total environmental water recommendation	2003 study shortfall environmental water recommendation	2013 study shortfall environmental water recommendation	2013 study shortfall (no overbank)	Measured flow
All years (mean)	36.58	17.44	21.88	9.05	5.10	45.21
All years (median)	36.57	20.45	23.17	6.15	4.82	27.35
Largest	36.70	26.00	35.90	33.97	10.55	210.93
Smallest	36.57	7.60	0.61	0.09	0.09	1.00
Drought (median)	36.57	7.60	32.44	5.92	5.92	4.58
Dry (median)	36.57	15.50	25.57	5.03	5.03	17.34
Average (median)	36.57	20.45	19.42	4.11	4.11	47.55
Wet (median)	36.57	26.00	12.20	19.97	4.76	71.60

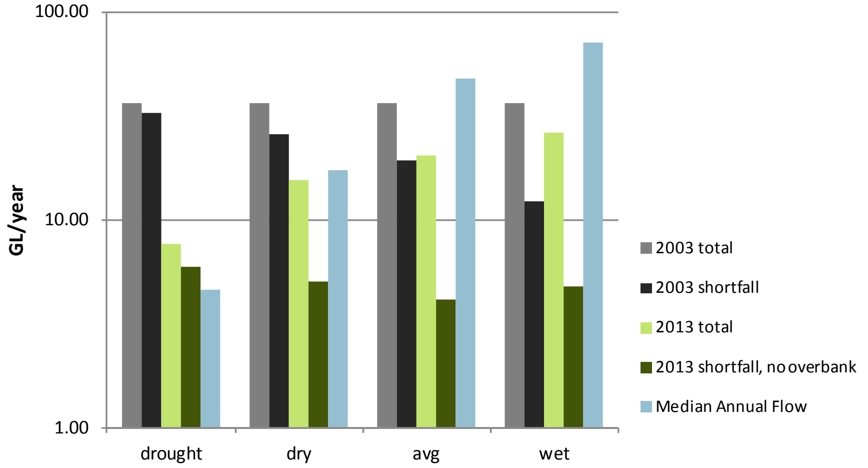


Figure 31. *Total environmental water recommendations by year type (note logarithmic Y axis makes values appear more similar).*

For the 2003 study, the same 39,500ML/y is recommended across every year type (Figure 32). For this study the flow recommendations varies from 2,190ML/y in drought years to 26,000ML/y in wet years to give a mean total flow requirement of 17,440ML/y across the reporting period. The overall environmental water recommendation for this reach is much less than for the previous study. However, because the flow recommendations vary between the prevailing year types, the relative shortfall (difference between flow recommendation and actual water delivered) should be considered for the different prevailing climatic conditions.

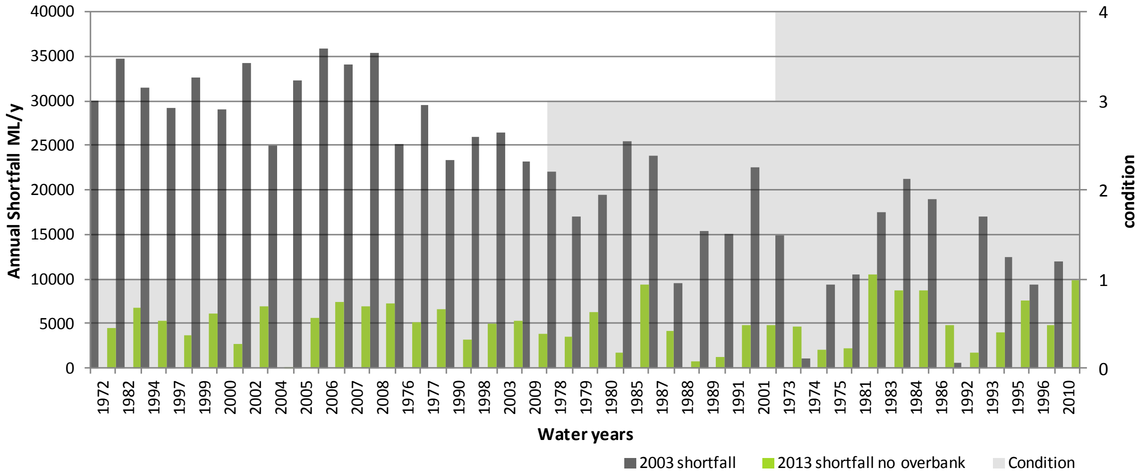


Figure 32. *Annual shortfall for different year types for the two studies*

5.4 Reach 2 Glenelg River from Chetwynd River to Wannon River

Downstream of the Chetwynd River confluence, the Glenelg River is a well-defined single-thread channel with low sinuosity (Figure 33). Small irrigation and domestic and stock diversions are present throughout the reach. There are intermittent depositional features throughout the reach however generally there is homogenous morphology. Some sections are also impacted by sand slugs which further reduce bed diversity.

Figure 33. *Section of well-defined single thread channel near Dergholm (flow direction right to left)*

Throughout the reach, the floodplain transitions from open woodland (River Red Gum, wattle species) to cleared areas with pasture grasses (SKM 2003a). Common Reed and Water Ribbons are present instream. Fish species recorded at the downstream end of the reach include marine vagrant species (i.e. bream and estuary perch. Sand deposition and active erosion are threats to the ecological values of this reach. Disturbances also arise from stock access, clearing of vegetation, exotic fish and weeds (SKM 2003a) (Figure 34).

Figure 34. *Reach 2 upstream of Dergholm (left) and downstream at Casterton (right).*

Environmental objectives

The environmental objectives for Reach 2 relate to native fish, vegetation, macroinvertebrates, platypus and geomorphic values:

- Protect, maintain and where possible, enhance populations of native fish, including diadromous species.
- Maintain healthy and diverse mosaics of water-dependent vegetation
- Achieve SEPP compliant macroinvertebrate communities
- Maintain existing platypus population
- Improve and maintain channel diversity using channel forming flow

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

Environmental flow recommendations

Environmental flow recommendations to achieve the environmental objectives for Glenelg River (Reach 2) are summarised in Table 25.

