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FINAL PAPER

Macalister River Environmental Flows Review

October 2015

West Gippsland Catchment Management Authority

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Project advisory group:

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Glossary of terms and abbreviations

DELWP	**Department of Environment, Land, Water and Planning** The new Victorian government department established in late 2014 that is now responsible for the state's water portfolio.
DEPI	**Department of Environment and Primary Industries** The previous Victorian government department (2010-2014) that was responsible for the state's water portfolio.
Ecological objectives	Measureable outcomes that are linked with the hydrologic management of environmental water. The achievement of ecological objectives should be able to be measured through monitoring programs. They may also be referred to as environmental objectives.
EFTP	**Environmental Flows Technical Panel** The technical panel is part of the broader project team and is comprised of scientists/engineers with expertise in the areas of vegetation, hydrology, fish biology and geomorphology. Their role is to undertake the technical assessments for the Macalister eflows project in order to determine the important flow requirements for the river.
Environmental flows	The flows required to maintain healthy aquatic ecosystems such as waterways, floodplains or wetlands. These flows reflect the needs of animals, plants, habitats and processes that are dependent on the specific hydraulic and physico-chemical conditions created with different flow events that help to maintain their ecological integrity.
Environmental water	Refer to *environmental flows*.
EWR	**Environmental Water Reserve** An amount of water set aside specifically to benefit the aquatic ecosystem for which it is to be delivered. This water includes statutory environmental water entitlements (i.e. environmental water held in storages), minimum passing flows that are delivered from consumptive water entitlements held by urban and rural water corporations and unregulated flows and spills from storages.
EWMP Scientific Panel	**Environmental Water Management Plan Scientific Panel** A state government mandated panel whose role is to review all the EWMPs developed around the state. They will be reviewing the Macalister River EWMP and the scientific integrity of the underlying data.
EWMP	**Environmental Water Management Plan** A long term scientifically-based management plan that will set the ecological objectives and the watering regime required to meet these objectives. The EWMP will inform the Seasonal Watering Proposals that set the annual priorities for watering in that year.
Flow regime	The hydrologic pattern of flows that occurs in a waterway, floodplain or wetland influencing the hydraulics, ecology and geomorphology of that ecosystem. Flow regimes are typically described using flow events (e.g. fresh, bankfull flow), as well as the duration, timing, frequency and magnitude parameters. Natural flow regimes are those where there is no human intervention to the natural flow patterns for the system. Developed or regulated flow regimes are those where human intervention has altered the natural flow pattern. Intervention may include the presence of water storages or flow control points, the extraction of water, or the input of water.
Flow regulation	The alteration of the natural flow pattern in an aquatic ecosystem through the installation of water storages that control the hydrology of a range of incoming flows. The Macalister River is considered a regulated river system due to the presence of Glenmaggie Weir and Maffra Weir.
FLOWS method:	A systematic, repeatable and scientific method provided by DEPI to determine the environmental water requirements for aquatic ecosystems in Victoria. The method has recently been updated in 2013 since its original release in 2002.
Flow recommendations	One of the outputs of the FLOWS method. The recommendations describe the full suite of flow components that would be present under a natural flow regime for a system. Flow recommendations will be determined with the Macalister eflows project.
Flow targets	Flow targets link the hydrologic objectives to a target site or reach. For example, an annual 4 day spring 800ML/day fresh in Reach 2 of the Macalister River.
Hydrologic objectives	These objectives are linked to the ecological objective and specify the duration, timing, frequency and magnitude ranges of the flow components to be delivered using environmental water. The hydrological objectives describe the watering regime over the long term.
Macalister eflows project:	The scientific study underlying the Macalister River EWMP. It implements many steps from the FLOWS method as well as stakeholder consultation to define and prioritise the flow

	requirements for the Macalister River and improve water management. The Macalister eflows (environmental flows) project is the short form for the official project name; the Macalister River Environmental Flows and Management Review Project.
Management goals	A long term health goal or vision statement reflective of the water dependent values of the Macalister River.
MID2030	**Macalister Irrigation District 2030** A project led by Southern Rural Water to modernise the water supply to the Macalister Irrigation District (MID). This is via a combination of pipelining and channel automation to achieve water savings, improve supply service and enable increased productivity in the MID.
PAG	**Project Advisory Group** A representation of stakeholders in the community linked to environmental water, and more broadly, water management within the Macalister River.
SC	**Steering Committee** This is a committee established specifically for this project. The members of this committee represent stakeholders that are directly involved in the management of environmental water. These stakeholders are DELWP, VEWH, SRW and WGCMA. The Steering Committee's role is to oversee the implementation of the project.
SRW	**Southern Rural Water** The company responsible for rural water supply for the Macalister catchment. They are the storage managers for Glenmaggie and Maffra Weirs.
ToR	**Terms of Reference** Statement of the purpose, structure and role of a project/group. For this project, two ToRs have been established to guide the PAG and the SC.
VEWH	**Victorian Environmental Water Holder** An independent statutory organisation that works with Catchment Management Authorities (CMAs) and Melbourne Water to ensure that Victoria's environmental water entitlements are effectively managed to achieve environmental outcomes.
Water dependent values	Components of the ecosystem that are dependent on water provided from the river for critical life history stages or maintenance of its ecological integrity. Values may be a species, a community, a place of natural value, a process or habitat.
WGCMA	**West Gippsland Catchment Management Authority** The waterway manager for all waterways within the West Gippsland region, including the Macalister River. The WGCMA is also the project manager for this project and a key stakeholder. As such, the WGCMA will be represented in the PAG and the SC.

1 Introduction

A FLOWS study was completed for the Macalister River in 2003 (SKM 2003), and was one of the first studies undertaken using the newly developed FLOWS method (NRE 2002). The study described the condition of the river system, identified ecological objectives and determined the flow requirements to achieve the objectives. To date, priority watering actions for the Macalister River have been informed by the flow recommendations from this study.

Over the last decade significant changes have occurred that warrant a review of the study - the FLOWS method has been updated (DEPI 2013); the Macalister system has encountered major flooding (potentially changing the shape of the channel); and monitoring has improved our knowledge base. In addition, there is a need to develop a long-term Environmental Water Management Plan (EWMP), a 10-year strategic plan that informs seasonal watering planning and delivery of the environmental water entitlement.

To meet these requirements, the West Gippsland Catchment Management Authority (WGCMA) has engaged Alluvium to undertake a review of the existing FLOWS study and contribute to the development of the EWMP. 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 Macalister River system. The intended outcome is to enhance the existing Macalister environmental flow recommendations by incorporating new information.

1.1 Study area

The study area for this investigation is Macalister River between Lake Glenmaggie and the confluence with the Thomson River (Figure 1). The study area is broken into two reaches - Reach 1 is from Lake Glenmaggie to the Maffra weir; Reach 2 is from Maffra weir to the confluence with the Thomson River.

Figure 1. *Study area (VEWH 2014)*

1.2 Project scope

The scope of this project includes:

- Establish an understanding of the current system condition and trajectory, water related threats to the values, and conceptual flow-ecology relationships.
- Develop robust, agreed and measureable ecological objectives for the environmental flows in the system
- Update the SKM 2003 environmental flow recommendations to reflect contemporary understanding of the system and the revised objectives
- Prioritise the environmental flow recommendations to achieve ecological and hydrological objectives under long term management scenarios

This project is not a full FLOWS study, but will build on the large amount of work already done to date in this system.

Stakeholder engagement

The WGCMA has established a project advisory group (PAG) comprising relevant interest groups. This project will be their first activity as a group. It is expected that the PAG will continue beyond the life of this environmental flows study. A project steering committee (SC) has been established comprising agency staff (CMA, Department of Environment, Land, Water and Planning (DELWP), Victorian Environmental Water Holder (VEWH), and Southern Rural Water (SRW)). All members of the SC have history working together on water management in the Macalister. The PAG and SC have been engaging with the project via three workshops and review periods of key documents.

1.3 Approach

The overall approach to the project is provided in Figure 2. Each of these stages relates to one of the three papers in this report.

Part A: Issues Paper

Stage 1 is presented in Part A: Issues Paper and includes the following sections:

- Section 2: System Description
- Section 3: Ecological Values
- Section 4: Objectives and conceptual models

The Issues Paper provides an update to the 2003 FLOWS study issues paper for the Macalister system. In particular, this report describes:

- the updated environmental values and threats in the Macalister system
- ecological objectives for flow depending environmental values

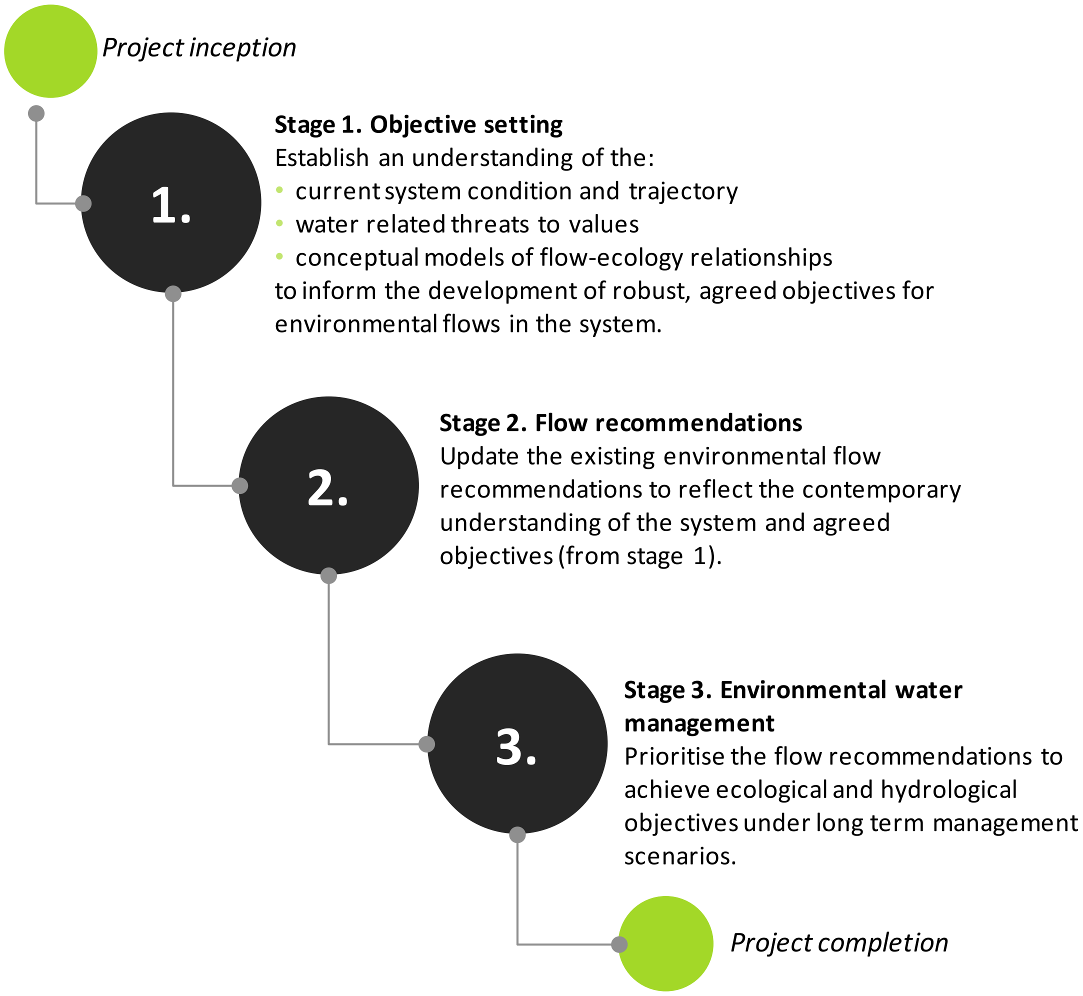


Figure 2. *Project approach*

Part B: Flow Recommendations Paper
Stage 2 is presented in Part B: Issues Paper and includes the following sections:

- Section 5: Values and objectives
- Section 6: How the updated environmental flow recommendations were derived
- Section 7: Environmental flow recommendations
- Section 8: Achievement of environmental flow recommendations

This Flow Recommendations Paper provides an update to the 2003 FLOWS study recommendations for the Macalister system. In particular, this report describes:

- the approach applied to updating the environmental flow recommendations
- environmental flow recommendations to achieve ecological objectives
- achievement of the recommendations under the current operating regime

Part C: Prioritisation Paper
Stage 3 is presented in Part C: Prioritisation Paper and includes the following sections:

- Section 9: Risk assessment

- Section 10: Management objectives
- Section 11: Testing success: monitoring requirement
- Section 12: Knowledge gaps

The Prioritisation Paper provides further information on how the information in this flows recommendations for the Macalister system. In particular, this report describes:

- a risk assessment based on the habitat preference curves of each ecological value
- prioritised management objectives (ecological and hydrological objectives) for different climatic scenarios
- monitoring requirements and knowledge gaps to improve environmental water management for the Macalister River

Part A: Issues paper

2 System description

2.1 Water resource development in the Macalister River

The Macalister River is located in West Gippsland, Victoria and covers an area of 1,891 km^2 (Ecos 2014) from its headwaters on the southern slopes of Mt Howitt, to its confluence with the Thomson River just downstream of Maffra. The catchment drains the southern slopes of the Snowy Ranges via an extensive stream network which flows downstream into Lake Glenmaggie, a dam constructed in 1926 to collect and store inflows, resulting in significant changes to the natural flow regime. Lake Glenmaggie is the primary source of water for the Macalister Irrigation District (MID) which is the area of greatest agricultural development in the catchment. Below Lake Glenmaggie the river flows through a cleared, narrow Quaternary floodplain for 55 km, to its junction with the Thomson River (SKM 2003).

Topography ranges from 1740 m AHD in the upper portion of the catchment, to around 30 m AHD with very little relief in the lower portion of the catchment (Ecos 2014). Climate data is shown in Figure 4. The average annual rainfall in the area is around 600 mm. The long term monthly averages show that rainfall is relatively consistent throughout the year, with no clear seasonal trends. In 2001-2007 there was below average annual rainfall which has increased in recent year's rainfall back to around the long term average.

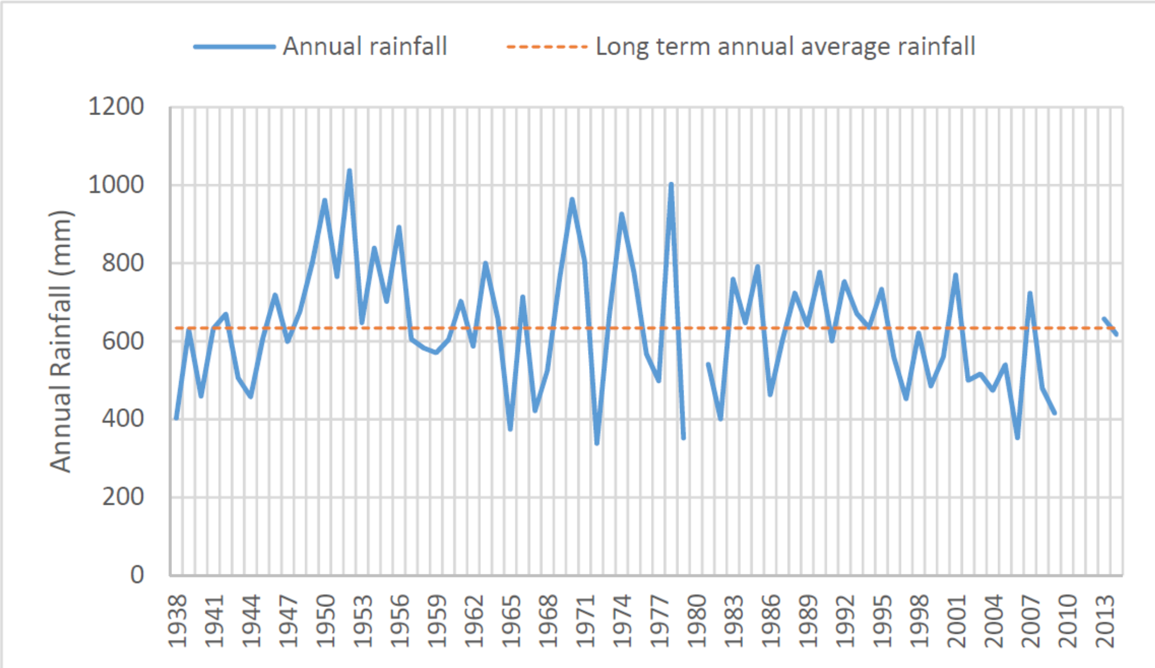


Figure 3. *Climate data for Glenmaggie Weir Station: long term annual rainfall data –station 85034)*

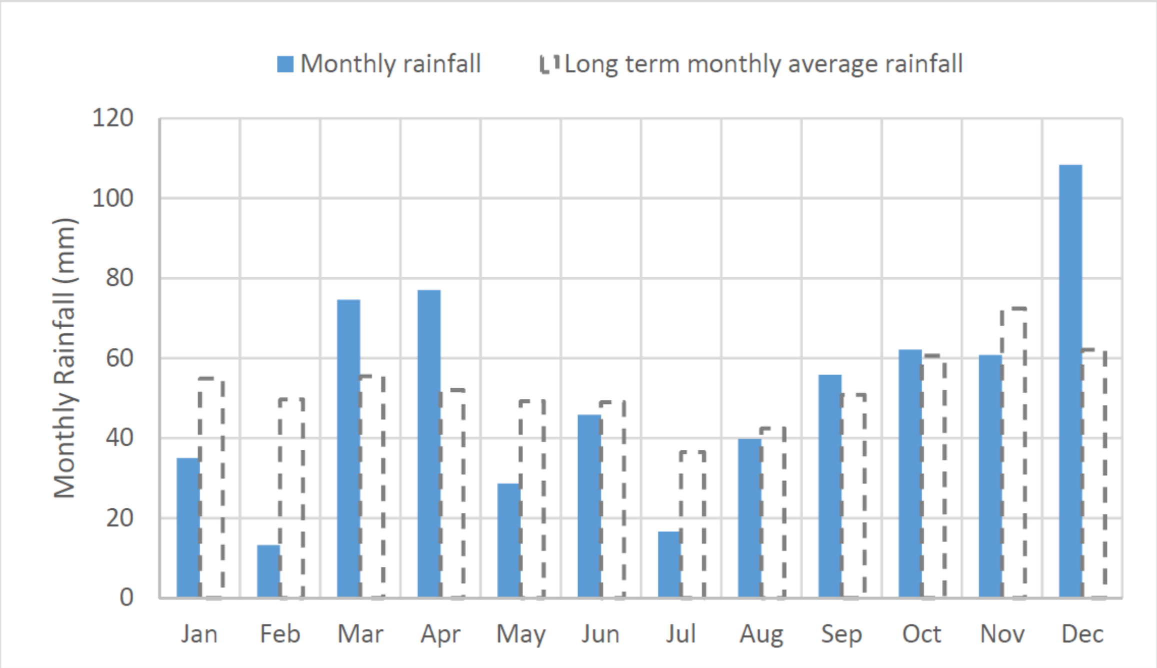


Figure 4. *Climate data for Glenmaggie Weir Station: monthly rainfall data for 2014 – station 85034)*

2.2 The Macalister River Environmental Water Reserve

The Environmental Water Reserve for the Macalister River refers to a number of water sources that can be used to protect and enhance the ecological health of the system. Table 1 provides a summary of the water sources, the extent to which they can be actively managed and the expected availability.

The *Macalister River Environmental Entitlement 2010* is the major water source that can be actively managed. The amount of water available each year, as part of the entitlement is governed by the inflows to Lake Glenmaggie. Where possible, water will be delivered to take advantage of seasonal conditions to maximise the efficiency of water usage in achieving ecological objectives (WGCMA 2014).

Table 1: Sources of environmental water (WGCMA 2014)

Water source		**Flexibility of management**	**Reaches**	**Conditions of availability**	**Conditions of use**
Nature of water source	**Volume or rate of water delivery**				
Entitlement					
Macalister River Environmental Entitlement 2010	Up to 18,690 ML/year stored in Lake Glenmaggie	Subject to carry over rules and delivery constraints	M1, M2	Includes high reliability share of 12,461* ML and low reliability share of 6,230* ML	Stored in Lake Glenmaggie. Used in accordance with the operating arrangements for the use of the environmental water holdings of the Macalister system.
Passing flow **					
Macalister River passing flows	Up to 60 ML/d	Upon agreement passing flows can be varied and savings accrued for later discretionary use	M1, M2		Passing flow savings are stored in Lake Glenmaggie. Used in accordance with the operating arrangements

Water source		Flexibility of management	Reaches	Conditions of availability	Conditions of use
Nature of water source	**Volume or rate of water delivery**				
Other sources					
Lake Glenmaggie unregulated flows	25,000 – 620,000 ML/ year#	Limited/no ability to manage	M1, M2	Subject to dam spilling	Can provide wetland watering opportunities
Maffra Weir dewatering water	~500 ML after the 15th of May	Limited ability to manage	M2	Subject to dewatering of Maffra Weir	Can provide piggy backing and wetland watering opportunities

** Passing flows are in the Southern Rural Water Bulk Entitlement

Unregulated flow volume based on SRW data for 2008-09 to 2013--14

2.3 Macalister River hydrology and water quality

The Macalister River is highly regulated and has been significantly affected by surface water diversions. Flows are artificially controlled by upstream reservoirs, which inhibit downstream flow variability during winter, when water is held in storage for regular releases during summer (GHD 2013). Median annual flows in the Macalister River have been reduced by 47% (CRCFE 1999) (Figure 5). The Macalister River is showing signs of stress as a result of regulation and over allocation of water for irrigation and consumptive use, and along the lower reach there is evidence of a narrowing river channel with large pools of poor water quality.