Table 25. Environmental flow recommendations for Glenelg River Reach 2

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendations
Cease to flow	Dec-May	0 ML/d	DROUGHT	As infrequently as possible	< 145 days	None of the environmental objectives require a cease to flow. This recommendation acknowledges that cease to flows naturally occur and provides guidance to ensure that stress on the environmental values is not exacerbated beyond the point of no return.	The total cease to flow duration in each period should not exceed the number of days recommended in this table. These durations are based on cease to flow periods in the unimpacted hydrology at Rocklands Reservoir. Refer note below this table about cease to flow periods for further detail.
			DRY		< 125 days		
			AVERAGE		< 110 days		
			WET				
	Jun-Nov	0 ML/d	DROUGHT	As infrequently as possible	< 110 days		
			DRY		< 55 days		
			AVERAGE		< 35 days		
			WET				
Baseflow	Dec-May	25 ML/d or natural	ALL	Continuous		Maintain edge habitats, pools and shallow water habitat availability for **platypus, macroinvertebrates** and **fish,** and prevent excessive terrestrial species growth.	Provides decent bed coverage in the shallow sections of the Warrock Road (xs118, xs241) and Section Rd (xs130).
	Jun-Nov	160 ML/d or natural	ALL	Continuous		Maintain shallow water habitat availability for **macroinvertebrate**s and facilitate annual dispersal **of juvenile platypus.**	400 ML/d is required to for a depth of 50cm over all modelled riffles (Burkes Bridge xs156). 160 ML/d achieves depth at all other sections and inundates low benches. Confidence in the 50cm requirement for platypus is not high enough to warrant recommending 400 ML/d.
Freshes	Dec-May	150 ML/d	DROUGHT	2 per period	2 days	Improve condition of emergent vegetation by wetting lower banks. Introduce wetting during summer to increase biofilm abundance on wood debris as a food source.	Increases depth by 16-35cm and inundates low benches at Bourkes Bridge and Section Rd. The frequency and durations are based on 60 ML/d unimpacted flow at Rocklands Reservoir. During dry and drought periods a 50ML/d flow is sufficient to flush pools to maintain water quality, however duration may need to be extended.
			DRY		3 days		
			AVERAGE				
			WET				
	Jun-Nov	300 ML/d	DROUGHT	1 per period	1 day	Wets benches to improve condition of **emergent vegetation** and maintain habitat diversity. Increases flow depth for upstream and downstream **fish migration** to expand populations of **native fish**.	Increases depth by 16-31cm and inundated additional benches (Burkes Bridge xs276 and Section Rd xs308). The frequency and durations are based on 550 ML/d unimpacted flows at Rocklands Reservoir. At least one fresh is required in October-November for fish migration.
			DRY	2 per period	3 days		
			AVERAGE	3 per period	5 days		
			WET	5 per period	5 days		
	Jun-Nov	1,800 ML/d	AVERAGE	1 per period	2 days	Facilitate scour of pools in sand bed for **fish** and flush surface substrate from hard substrates to support **macroinvertebrates** Wets additional benches.	Achieves shear stress of 1.1N/m^2 and inundates additional benches. The frequency and durations are based on 2,600 ML/d unimpacted flows in the Wimmera River at Glenorchy. This was a last resort due to no comparable fresh in the Glenelg system with unimpacted hydrology.
			WET	2 per period	3 days		

Flow component	Period	Magnitude	Condition	Frequency	Duration	Objectives achieved	Notes on environmental flow recommendations
Bankfull	Any	6,000 ML/d	AVERAGE	1 per year or natural	1 day	Inundate **riparian vegetation** to maintain condition and facilitate recruitment. Entrain organic debris in the channel to support **macroinvertebrate**s. Maintain **structural integrity of channel**.	Frequency and duration recommendation is based on natural bankfull for Glenelg 1a. River Red Gums require inundation 2-3 times per decade and Tea-trees require it 2-5 times per decade.
			WET		3 days		
Overbank	Aug-Nov	9,000 ML/d	DROUGHT	1 per period or natural	5 days	Inundate **floodplain vegetation** to maintain condition and facilitate recruitment. Entrain organic debris from the floodplain to support **macroinvertebrates**. Maintains floodplain geomorphic features.	Frequency and duration recommendation is based on natural overbank for Glenelg 1a. . River Red Gums require inundation 2-3 times per decade and Tea-trees require it 2-5 times per decade. Black box require inundation 1-3 times per decade.

Notes on environmental flow recommendations

Cease to flow periods

Periods without flow are a distinctive feature of the hydrology of the Glenelg River both prior to and since regulation. Cease to flow periods can play a number of important ecological roles in rivers, especially in the breakdown and cycling of organic matter, and can also favour native taxa over introduced species such as trout, carp and redfin due to differences in tolerances and breeding requirements (McNeil & Closs 2007; McNeil *et al.* 2009). Cease to flow periods nevertheless pose a risk to native fish populations, especially since sand sedimentation has greatly reduced the size of refuge pools. For this reason, while it is acknowledged that cease to flow spells will continue to occur in the Glenelg River, especially during drought periods, they have not been recommended as a flow component. Instead, the recommendation is that cease to flow spells not be extended in duration above that expected to occur naturally during any particular event. In addition, during extended drought periods it may be necessary to periodically release water to replenish refuge pools. However, the volumes required are hard to estimate and thus no specific recommendation has been made around such releases.

Hydraulic model quality

Three suitable HEC-RAS models were used in this review to determine the flow magnitudes required for this reach. The models were located at Burkes Bridge (downstream of the Chetwynd River), Warrock Road (mid-way along the reach) and at Section Road (approximately 20km upstream of the Wannon River).

All three models were created as part of the VEFMAP assessments in 2009, and were based on adequate survey information. Each site includes a sequence of pools and riffles and incorporates benches representative of the single thread channels in this reach. A summary of the site characteristics and representativeness is provided below (Table 26).

Table 26. Reach 2 hydraulic model characteristics

Model site	Model extent	Habitat features at the site	Characteristics
Downstream Burkes Bridge	16 cross-sections covering approximately 700 m	One pool riffle sequence, large back water pool takes 80 % of the reach. Sand slug throughout the reach consequently numerous benches and island	Single thread channel with high sand load is representative of sections of reach 1 that are impacted by sand.
Warrock Road	15 cross-sections covering 400 m	One pool riffle sequence. Benches throughout the site.	Generally representative of the single thread channels in reach 2
Section Road	15 cross-section covering 470 m	One pool riffle sequence. Benches throughout the site.	Generally representative of the single thread channels in reach 2

The models were all 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 (Figure 35).