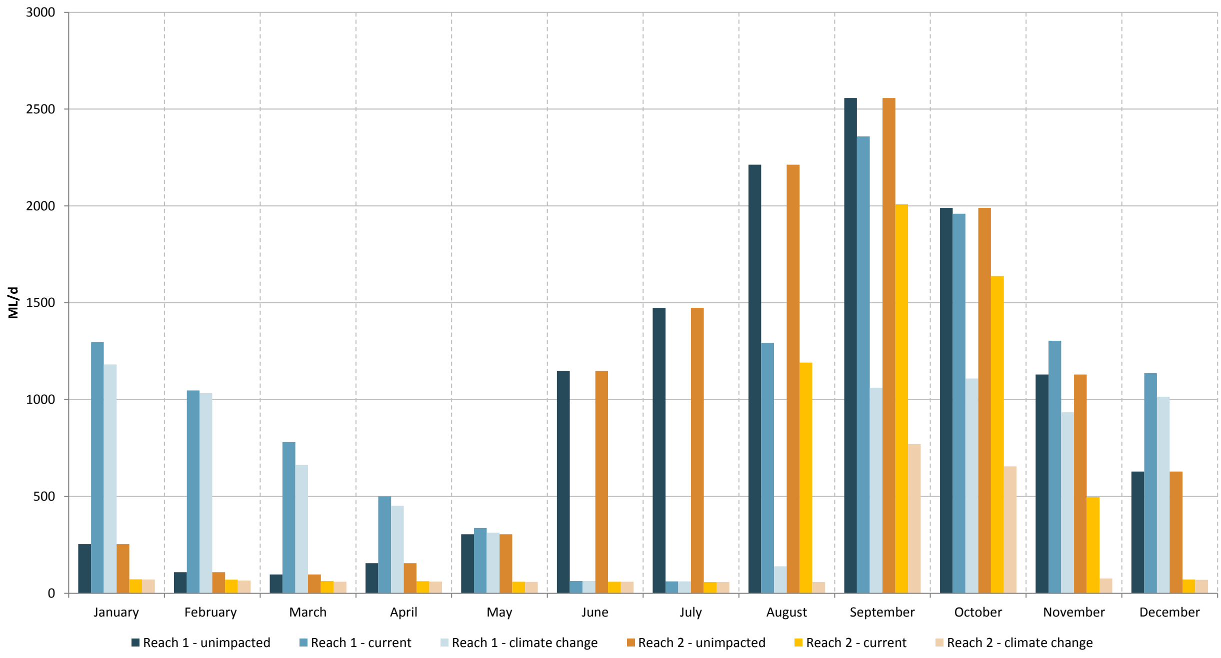


Figure 5. *Average monthly flows in the Macalister River – reaches 1 and 2, under unimpacted, current and climate change conditions (Data source: REALM model - SKM 2005).*

Stream flows in the catchment follow a common pattern for Victorian streams with the high flow period beginning in May/June, peaking in September and October before declining back to the dry summer – autumn period (January to April/May) (Ecos 2014).

Previous prolonged drought conditions have significantly reduced inflows into Lake Glenmaggie. Inflows during 2006-07 were the lowest on record with a total annual inflow of 65,000 ML, compared with an average annual inflow of around 450,000 ML (SKM 2009). On average Lake Glenmaggie will spill 9 out of every 10 years during the August to October period which provides a valuable fresh water supply to the lower Macalister River (SKM 2009). Heavy rainfall in late June 2007 caused a 1 in 100+ year flood downstream of Lake Glenmaggie (WGCMA 2008; SKM 2009).

Electrical Conductivity (EC) in the catchment is generally consistent with the pattern often seen in waterways and storages. EC tends to decrease in the wetter late autumn, winter and spring months due to the input of freshwater flows (rainfall, snow melt) (Ecos 2014). The EC observed at the Glenmaggie Creek site at the Gorge has been consistently higher than the other sites in the catchment, suggesting a potential groundwater influx that elevates EC at this site (Ecos 2014). Salinity immediately downstream of Lake Glenmaggie is consistently very fresh (<500 uS/cm) and tends to increase with distance downstream (SKM 2003). The pH in the catchment is generally neutral and consistent throughout the year, with the most variable site at Glenmaggie Creek at the gorge, which may be due to an influx of groundwater (SKM 2003).

2.4 Groundwater connection with Macalister River and wetlands

It is likely that there is groundwater-surface water connectivity, whereby groundwater discharges into the main river, or its adjacent wetlands, and contributes to baseflows. However, the dynamics of this relationship and the extent of connectivity have not been quantified.

Since European settlement there has being significant changes to the hydrology of the catchment due to: deforestation, drainage of low lying water logged regions, surface water extraction, farms dams and the construction of Lake Glenmaggie. Alterations to drainage and wetland hydrology (due to less frequent filling flows from reduced flooding) has caused a significant decline in wetland condition. Historically, the drained wetlands were shallow freshwater marshes which were waterlogged throughout the year and surface waters (<0.5m) may be present for 6-8 months annually. Most of remaining wetlands on agricultural lands are hydrologically disconnected from the parent river and are likely to be maintained primarily by groundwater flows rather than surface water floods (SKM 2003).

Since European settlement, the impact on the groundwater connection to the river is more subtle. The impacts of regulating the stream will influence river stage heights and movement of groundwater into the river and surface water back into the groundwater. The change in land use, and alteration of the surface water systems across the floodplain will likely have impacts on recharge rates to the groundwater, and subsequent groundwater levels and fluxes to the river.

Groundwater levels and quality

The water table is contained within Quaternary and Recent aged Alluvials and Tertiary aged Haunted Hills Formation (SKM 2012). Recent mapping of observed groundwater levels indicates that the water table is between 60 m AHD near the tail of Glenmaggie dam, to around 30-10 m AHD on the plains west of Maffra (Jacobs, 2014) and generally within 10 metres of the natural surface (SKM 2012). Groundwater salinity in the floodplain and alluvium is very fresh (<500 µs/cm) (VVG 2014), consistent with salinities observed in the river (SKM 2003).

Hydrographs were prepared for selected representative bores, located in the alluvium of the river (Appendix A). The majority of hydrographs show a generally declining trend in groundwater levels since 1990. A decadal trend of lower groundwater levels is evident in several bores (131257, 130371, 95495, 130367, 130370), which coincides with the drought period from 2001-2007 (Figure 6, Appendix A). The decline in groundwater levels is likely a result of reduced groundwater recharge via river flows and rainfall, water level decline will be exacerbated locally around zones of groundwater abstractions.

It should be noted that the decline in groundwater levels within the alluvial system is considerably less than what occurred in similar system in the central, northern and west regions of Victoria. The relatively consistent rainfall and river flow have maintained recharge and in terms of the rest of Victoria relatively stable groundwater system.

The large rainfall event in 2007 is evident in many of the hydrographs (95492, 95401, 130257, 130367, 95495, 130371), when a marked increase in groundwater levels occurred (Figure 6, Appendix A). This illustrates the strong influence large flow events and rainfall will have on the recharge to the underlying aquifer.

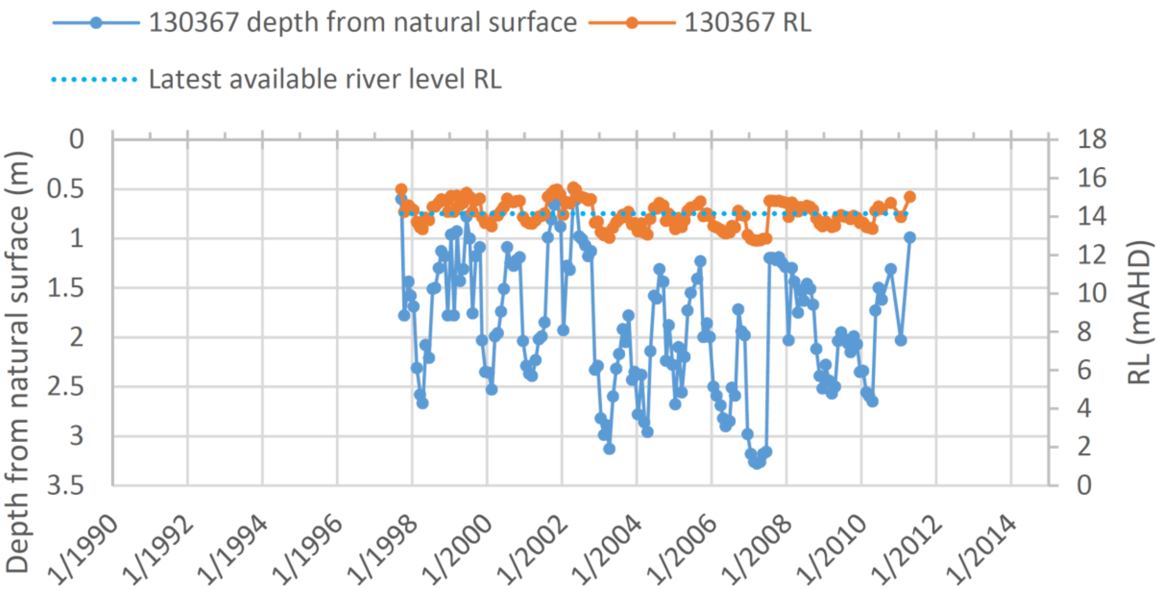


Figure 6. *Groundwater hydrograph for station 130367*

Groundwater bores to the north of Macalister River, in the vicinity of the numerous wetlands, show declining water levels (WRK066182, 76894; see Appendix A), likely because they are situated some distance from the regulated river and are not receiving surface flows that in the past would have maintained recharge and thus shallow water tables. It is interesting to note that the large rainfall event in 2007 appears not to have induced any recharge around the wetlands. In terms of the wetlands, they have altered from a gaining system (receiving groundwater) to a losing system (recharging groundwater via surface water).

The hydrographs show that at some locations (95492, 130373, 95489, 95495, 130371; see Appendix A) the water table has responded to the increased rainfall in recent years, which agrees with findings of SKM (2012). SKM (2012) also found that groundwater levels for locations which are adjacent to lakes and rivers tend to fluctuate less, compared to the areas in open land, suggesting a connection between the water table and the local rivers and creeks. A number of wells show relatively constant water levels over time (130373, 130370, 130367, 95401), likely a result of strong connectivity with the river.

The LiDAR spot heights in comparison with the groundwater levels indicate that the hydraulic gradient is primarily variable. There are periods where the river height is below the groundwater level and is likely to be receiving baseflow, as well as periods where the river height is above the groundwater level and is therefore likely to be losing flows to the underlying alluvial aquifer. In general, the hydrographs which indicate a dominant flow gradient from surface water to groundwater (groundwater levels lower that the river) are located in the upper elevated portions of the catchment (130373, 131257, 95495, 95491, 95492, 95489). In the lower portions of the catchment groundwater levels are dominantly higher or equal to the river, and suggest river recharge by groundwater (95401, 130372, 130371, 131257,).

Baseflow analyses

Baseflow analyses conducted for the Macalister River (GHD 2013) has found that the river loses flow to the underlying sedimentary aquifers of the alluvial plains. These results need to be considered in light of how baseflow analyses averages out hydrology across the entire length of the river. It is likely that while there may be localised occurrences of groundwater flux to the river, the predominant pattern is of surface water entry into the groundwater table. It is apparent that during dry year and low flow periods, the river is mainly losing water to the groundwater system, however during the wet years post 2010, the river is mainly gaining water from the groundwater system.

Additionally, the sedimentary (alluvial) aquifers provide large, porous and relatively permeable storage reservoirs on the alluvial plains, resulting in increased transmissivity, which markedly increases groundwater flow path lengths. Along the alluvial fringe in particular, this provides the hydraulic potential of leakage from the rivers into the underlying aquifer, especially during periods of high river stage and flood events, and more so when coincident with relatively depressed groundwater levels. However, in the lower reaches of the Macalister River, where the topography is relatively flat over large areas, the potential for stream loss decreases and eventually reverses to groundwater discharge (i.e. baseflow) potential.

Implications for environmental flow management

The following points may require consideration within delivering environmental flows:

- The system was historically flood driven, with regular flood events providing freshwater to wetlands. This maintained high rates of recharge and shallow water tables that were connected to waterways and wetlands
- Since construction of the Lake Glenmaggie and agricultural development, river flows have been heavily regulated downstream and groundwater has been accessed for irrigation purposes. As a result, groundwater levels have generally been in decline
- The most notable groundwater decline is observed in areas to the north of the river around numerous wetlands; prior to 1990 these wetlands were connected to the groundwater and have since been disconnected
- There exists a fluctuating state of the river changing from gaining to losing depending on decadal rainfall and stream flow events
- The alluvial aquifer is likely to be flood and rainfall recharge driven, with increases in the water table occurring in wet years, and decreases during periods of drought. This occurs for two reasons – limited private pumping during wet years, and increased infiltration into the soil profile from runoff and recharge (SKM 2012)
- The groundwater system is closely linked with the surface system, such that any changes to stream flow, flooding and environmental watering will potentially cause a change in the nature of groundwater connection with surface water systems
- Previous studies indicate that the river is primarily a losing feature, providing recharge to the groundwater system. Hydrographs with LiDAR spot heights indicate that the river primarily loses flows to groundwater during dry periods and that baseflow is more likely to occur in areas where elevation is low and flat. Water quality data has indicated that baseflow may be occurring at the tail of Lake Glenmaggie, where elevated EC and variable pH has been observed. However, in general, little impact to the water quality is expected as a result of baseflow, as groundwater salinity is very low and consistent with salinities observed in the river
- There appears little to no risk to river values from groundwater inflows into the waterways.
- There appears a risk to river values from reduced recharge which is lowering water tables, thus reducing the available water for wetlands and any associated riparian vegetation. This risk may be reduced by delivering more surface water flow to waterways and wetlands outside of the main river channel

2.5 Geomorphology

The study reach has experienced a long and active history of channel adjustment, with a number of large-scale geomorphic processes occurring:

- channel avulsions
- anabranch development
- meander cutoffs
- bank erosion
- channel widening and straightening
- bed lowering

There are three main river systems that traverse the Macalister River floodplain (in addition to numerous abandoned courses and artificial channels): Newry Creek, the contemporary Macalister River and Boggy Creek. Newry Creek is an old course of the river that was abandoned following an avulsion into the current Macalister River. Boggy Creek, to the south of the Macalister River, is actively eroding towards the Macalister, and—according to Erskine *et al.* (1990) will eventually capture the Macalister River, forming a new course that will join the Thomson River some 16 km upstream from the present Thomson/Macalister Rivers confluence.

Since the 1870s the Macalister River has become shorter, steeper and wider. Where the bed is not armoured by gravels the channel is also deeper. Contributing factors for these changes are:

- changed flow and sediment regime due to the construction of Lake Glenmaggie
- natural and artificial cutoffs
- removal of bank vegetation
- concentration of flow due to the building of levees
- de-snagging operations
- high water tables from adjacent irrigation.

Lake Glenmaggie has introduced a major sediment discontinuity to the Macalister River. Lake Glenmaggie has a sediment trap efficiency of between 90% and 98% (Erskine *et al*., 1990 after Brune, 1953). Erosion from clear-water releases could have caused some downstream channel adjustment. Erskine *et al.* attribute bed armouring, channel widening and meander extension in the reach immediately below the dam to reduced sediment loads in the river.

The Macalister system has the following geomorphic features:

- Limited floodplain connectivity due to entrenched channel with large capacity
- The channel generally has a regular shape, with steep sides and benches in some locations
- Pools are provided throughout the system, with riffles only in some locations
- Coarse sediment generally dominates the bed and banks, with a significant sediment supply due to bank erosion; there is an increase in finer substrate downstream

3 Ecological values

This section provides a summary of the current ecological condition of the Macalister system (reach 1 and 2). Further detail on the current condition, trajectory and conceptual models for each water dependent value (native fish; water dependent vegetation; macroinvertebrates; Platypus and Rakali; birds, reptiles and frogs; and physical habitat) is provided in Section 4.

3.1 Water dependent values

Water dependent environmental values for the Macalister River catchment were identified by the Macalister River Project Advisory Group, West Gippsland CMA and the environmental flows Technical Panel through literature review and field assessment (Figure 7, detailed lists provided in Appendix B). These represent the overarching values to be maintained and or improved through the management of water for environmental benefit.

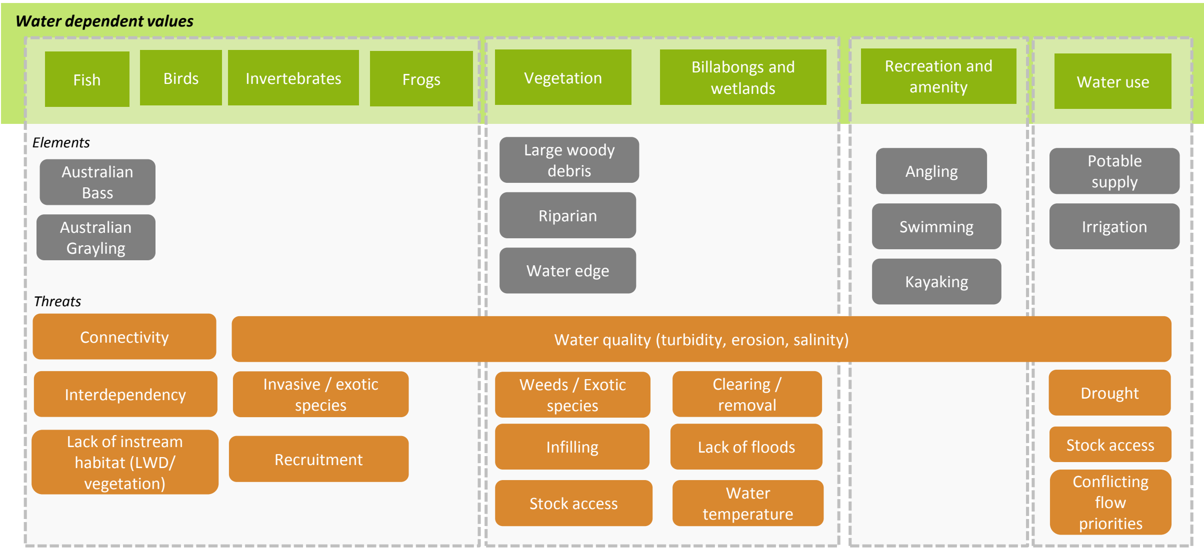


Figure 7. *Water dependent values and threats identified by the PAG 10 February 2015*

3.2 Catchment influences

There are a number of issues that influence the condition of water dependent values in the Macalister River system, there include:

- **Flow regulation** – The current operation of the MID has significantly altered the streamflow of the river from that occurring naturally downstream of Lake Glenmaggie. Notwithstanding the baseflows provided by Bulk Entitlement releases from Lake Glenmaggie, the current flow regime has reduced annual flow; sustained high discharges during the irrigation season; reversed flow seasonality (higher summer flows and lower winter flows); lost longitudinal connectivity (due to Lake Glenmaggie and Maffra Weir); and lost lateral connectivity (to the floodplain and adjacent wetlands) (SKM 2003).These changes have implications for water quality, geomorphological processes and direct and indirect effects on instream and riparian biota (SKM 2003).

- **Bushfire** - While the study reaches are minimally affected (mainly only by grass fires), bushfires upstream of Lake Glenmaggie are more common. In recent times, much of the area was burnt at some intensity in fires during 2006/7 and 2013. Such fires have dramatic impacts, particularly if followed by rain that transports ash and sediment into downstream areas (SKM, 2008; Smith et al., 2011). Such fires are probably a common part of the area's history, with some vegetation species present that are fire dependent, and it is likely that it will be subject to fire in the future.

- **Stream bed, bank and floodplain condition** – agricultural development of the lower Macalister River's floodplain has a left a legacy of channel instability (bed and bank erosion), riparian degradation (clearing and exotic species colonisation) and diminution of the ecological function of the floodplain and its wetlands (SKM 2003).
- **Barriers** - Dams and weirs within rivers and streams can affect the distribution and diversity of native fish. These structures act as barriers, restricting the movement of fish that migrate to complete a component of their lifecycle. Both Maffra weir and Lake Glenmaggie are significant barriers in the system.
- **Environmental entitlement** – a limit on the volume of water available for environmental watering in the Macalister system is set out in the Environmental Entitlement. Delivery of environmental water is subject to the operational arrangements made with the storage manager (Southern Rural Water).

This study will recommend actions to improve the flow regime to achieve ecological objectives (discussed in the next project report – Part B). However, the issues listed above also require complementary management in order to maximise the ecological benefits of environmental watering in the river (this will also be provided in the next report – Part B).