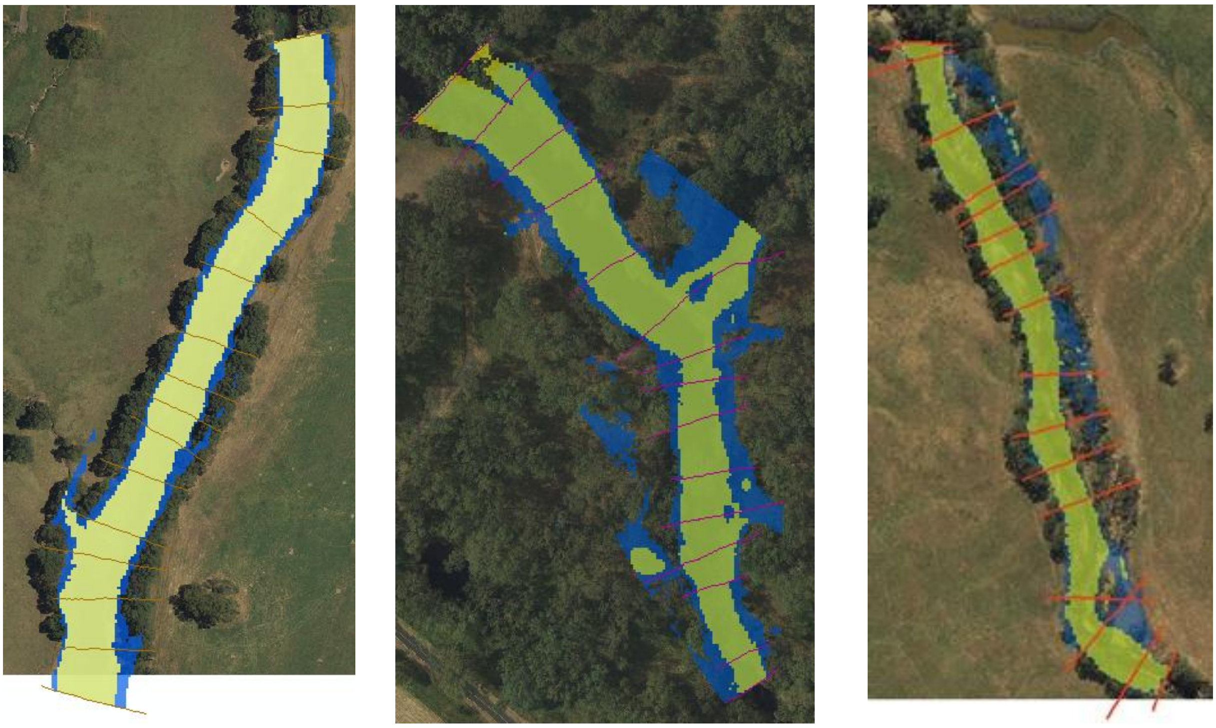


Figure 35. *Modelled inundations on Reach 2 for 4,000 ML/d and 9,000 ML/d – Left: Section Road, Middle: Warrock Road, Right: Burkes Bridge (rotated so that North is pointing from left to right across the page)*

Hydrology

Modelled hydrology was not available for this reach of the Glenelg River so the recommended seasonal frequency and durations have been derived from the frequencies and durations recommended for Reach 1a. Footnotes to Table 25 identify where the assumptions have been derived from. This introduces some uncertainty in the validity of the recommended frequency and durations, but not the flow magnitude, which is based on site by site hydraulic models. If natural or unimpacted modelled flow data becomes available it is recommended that spells analysis is undertaken to update the recommended frequencies and durations for seasonal conditions.

Compliance points

The current compliance point for this reach is at Dergholm (gauge 238211), which is approximately mid-way along the reach. Two of the three hydraulic model sites are located downstream of Dergholm as shown in Figure 36. There is also a flows gauge in the upper part of the reach at Burkes Bridge (gauge 238249), and another just downstream of the reach at Sandford (238202). The Sandford gauge includes inflows from the Wannon River which will be considerable and so therefore not a good measure of the flow in the reach. As the most downstream gauge in the reach, Dergholm provides a good indication of the flow that has passed Burkes Bridge, Warrock Road and Section Road.

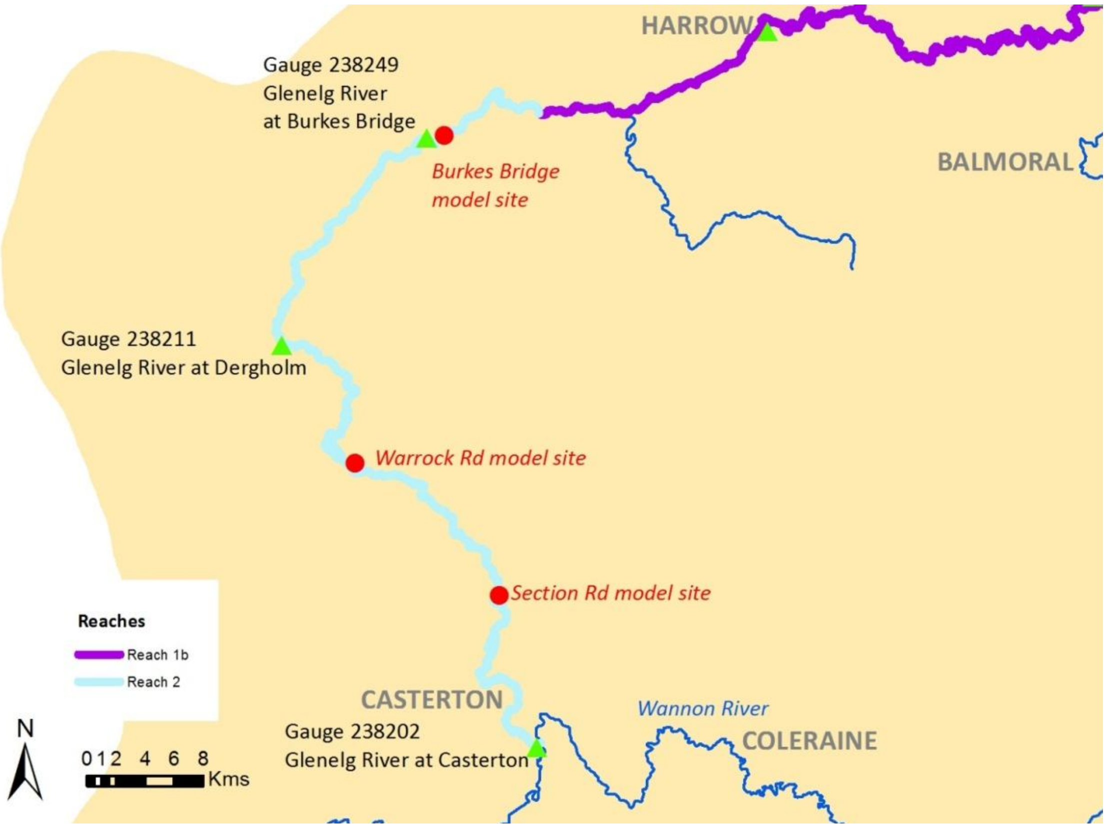


Figure 36. *Location of current compliance point and hydraulic model site for Reach 2*