3.3 Waterway management priorities

The management priority of the water dependent values is guided by the WGCMA *West Gippsland Waterway Strategy 2014-2022*. The Macalister system downstream of Glenmaggie is considered a Priority River – threat reduction. For the Lower Latrobe, Thomson and Macalister Work Program, *Long Term Resource Condition Targets* include:

- All expected native fish species (migratory and non-migratory) are found in the reach and their abundance has increased.
- Populations of Australian Grayling are self-sustaining.
- Vegetation establishment provides a robust buffer, improves vegetation connectivity and shading of waterways.
- Water regime is managed to provide required base flows and flow variability within and between seasons.
- Habitat for birds particularly in terms of the condition and extent of wetlands is maintained.
- Riparian vegetation provides improved visual amenity and contributes to community use.
- Community uses are maintained through improvements to water quality and erosion.
- Waterways in the catchment provide water of suitable quality to support economic uses including township, rural uses and fishing.
- Waterways are physically stable (not actively eroding at high rates) and their values are not threatened by waterway instability.
- The extent of freshwater wetlands (including Seasonal Herbaceous Wetlands of the Temperate Lowland Plain) is maintained and their condition has improved.

The values linked to Regional Goals include fish, birds, invertebrates, vegetation, landscape, social, economic, and hydrology. These management priorities guide the objectives for environmental flows in the system.

4 Objectives and conceptual models

4.1 Ecological flow functions

The diagram below (Figure 8) identifies the ecological flow functions for each of the water dependent values. Note that for each theme there are also non-flow related ecological objectives that will influence the condition of each value.

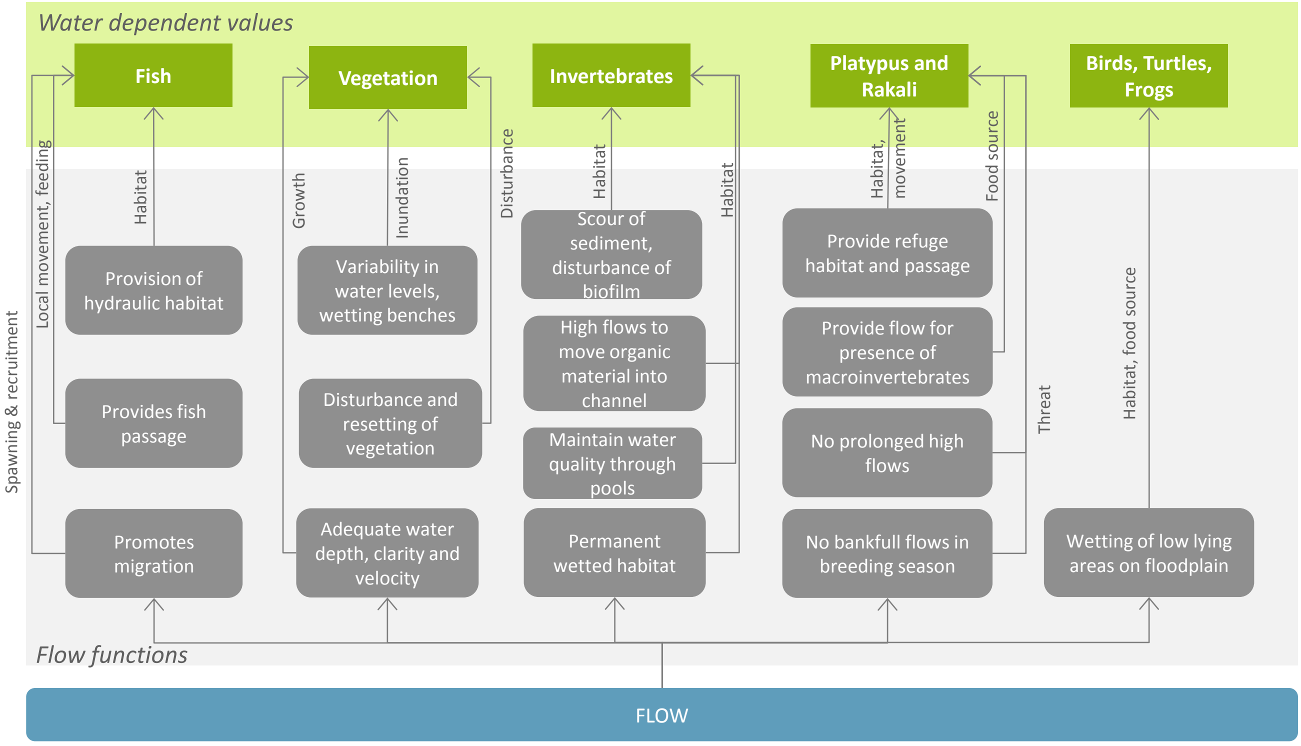


Figure 8. *Flow functions, categorised under the relevant water dependent value. Note that the condition of each water dependent value is also influenced by non-flow related factors (e.g. land use).*

Conceptual models that describe the links between flow and ecology have been developed by the technical panel for the water-dependent values of the Macalister system. These models explore the ecological flow functions described above.

In this section, a detailed description of the current condition of water dependent values and their conceptual models is provided.

4.2 Fish

Description

Since 2003 there has been a considerable number of additional fish surveys conducted in the river downstream of Lake Glenmaggie as part of the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP), which has improved our understanding of the fish assemblages present. A summary of the current condition of fish assemblages in the Macalister River below Lake Glenmaggie based on this new information is provided below.

Eleven native freshwater fish species have been recorded in the lower Macalister River (Amtstaetter and O'Connor 2014). Three species, Australian bass, short-headed lamprey, and dwarf flat-headed gudgeon, were not previously listed as recorded in the lower Macalister River, although the two former species had been recorded upstream of Lake Glenmaggie (SKM 2003). Records of Australian bass in the recent surveys likely reflect artificial stocking in recent times[1], while the lack of previous records of dwarf flat-headed gudgeon

[1] Australian bass were released into the lower Macalister River annually between 2010-2014 with the exception of 2012

possibly reflects some misidentifications of the morphologically similar flat-headed gudgeon. Only low numbers of dwarf flat-headed gudgeon and short-headed lamprey have been recorded in the recent surveys. Estuary perch, which predominantly inhabit estuarine waters, have also occasionally been recorded in the lower Macalister River.

Diadromous species
Six of the native freshwater fish species exhibit obligatory diadromous life histories (i.e. move between freshwater and marine habitats at some stage during their life cycle (Harris 1984)). Several specific modes of diadromous migration are recognised, including anadromy, catadromy and amphidromy (Myers 1949; McDowall 1988). 'Anadromous' fishes, enter rivers from the sea as mature adults and migrate to upstream spawning grounds, with juveniles later migrating downstream to the sea. 'Catadromous' fishes enter rivers from the sea as juveniles, and adults return to the sea or estuary to spawn. 'Amphidromous' fishes mature and spawn in fresh water and the larvae drift downstream to the sea, with juveniles migrating back into fresh water. Of the diadromous species in the Macalister River, most are catadromous (e.g. tupong, short-finned eel, long-finned eel, common galaxias, Australian bass), but a small number of species are amphidromous (e.g. Australian grayling) or anadromous (e.g. short-headed lamprey).

Most diadromous fish species in the Macalister River are more prevalent in the lower reaches below Maffra Weir (Figure 9), which has been identified in the Victorian State Fishway Program as a barrier to fish movement (McGuckin and Bennett 1999) - exceptions include eels, which are capable of climbing over barriers. Although the Weir gates are opened from May-August, a knife edge weir immediately downstream of the gates likely impedes any upstream passage unless it is 'drowned' out during elevated flows (Figure 9). Indeed, one of the most significant findings of the recent surveys was collections of low numbers of Australian grayling and tupong upstream of the Weir (Amtstaetter and O'Connor 2014), which indicate that some fish have been able to take advantage of such occasional migration opportunities.

Figure 9. *Maffra Weir gates (left) and knife edge weir (right) on the Macalister River*

Non-migratory species
Five of the native freshwater species in the lower Macalister River are 'non-migratory', although one species, Australian smelt, may have both diadromous and non-diadromous components (Crook *et al.* 2008). The results of recent surveys and earlier records indicate that Australian smelt is widely distributed within the lower Macalister River (SKM 2003; Amtstaetter and O'Connor 2014).

River blackfish also reportedly previously had a wide distribution (SKM 2003), but only one individual was collected in the recent surveys, which suggests that populations of this species in the lower Macalister River are currently small and limited in distribution. It has been suggested that river blackfish are not particularly flow sensitive (Davies 1989) and that impacts such as removal of woody debris, sedimentation and cold-water pollution may have a greater impact on this species than flow regulation (Doeg and Koehn 1994; Gippel and Stewardson 1995). Lake Glenmaggie has modified the water temperature of the river downstream (Ryan 2001), which could result in the loss or disruption of important biological cues. Spawning of river blackfish, for example, is thought to be water temperature dependent (Koehn and O'Connor 1990). The degree of impact of recent (e.g. 2006-07) fires and associated sediment deposition on river blackfish and other fish in the Macalister River is unknown. These events could have had impacts by decreasing pool depth by filling with sediment, reducing food supply and reducing the useable resting and spawning habitats.

Little detailed information is provided on southern pygmy perch in the previous flows assessment (SKM 2003), but recent surveys indicate that populations are currently small and limited in distribution. Southern pygmy perch have a strong preference for abundant aquatic vegetation in slow flowing water (Humphries 1995). A general lack of aquatic vegetation in the lower Macalister River may explain the lack of southern pygmy perch.

Flat-headed gudgeon reportedly had a previously limited distribution in the lower Macalister River (SKM 2003), however, recent surveys have recorded this species from numerous sites (Amtstaetter and O'Connor 2014). This species generally tolerates a wide range of environmental conditions and flow regulation is unlikely to have a major adverse effect on them (Balcombe *et al.* 2011; Humphries *et al.* 2012).

Introduced species

Five introduced fish species have been recorded in the lower Macalister River. Recent surveys indicate that carp dominate fish biomass (Amtstaetter and O'Connor 2014, ARI unpublished VEFMAP data). In contrast, carp were not recorded in surveys of the Macalister River in the late 1980s (Hall 1989). Eastern gambusia are also widespread and abundant biomass (Amtstaetter and O'Connor 2014, ARI unpublished VEFMAP data).This introduced species is a highly successful invader of aquatic environments, thought to detrimentally impact native fishes directly (Macdonald *et al.* 2012). Goldfish and redfin are also present in lower numbers biomass (Amtstaetter and O'Connor 2014, ARI unpublished VEFMAP data).

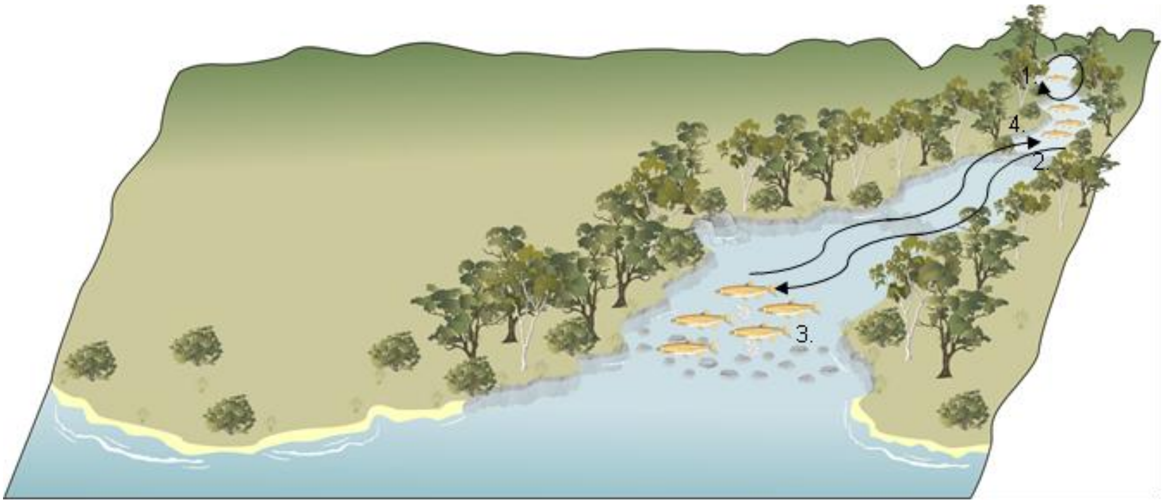
Conceptual model – flow-ecology links

Since the original flows assessment (SKM 2003), significant new information has been obtained to improve our understanding of the flow-ecology relationships for Australian grayling. A summary of this increased understanding is provided below.

The most comprehensive previous study of the life history of Australian grayling, in the Tambo River, suggested that spawning most likely occurs in upriver freshwater reaches (Berra 1982). In contrast, recent research demonstrates the existence of a long-distance downstream spawning migration to lower river reaches immediately upstream of the estuary, associated with increased river discharge in autumn (Figure 10) (Koster *et al.* 2013). The large distances (e.g. ~ 30 km) often travelled, and a tendency of Australian grayling to cease downstream migration when discharge declines, highlights a need to provide flow events of sufficient magnitude and duration to allow adults to reach spawning areas. In the previous flows assessment (SKM 2003), flow recommendations focused on flow events in June-July to trigger spawning. However, downstream migration and peak egg abundance occur predominantly in April-May (Koster *et al.* 2013). As previously discussed, increased flows in spring-summer are often recommended to trigger upstream migration of juvenile Australian grayling and other diadromous species(e.g. Earth Tech 2003; SKM 2003), but the influence of flow on the migration of these species is poorly understood.

Our understanding of the flow-ecology relationships for tupong has also improved. In the previous flows assessment (SKM 2003), flows were recommended in spring to trigger migration. However, recent research shows that downstream migration to the sea occurs predominantly in May-August (Crook *et al.* 2010).

Recent research has also improved our understanding of the flow-ecology relationships for river blackfish. Previous studies suggest that the river blackfish is a sedentary species that occupies a highly restricted range (<30 m) (Koehn 1986; Khan *et al.* 2004). However, at times they also undertake frequent localised movements among habitats at night, longer-distance upstream movements, and lateral movements onto inundated riparian areas during or following increased discharge (Koster and Crook 2008). Flows to maintain adequate depths through riffles to allow for fish passage may be important for river blackfish to allow them to move through shallower areas between their usual locations in deeper habitats.



1. Fish display only small-scale movement prior to migrating downstream
2. Fish undertake rapid long-distance downstream migrations to the lower reaches of rivers in April–May, coinciding with increased flows. Fish that have not arrived at the lower reaches during the high flows cease their migrations temporarily, and then recommence migration on the next flow event.
3. Spawning activity is concentrated in the lower freshwater reaches
4. Following downstream migration, most individuals return upstream to the area they previously occupied

Figure 10. *Summary of movement behaviours of adult Australian grayling and links to flow*

4.3 Vegetation

Information on water-dependent vegetation of the Macalister River is available through:

- 2003 Macalister River environmental flows study – SKM 2003
- VEFMAP vegetation assessments - Practical Ecology 2009, Water Technology 2012
- Vegetation community mapping – Biodiversity Interactive maps

The 2003 FLOWS study (SKM 2003a, b) provided only a small amount of information on water-dependent vegetation, but did note the presence of Water Ribbons and charophytes (macrophytic green algae) in Reach 1. Knotweeds (*Perscaria* spp.) were observed along the banks. There was little instream or submerged vegetation in Reach 2, but small beds of Common Reed were present along the banks. The riparian zone was dominated by willows, River Red Gum and Silver Wattle (*Acacia dealbata*). Many exotic and weedy species were reported for the riparian zone of Reach 2, including Box Thorn (*Lycium ferocissimum*) and Blackberry (*Rumex* spp.).

Practical Ecology (2009) provided a detailed assessment of water-dependent and fringing terrestrial vegetation in the two reaches. The canopy layer in Reach 1 was dominated by Mountain Grey Gum (*Eucalyptus cypellocarpa*) and Narrow-leaf Peppermint (*Eucalyptus radiata*). The shrub layer included dense stands of Burgan (*Kunzea ericoides*), Mountain Tea-tree (*Leptospermum grandifolium*), Woolly Tea-tree (*Leptospermum lanigerum*) and Silver Wattle. The zone nearest the stream was vegetated with a mix of native and exotic taxa, the former including *Carex* spp., *Juncus* spp., River Club-sedge (*Schoenoplectus tabernaemontani*) and knotweeds. Exotic species were abundant (e.g. Kikuyu **Pennisetum clandestinum*), but many sites had been successfully revegetated with native and possibly non-local eucalypts, wattles, and bottlebrushes. In Reach 2 the canopy layer was dominated by River Red Gum and '… an often dense, impenetrable mid-storey of willows **Salix* spp. and blackberry **Rubus fruiticosus* spp. agg.' (Practical Ecology 2009, page 45). There was little instream or fringing vegetation other than occasional beds of Common Reed.

Water Technology (2012) repeated the assessment undertaken three years earlier by Practical Ecology (2009). They reported the fringing terrestrial vegetation in Reach 1 included a number of different ecological vegetation classes (EVCs) and that repeat photography of given sites showed dramatic increases in the density of native understorey woody vegetation. Vegetation condition was rated as 'medium-high' in the upper parts of Reach 1 and 'medium-low' in lower parts dominated by willow. Although the canopy layer was frequently dominated by native taxa (e.g. River Red Gum and Silver Wattle), the shrub layer was often dominated by exotic taxa, including introduced grasses, blackberry and *Tradescantia fluminensis*. Canopy species in Reach 2 included River Red Gum and Silver Wattle, but the understorey was frequently dominated by exotics, with a similar floristic composition to that recorded for upstream sampling sites. Vegetation condition was scored as 'medium-low'.

The Biodiversity Interactive Map, Version 3.2[2] provides modelled information on the presence and distribution of current (2005) and pre-European (1750) EVCs in the study region (Figure 11 and Figure 12).

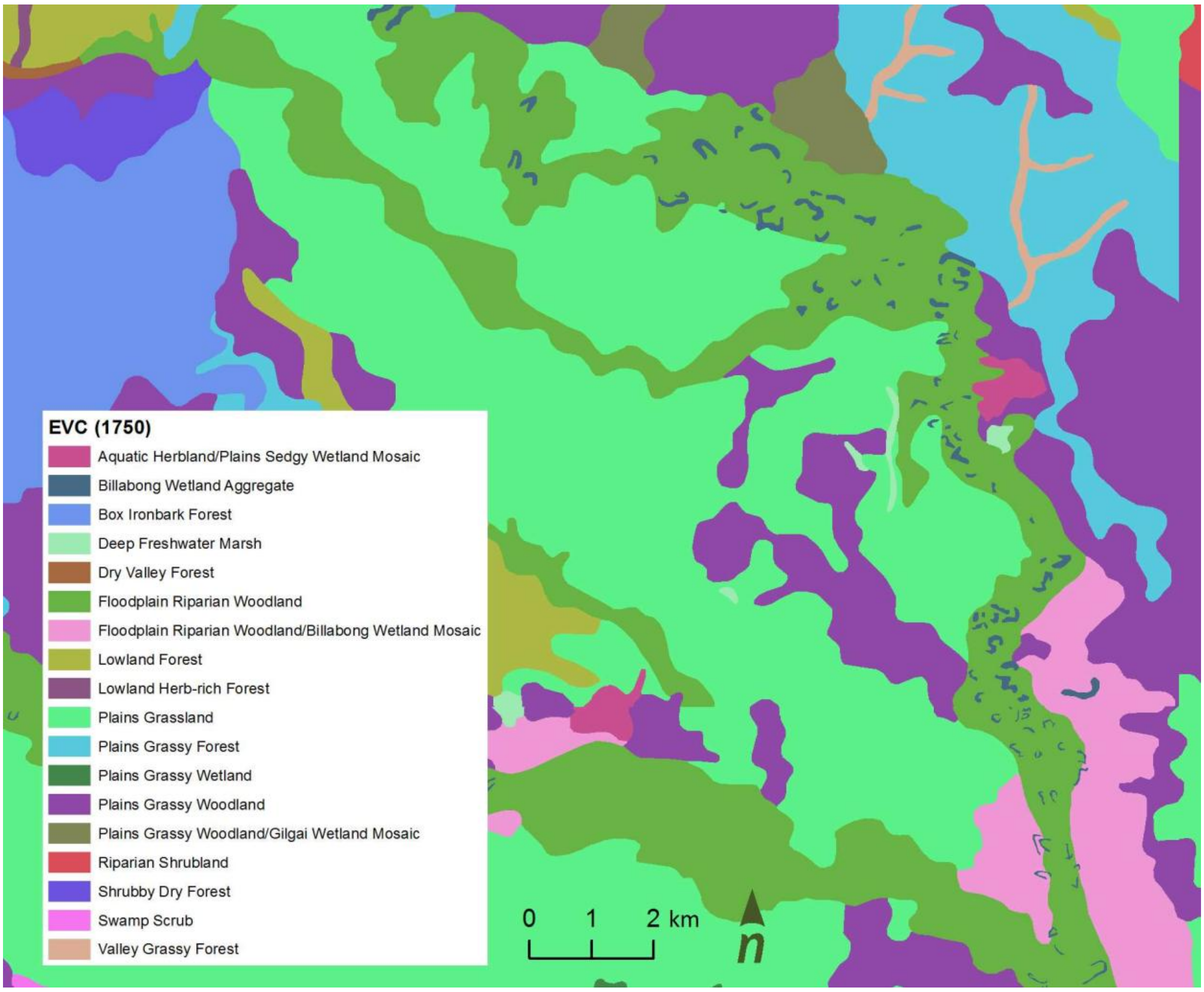


Figure 11. *EVCs in the Macalister system – 1750*

[2] http://mapshare2.dse.vic.gov.au/MapShare2EXT/imf.jsp?site=bim

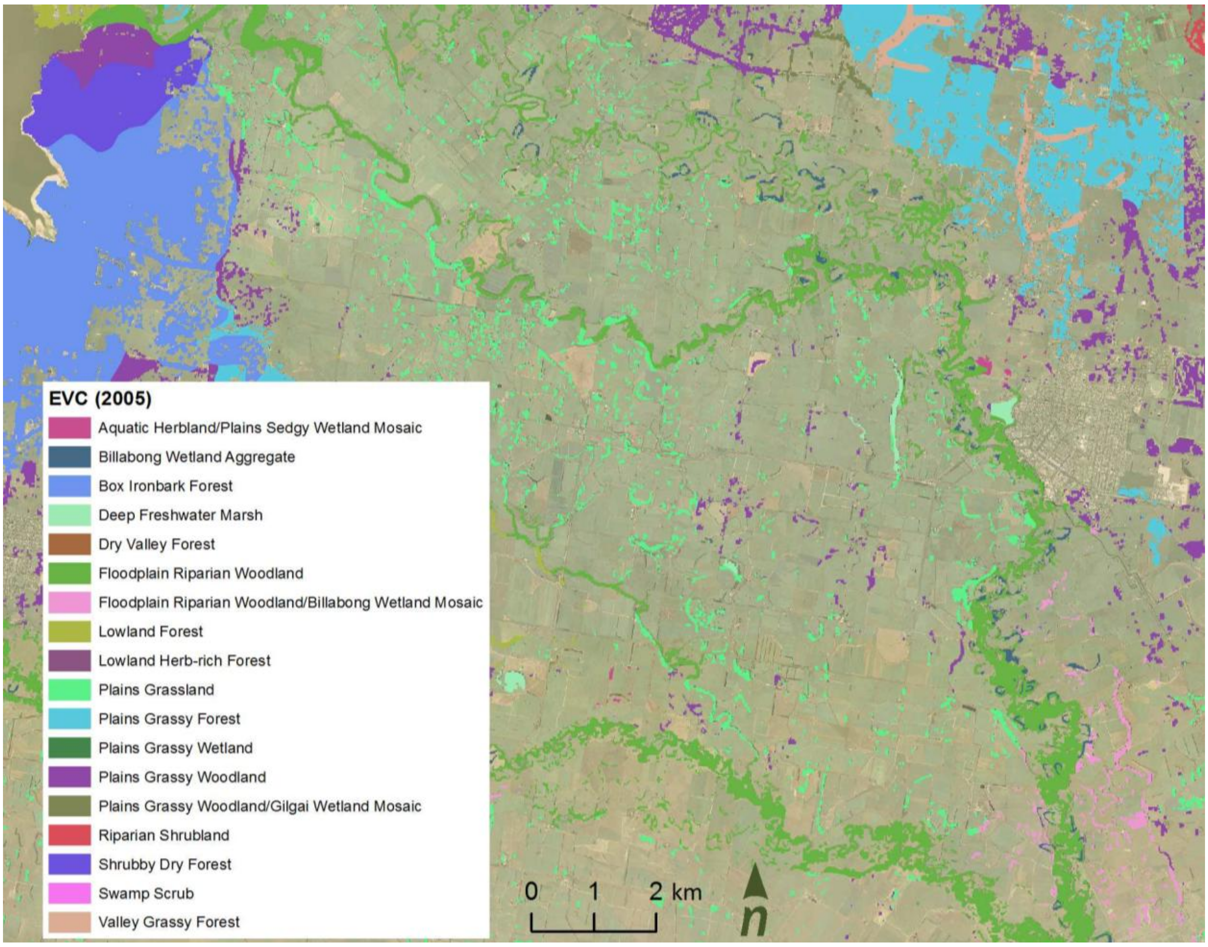


Figure 12. *EVCs in the Macalister system – 2005*

Information gathered during the field inspections (9 and 10 February 2015) can be used to supplement the information available in the existing reports and from the Biodiversity Interactive Maps. Four sites in Reach 1 were examined during the field excursions: Lanigans Bridge; Hagens Bridge; Factory Lane; and Bellbird Corner. Little or no instream vegetation was observed at any of these sites, although there were scattered and small swards of emergent non-woody macrophytes (*Bolboschoenu*s, *Cyperus* and *Schoenoplectus* spp.) as well as dense bands of fringing shrubs, mostly Silver Wattle and various species of bottlebrush and tea-tree. Many of the woody species resulted from earlier revegetation and riparian-fencing programs. Instream vegetation was not observed in the upstream or downstream sections of Reach 1, in contrast to the observations reported in the original FLOWs study of 2003. As outlined in the following section, turbid water may be a reason for the absence of submerged vegetation in the river.

Description of water-dependent vegetation types

There are three vegetation types associated with the Macalister River – instream plants, emergent non woody vegetation and fringing woody vegetation (Table 1).


Figure 13. *Fringing vegetation near Hagens Bridge (left) and near Factory Lane. Photograph by Paul Boon, February 2015*

Table 1. Summary of vegetation type condition in the system

Vegetation type	Description of vegetation type	Summary of condition in the Macalister system
Instream plants with submerged or floating leaves	Examples: - submerged-leaf aquatic plant common across south-eastern Australia is Ribbonweed or Eelweed (*Vallisneria australis*) - species with floating leaves is Water Ribbons (*Triglochin procerum*) - Many pondweeds (*Potamogeton* spp.) also have floating leaves. Although a wide variety of native submerged plants occur in streams of south-eastern Australia, introduced species may be present too, usually in empoundments.	Little or no instream vegetation currently observed, despite having previously been present.
Emergent non-woody vegetation in the shallow margins of the stream or on the lower banks	This is often a floristically diverse group and may include plants in the Family Juncaceae such as rushes (*Juncus* spp.), as well as many genera in the Family Cyperaceae, including twigrushes (*Baumea* spp.), clubrushes or clubsedges (*Bolboschoenus* and *Schoenoplectus* spp.), sedges (*Carex* and *Cyperus* spp.), spikerushes (*Eleocharis* spp.), sawsedges (*Gahnia* spp.). Grasses (in the Family Poacea) may also be present. A widespread native example is the Common Reed (*Phragmites australis*), but there may be also a large number of exotics and weeds, usually escaped and invasive pasture species. Cumbungi (*Typha* spp., in the Family Typhaceae) may also be found in this ecotone. Two species of Typha in Australia are native and one (**Typha latifolia*) is introduced: the introduced species has been reported episodically from various parts of Gippsland.	Scattered areas of emergent non-woody macrophytes, reduced from previous assessments
Fringing woody vegetation in the riparian zone	The most widely distributed example in this group is the River Red Gum (*Eucalyptus camaldulensis*), but in the Gippsland region other common taxa include paperbarks (*Melalauca* spp.), bottlebrushes (*Callistemon* spp.) and teatrees (*Leptospermum* spp.). The riparian zone is highly susceptible to invasion by woody weeds: willows (**Salix* spp.) and poplars (**Populus* spp.) are examples from Gippsland.	Dense bands of fringing shrubs (resulted from revegetation and fencing programs): Silver Wattle, bottlebrush and tea-tree Canopy layer: Mountain Grey Gum, Narrow-Leaf Peppermint, River Red Gum Some areas of exotic woody and non-woody species – willows and poplars, grasses, blackberries

The interaction between flow and landscape topography creates a mosaic of wetting and drying regimes at a wide range of spatial scales in the riparian zones, and fringing are variously advantaged by this subtle suite of hydrological conditions. Without action (flows and source of propagules), instream and non-woody emergent vegetation will not be present. Also without a focus on grazing and weed pressures, the riparian zone may decline in quality.

At the Weir Road site downstream of the outfall, vegetation condition may improve if the exotic species can be controlled (Water Technology 2012). Downstream of Maffra Road, vegetation condition may improve if there continues to be sufficient rainfall and if stock remain excluded from the site (Water Technology 2012). At the Newry Creek confluence, vegetation condition may improve if the exotic understorey can be suppressed (Water Technology 2012). Near Forsyths Lane, vegetation condition is expected to remain in its current condition or decline further, unless stock is excluded and there is significant weed control.

Conceptual model – flow-ecology links

Figure 11 shows a conceptual model of the way different vegetation types respond to variations in flow in the Macalister River.

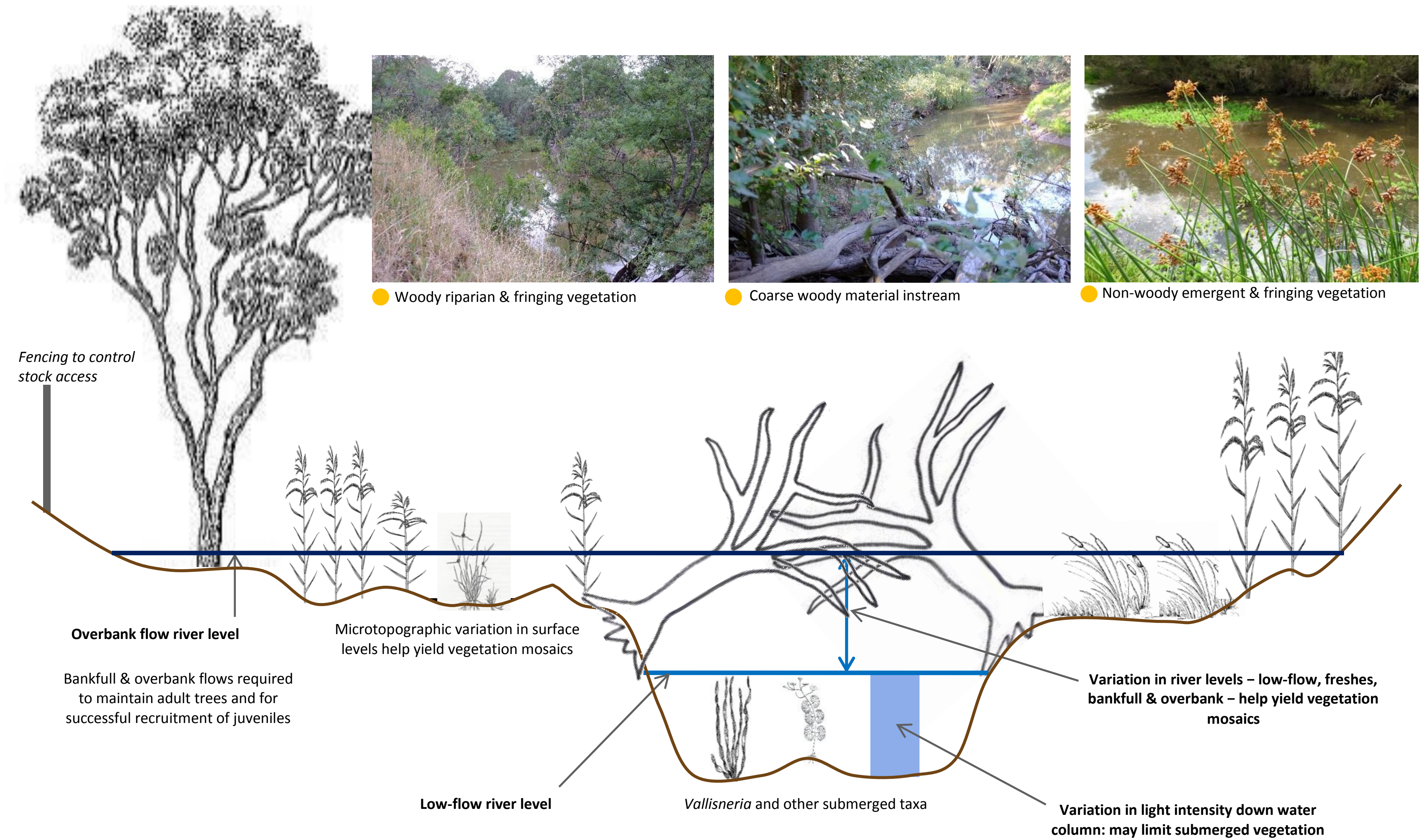


Figure 14. *Conceptual model of the relationship between vegetation and flows in the Macalister River*

Instream vegetation
An important factor for the presence of instream vegetation is the availability of deep water to support plant growth, however there are other factors that may be limiting the presence of instream vegetation in the Macalister system. The conceptual model shows that instream vegetation may be limited by a number of factors:

- **Water clarity**: water that is too turbid or coloured limits the depth to which plants with submerged leaves can grow. In contrast, species with floating leaves may not be excluded from even highly turbid waters, as their photosynthetic organs are exposed to sufficient light at all times of the day to maintain a positive carbon balance
- **Water depth**: water that is too deep, especially if it is turbid or coloured, will not support submerged taxa.
- **Water velocity**: fast-flowing water may physically uproot submerged plants, many of which have only a poorly developed root system (since they obtain their nutrients from the water column (Madsen & Cedergreen 2002; Angelstein & Schubert 2008; Wersal & Madsen 2011).
- **Substratum**: dense clay sediments may be largely impenetrable to plant roots (as submerged plants have a weakly developed root system); conversely, sandy sediment may be too unstable to allow plants to establish. Rocky substrata may also be unsuitable.
- **Source of propagules**: for plants to establish in a given area there must be a source of propagules, either as seed (which can be brought in via water, wind, or on animals) or as plant fragments (usually brought from upstream, via flow).
- **Grazing pressure**: the consumption of plants, by aquatic animals (e.g. carp), birds (e.g. swans) or stock (e.g. cattle) may limit to biomass of instream vegetation that accrues over time.

Emergent and fringing vegetation
Fringing woody and non-woody vegetation may be affected by a similarly broad suite of environmental factors. Because they have aerial photosynthetic organs, these vegetation groups are not strongly affected by water clarity. They are, however, very susceptible to herbivory, especially by domestic stock. Aquatic taxa are often softer and more palatable to stock than are terrestrial plant species; and the seedlings and young plants of even woody riparian taxa are often eagerly consumed by herbivores (Jane Roberts pers comm.; Price & Lovett 2002). Successful recruitment of young plants into the population is therefore almost always contingent upon the control of grazing pressures (either by native animals, such as kangaroos and wallabies; feral species, such as rabbits; or domestic stock such as cattle). A specific example in the Macalister River is the loss of the Common Reed. Figure 15 shows Macalister River at Bellbird Corner in the 1930s with Common Reed present (left photo) and 2015 without the instream vegetation (right photo). Roberts (2000) has found a similar trend across agricultural areas of south-eastern Australia which may be attributable to grazing pressure.

Figure 15. *Macalister River at Bellbird Corner in the 1930s (left) and 2015 (right). Photographs by Duncan Fraser and Paul Boon respectively*

There is now a robust literature on the way that different water-dependent groups of plants, and in some cases even specific taxa, respond to different water regimes (e.g. see Ganf *et al*. 2010; Roberts & Marston 2011; Rogers & Ralph 2011). The information base is, alas, based strongly on examples from the Murray-Darling Basin and it is unclear how well plant behaviour there can be extrapolated to wetter regions, such as many parts of Gippsland. Little is known, for example, about the water-regime requirements of the paperbark, bottlebrush or tea-tree taxa common throughout Gippsland (e.g. see Hamilton-Brown *et al*. 2009). Existing information is limited too to a relatively small number of well-studied species, and it is often necessary to infer optimal water regimes for broad plant groups (Brock & Casanova 2000; Rogers *et al*. 2012).

The patterning of fringing woody and non-woody vegetation is controlled not only by water regime *per se* but even more so by the interactive relationship among water regime, elevation (e.g. up a bank) and small-scale variations in topography (Raulings *et al*. 2010; Boon 2011). The interaction between flow and landscape topography creates a mosaic of wetting and drying regimes at a wide range of spatial scales in the riparian zones that fringe a stream, and different types of fringing vegetation are variously advantaged or selected against by this subtle suite of hydrological conditions.

Water-regime requirements of broad vegetation types

The environmental objectives for vegetation in Reaches 1 and 2 were finalised at the workshop of 18 March 2015:

- rehabilitate submerged aquatic vegetation
- rehabilitate emergent and fringing aquatic vegetation
- rehabilitate native riparian vegetation
- limit encroachment of undesirable species.

The water regimes best suited to achieving the first three objectives are shown in Table 2. The fourth objective is unlikely to be met with changes to water regime and is best addressed through complementary riparian management activities.

Note that water requirements for instream submerged vegetation are reasonably well understood, whereas those for fringing non-woody vegetation are based on generic wetting and drying cycles to maintain rushes, reeds and sedges and other types of emergent water-dependent vegetation. The water regime requirements for the fringing woody taxa that occur in the study site (e.g. *Callistemon, Leptospermum* and *Melaleuca* spp.) are very poorly understood. The following broad recommendations are drawn primarily from Roberts & Marston (2011) and Rogers & Ralph (2011). Note that both these references deal with aquatic plants in the Murray-Darling Basin; comparable collations are not available for plant taxa (or for broader groups, such as EVCs) in the study area.

Table 2. Water requirements of three broad types of water-dependent vegetation associated with the Macalister River.

Hydrological component	Instream vegetation	Fringing non-woody vegetation	Fringing woody vegetation
Ideal timing	Annual	Annual, preferably in spring to summer	Not well known, but likely to be late winter, through spring, to early summer.
Frequency to maintain adults	Constant	7-10 years per decade	Annual
Duration to maintain adults	9–12 months	2-10 months, but more typically 2-6 months	Not known, but likely to be < 3 months
Maximum period between floods to maintain adults	0 months	10 months	Not known, but various woody taxa can probably withstand an absence of inundation for a number of years (albeit with loss of plant vigour) as long as they maintain access to shallow groundwater or hyporheic water.

Hydrological component	Instream vegetation	Fringing non-woody vegetation	Fringing woody vegetation
Maximum period of inundation	Constant	Varies widely with taxa and their position along an elevational gradient from the river. Species will sort along this elevational gradient; those closest to the river will withstand prolonged inundation; those on more elevated land will withstand less. This sorting accounts for the wide variation in the duration to maintain adults. Maximum biodiversity and plant vigour is obtained with shallow and fluctuating water levels.	Not known, and likely to vary widely among taxa. *Melaleuca ericifolia* in wetlands of the Gippsland Lakes, for example, can withstand inundation for >10 years, but with the loss of sexual reproduction and marked reductions in the health of adult specimens. The position of these taxa on the stream bank in the conceptual model (see Figure 14) indicates they are tolerant of regular or episodic but not permanent inundation.
Recruitment requirements	Not well known. Many taxa can establish via sexual (i.e. seed) and non-sexual (i.e plant fragments) means.	Not well known, but periodic drawdowns probably required to create damp areas for seeds to germinate.	Periodic drawdown or dry periods over spring to early summer to allow seed germination and the establishment of young plants.

Issues

The three most critical issues relating to water-dependent vegetation in Reach 1 and Reach 2 of the Macalister River are:

- The absence of instream vegetation, particularly of the submerged charophtyes and of the floating -leaved Water Ribbons recorded in the original (2003) FLOWS study
- The paucity of native non-woody vegetation in the shallow margins of the stream or along the lower banks. Historical evidence (e.g. Figure 6) suggests that the river has previously supported extensive beds of emergent macrophytes, particularly Common Reed.
- The dominance of the canopy layer of the riparian zone by woody introduced species, such as willows and poplars, and of the shrub and ground layers by introduced herbs, forbes and grasses.

Offsetting these problems is the effort that has been put into willow control (especially in Reach 1) and in controlling stock access via a highly effective program of riparian fencing. In many cases the widths of riparian zone protected by fencing accords well with the recommendations outlined in Land & Water Australia (2005).

Given that many of the vegetation issues in Reaches 1 and 2 relate primarily to land-use practices (e.g. fencing, stock access, weed control etc), it is the ancillary actions that are likely to be most beneficial to maintaining or rehabilitating water-dependent vegetation associated with the river. Environmental flows, however, may play an important role in re-establishing structurally and floristically diverse bands of native fringing vegetation (e.g. rushes, reeds, sedges etc). Water quality, particularly water clarity, may have an important role in facilitating the re-establishment of instream vegetation. For taxa that are currently 'missing' from the river requires, however, that there be a source of propagules to allow the colonization of presently unvegetated areas. It is not clear whether Lake Glenmaggie supports populations of the instream taxa that might be desirable in downstream reaches, not whether propagules in the river upstream of the reservoir could survive passage through it.

4.4 Macroinvertebrates

Description

Historically, the reach has undergone significant changes, becoming shorter, steeper and wider due to a variety of impacts, including changed flow and sediment regime, natural and artificial cutoffs, vegetation removal, levee construction, de-snagging and artificially high water tables from adjacent irrigation (leading to increased frequency of bank slumping). These have presumably led to reductions in the quality of available habitats for aquatic macroinvertebrates.