Performance and risk assessment

Performance reporting point for Reach 2:

Gauge	238211
Name	Glenelg River @ Dergholm
Status	Open / Active
Start for assessment period for Gauge 238211	1 June 2005
End for assessment period for Gauge 238211	30 May 2011
Start for assessment period – for Gauge 238212 [1]	1 July 1961
End for assessment period– for Gauge 238212 [1]	30 June 1989

1. The compliance point for this reach (Glenelg River @ Dergholm) has only been open since 2004. To allow a review of earlier (and wetter) periods for the purpose of the performance assessment, gauge 238212 (Glenelg @ Casterton) has been used for the period 1960-1988. The results presented here are a combination of these two analysis periods and locations.

For performance reporting (Table 27), 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).

Table 27. Performance of environmental flow recommendations for Glenelg Reach 2 (% compliance)

				Flow recommendation																				
	Years	total annual flow	shortfall(GL) no overbank	Drought summer fresh 150	drought Jun-Nov 300Ml/d x	Drought summer baseflow 2	Drought Winter baseflow 1	Dry Summer fresh 150ML/d	Dry Jun-Nov 300ML/dx2 for	Dry Sumemr Baseflow 25Ml/	Dry Winter Baseflow 160Ml	Avg Summer Fresh 150ML/d	Avg june nov fresh 300ml/	Avg bankfull 6000Ml/d x1	Avg Summer baseflow 25Ml/	Avg Winter Baseflow 160ML	Avg jun-Nov 1800Ml/d fres	Wet Overbank 9000ML/d x1	wet Summer fresh 150 ML/d	wet winterfresh 300ML/d x	Wet Bankfull 6000ML/d x1	wet summer baseflow 25ML/	Wet Winter Baseflow 160ML	Wet june-Noc 1800ML/d x 5
	median	118.5	2.7	25	0	64	2	0	100	100	84	50	33	100	100	90	100	0	75	20	100	100	100	100
	mean	144.4	5.8	38	38	56	24	14	93	78	78	33	33	78	85	89	100	10	65	20	60	99	91	95
Drought	1967	7.9	10.4	50	0	100	1																	
	1969	35.7	1.9	0	100	100	70																	
	1972	46.2	0.0	100	100	100	100																	
	1982	8.2	10.0	100	0	100	0																	
	2005	10.8	7.1	0	0	0	3																	
	2006	3.0	11.4	50	0	22	0																	
	2007	12.5	7.6	0	100	0	15																	
	2008	4.8	10.5	0	0	28	1																	
Dry	1961	40.2	0.9					0	100	100	84													
	1965	80.1	3.9					0	50	87	73													
	1966	60.1	1.5					0	100	57	80													
	1976	111.5	0.9					0	100	100	86													
	1977	51.2	1.1					100	100	100	84													
	2009	37.5	6.5					0	100	4	45													
	2011	126.9	0.4					0	100	100	91													
Average	1962	111.1	11.4									100	33	0	92	100	100							
	1963	135.7	16.1									0	0	100	42	77	100							
	1968	177.8	1.5									0	0	0	100	100	100							
	1970	131.7	2.6									50	67	100	100	91	100							
	1978	148.0	5.1									0	33	100	100	88	100							
	1979	182.3	1.8									50	33	100	100	79	100							
	1980	139.1	0.3									0	33	100	32	100	100							
	1985	69.0	15.4									50	33	100	100	78	100							
	1987	125.5	2.8									50	67	100	100	90	100							
Wet	1964	491.8	0.4															0	50	20	100	100	100	100
	1971	287.8	0.0															0	100	20	100	100	100	100
	1973	249.8	7.0															0	100	20	100	100	100	100
	1974	418.1	0.0															0	100	20	0	100	100	100
	1975	446.4	21.8															100	50	20	100	100	99	100
	1981	357.5	4.9															0	0	20	0	92	86	100
	1983	259.4	1.0															0	50	20	100	100	100	100
	1984	205.1	2.4															0	0	20	0	100	84	100
	1986	228.2	2.7															0	100	20	0	100	100	100
	2010	107.9	25.0															0	100	20	100	100	38	50

This ‘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 (Figure 37). The flow recommendations vary by season and so too does the recommended environmental water. For the reporting period the mean annual flow was 144GL and the mean shortfall was 11.4GL (including overbank flow). However the shortfall varied tremendously from as little as 0ML in 1972 to 25GL in 2010. If we don’t consider the overbank flow requirement as one that would normally be delivered as part of the operational environmental water delivery then the overall shortfall drops from 11.4GL/y to 5.8GL/y (mean) or 2.7GL/y median.

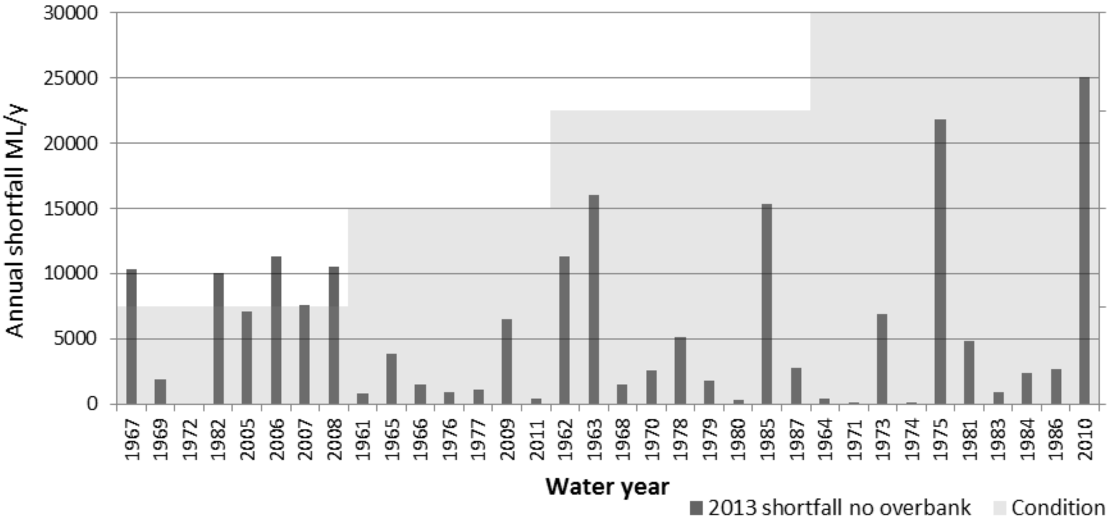


Figure 37. *Total Annual Shortfall across year types (1=Drought, 2=Dry, 3=Average, 4=Wet)*

The implications of this shortfall analysis is that, if we assume the assessment period is typical of the current hydrology, then an additional 2.7 GL/yr of environmental water releases will achieve compliance in 50% of all years (Figure 38). Considering drought years; if 8.8 GL was provided on a drought year, one could expect that full compliance would be achieved in half of years, or to consider this another way, full compliance would be achieved on a typical (median) drought year if 8.8 GL of additional water was effectively delivered.

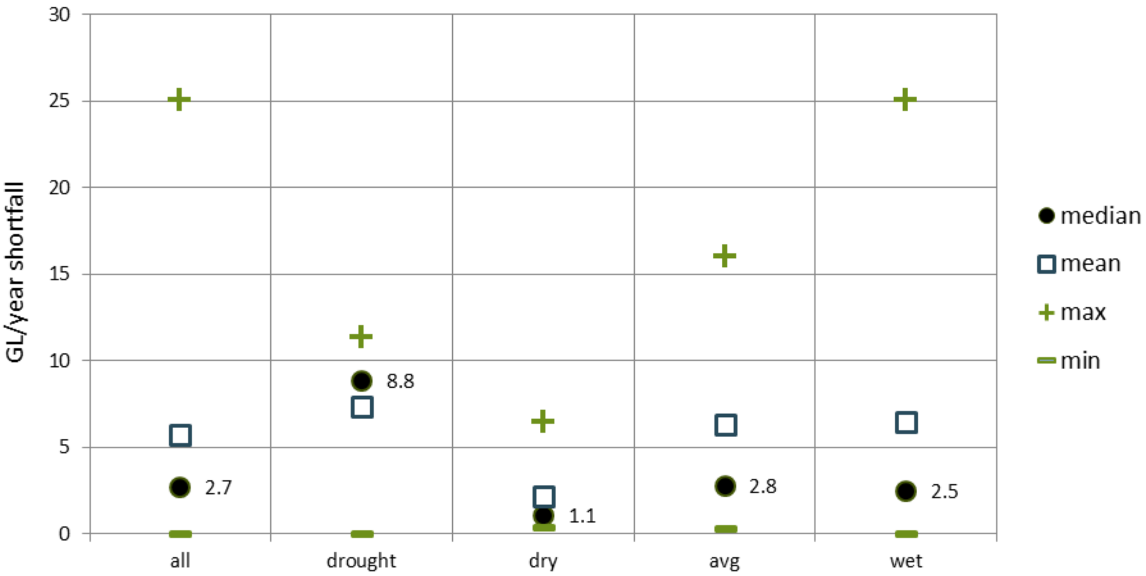


Figure 38. *Glenelg Reach 2 shortfall summary by Climatic Condition (median values shown)*

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 39). Say for example if 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 60% of years, which ranges from only 25% of drought years to around 90% in dry years.

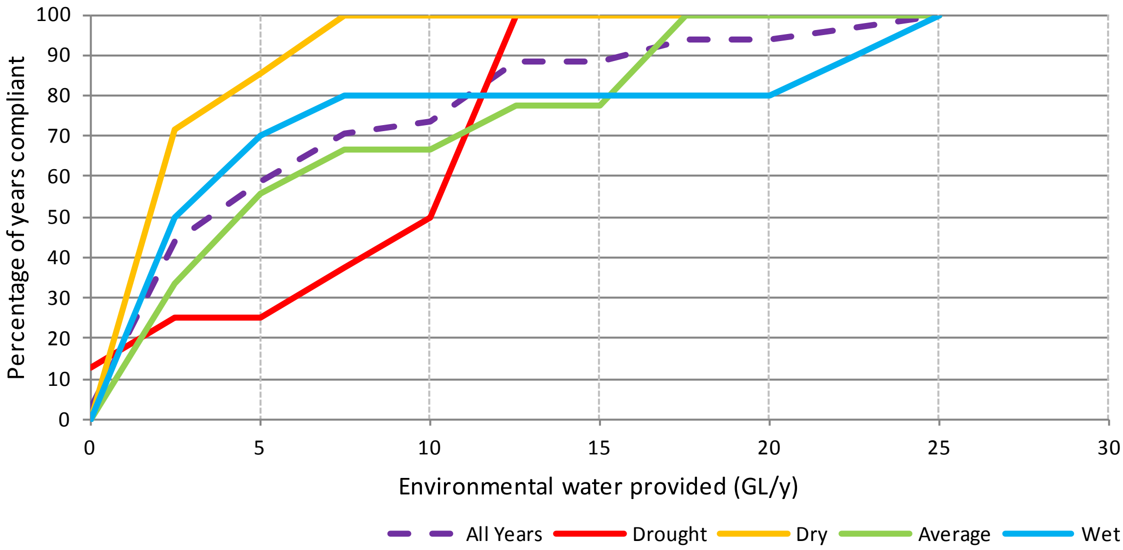


Figure 39. *Percentage of years compliant under different environmental water delivery (excludes overbank flow recommendation)*

Summary of performance:

Drought conditions: In drought conditions the winter baseflow requirement is rarely met. However the much lower summer baseflow was met in half of the drought years. The summer and winter freshes requirement had the same average compliance of 38%. Only 2005 had no requirements met, and 1972 had all drought requirements met, but most drought years partially met one or more of the flow requirements.

Dry conditions: Baseflow conditions were close to being met in most dry years (both summer and winter). Similarly the winter freshes requirement for dry years was met in most years. However the summer freshes requirement (150ML/d fresh) was only met in 1977.

Average conditions: The baseflow conditions were well met in both summer and winter in most average years. The single large events (bankfull and 1800ML/d) were also well met in most years. However the multiple event freshes in both winter and summer had a similar low level of compliance (mean 33%), this is largely a reflection that the overall volume of water delivered in average years is adequate, but it tended to occur as prolonged events rather than multiple events.