Both the flow regime and water quality downstream of Lake Glenmaggie have altered from what is presumed to be historical patterns. Further, the reach has been impacted by fire. While the immediate reach is little affected (mainly by grass fires), bushfires upstream of Lake Glenmaggie are more common. In recent times, much of the area was burnt at some intensity in fires during 2006/7 and 2013. Such fires have dramatic impacts, particularly if followed by rain that transports ash and sediment into downstream areas (SKM, 2008; Smith *et al*., 2011). Such fires are probably a common part of the area's history and it is likely that it will be subject to fire in the future.

Macroinvertebrate data from the study area are relatively sparse. The original FLOWS study details macroinvertebrate data assessed from one EPA site at Bellbird (just upstream of Maffra) on two occasions in autumn and spring, 1997. Macroinvertebrate indicators failed to meet the respective EPA objectives for AUSRIVAS, total numbers of families and number of key families (Table 3). The SIGNAL indicator only just managed to pass the EPA objective.

SKM (2003) suggested that due to the SIGNAL score of 5.55 complying with the SEPP objective for cleared hills and coastal plains segments of (EPA, 2001), habitat rather than water quality was potentially the limiting factor on stream health.

Table 3. Macroinvertebrate indicators from Bellbird (1997) and Riverslea (1997-8). Only edge data were recorded[3]. EPA Objectives for Cleared Hills and Coastal Plains segments in parentheses.

Site	Date	AUSRIVAS (A)	SIGNAL (5.5)	Families (26)	Key Families (22)
Bellbird Corner	1997	C[4]	5.55	21	16
Riverslea	1997/8		4.95		

Cameron and Vertessy (1998) sampled the Macalister River at Licola (upstream of the study area) and at Riverslea in Spring 1997 and Autumn 1998. Both sites were assessed as having very low aquatic diversity, with SIGNAL indicative of probable moderate pollution. They suggested, at least for the Licola site, that poor water quality due to alpine fires might have impacted upon the macroinvertebrate assemblages observed.

In general macroinvertebrate communities in the Macalister River at the time of the 2003 study were indicative of poor environmental conditions, with fewer taxa that expected and taxa that would indicate the river was in good condition missing. SIGNAL scores were borderline acceptable under EPA objectives. It should be noted that EPA objectives in these predominantly rural areas recognise that some disturbance from land clearing and use has occurred, so the objectives describe the minimum macroinvertebrate community attributes that would determine a "healthy as reasonably expected" state (so a SIGNAL score that meets the objectives does not represent "clean" undisturbed conditions).

Additional macroinvertebrate data was obtained after the original FLOWS study. Two sites were sampled by Matthews (2006) in Autumn 2002 and Autumn 2006 – Manson's Bridge just downstream of Lake Glenmaggie and Bellbird Corner in Maffra. The data reflected earlier conditions, with low diversity and SIGNAL grades (Table 4).

Table 4. Macroinvertebrate indicators from two sites in 2002 and 2006 (edge data only)

Site	Date	Families	SIGNAL
Manson's Bridge	2002	16	4.9
	2006	24	5.0

[3] Normally, assessments of macroinvertebrate communities are based on a combination of edge and riffle habitats. Few riffles occur in the lower Macalister and samples from these habitats are uncommon, so all data available are based only on edge habitat samples.
[4] An AUSRIVAS rating of B for the same data is stated in the EPA summary document – EPA (2002) *Environmental Condition of Rivers and Streams in the Latrobe, Thomson and Avon Catchments*. Publication 83. EPA Victoria, Southbank.

Bellbird Corner	2002	19	4.7
	2006	21	4.1

Data from edge habitats between 2005 and 2006 (Crowther and Papas, 2006) reiterate previous samples (Table 5) where only a few indicators at a few sites meet EPA objectives. They attributed the low diversity to "…poor riparian and instream habitat and impaired water quality." (Crowther and Papas, 2006, p. 22).

Table 5. Macroinvertebrate data from four sites in 2005-2006 (Crowther and Papas, 2006 – edge data only). Green cells indicate samples that meet EPA objectives

Site	Date	AUSRIVAS	Families	SIGNAL
MAC3 – 1 km d/s dam	2005	B	22	5.0
	2005-6	B	21	5.0
	2006	B	23	5.1
MAC4 – 25 km d/s dam	2005	B	27	5.3
	2005-6	B	29	5.2
	2006	B	24	5.5
MAC5 – 31 km d/s dam	2005	B	24	4.9
	2005-6	B	21	5.3
	2006	B	29	5.0
MAC6 – 35 km d/s dam	2005	B	23	4.9
	2005-6	B	21	4.9
	2006	B	23	5.1

Since these studies, bushfires in 2006/07 bushfires affected much of the upper Macalister River catchment. During February 2007, severe storms resulted in significant sediment and ash loads into Lake Glenmaggie. Additionally, rainfall in late June 2007 caused a 1 in 100+ year flood downstream of Lake Glenmaggie (SKM, 2009). This caused large-scale bank erosion and mass sediment mobilisation in the upper reaches (and presumably in-channel scouring).

The fires did not directly affect the study area, so that the riparian and fringing vegetation have remained relatively unchanged over time. However, recent observations (2015 – see vegetation section) suggest a decline in instream vegetation components, in contrast to the observations reported in the original FLOWs study of 2003. This may be due to a number of factors, including indirect bushfire effects.

There are no data available detailing the impact of the 2006/7 fires and floods, or the 2013 fires in the Macalister River. It is likely that the severe habitat and water quality impact in 2006/7 would have, at least temporarily, reduced the diversity of the community. Whether this potential reduction has persisted remains unknown.

Conceptual model – flow-ecology links

The four major determinants of the abundance and composition of the aquatic macroinvertebrate fauna are:

- Available habitat
- Sources of food
- Water quality
- Flow regime

In the main, the key habitats for macroinvertebrates in rivers are the stream bed, instream vegetation, the stream edge and woody debris. The abundance and availability of these habitats determine the overall diversity and composition of the stream macroinvertebrates. Within this stream community, there are taxa that can occupy all of these habitats, but there are also taxa specifically adapted to only one or some of these habitats. The overall diversity of a stream macroinvertebrate community is the combination of generalist and habitat-specific taxa. Monitoring macroinvertebrate communities over Victoria concentrate only on riffle (fast-flowing sections of stream bed) and edge habitats, so the communities identified in monitoring are only a subset of all the taxa present. In the lower Macalister River, monitoring data are primarily sourced from edge habitat samples, so the communities identified may represent only a fraction of the total species present.

Apart from the abundance and availability of the different habitat types, the quality of these habitats is important. Of particular concern, higher than natural levels of sediment deposited on the habitat surfaces has a major impact on the macroinvertebrate fauna, reducing the types of species that can be present.

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

Relatively little is known on the water quality tolerances of many macroinvertebrates, but water temperature, salinity and turbidity, are well known to have a major direct influence.

All three of the previous determinants are influenced by the flow regime. The major flow components of a flow regime all have specific, but mainly indirect, influences on the macroinvertebrate community of a stream.

Baseflows (low flows), both summer and winter, provide for wetted habitat. The macroinvertebrate fauna recorded in the Macalister River contains species (and families) typical of permanently flowing streams (such as mayflies, stoneflies and shrimps), so that providing permanent wetted habitat is essential to maintain the full diversity of the community. Over the dry summer and autumn period, baseflows maintain the level of water in pools, ensuring that edge vegetation is inundated. Inadequate summer/autumn low flows reduce the availability of pool edge habitats, but also influence water quality through elevated water temperatures and reduced dissolved oxygen levels. The naturally low dry season baseflows may result in restricted shallow water habitat.

The natural increase in baseflows over the winter and spring period produce more shallow water habitat, but also inundate low benches on the edge of the stream channel, again providing additional productive habitat areas. Wet season baseflows generally do not increase pool habitat areas (there is little increase in the depth and extent of pool water) but serve to maintain wetted edge habitats throughout the year.

Additional to adequate low flows, short periods of higher flows (freshes) are required to prevent the accumulation of fine sediment on habitats in the river at times of year when flows are low. Higher scouring flows are required to disturb the algae/bacteria/organic biofilm present on hard surfaces (a major food source for some macroinvertebrates). This disturbance is believed to maintain a diversity of available food sources, preventing any restriction to a small set of available food species (as seen in the dominance of filamentous algae in some rivers with inadequate scouring flows).

Flows that inundate in channel benches and bankfull flows that reach the riparian zones move organic material from the banks into the channel. This terrestrial organic material forms a major instream food source. These larger flows also have a role in retaining the channel form, preventing sediment accumulations that reduce available habitat.

4.5 Platypus and Rakali

Description

Platypuses (*Ornithorhynchus anatinus*) and Rakali/water rats (*Hydromys chrysogaster*) are native, semi-aquatic mammals found throughout a variety of permanent water bodies in Victoria, including the Macalister River (Grant 1992, Van Dyck and Strahan 2008). Although no targeted population studies have been conducted in the Macalister River on either species, data from online databases (Atlas of Living Australia, Victorian Biodiversity Atlas; accessed 10th March 2015) indicate the species' are widely distributed throughout the Macalister River and its tributaries. However, the distribution data from these sources is generally sparse, derived from anecdotal sightings, and more than 20 years old. As such, there is little information on the population trends, or the current distribution, abundance, or status of platypuses and Rakali in the Macalister system.

Population trends for platypuses and Rakali are poorly understood due to a lack of long term monitoring studies. Overall abundance of both species across their range have almost certainly declined significantly since European settlement through a combination of habitat destruction and degradation from altered land use practices and flow regimes, introduced predators, and poor fishing practices.

Historically both species were hunted extensively for their fur, many were drowned in commercial fishing nets, and Rakali were widely exterminated as vermin. It is unknown how prevalent these practices were in the Macalister River region. A recent assessment of the conservation status of platypuses throughout their national distribution indicated an overall population decline approaching 30% over the last 3 decades, with more substantial declines in Victoria (Woinarski et al. 2014). Similarly, Rakali are estimated to have undergone a decline in abundance of 10-50% throughout their range (Lee 1995).

More recently, localised extinctions and significant declines in the distribution and abundance of platypuses have been recorded in a number of river systems across Victoria where long term monitoring is conducted (Serena and Williams 2004, Williams 2010, Griffiths and Weeks 2011, 2013). These declines have been largely attributed to the severe drought conditions experienced during the first decade of this century and it is reasonable to assume that declines also occurred in other areas of Victoria, including the Macalister River. Given their reliance on aquatic ecosystems, it is likely the Millenium drought had a similar impact on Rakali populations as well.

In summary, both platypuses and Rakali are assumed to be relatively widespread throughout the Macalister system although at low abundance. Platypuses are predicted to be more abundant in the upper, forested reaches while Rakali may be more common near population centres in the lower reaches. Both species are thought to have experienced substantial declines in the area, most recently due to severe drought conditions. Platypus populations are likely to be taking longer to recover and may be considered vulnerable.

Known threats and conservation issues

Both platypuses and Rakali are highly adaptable species and can be found inhabiting a variety of different water bodies and environmental conditions. Both species are dependent on permanent water for feeding (although Rakali will also forage on land) and refuge from predators. Therefore the availability of sufficient surface water is a key habitat requirement.

Riparian vegetation is also important to stabilise banks for burrow construction, as well as providing cover while foraging (particularly for Rakali), reducing bank erosion and instream sedimentation, and important habitat for aquatic invertebrates. Many threats to platypuses and Rakali are through indirect impacts on their aquatic invertebrate prey. Threats to both species are predicted to increase due to human population growth and climate change (30% reduction in suitable platypus habitat predicted by 2070; Klamt et al. 2011). The opportunistic and adaptable nature of the Rakali probably enable it to cope with threats better than the platypus, and its greater fecundity allows populations to recover more quickly following disturbances.

Conservation Threat	Potential Impacts
Lack of surface water due to drought or altered flow regimes	reduction in available foraging habitat; loss of deeper refuge areas; inhibits movement and dispersal; fragmentation of populations through reduced connectivity; increased predation; reduction/alteration in aquatic invertebrate populations; lowers water quality; facilitates sedimentation; negatively impacts riparian vegetation; reduced juvenile recruitment.
Removal of riparian vegetation	banks unable to maintain stable burrows; reduction of cover while foraging; increased erosion and instream sedimentation degrading habitat quality for benthic invertebrates; reduced shading of water; access by stock increasing erosion; reduced organic input to stream; reduced instream habitat complexity and food for invertebrates.

Conservation Threat	Potential Impacts
Poor water quality	pollution from agriculture, industry and urban areas degrade water quality and impacts abundance and diversity of aquatic invertebrates; sedimentation reduces habitat quality for benthic invertebrates.
Floods	inundation of maternal burrows during breeding season with drowning or displacement of dependent young; displacement of adults to poor/unfamiliar habitat; increased foraging energetics; increased bank erosion.
Introduced predators	predation from foxes, dogs and cats; exacerbated by lack of water or instream barriers forcing individuals to traverse shallow water or land.
Dams and weirs	fragmentation of populations; increased predation; deeper impoundments generally unsuitable for foraging
Litter	direct mortality and injury from entanglement in enclosed loops
Poor fishing practices	direct mortality due to drowning in opera house nets (or similar), mesh nets and set lines; injury and mortality from entanglement in discarded fishing line and hooks

Conceptual model – flow-ecology links

There is a lack of empirical evidence on the impacts of flow regimes on platypuses and Rakali although the species do not require a particular flow event as a biological trigger (i.e. to stimulate reproduction). Both species are still found in a number of regulated rivers (although their abundance may have declined), suggesting they are tolerant of altered flow regimes. Environmental flows should replicate natural flow regimes as much possible. However, a number of general recommendations can be made based upon knowledge of the species' ecology and habitat requirements to minimise the impacts of altered flows.

Maintain baseflows throughout year

Reduction in available surface water through drought or extraction for agricultural, industrial or urban uses has multiple impacts on aquatic ecosystems (see table above). Ideally, baseflows should be maintained throughout the year to provide a minimum water depth of 10-20cm through the shallow riffle areas along the entire waterway to ensure connectivity of refuge areas, allow free movement of individuals along the river without leaving the water, provide protection from predators, and maintain invertebrate populations. If available water is limited, environmental flows should be directed towards maintaining baseflows during the juvenile emergence and dispersal period for platypuses (February to June) followed by female lactation (October to February) and mating season (August to October). If minimum flows can't be maintained throughout these periods, intermittent flows should be provided.

Avoid bankfull flows during breeding season

In many regulated rivers in southern Australia, water releases for irrigation are often at their highest during the summer months. Unfortunately this also coincides with the breeding season for platypuses where young are restricted to the maternal burrow and completely dependent on their mother (October to March in Victoria). Although Rakali can breed throughout the year if conditions are suitable, peak breeding season is generally during this period as well (Van Dyck and Strahan 2008). Bankfull flows during this period can potentially inundate maternal burrows, drowning or displacing nestling platypuses. Significantly fewer juvenile platypuses were captured in Melbourne streams following summer flood events (Serena et al. 2014). There are also several instances where nestling platypuses have been found displaced from burrows following floods. Rakali are predicted to be less impacted by temporary bankfull flows during the breeding season as they have a more flexible reproductive strategy and can produce multiple litters during breeding season. Bankfull or overbank flows at other times of the year may actually be beneficial for the species' by inundating adjoining wetlands and opening up new foraging areas.

Extended high flow events

High flows can potentially increase the foraging energetics for aquatic animals if they must swim against strong currents. High flows (< 150ML/day) have been found to alter the foraging behaviour of platypuses in a small urban stream (Griffiths et al. 2014). While individuals may be able to cope with short term high flow events prolonged periods of high flow could lead to loss of condition. High flow events can also reduce available food by displacing benthic invertebrates (Walsh et al. 2005), further compromising foraging efficiency. The impact of high flow events will vary between waterways depending on channel morphology and availability of slower flowing refuge areas (i.e. natural meandering streams will be less impacted than straightened drainage channels) and it is unknown how platypuses in the Macalister River may be impacted. Platypuses are highly mobile and are known to avoid strong currents where possible by foraging in backwaters (Gust and Handasyde 1995), in eddies or close to the bank where flows are reduced, or in adjoining wetlands or floodplains (Grant 2007).

Impact of cold water/low oxygen releases from reservoirs.
Water releases from large impoundments may originate from near the bottom of the reservoir where water temperature dissolved oxygen may be substantially reduced. Colder waters may increase the energetics required for thermoregulation for platypuses and Rakali. However, both species are known to inhabit cold waters and this is not anticipated to significantly impact either species. Rakali can become hypothermic during extended periods in water below 5oC (Dawson and Fanning 1981) but will leave the water to periodically warm up. More concerning is the potential for cold waters and low dissolved oxygen to impact the abundance or composition of aquatic invertebrates.

4.6 Bird, Reptiles and Frogs

Description
No listed taxa is confined to the lower Macalister River or its floodplain. Relative to the wider distributional ranges of the listed species covered by the review, the study area does not provide crucial or limiting resources to any of them. However, corridors of riparian vegetation along the river and around some meanders and billabongs and the wetland components of these, provide habitats for a variety of birds, reptiles and frogs. At the local level these will be maintaining the populations of many species. At the regional level they will also be serving to permit movements, particularly by birds. A variety of bird species move seasonally. These include species that migrate annually between lower and higher altitudes. Cover provided by vegetated corridors will be used by such species particularly as they move up and down between the nearby forested hill country and lowland plains.

The following listed species have a high likely occurrence in the study area: Clamorous Reed Warbler, Australian Shoveler, Fork-Tailed Swift, Eastern Great Egret, Hardhead, Musk Duck, Cattle Egret, Azure Kingfisher, Little Egret, Latham's Snipe, White-bellied Sea-Eagle, White-throated Needletail, Rainbow Bee-eater, Satin Flycatcher, Nankeen Night Heron, Pied Cormorant, Royal Spoonbill, Rufous Fantail, and Common long-necked Turtle.

Conceptual model – flow-ecology links
Birds, reptiles and frogs depend on the availability of aquatic habitat and high levels of productivity to maintain food resources including invertebrates, algae, macrophytes and fish. These species therefore depend on a seasonal flow regime that provides productive aquatic habitat particularly during breeding periods (mainly spring and summer).

Field investigations of the bird, reptile and frog fauna for the purpose of informing assessment of environmental flows of the lower Macalister River floodplain have not been undertaken. Information about the presence of species was obtained from searches of publicly available databases of species records maintained by BirdLife Australia and Victorian and Commonwealth government agencies. Due to the number of taxa and diverse ecologies of birds, reptiles and frogs, it is not practicable to consider the variable influences of flow regimes on each taxon. For this reason specific consideration is provided in Table 6 for the potential responses to flow regimes by each species of these groups that is listed as threatened or migratory under provisions of State and Commonwealth legislation or policy and that has a high likelihood of occurrence on the Macalister River floodplain. Nonetheless, the following discussion outlines some general concepts and examples related to effects of flows on birds, reptiles and frogs.

As a general rule, all fauna species that are associated with waterbodies are adapted to the natural regime that follows seasonal rainfall patterns. Manipulated flows that vary significantly from natural seasonal flows may have deleterious effects.

Amongst birds, waterbirds are the most directly ecologically reliant on flows in the Macalister River floodplain. 'Waterbirds' is a general categorisation and for this purpose they fall into a number of functional guilds (following Roshier et al. 2002). These guilds do not necessarily reflect taxonomic groups. The guilds are:

- Shoreline foragers, including lapwings, rails, crakes
- Deep-water foragers, including some ducks and Black Swan
- Dabblers, including small grebes and dabbling ducks
- Terrestrial grazing ducks
- Small waders, including migratory and resident shorebirds
- Large wading birds, including ibis, spoonbills, herons and egrets.
- Fishers, including kingfishers, cormorants, gulls, terns, Australian Pelican and White-bellied Sea-eagle.

Initial rising water levels promote productive conditions most suitable for large waders. High productivity for deep-water foragers, dabblers and some fishers tends to occur at, or immediately following high flows. Subsequent falls from peak water levels create prime foraging resources for shoreline foragers, terrestrial grazing ducks small waders and many fishers.