Wet conditions: Overbank flows were expected in wet years, only 1975 achieved the overbank flow target of 9000ML/d. Other flow recommendations for wet years were well met with the exception of the wet winter fresh (300ML/d) where five events were expected, but only a single event occurred in all the wet years. That single event was of a longer duration that the minimum required.

Comparison to 2003 study

In the 2003 FLOWS study (SKM 2003a) recommendations were made for the Glenelg River between Chetwynd and Wannon Rivers. Note that these recommendations were not incorporated in the *Wimmera Glenelg Bulk Entitlement Conversion* report. The recommendations for reach 2 made in 2003 are provided in Table 19. These are different from the current recommendations due to revised environmental objectives, an improved hydraulic model and consideration of varying climatic conditions between years. They compare with the current recommendations as follows:

- A cease to flow is no longer recommended
- A summer baseflows of 25 ML/d has been identified which is within the range (16-77 ML/d) recommended previously.
- The magnitude of summer fresh recommended has increased (from 77 ML/d to 150 ML/d), however is required less frequently only twice per year compared with 4 times per year.

- Winter baseflows have been halved (previously 385 ML/d, and now 160 ML/d).
- A wider range of winter and spring freshes are now recommended including a high fresh of 1,800 ML/d).
- Bankfull flows (6,000 ML/d) are now recommended in average and wet years and overbank flows (9,000 ML/d) in wet years only.

The 2003 study had no consideration for variation in seasonal conditions (i.e. different requirements in drought, dry, average and wet years).

Table 28. 2003 flow recommendations for Glenelg River from Chetwynd River to Wannon River

Season	Magnitude	Frequency	Duration
Dec – May	0 ML/d	3 times annually	Maximum 8 days
	Min 16-77 ML/d	Annual	Continuous (except 0 ML/d periods)
	>77 ML/d	4 times annually	7 – 15 days
Jun	93 ML/d	Annual	Continuous
Jul – Oct	Min 385 ML/d	Annual	Continuous
	>3,600 ML/d	2 times annually	Minimum 4 days
Nov	110 ML/d	Annual	Continuous
Jul – Nov	>700 ML/d	2 – 3 times annually	5 days

Comparison of performance assessment

Since the flow recommendations include temporally varying flow based on flow conditions, they provide a closer reflection of unimpacted flow regimes than the 2003 study (Figure 40). As a consequence the resulting flow regime is a closer reflection of a natural flow regime, and also more closely reflects the water management environment whereby more water is available in wetter years than dry years.

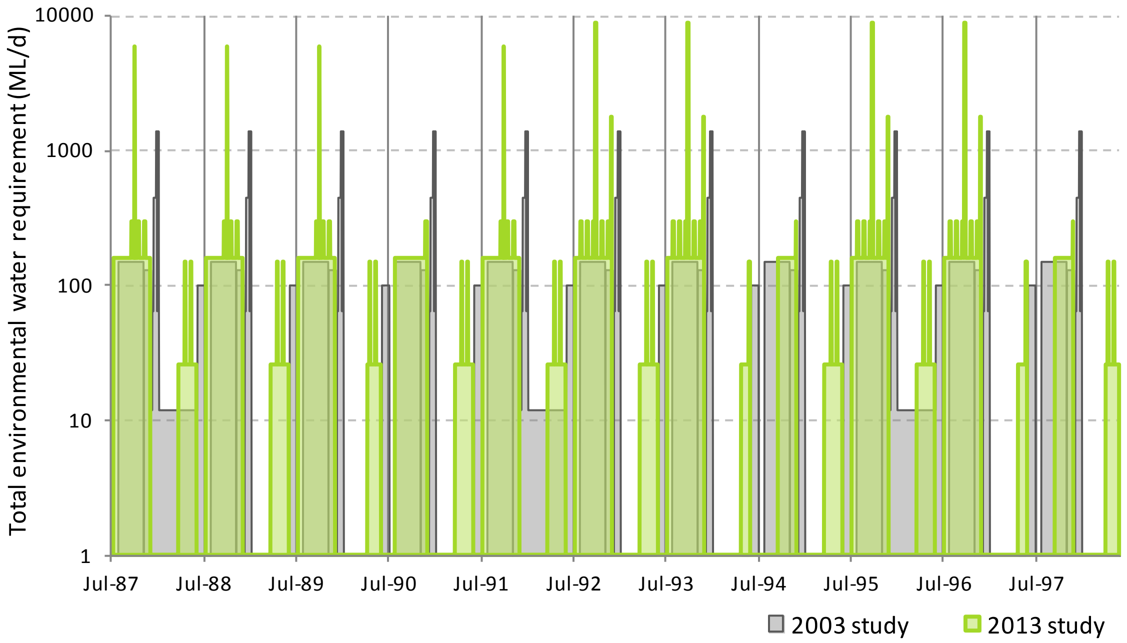


Figure 40. *Comparison of total environmental water recommendations for two studies.*

The overall total environmental water recommendations as part of this study are around 3.7GL/y more than those recommended as part of the 2003 project flow recommendations (Table 29, Figure 41). 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 the water shortfall from 2003 from 10.5GL/y to 5.8GL/y (excluding overbank requirements).

Table 29. Headline figures for flow shortfall for period 1987-2011 (GL/y)

Year type	2003 study total environmental water recommendation	2013 study total environmental water recommendation	2003 study shortfall environmental water recommendation	2013 study shortfall environmental water recommendation	2013 study shortfall (no overbank)	Measured flow
All years (mean)	39.5	43.2	10.5	11.4	5.8	144.4
All years (median)	39.5	39.2	6.9	5.8	2.7	118.5
Largest	39.5	87.2	34.3	77.6	25.0	491.8
Smallest	39.5	12.0	0.0	0.0	0.0	3.0
Drought (median)	39.5	12.0	28.1	8.8	8.8	9.5
Dry (median)	39.5	21.5	8.9	1.1	1.1	60.1
Average (median)	39.5	39.2	5.4	2.8	2.8	135.7
Wet (median)	39.5	87.2	4.7	17.9	2.5	273.6

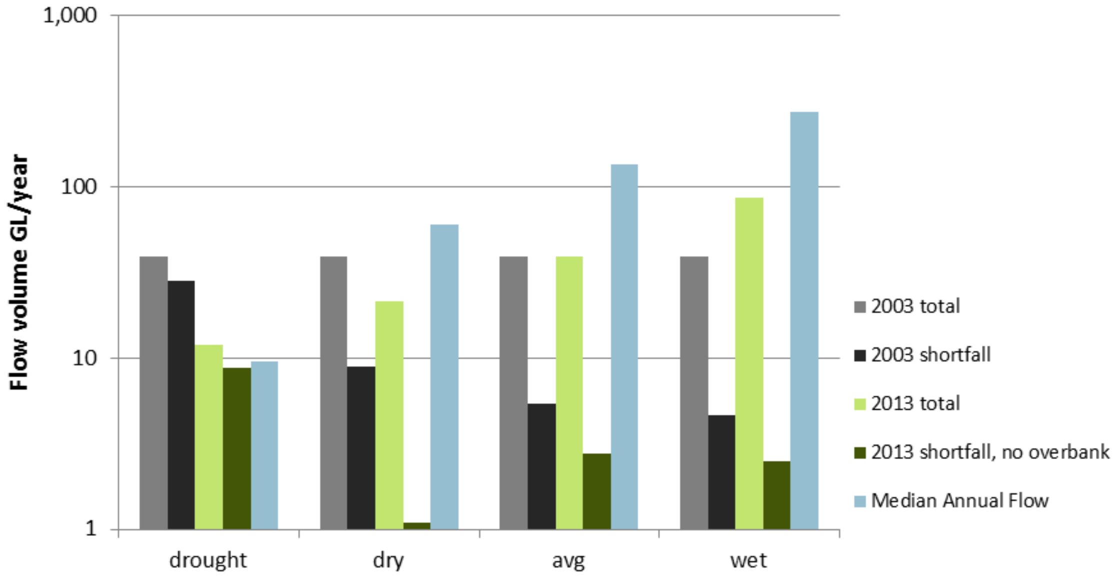


Figure 41. *Total environmental water recommendations by year type (note logarithmic Y axis makes vales appear more similar).*

For the 2003 study, the same 39.5 GL/y is recommended across every year type (Figure 42). For this study the flow recommendations varies from 12.0 GL/y in drought years to 87.2GL/y in wet years to give a mean total flow requirement of 43.2GL/y across the reporting period. The overall environmental water recommendation for this reach is slightly higher than for the previous study. However, because the flow recommendations vary between the prevailing year types, the relative shortfall (difference between flow recommendation and actual water delivered) should be considered for the different prevailing climatic conditions. The resulting shortfall for this study is very similar to that of 2003 study (11.4GL/y compared to 10.5GL/y). However if overbank flow requirements are rarely likely to be delivered as part of operational water delivery the mean annual environmental water requirement for this study was 5.8GL/y.

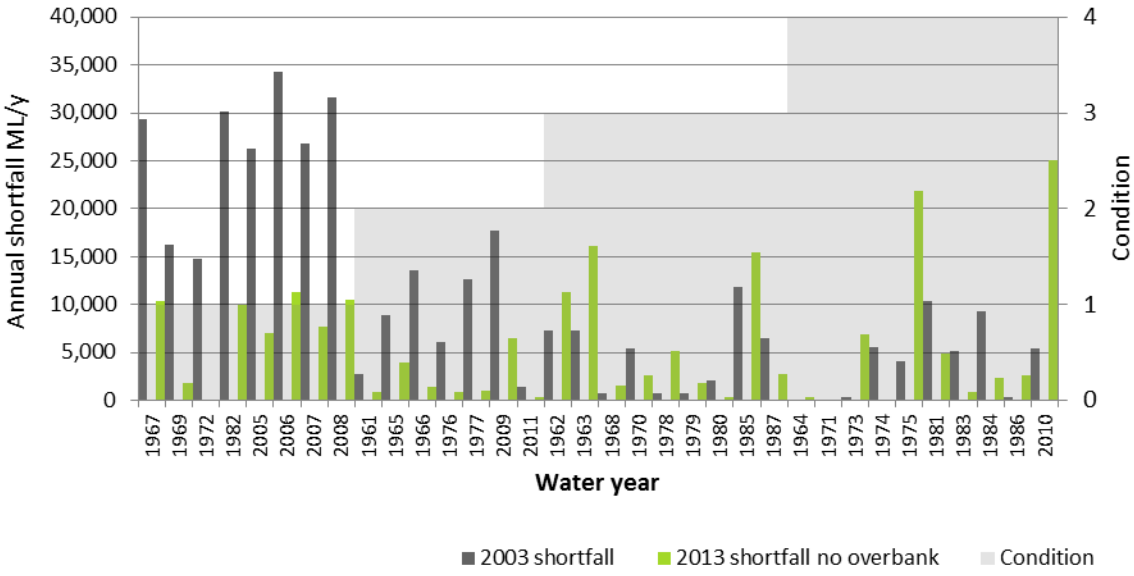


Figure 42. *Annual shortfall for different year types for the two studies*

6 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 tasks project 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. In this phase, it was recommended that Reach 1 was split into two reaches – Reach 1a upstream of Five Mile Outlet, and Reach 1b downstream of the Outlet. Recommended compliance points for all reaches (1a, 1b and 2) have been specified in Section 4 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 Glenelg Hopkins 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 4). 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 Section 4.

- *Improve information at 'b' sites*
  The 'b' site recommended for further assessment in the Glenelg catchment was Reach 0 – Glenelg River between Moora Moora and Rocklands Reservoir. During the review phase of the project it was recommended that it was a higher priority to improve information for Reach 1a rather than Reach 0. Summary information on Reach 0 is provided in Section 4.2 and full environmental flow recommendations for Reach 1a in Section 4.3.

- *Updated FLOWS study*
  This report documents the updated FLOWS study for the Glenelg River. 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 Glenelg River. The following activities are recommended to achieve the optimum outcome from environmental water management:

- Install a streamflow gauge to assess compliance of environmental flows in Reach 1a with the environmental flow requirements outlined in this report.

- Improve extent of modelled daily flow data. Unimpacted modelled hydrology data (daily time series) for the Glenelg were only available for inflows to Rocklands Reservoir. 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 and operating decisions.

- Identify complementary river health activities such as sand management, stock exclusion, revegetation, pest animal and weed control; that will work towards addressing the other system limitations (outlined in Section 3) to achieving environmental objectives. Implement in priority locations to ensure the river health outcomes sought from the environmental flow recommendations are achieved.