Table 6. Potential influences of flow regimes on listed species in the Lower Macalister River floodplain

Scientific Name	Common Name	Resident status in Gippsland	Influence of flow regime
Acrocephalus stentoreus	Clamorous Reed Warbler	Migratory	Primarily inhabits shallow areas of wetlands with dense reedbeds. Local effects on population could be expected to occur if flow regime alters this habitat.
Anas rhynchotis	Australasian Shoveler	Nomadic	Little effect likely as the species is highly nomadic across the continent.
Ardea modesta	Eastern Great Egret	Nomadic	Local effects only. Likely to be responsive to wetting of low-lying areas of paddocks and of billabongs.
Aythya australis	Hardhead	Nomadic	Little effect likely as the species is highly nomadic across the continent.
Biziura lobata	Musk Duck	Nomadic	Little effect likely as the species is highly nomadic across the continent.
Bubulcus ibis	Cattle Egret	Nomadic	Local effects only. Likely to be responsive to wetting of low-lying areas of paddocks and of billabongs.
Ceyx azureus	Azure Kingfisher	Resident	Local effects only. Slower flows and standing water in billabongs likely to be preferred conditions for the species.
Egretta garzetta	Little Egret	Nomadic	Local effects only. Likely to be responsive to wetting of low-lying areas of paddocks and of billabongs.
Gallinago hardwickii	Latham's Snipe	Migratory	Local effects only. Likely to be responsive to wetting of low-lying areas of paddocks and of billabongs.
Haliaeetus leucogaster	White-bellied Sea-Eagle	Resident	Birds locally probably largely reliant on Lake Glenmaggie. Influences of flows on fish stocks in billabongs can be expected to affect value of those habitats to the species.
Hirundapus caudacutus	White-throated Needletail	Migratory	Little effect likely as the species is highly nomadic across the continent.
Nycticorax caledonicus hillii	Nankeen Night Heron	Nomadic	Local effects only. Likely to be responsive to wetting of low-lying areas of paddocks and of billabongs.
Platalea regia	Royal Spoonbill	Nomadic	Local effects only. Likely to be responsive to wetting of low-lying areas of paddocks and of billabongs.
Chelodina	Common Long-	Resident	The species is likely to have highest densities in billabongs but

longicollis	necked Turtle	to retreat to permanent water of the river and channels if they dry out. Re-flooding of billabongs creates highly productive microenvironment for the species.

It is worth noting that while a few species of waterbirds will be locally resident, the majority of them are highly mobile at the continental or international scale. This means that such species have ready capacity to move into the Macalister River floodplain whenever conditions are specifically favourable and to move elsewhere when they are not. It also means that they may not respond to such local or regional effects if these are effectively masked by greater influences elsewhere. For example, major flooding events in inland Australia may result in substantial aggregations of birds into that area regardless of the local effects of flow regimes at locations like the Macalister River floodplain. On the other hand species that are year-round residents of the floodplain will be more directly influenced. The resident or transient behaviours of birds are noted for each species in Table 2.

A large number of other birds that are not obligatorily reliant on waterbodies may not be directly affected by flow regimes per se but flows may influence key ecological resources for them such as abundance or availability of food. For example, population size and density of invertebrates that have aquatic life-stages may be altered by variations in flows and the effects of these on billabongs, meanders and artificial channels, as outlined in previous sections. In turn, this will affect particular species of birds, reptiles and frogs that prey upon particular invertebrate species. A number of birds, such as Azure Kingfisher Alcedo azurea, Sacred Kingfisher Todiramphus sanctus, Rainbow Bee-eater Merops ornatus, Spotted Padalote Pardalotus punctuates and Striated Pardalote Pardalotus striatus, routinely or occasionally nest in soil banks. Nests of some pairs built adjacent to water could conceivably be lost if water level was to rise during the spring-summer period.

The only reptile species of the Macalister River that is wholly dependent on wetlands is the Common Long-necked Turtle Chelodina longicollis. The species feeds only underwater and is principally reliant on aquatic invertebrate prey. It does have substantial capacity to move overland between waterbodies and females lay their eggs in the soil above the waterline. As water levels rise and productivity of newly inundated billabongs rises, the turtles tend to respond rapidly by moving into such environments. As billabongs dry they retreat to permanent water of the river and channels. Eggs are laid in November to December and hatchlings emerge from January to March, hence inundation of nest areas (i.e. terrestrial soil above the November high-water level) may result in destruction of an annual cohort of eggs. Some other reptiles tend to occur at highest densities in humid riparian zones. Examples include Eastern Water Dragon Intellagama leseurii, Yellow-bellied Water Skink Eulamprus heatwolei and Red-bellied Black Snake Pseudechis porphyriacus. As a general rule these species are adapted to variable flows and their populations are unlikely to be significantly affected by short-term artificially altered flows.

At least thirteen species of frogs are recorded from the Macalister River catchment, although a few of these are not likely to occur in the lower reaches under consideration here. All frogs require high humidity and most, but not all, require open water for the development of eggs and tadpoles. The responses of frogs to variable flows can be illustrated by two examples. In Gippsland, Lesueur's Frog Litoria lesueri inhabits the faster-flowing rocky reaches of most rivers. It is well adapted to the dynamics of naturally rapid, short-term variations in flows due to rainfall events which may be substantial in those portions of relevant rivers. On the other hand the Growling Grass Frog Litoria raniformis requires relatively deep, slow-flowing or still waters with dense aquatic and emergent vegetation. During the summer breeding season for this species, desiccation of billabongs or sudden influx of water into them may both be deleterious it.

Part B: Flow recommendations paper

5 Values and objectives for environmental flow recommendations

The Issues Paper (Part A) identified the current condition and trajectory of water dependent values of the Macalister River. **Water dependent values** were assessed in the following groups:

- Fish
- Vegetation
- Invertebrates
- Platypus and rakali
- Birds, turtles and frogs.

Conceptual models that describe the flow-ecology response for each of the groups are also described in Part A of this study. Each model outlined the type and characteristics of flows that are required to sustain populations or condition of the water dependent values. Habitat and water quality conceptual models were also presented as they are both important influences on the condition of water dependent values.

The existing condition of each water dependent value within the Macalister system, regional priorities for waterway management, and the conceptual models informed the identification and establishment of '**ecological objectives'** for each of the water dependent values. Ecological objectives are used to guide watering actions and priorities in the system. The proposed ecological objectives for the Macalister River (both reaches) are:

- Improve spawning and recruitment opportunities for migratory fish species (including Australian Grayling; Short-finned Eels, Australian Bass and Tupong)
- Improve the distribution and abundance of Australian grayling
- Maintain the distribution and abundance of all expected native fish species
- Reinstate native submerged vegetation
- Improve native emergent (non-woody) vegetation
- Maintain fringing native woody vegetation in the riparian zone
- Maintain the abundance and number of functional groups of macroinvertebrates
- Improve abundance of platypus and rakali

The ecological objectives listed above are influenced by a number of flow and non-flow related factors (e.g. land use). As the focus of environmental watering and improved flow management is solely on flows, objectives that are achievable entirely through flow management have been established. There are referred to as '**flow functions'.** These stipulate the flow characteristics required for each ecological objective, and as such, relate to a specific ecological objective. Figure 8 identifies the flow functions for each of the water dependent values.

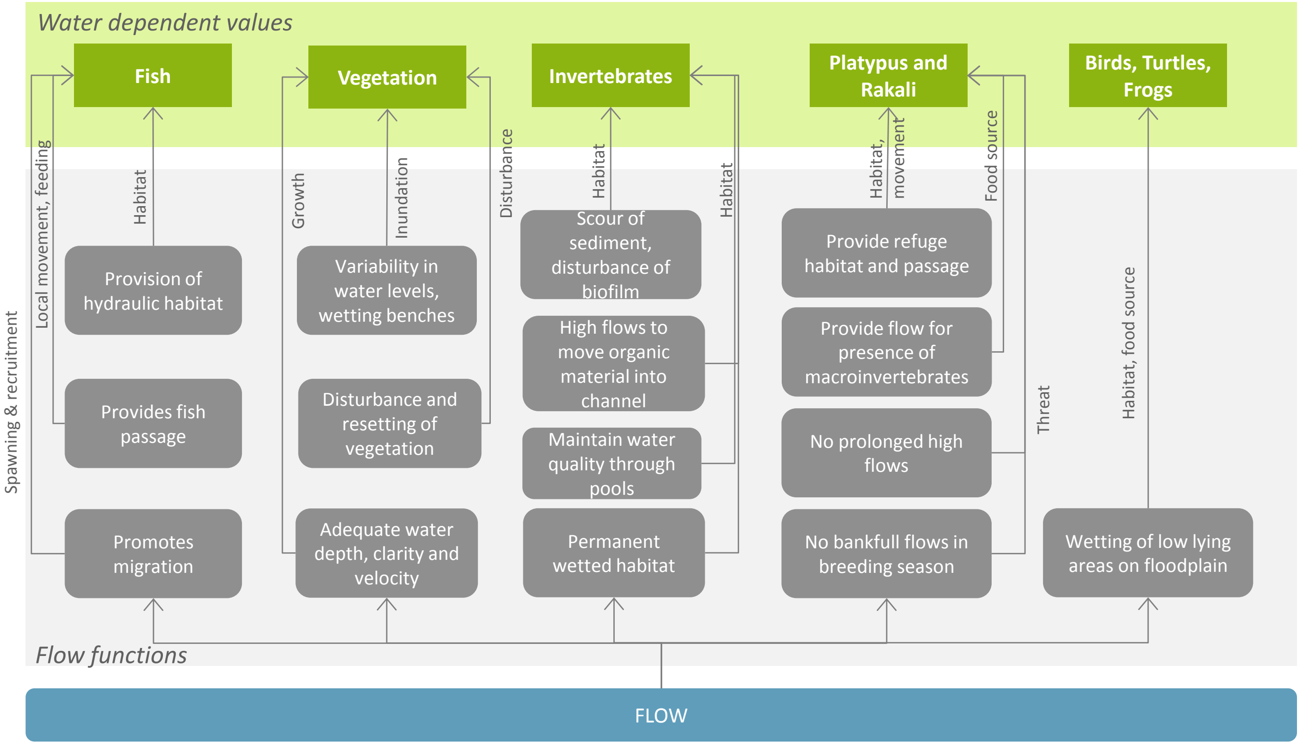


Figure 16. *Flow functions, categorised under the relevant water dependent value. Note that the condition of each water dependent value is also influenced by non-flow related factors (e.g. land use).*

Environmental flow recommendations have been derived to achieve each of the flow functions and ecological objectives. These recommendations are described in Section 4. The method used to obtain the environmental flow recommendations is described further in Section 3.

6 How the updated environmental flow recommendations were derived

This project is a review of the existing flows study (SKM 2003), so the focus of our analysis was on changes in with implications on the flow recommendations, including:

- Major flooding that has potentially changed the shape of the channel, and consequently the flow processes
- Updates to the FLOWS method (DEPI 2013), including the inclusion of recommendations for:
    - different climatic seasons, and
    - broader water dependent values (platypus, frogs, birds etc)
- Improvements in our knowledge of values in the system and their conceptual models that underpin the flow recommendations

The process for deriving environmental flow recommendations (Figure 17) includes identifying water dependent value in the system and ecological objectives to support those values (see section 5). The flow components and hydraulic criteria (section 6.1) are derived from these objectives using conceptual models as described in the *Issues Paper* (Part A). Based on the hydraulic criteria, relevant hydraulic models (section 6.2) are used to determine the magnitude of the flow recommendation. An understanding of the system hydrology (section 6.3) is used in conjunction with the conceptual models and hydraulic criteria to determine the frequency, duration and timing of the flow recommendation. The determination of the number and duration of recommended flow events has then been considered in this study for four prevailing climatic conditions; drought, dry, average and wet years (section 6.4).

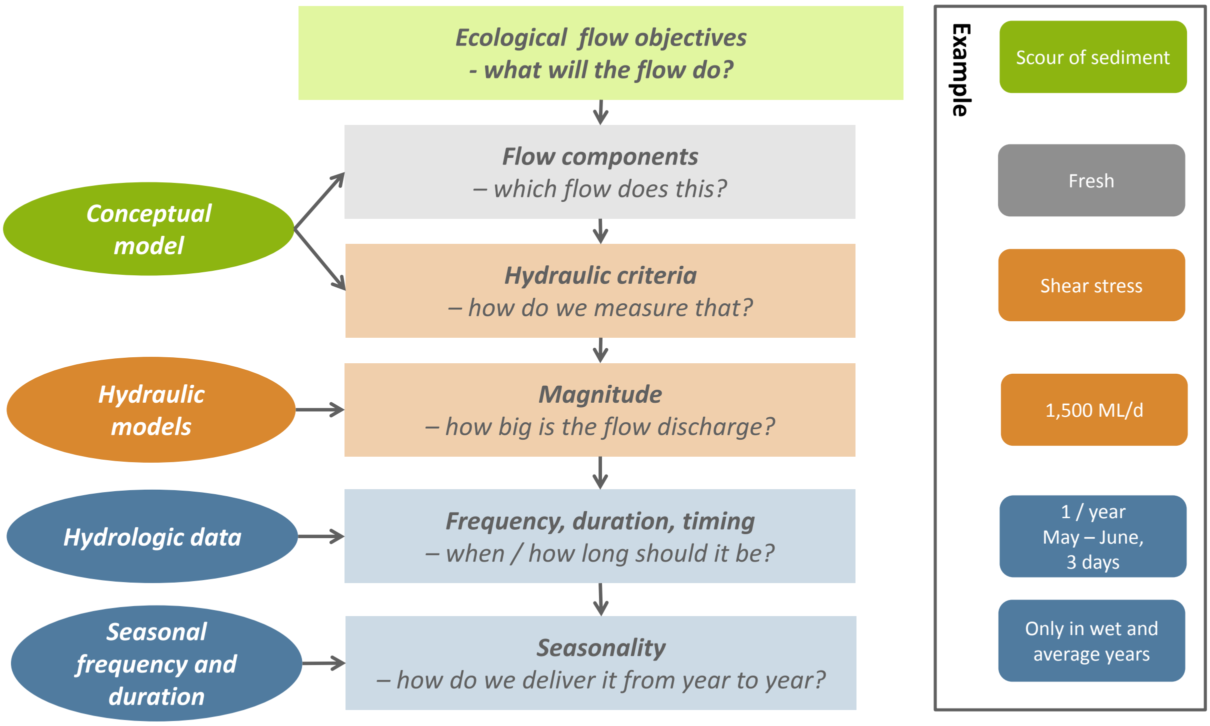


Figure 17. *Process for determining environmental flow requirements*

6.1 Application of hydraulic criteria

The water-dependent values of the Macalister system were identified in Part A. The hydraulic criteria required to support these values are provided in Table 7.

Table 7. Hydraulic criteria for the Macalister River reach 1 & 2

VALUE	Ecological objective	Flow function	ID	Flow component	Timing	Duration	Frequency	Criteria
FISH	Improve the distribution and abundance of Australian grayling and Maintain the distribution and abundance of all native fish species	Provide hydraulic habitat	F1	Baseflow	All year	Continuous	Continuous	Minimum depth through pools
		Provide fish passage for local movement	F2	Baseflow	All year	Continuous	Continuous	Provide minimum depth over riffles of 0.2 m.
	Improve spawning and recruitment opportunities for migratory fish species	Promote downstream migration for spawning - Eels	F3	Fresh	Dec - May	3 days [6 days from start of rise to start of fall]	1/year	Provide flow cue by increase in depth
		Promote downstream migration for spawning - Grayling	F4	Fresh	April-May	3 days [6 days from start of rise to start of fall]	1/year	Provide flow cue by increase in depth
		Promote downstream migration for spawning - Tupong	F5	Fresh	May-Aug	3 days [6 days from start of rise to start of fall]	1/year	Provide flow cue by increase in depth.
		Promote downstream migration for spawning - Bass	F6	Fresh	May-Aug	3 days [6 days from start of rise to start of fall]	1/year	Provide flow cue by increase in depth
		Promote upstream migration of adult anadromous and juvenile catadromous and amphidromous fish	F7	Fresh	Sep - Dec	3 days [6 days from start of rise to start of fall]	1/year	Provide flow cue by increase in depth
VEGETATION	Re-instate submerged aquatic vegetation	Provide water in stream channel to allow submerged aquatic plants to establish. Water must have low velocity, good clarity and appropriate depth for submerged vegetation	V1	Baseflow	Dec - May	Continuous	Continuous	Low water velocity, clarity and depth for submerged vegetation
	Re-instate submerged aquatic vegetation & Improve native emergent (non-woody) vegetation	Inundate stream channel to greater depth and width to limit encroachment of terrestrial vegetation	V2	Baseflow	Jun - Nov	Continuous	Continuous	Stream channel inundated
	Improve native emergent (non-woody) vegetation	Inundate benches to provide variability in water levels and to facilitate longitudinal spread of emergent vegetation	V3	Fresh	Dec-Mar	2 days	3 / year	Wetting low benches; Increase in wetted area and depth compared with low flow

VALUE	Ecological objective	Flow function	ID	Flow component	Timing	Duration	Frequency	Criteria
	Improve fringing woody vegetation in the riparian zone	Inundate fringing vegetation and provide variability in water levels	V4	Fresh	Sep-Oct	3 days	1/year	Inundation of mid level benches
		Inundate woody vegetation and provide variability in water levels	V5	Fresh	Sep-Dec	3 days	1/year	Inundation of higher benches
		Disturb and reset fringing vegetation	V6	Bankfull	Any time	1 – 2 days	Once every two years	Water level at top of bank
MACRO-INVERTEBRATES	Maintain the abundance and number of functional groups of macroinvertebrate	Provide permanent wetted habitat	M1	Baseflow	All year	Continuous	Continuous	Minimum depth through pools (1 m)
		Scour sediment and disturb of biofilm for food source	M2	Fresh	Any time	1-2 days	Once every two years	Shear stress – refer physical form
		Move organic material from benches to channel to provide habitat	M3	Fresh	Any time	1-2 days	Once every two years	Inundation of higher benches
		Provide adequate water quality through pools for habitat	M4	Fresh	Dec - May	2 days	3 / year	Adequate depth over riffles / turnover time
		Provide increased wetted habitat	M5	Fresh	Dec - May	2 days	3 / year	Increased wetted area
PLATYPUS AND RAKALI	Improve abundance of platypus and rakali	Provide refuge habitat and passage for local movement	P1	Baseflow	All year	Continuous	Continuous	Minimum depth over riffles 0.2 m
		Support breeding opportunities by avoiding bankfull flows	-	Bankfull	October - March	-	-	*To be addressed in risk section*
		Avoid extended high flows events to allow for foraging	-	Fresh / Bankfull	All year	-	-	
BIRDS, TUTRLES, FROGS	Maintain abundance of frog, turtle and waterbird communities	Wet low lying areas on floodplain to provide habitat and food sources	B1	Overbank / Bankfull	July - October	1-2 days	Once every two years	Ensure variable periodic wetting/drying of riparian habitats, especially billabongs. Coincide peak wetting with natural seasonal regime.
PHYSICAL FORM	Improve physical habitat	Slow water quality degradation occurring in pools	G1	Baseflow	Dec - May	Continuous	Continuous	Minimum depth over riffles / turnover time
		Flush and turn over pools	G2	Fresh	Dec - May	2 days	3 / year	Minimum depth over riffles / turnover time
		Disturb lower channel features by exposing and drying.	G3	Baseflow	Dec - May	Continuous	Continuous	Lower channel, benches and streambed periodically exposed.

VALUE	Ecological objective	Flow function	ID	Flow component	Timing	Duration	Frequency	Criteria
		Scour sediment to flush fine material from interstices	G4	Fresh	Any time	1-2 days	Once every two years	Shear stress
		Maintain gross channel form and prevent channel contraction.	G5	Bankfull	Any time	1-2 days	Once every two years	Water level at top of bank

6.2 Hydraulic modelling

The magnitudes of the flows required to achieve the flow functions were estimated using hydraulic models. There were three model sources available for this study:

1. Two 1D hydraulic models used in the 2003 Macalister FLOWS study. These models are referred to as the *2003 FLOWS study models*.
2. Four new 1D hydraulic models for sites within the study area were developed for the Victorian Environmental Flows Monitoring Program (VEFMAP) physical habitat assessment undertaken by Alluvium in 2010. These models are referred to as the *VEFMAP models*.
3. A 2D hydrodynamic model for the Macalister system developed for this study.

The model details are outlined in Table 8 and their spatial extents are shown in Figure 18.

Table 8. Hydraulic models available for reach 1 and reach 2

Project (Year)	Reach	Description	Model type	Topography data	Hydraulic outputs	Length of model
Macalister River Environmental Flows Study (2003)	1	Upstream Newry creek confluence (Site 4)	HEC-RAS (1D)	Feature survey (2003)	Depth	0.5 km / 36 km 7 cross-section
	2	Upstream Forsythe Lane crossing (site 6)	HEC-RAS (1D)			0.5 km / 19 km 4 Cross-sections
VEFMAP physical habitat component (2011)	1	Downstream of Glenmaggie Weir (Ma0104)	HEC-RAS (1D)	Feature survey (2011)	Depth, shear stress	0.6 km / 36 km 16 Cross-sections
		Hagen's Bridge downstream Webster's Road crossing (Ma0105)	HEC-RAS (1D)			1.2 km / 36 km 15 Cross-sections
		Upstream Newry confluence (Ma0102)	HEC-RAS (1D)			0.3 km / 36 km 15 Cross-sections
	2	Upstream Forsythe Lane crossing (Ma0202)	HEC-RAS (1D)			0.4 km / 19km 15 Cross-sections
Macalister Flows update Project (2015)	1	Macalister River from Glenmaggie weir down to Maffra weir.	XPSWMM (2D)	LiDAR (2011)	Depth, shear stress	Results for 36 km of 36 km
	2	Macalister River from Maffra weir down to confluence with Thompson	XPSWMM (2D)			Results for 19 km of 19 km

Compared to the 2003 FLOWS study models, the VEFMAP models are based on higher resolution and more recent channel survey, so better characterise the current channel form. They also cover a greater extent of the study reach for this study than the 2003 FLOWS study models. The VEFMAP models were calibrated to observed water levels at each site. On this basis, the VEFMAP models were selected for use in this study. No changes have been made to these existing models for this study: the existing channel geometry, upstream and downstream boundary conditions and hydraulic roughness factors were assumed to be correct.