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Attachment A
Environmental flow objectives

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
FISH	Protect, maintain and where possible, enhance populations of diadromous native fish species[19],[20]	Maintain area of pool habitat > 1.5m deep for large-bodied species	Baseflow	All year	
		Maintain shallow water littoral habitats for small bodied species (e.g. common galaxias)	Baseflow	All year	
		Provide stimulus and opportunity for downstream migration (e.g. Tupong)	High flow fresh	June-August	Rise to above median flows (crook
		Provide stimulus and opportunity for upstream migration (e.g. G. maculatus YOY)	High flow fresh	October-November	minimum depth over barriers of 0.1~0.2 m
	Protect, maintain and where possible enhance populations of non-diadromous native fish species [21]	Maintain area of pool habitat > 1.5m deep for large-bodied species	Baseflow	All year	
		Maintain shallow water littoral habitats for small bodied species (e.g. pygmy perch, flathead gudgeon)	Baseflow	All year	
		Maintain depth over shallow riffle areas	Base flow	All year	Minimum cross-section depths ~ 0.1-0.2m
		Provide opportunities for local movement and stimulus to recolonise following drought	High flow pulse	Winter high flow season	
	Expand populations of non-diadromous native fish species[22]	Facilitate scour of pools in sand-bed reaches	High flow pulse Low flow pulse	Winter high flow period	
		Promote growth of macrophytes for habitat/spawning sites (see veg section)	May include a cease to flow	All year	
	Limit recruitment of introduced fish species including translocated species native to Australia	No flow recommendation due to significance of management decisions in achieving this objective.			

[19] Short-finned eel, Spotted galaxias, Climbing galaxias, Common galaxias, Pouched lamprey, Short-headed lamprey, Tupong, Black Bream, Elongate hardyhead, Small mouthed hardyhead, Estuary Perch
[20] Australian grayling (lower priority than others because no confirmed sitings in the last 100 years
[21] *River blackfish, Mountain galaxias, Southern pygmy perch, Flat-headed gudgeon, Australian smelt*
[22] Southern pygmy perch, Dwarf galaxias, Variegated pygmy perch

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
VEGETATION	Improve condition, extent and diversity of instream native vegetation	Maintain adequate depth of permanent water in instream channel to permit long-term survival and recruitment of submerged plant taxa. Also serves to limit terrestrial encroachment into aquatic habitats.	Low flow (winter-autumn and spring-summer) Note: freshes may be required for WQ purposes (see below for related objectives).	All year	Minimum instream water depth >0.5 m all year (maximum water depth of ~2 m for obligately submerged taxa).
	Maintain and improve condition, extent and diversity of emergent native vegetation	Maintain adequate depth of permanent water in stream channel to limit terrestrial encroachment into aquatic habitats.	Low flow (winter-autumn and spring-summer)	All year	Minimum instream water depth >0.5 m all year.
		Inundate riparian zone (bankfull) and floodplain (overbank) in order to maintain condition of adults and facilitate sexual recruitment	Low flow fresh	Spring – Summer	Variations in water depth of ~10-20 cm over low-flow levels in each of the two flow seasons.
			High flow fresh	Autumn – winter	Periodicity as per natural 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.
	Maintain, protect and enhance condition and extent of flow dependent threatened species within ▪ River Red Gum woodland ▪ Tea Tree ▪ Black Box woodland *Callistemon wimmerensis*	Inundate riparian zone (bankfull) and floodplain (overbank) in order to maintain condition of adults and facilitate sexual recruitment	Bankfull flow (riparian vegetation)	Spring-summer	Bankfull flow and overbank flows as per natural return interval (as determined, e.g., by spells analysis) or, if this information is not available, 2-3 times per decade for River Red Gum woodland and 3-5 times per decade for River Red Gum forest (if present or desired).
			Overbank flow (floodplain vegetation)	Autumn - Winter	

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
MACRO-INVERTEBRATES	Maintain 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	Late low flow season (May/June)	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
	Maintain self sustaining popuation of Glenelg freshwater mussel (*Hyridella glenelgensis*)	Maintain shallow water habitat availability[23]	Low flow	All year	Water depth 30 cm, velocity <0.2 m/sec
	Maintain self sustaining population of Glenelg Spiny Cray	Maintain habitat availability [24]	Low flow	All year	No criteria available due to wide habitat tolerance [25]

[23] mussels are found in firm, coarse sandy sediments in shallow (between 20 and 48 cm with a mean depth of 28 cm), narrow (2-5 m), flowing (mean velocity mean 0.1m/s) sections of the Crawford River (not clear if it actually occurs in the Glenelg main stem as "the Glenelg main stem offers few similar habitats and no mussels were found at three sites" – Playford and Walker 2008). Playford and Walker (2008) *Aquatic Conservation: Marine and Freshwater Ecosystems* **18**: 679–691.

[24] Glenelg spiny freshwater crayfish is found in cool, shaded, flowing habitats with high water quality and intact riparian vegetation. In these habitats, Glenelg spiny freshwater crayfish use undercut banks, woody debris, rock boulders and cobbled river beds as refuges when not feeding, resting or moulting (Approved Conservation Advice for Euastacus bispinosus (Glenelg spiny freshwater crayfish) 23 Dec 2010.

[25] Crayfish were found in streams that "varied greatly in width, depth, bank vegetation, in-stream woody debris, substrate and soil type" (Honan JA (2004). Habitats of Glenelg spiny crayfish (Euastacus bispinosus) in the Glenelg River Drainage. Report to Glenelg-Hopkins Catchment Management Authority. page iii) suggesting criteria suitable for use in FLOWS cannot be determined. Also: "The main role of flow appears to be in maintaining adequate water quality" (p. 11)

Asset	Objective	Flow process/function	Flow components	Timing	Criteria
	(*Euastacus bispinosis*)				
MAMMALS	Maintain suitable habitat for platypus and water rat	Provide for instream habitat availability	Low flow	All year	Continuous flow to maintain area of pool water depths less than 5 m
		Provision of access to food supply	Low 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 Glenelg River	Connectivity between habitats	High Flow	June-December	Depth in riffles > 50 cm
GEOMORPHOLOGY	Maintain hydraulic capacity at tributary junction plugs	Flows not recommended to achieve this objective			
	Improve in channel habitat diversity and condition	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 natural flow regime
		Provide critical flows for maintenance of inchannel diversity (i.e. pools and benches)	Fresh	Any time	Shear stress =>1.1 N/m^2 to mobilise coarse sand Depth of flow of 1 m over benches
	Maintain deep pools for in-channel habitat	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 natural flow regime