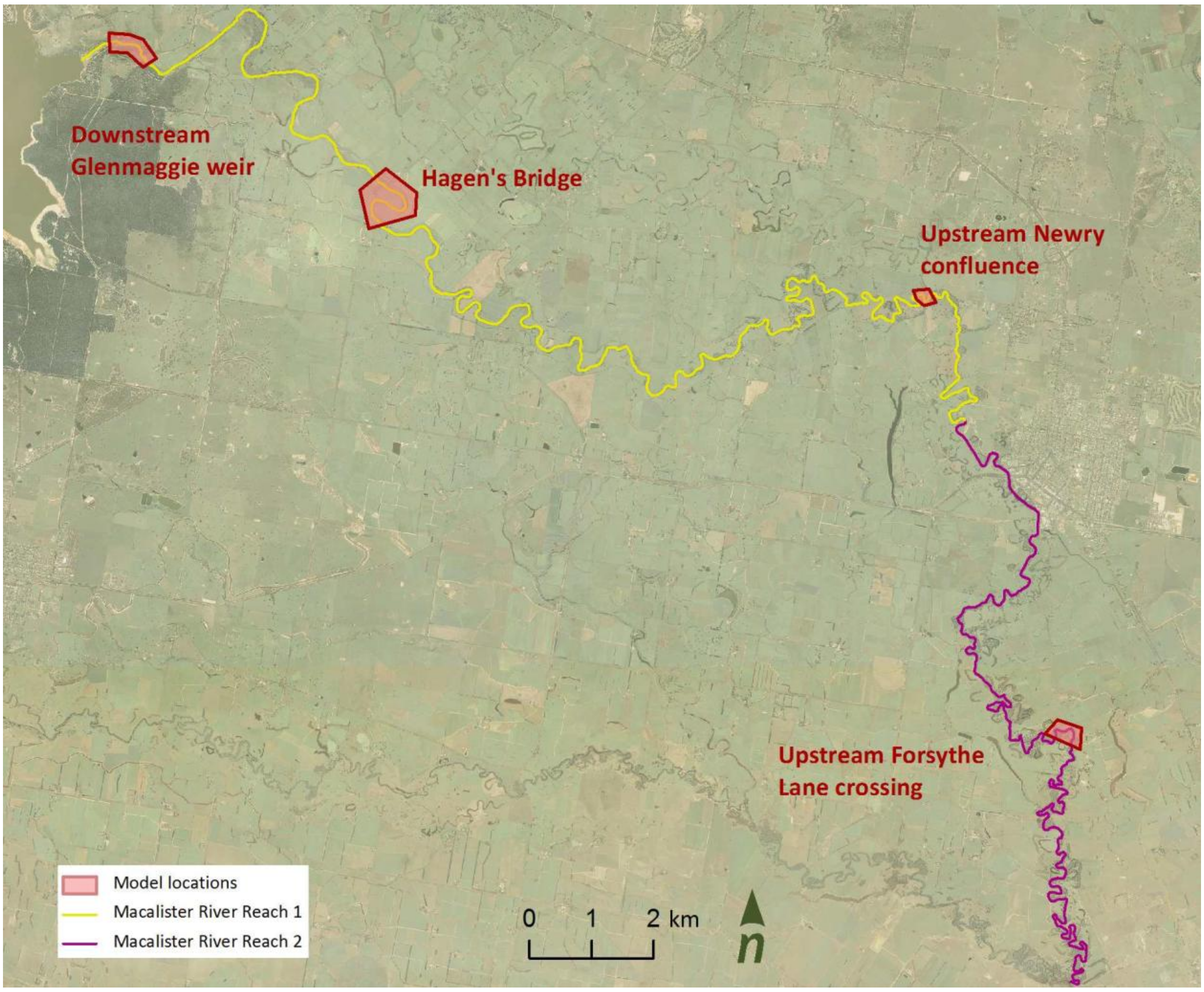


Figure 18. *Location of VEFMAP models in the Macalister River study area*

In addition to the VEFMAP models, a 2D model of the Macalister system was developed in XPSWMM specifically for this study. Using LiDAR topography data, the model provides hydraulic results for the entire study area, rather than at discrete, representative locations.

LiDAR data has transformed hydraulic modelling since its widespread adoption over the last ten years, but one of its central limitations is its inability to penetrate water. The implications for this study are that the 2D model can only provide information on hydraulics above the water level in the river at the time the LiDAR data were collected.

Three primary inputs were used to develop the XPSWMM model:

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

The model was developed and then calibrated to two flow gauges:

- Reach1 – Macalister River at Lake Glenmaggie (225205)

- Reach 2 – Macalister River at Riverslea (225247)

Table 9 lists the boundary conditions and hydraulic roughness adopted for each model. These parameters were adopted on the basis of the calibration, field observations and aerial photography.

Table 9. Hydraulic parameters adopted in XPSWMM model

Hydraulic parameter	Reach 1	Reach 2
Manning's roughness - channel	0.02	0.06
Manning's roughness - trees	0.08	0.12
Manning's roughness - floodplain	0.035	0.045
Downstream boundary	Slope = 0.001	Stage-discharge curve from downstream gauge

The results and analysis of the two-dimensional hydraulic modelling is presented in Appendix C.

6.3 Hydrologic data

There are several stream flow gauges available for the Macalister study area used to characterise the hydrology of the system and assess compliance with the environmental flow recommendations. The gauge details and locations are provided below (Table 10 and Figure 19). The gauges used as compliance points for each reach are shown in the table below.

Table 10. Flow gauges in the Macalister study area

Gauge name	ID	Data period	Modelling	Compliance point for environmental entitlement
Macalister River at Lake Glenmaggie (tail gauge)	225204	1924 - 2015	✓	✓ (Reach 1)
Macalister River at Maffra weir	225242		-	✓ (Reach 2)
Macalister River at Riverslea	225247	2001 - 2015	✓	-
Thomson River at Bundalaguah	225232	1976 - 2014	✓	-

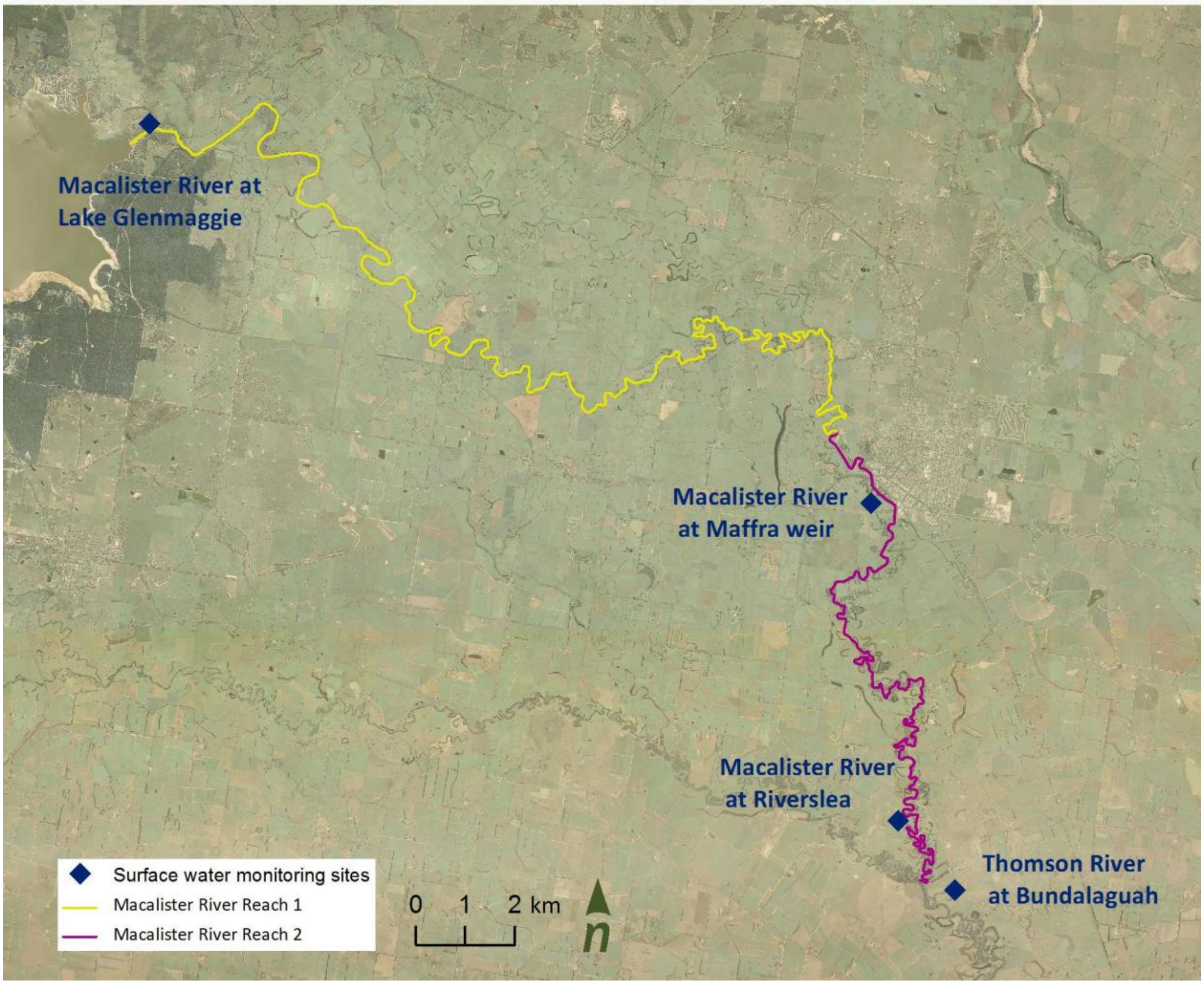


Figure 19. *Macalister River system flow gauge locations*

The Thomson Macalister REALM model was updated in 2006 as part of the *Central Region Sustainable Water Strategy* (SKM 2006). A daily streamflow series was extracted (by Jacobs) from the REALM model for use in this environmental flows study (Jacobs 2015). A daily pattern based on unregulated gauged flows, infilled using rainfall-runoff models, was used to disaggregate the unimpacted monthly flow series. The streamflow series represent current, unimpacted and climate change conditions for the two reaches of the Macalister River over the period 1 July 1955 to 30 June 2013. A monthly analysis of these daily flow series is provided in Figure 5.

Unimpacted conditions represent flows in the river in the absence of diversions from the river and flow regulating structures, but under historical land cover. **Current conditions** represent regulated flows at current entitlement volumes, the 2004 level of demand and irrigator behaviour, and historical land cover. Current conditions assume no active use of the Environmental Entitlement, which therefore is assumed to only contribute to reservoir spills. The **climate change** series are the same as the current conditions series, but under 1997-2009 climate conditions. This provides a long-term representation of “return-to-dry” climate conditions experienced during the Millennium Drought from 1997-2009.

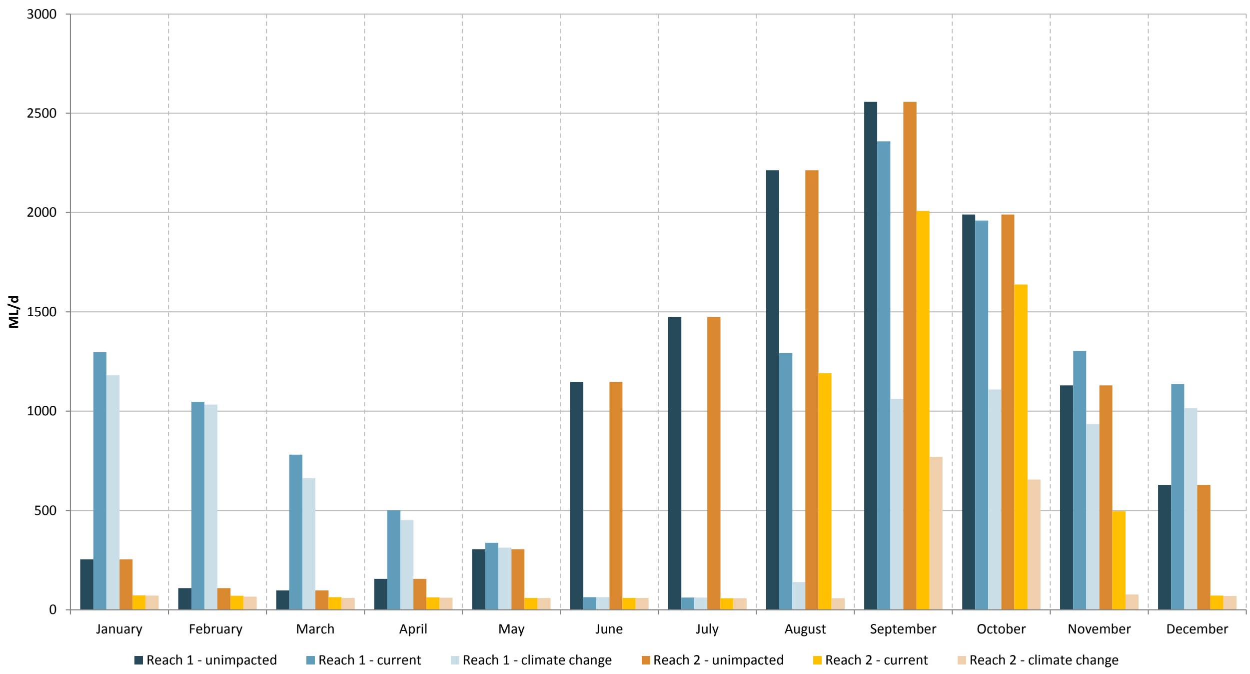


Figure 20. *Average monthly flows in the Macalister River – reaches 1 and 2, under unimpacted, current and climate change conditions (Data source: REALM model - SKM 2005, Jacobs 2015).*

6.4 Seasonal frequency and duration

Where known, the frequency and duration of the flow recommendations were informed by the life cycle traits of the value. The unimpacted flow scenario is then used where life cycle traits are not known and ensure the flow recommendations align with the unimpacted frequency and duration of the flow events.

The determination of the number and duration of recommended flow events has been considered in this study for four prevailing climatic conditions; drought, dry, average and wet years. These climatic conditions can be used in combination with other factors 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 defined as:

- Wet years - when the total annual flow is exceeded in greater than 75% of years,
- Average years - when the total annual flow is exceeded in 25 - 75% of years
- Dry years - when the total annual flow is exceeded in 10 - 25% of years.
- Drought years - when the total annual flow is exceeded in less than 10% of years.

The climatic conditions were determined based on the 58 year (1955-2013) modelled unimpacted flow sequence (Jacobs 2015). The modelled unimpacted sequence of inflow to Lake Glenmaggie and Maffra Weir were used as the basis for determining the prevailing climatic condition for Reach 1 and Reach 2 respectively.

7 Environmental flow recommendations

Environmental flow recommendations have been determined for both river reaches of the Macalister between Lake Glenmaggie and the confluence with the Thomson River. The recommendations meet each of the flow functions (outlined in Section 2). Each recommendation is comprised of a flow component, discharge (magnitude), timing, duration and frequency, as well as the inclusion of seasonality (Figure 21, Figure 22). In this section, the recommendations are described for each water-dependent value and for each reach.

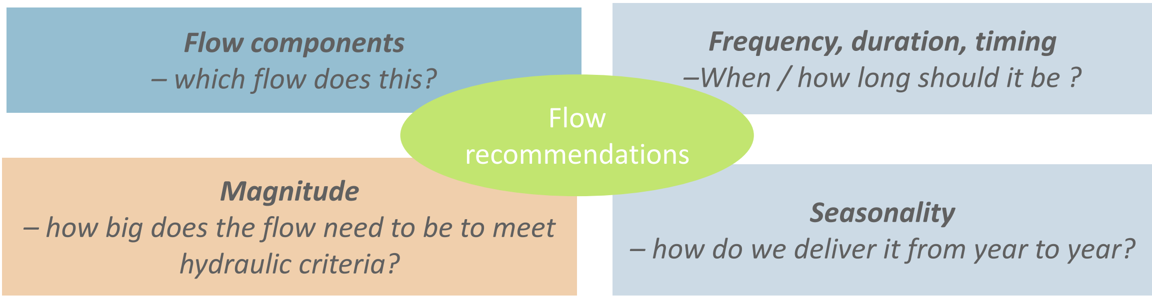


Figure 21. *What is a flow recommendation?*

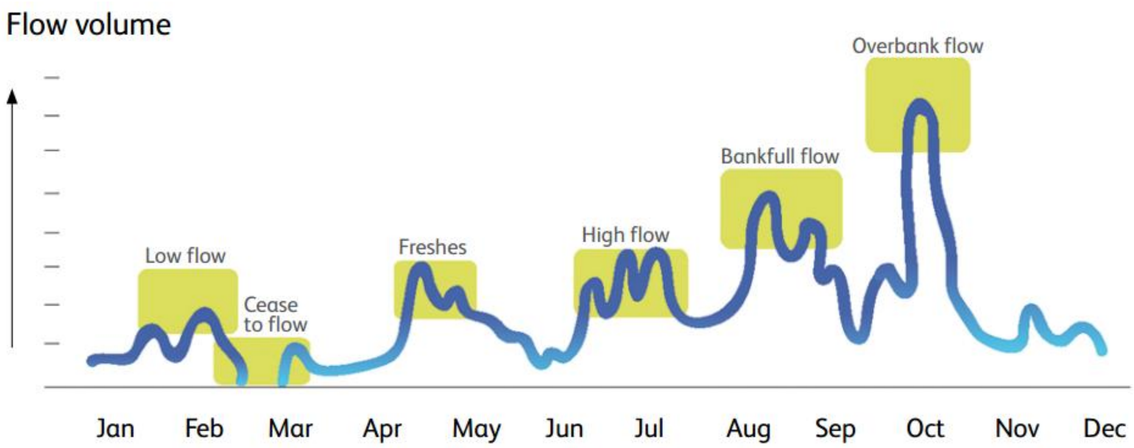


Figure 22. *Flow components*

The approach used to determine the recommendations is described later in Section 5.

Note for reach 1 and reach 2, the same ecological objectives and therefore hydraulic criteria were applied. However, due to the difference in channel form, our investigation resulted in different flow magnitudes recommended for each reach. The delivery of the environmental flows may focus on the flow recommendation for one reach over the other. This prioritisation is discussed in the next report, Paper C.

7.1 Recommendations by water-dependent value

Fish

Three ecological objectives relate to native fish:

- Improve spawning and recruitment opportunities for migratory fish species (including Australian Grayling; Short-finned Eels, Australian Bass and Tupong)
- Improve the distribution and abundance of Australian grayling
- Maintain the distribution and abundance of all expected native fish species

There are significant populations of native fish in the system, in particular Australian Grayling. They depend on an appropriate flow regime to support their habitat, feeding, local movement, spawning and recruitment. Native fish in the Macalister system require baseflows for their habitat and local movement, and freshes as a trigger to promote spawning and recruitment in migratory species.

Table 11. Flow recommendations by value: fish

<table>
<tr><th>Flow function</th><th colspan="2">Flow component</th><th colspan="2">Reach 1</th><th>Reach 2</th></tr>
<tr><td>Provide hydraulic habitat</td><td colspan="2" rowspan="2">Baseflow</td><td colspan="2">Dec-May
90ML/d</td><td>Dec-May
35 ML/d</td></tr>
<tr><td>Provide fish passage for local movement</td><td colspan="2">Jun-Nov
320 ML/d</td><td>Jun-Nov
300 ML/d</td></tr>
<tr><td rowspan="3">Promote downstream migration for spawning in key migratory species</td><td rowspan="3">Fresh</td><td>Grayling</td><td>Apr-May
350 ML/d
1/ year
min 3 days duration</td><td rowspan="4">Flow required in reach 1 only once fish barrier at Maffra Weir removed</td><td>Apr-May
140 ML/d
1/ year
min 3 days duration</td></tr>
<tr><td>Tupong</td><td>Jun-Aug
1500 ML/d
1/ year
min 3 days duration</td><td>Jun-Aug
700 ML/d
1/ year
min 3 days duration</td></tr>
<tr><td>Bass</td><td>May-Aug
1500 ML/d
1/ year
min 3 days duration</td><td>May-Aug
700 ML/d
1/ year
min 3 days duration</td></tr>
<tr><td>Promote upstream migration of adult anadromous and juvenile catadromous and amphidromous fish</td><td colspan="2">Fresh</td><td>Sep – Dec
1500 ML/d
1/ year
min 3 days duration</td><td>Sep – Dec
700 ML/d
1/ year
min 3 days duration</td></tr>
</table>

Note that the recommendations for spawning and recruitment of fish species should only be delivered in reach 1 once the barrier to fish passage at Maffra weir is removed. While the barrier is present, the Reach 2 recommendations should still be delivered.

Vegetation

Two ecological objectives relate to vegetation:

- Reinstate native submerged vegetation
- Improve native emergent (non-woody) vegetation
- Maintain fringing native woody vegetation in the riparian

The vegetation in the Macalister system requires a flow regime to support the reinstatement of submerged vegetation. This is also dependent on complementary works. Instream submerged vegetation requires deep, clear water with low velocities. The emergent (woody and non-woody) vegetation is dependent on a mosaic of wetting and drying regimes across the zones of vegetation working up from the waterway edge. This mosaic of wetting and drying is provided by base flow, fresh and bankfull flow components.

Table 12. Flow recommendations by value: vegetation

Flow function	Flow component	Reach 1	Reach 2
Provide water in stream channel to allow submerged aquatic plants to establish. Water must have low velocity,	Base flow	Dec-May 90ML/d	Dec-May 35 ML/d

good clarity and appropriate depth for submerged vegetation			
Inundate stream channel to greater depth and width to limit encroachment of terrestrial vegetation		Jun-Nov 320 ML/d	Jun-Nov 300 ML/d
Inundate benches to provide variability in water levels and to facilitate longitudinal spread of emergent vegetation	Fresh	Dec-Mar 350 ML/d Minimum duration 2 days 3 / year	Dec-Mar 140 ML/d Minimum duration 2 days 3 / year
Inundate fringing vegetation and provide variability in water levels		Sep-Oct 1500 ML/d 1 event per year 3 day minimum	Sep-Oct 700 ML/d 1 event per year 3 day minimum
Inundate woody vegetation and provide variability in water levels		Sep-Dec 2500 ML/d 2 events per year 3 day minimum	Sep-Dec 1500 ML/d 2 events per year 3 day minimum
Disturb and reset fringing vegetation	Bankfull	Any time 10,000 ML/d Once every two years 1-2 day minimum duration	Any time 10,000 ML/d Once every two years 1-2 day minimum duration

Macroinvertebrates

The ecological objective for this water dependent value is to maintain the abundance and number of functional groups of macroinvertebrates.

Macroinvertebrate communities are an important part of the ecosystem, particularly as a food source for other aquatic species (i.e. fish, platypus, rakali). These communities require baseflows and freshes to provide wetted habitats with good water quality. Freshes are also important to provide organic material to form habitats and disturb biofilms that are an important food source.

Table 13. Flow recommendations by value: macroinvertebrates

Flow function	Flow component	Reach 1	Reach 2
Provide permanent wetted habitat	Base flow	All year 90ML/d	All year 35 ML/d
Provide adequate water quality through pools for habitat. Provide increased wetted habitat	Fresh	Dec-Mar 350 ML/d 3 / year 2 day minimum	Dec-Mar 140 ML/d 3 / year 2 day minimum
Scour sediment and disturb of biofilm for food source		Any time 3,000 ML/d 1 event per 2 years 1 day minimum	Any time 1,500 ML/d 1 event per 2 years 1 day minimum
Move organic material from benches to channel to provide habitat		Any time 2,500 ML/d 1 event per 2 years 1 day minimum	Any time 1,500 ML/d 1 event per 2 years 1 day minimum

Platypus and rakali

The ecological objective for Platypus and Rakali is to increase the abundance of their populations in the flow regulated reaches of the Macalister River.

Platypuses and Rakali are assumed to be relatively widespread throughout the Macalister system although at low abundance. Platypuses are predicted to be more abundant in the upper, forested reaches while Rakali may be more common near population centres in the lower reaches. Both species are thought to have experienced substantial declines in the area, most recently due to severe drought conditions. Platypus populations are likely to be taking longer to recover and may be considered vulnerable.

Both platypuses and Rakali are highly adaptable species and can be found inhabiting a variety of different water bodies and environmental conditions. Both species are dependent on permanent water for feeding (although Rakali will also forage on land) and refuge from predators. Therefore the availability of sufficient surface water is a key habitat requirement.

There is a lack of empirical evidence on the impacts of flow regimes on platypuses and Rakali although the species do not require a particular flow event as a biological trigger (i.e. to stimulate reproduction).

Table 14. Flow recommendations by value: platypus and rakali

Flow function	Flow component	Reach 1	Reach 2
Provide refuge habitat and passage for local movement	Base flow	All year 90ML/d	All year 35 ML/d

Frog, turtle and waterbird

The ecological objective for frogs, reptiles and waterbirds is to increase the abundance of these communities.

Birds, reptiles and frogs depend on the availability of aquatic habitat and high levels of productivity to maintain food resources including invertebrates, algae, macrophytes and fish. These species depend on a seasonal flow regime that provides productive aquatic habitat particularly during breeding periods (mainly spring and summer). Floodplain areas wetted through bankfull and overbank events are important habitat for waterbirds, reptiles and frogs.

Table 15. Flow recommendations by value: frog, turtle and waterbird

Flow function	Flow component	Reach 1	Reach 2
Wets low lying areas on the floodplain to provide habitat and food source	Bankfull	Any time 10,000 ML/d Once every two years 1-2 day minimum	Any time 10,000 ML/d Once every two years 1-2 day minimum

All values

For all values discussed above, the appropriate physical habitat is appropriate. Therefore an objective to improve physical habitat is included, and relates to all values.

Table 16. Flow recommendations by value: physical habitat

Flow function	Flow component	Reach 1	Reach 2
Slow water quality degradation occurring in pools Disturb lower channel features by exposing and drying.	Baseflow	Dec- May 90 ML/d Continuous	Dec- May 90 ML/d Continuous
Flush and turn over pools	Fresh	Dec- May 350 ML/d 3 / year 2 day minimum	Dec- May 140 ML/d 3 / year 2 day minimum
Scour sediment to flush fine material from interstices		Any time 3,000 ML/d Once every two years 1 day minimum	Any time 1,500 ML/d Once every two years 1 day minimum
Maintain gross channel form and prevent channel contraction.	Bankfull	Any time 10,000 ML/d Once every two years 1-2 day minimum	Any time 10,000 ML/d Once every two years 1-2 day minimum

7.2 Recommendations by reach

Environmental flow recommendations to achieve the ecological objectives for Reach 1 and 2 of the Macalister River are summarised in Table 17. These tables include the seasonal recommendations for drought, dry, average and wet years (see section 6.4).

The hydraulic criteria used to determine the flow recommendations are outlined in Table 7. The hydraulic criteria that are met by each flow recommendation is provided in the tables below.

Note: 'or natural'

A component of the flow recommendations is the minimum frequency, minimum total duration and minimum event duration. The minimum event duration defines what qualifies as an 'event' for that flow recommendation (at the required magnitude). A number of these events can be delivered per year (frequency) to meet the required total duration. These recommendations are based on the unimpacted flow regime for the desired flow magnitude. This format allows for greater flexibility in delivering the flow recommendations and the approach allows for ecologically important natural flow variability that has been identified in unimpacted and natural flow regimes.

Table 17. Flow recommendations for reach 1 – Lake Glenmaggie to Maffra Weir. ***Note: DRT = drought; AVG = average***

Flow ID	Period	Magnitude (ML/d)	Frequency (per year)		Total duration (minimum days)		Minimum event duration	Hydraulic criteria met	Description (flow function and value)
		BASE FLOW							
LF 1	Dec - May	90 ML/d or natural	DRT DRY AVG WET	Cont	DRT DRY AVG WET	Cont	Cont	G1, G3, V1	Provide clear, shallow, slow moving water for submerged aquatic vegetation Maintain water quality in pools and disturb lower channel features to improve geomorphic habitat.

Flow ID	Period	Magnitude (ML/d)	Frequency (per year)		Total duration (minimum days)		Minimum event duration	Hydraulic criteria met	Description (flow function and value)
LF 2	All year	90 ML/d or natural	DRT	Cont	DRT	Cont	Cont	F1, F2, M1, P1	Provide wetted habitat and refuges for fish, platypus and rakali, and macroinvertebrates Provide passage for local movement of fish and platypus.
			DRY		DRY				
			AVG		AVG				
			WET		WET				
LF 3	Jun - Nov	320 ML/d or natural	DRT	Cont	DRT	Cont	Cont	V2	Provide sustained wetting of lower benches and prevents vegetation encroachment
			DRY		DRY				
			AVG		AVG				
			WET		WET				
		FRESHES							
FR 1	Dec - May	350 ML/d	DRT	1	DRT	3	3 [Minimum 6 days from start of event to start of fall]	M4, M5, G2, V3, F3	Increase wetted habitat for macroinvertebrates Flush and turn over pools to maintain water quality Wet benches and provide variability in water level for emergent vegetation Promote migration of key native fish species (Eels)
			DRY	≥1	DRY	5			
			AVG	≥1	AVG	10			
			WET	≥1	WET	20			
FR 2	April - May	350 ML/d	DRT	1	DRT	3	3 [Minimum 6 days from start of event to start of fall]	F4[5]	Promotes migration of key native fish species (Grayling)
			DRY	1	DRY	3			
			AVG	≥1	AVG	5			
			WET	≥1	WET	5			
FR 3	May - Aug	1,500 ML/d	DRT	1	DRT	3	3 [Minimum 6 days from start of event to start of fall]	F5[6]F6[7]	Promotes migration of key native fish species (Bass) Promotes migration of key native fish species (Tupong)
			DRY	1	DRY	5			
			AVG	≥1	AVG	10			
			WET	≥1	WET	20			
Fr 4	Sep - Oct	1,500 ML/d	DRT	1	DRT	3	3	V4	Wets tea tree and paperbark vegetation (fringing woody vegetation). Provides variability in water levels.
			DRY	1	DRY	5			
			AVG	≥1	AVG	10			
			WET	≥1	WET	20			
Fr 5	Sep - Dec	1,500 ML/d	DRT	1	DRT	3	3	F7	Promote upstream migration of adult anadromous and juvenile catadromous and amphidromous fish
			DRY	1	DRY	5			
			AVG	≥1	AVG	10			
			WET	≥1	WET	20			
FR 6	Sep - Dec	2,500 ML/d	DRY	≥1	DRY	5	3	M3, V5	Scours sediment and disturbs biofilm to provide habitat and food sources for macroinvertebrate communities. Maintains fringing woody vegetation higher up the streamside zone. Provides variability in water levels.
			AVG	≥1	AVG	10			
			WET	≥1	WET	20			

[5] Flow required only once fish barrier removed
[6] Flow required only once fish barrier removed.
[7] Flow required only once fish barrier removed

Flow ID	Period	Magnitude (ML/d)	Frequency (per year)		Total duration (minimum days)		Minimum event duration	Hydraulic criteria met	Description (flow function and value)
FR 7	Any	3,000 ML/d	DRY	1	DRY	1	3	M2, G4	Moves organic material into channel to provide habitat for macroinvertebrate communities. Scours and moves sediment in pools to improve geomorphic habitat.
			AVG	1	AVG	1			
			WET	1	WET	2			
		BANKFULL							
BK 1	Any	10,000 ML/d	AVG	1	AVG	1	1	B1, G5, V6	Wets low lying areas on the floodplain to provide habitat and food source for frog, turtle and waterbird communities. Maintains channel form and transports sediment and organic matter. Provides disturbance and resetting (some removal) of aquatic and riparian vegetation.
			WET	1	WET	1			

Table 18. Flow recommendations for Reach 2 – Maffra Weir to Thomson River confluence
Note: DRT = drought; AVG = average

Flow ID	Period	Magnitude (ML/d)	Frequency (per year)		Total duration (minimum days)		Minimum event duration (days)	Hydraulic criteria met	Description (flow function and value)
		BASE FLOW							
LF 1	Dec - May	35 ML/d or natural	DRT	Cont	DRT	Cont	Cont	G1, G3, V1	Maintain water quality in pools. Disturb lower channel features to improve geomorphic habitat. Provide clear, shallow, slow moving water for submerged aquatic vegetation
			DRY		DRY				
			AVG		AVG				
			WET		WET				
LF 2	All year	35 ML/d or natural	DRT	Cont	DRT	Cont	Cont	F1, F2, M1, P1,	Provision of habitat and local movement for native fish species. Permanent wetted habitat for macroinvertebrate communities. Maintain refuge pools and connectivity for platypus and rakali communities.
			DRY		DRY				
			AVG		AVG				
			WET		WET				
LF 3	Jun - Nov	300 ML/d or natural	DRT	Cont	DRT	Cont	Cont	F3, V2	Provide longitudinal connectivity for movement of native fish species Provide sustained wetting of lower benches and prevents vegetation encroachment
			DRY		DRY				
			AVG		AVG				
			WET		WET				
		FRESHES							
FR 1	Dec - May	140 ML/d	DRT	1	DRT	20	3 [Minimum 6 days from start of event to start of fall]	M4, M5, G2, V3	Maintains water quality and increases connectivity for macroinvertebrate communities Flushes and turns over pools to maintain water quality Wets benches and provide variability in water level for emergent vegetation
			DRY	≥1	DRY	40			
			AVG	≥1	AVG	40			
			WET	≥1	WET	60			
FR 2	April - May	140 ML/d	DRT	1	DRT	3	3 [Minimum 6 days from start	F4	Promotes migration of key native fish species (Grayling)
			DRY	1	DRY	5			
			AVG	≥1	AVG	15			
			WET	≥1	WET	25			

Flow ID	Period	Magnitude (ML/d)	Frequency (per year)		Total duration (minimum days)		Minimum event duration (days)	Hydraulic criteria met	Description (flow function and value)
							of event to start of fall]		
FR 3	May - Aug	700 ML/d	DRT	1	DRT	3	3 [Minimum 6 days from start of event to start of fall]	F5, F	Promotes migration of key native fish species (Tupong) Promotes migration of key native fish species (Bass)
			DRY	1	DRY	5			
			AVG	≥1	AVG	15			
			WET	≥1	WET	25			
FR 4	Sep - Oct	700 ML/d	DRT	1	DRT	3	3	V4	Wets tea tree and paperbark vegetation (fringing woody vegetation). Provides variability in water levels.
			DRY	1	DRY	5			
			AVG	≥1	AVG	15			
			WET	≥1	WET	25			
FR 5	Sep - Oct	700 ML/d	DRT	1	DRT	3	3	F7	Promote upstream migration of adult anadromous and juvenile catadromous and amphidromous fish
			DRY	1	DRY	5			
			AVG	≥1	AVG	15			
			WET	≥1	WET	25			
FR 6	Sep - Dec	1,500 ML/d	DRY	≥1	DRY	5	3	M3, V5	Scours sediment and disturbs biofilm to provide habitat and food sources for macroinvertebrate communities. Maintains fringing woody vegetation higher up the streamside zone. Provides variability in water levels.
			AVG	≥1	AVG	10			
			WET	≥1	WET	20			
FR 7	Any	1,500 ML/d	DRY	1	DRY	1	1	M2, G4	Moves organic material into channel to provide habitat for macroinvertebrate communities. Scours and moves sediment in pools to improve geomorphic habitat.
			AVG	1	AVG	1			
			WET	1	WET	2			
		BANKFULL							
BK 1	Any	10,000 ML/d	AVG	1	AVG	1	1	B1, G5, V6	Wet low lying areas on the floodplain to provide habitat and food source for frog, turtle and waterbird communities. Maintain channel form and transports sediment and organic matter. Disturb and reset aquatic and riparian vegetation.
			WET	1	WET	1			

7.3 Rates of rise and fall

The rate of rise and fall relates to the rate of change in flow from day to day, with a focus on the rate of increase up to a target flow and a rate of decrease from this target flow. 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.

Within the context of flow management, recommended rates of rise and fall are useful to ensure that the delivery of *managed* flows is such that ecological harm is minimised. The recommended rates of rise and fall were determined from the modelled unimpacted daily flow data. 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 target flow is 100 ML/d and the recommended rate of fall is 0.7, the flow on the following day should not be below 70 ML/d. Similarly, if the flow rate was 100 ML/d and the recommended rate of rise is 1.8, the flow on the following day should not exceed 180 ML/d.

The recommended maximum rate of rise and fall have been defined as the long term median rates of rise and fall for modelled unimpacted case (Table 19). These criteria were used in the previous environmental flow study on the Macalister River.

Table 19. Rates of rise and fall for the Macalister River

Component	Flow range R1	Flow range R2	Rise	Fall
Baseflow	90-350 ML/d	35-300 ML/d	1.8	0.7
Fresh	350-3,000ML/d	300-1,500ML/d	2.5	0.7
Bankfull	3,000-10,00 ML/d	1,500-10,00 ML/d	4.2	0.6

8 Achievement of environmental flow recommendations

An assessment of the performance of the updated environmental flow recommendations against the observed gauge records has been undertaken to demonstrate the achievement and shortfalls associated with current water management in the Macalister River system. Delivery of the recommended environmental flows (baseflow and freshes) has been simulated in eFlow Predictor for the following periods:

- Reach 1 – 55 years (based on Macalister@ Glenmaggie tail water gauge, 1960 – 2015)
- Reach 2- 14 years (based on Macalister @ Riverslea gauge, 2001-2015)
  Note: the shortfall assessment results for Reach 2 should be viewed in the context of the limited record available. Results shown by climate scenario for Reach 2 are based on a very limited number of years and do not present a statistically significant assessment. For example, there were not 'wet' years in this period

Figure 23 and Figure 24 show the additional water required to achieve full compliance with environmental flow recommendations, i.e. the environmental 'shortfall'. Figure 23 shows the shortfall for each of the climatic seasons (drought, dry, average and wet); whereas Figure 24 shows the shortfall by flow component.

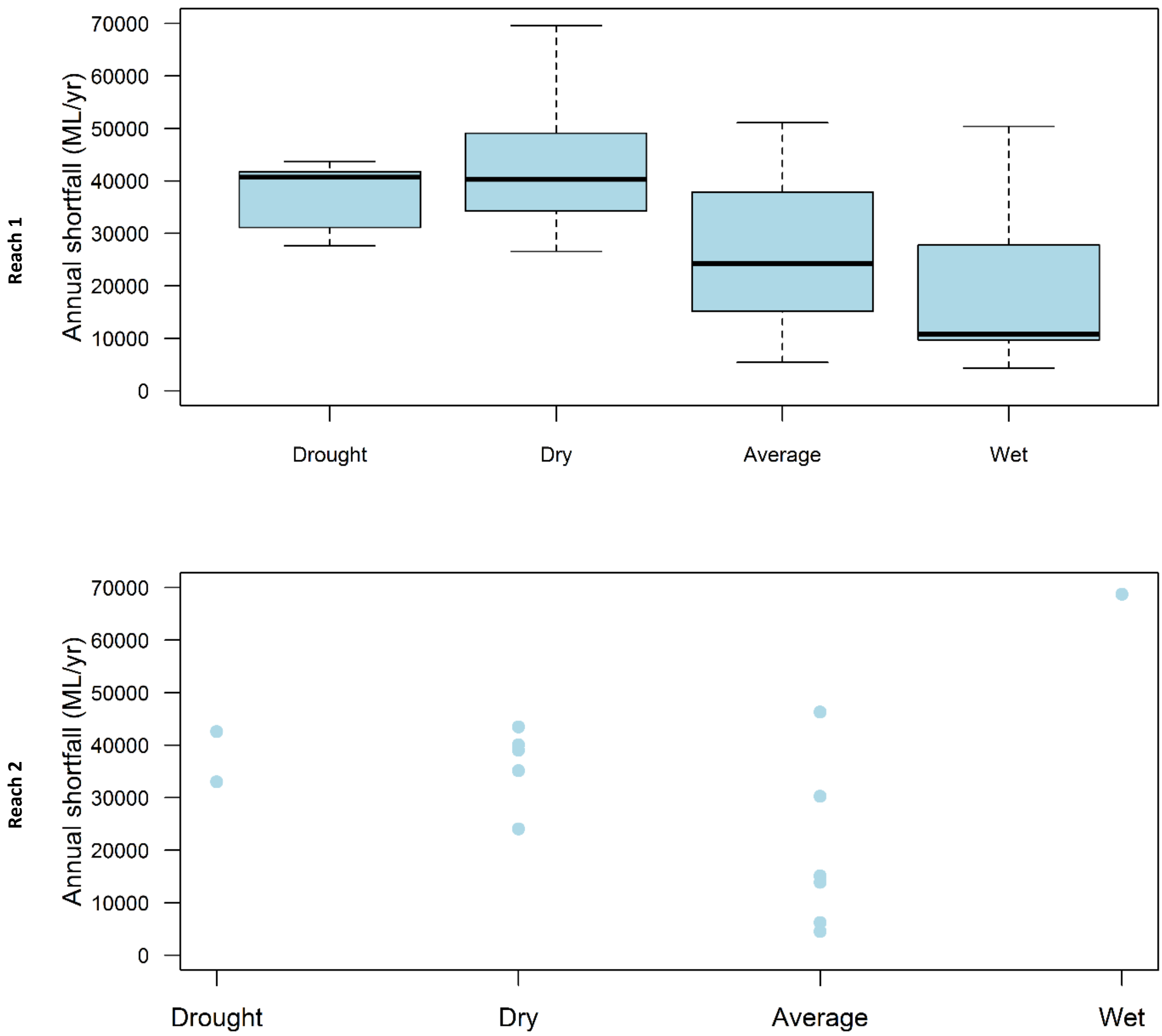


Figure 23. *Reach 1 and 2 –distribution of total annual shortfall volume by seasonal climate scenario. Reach 1 shown on top chart, Reach 2 on bottom chart. Note that for reach 2, there is no data available for wet years.*

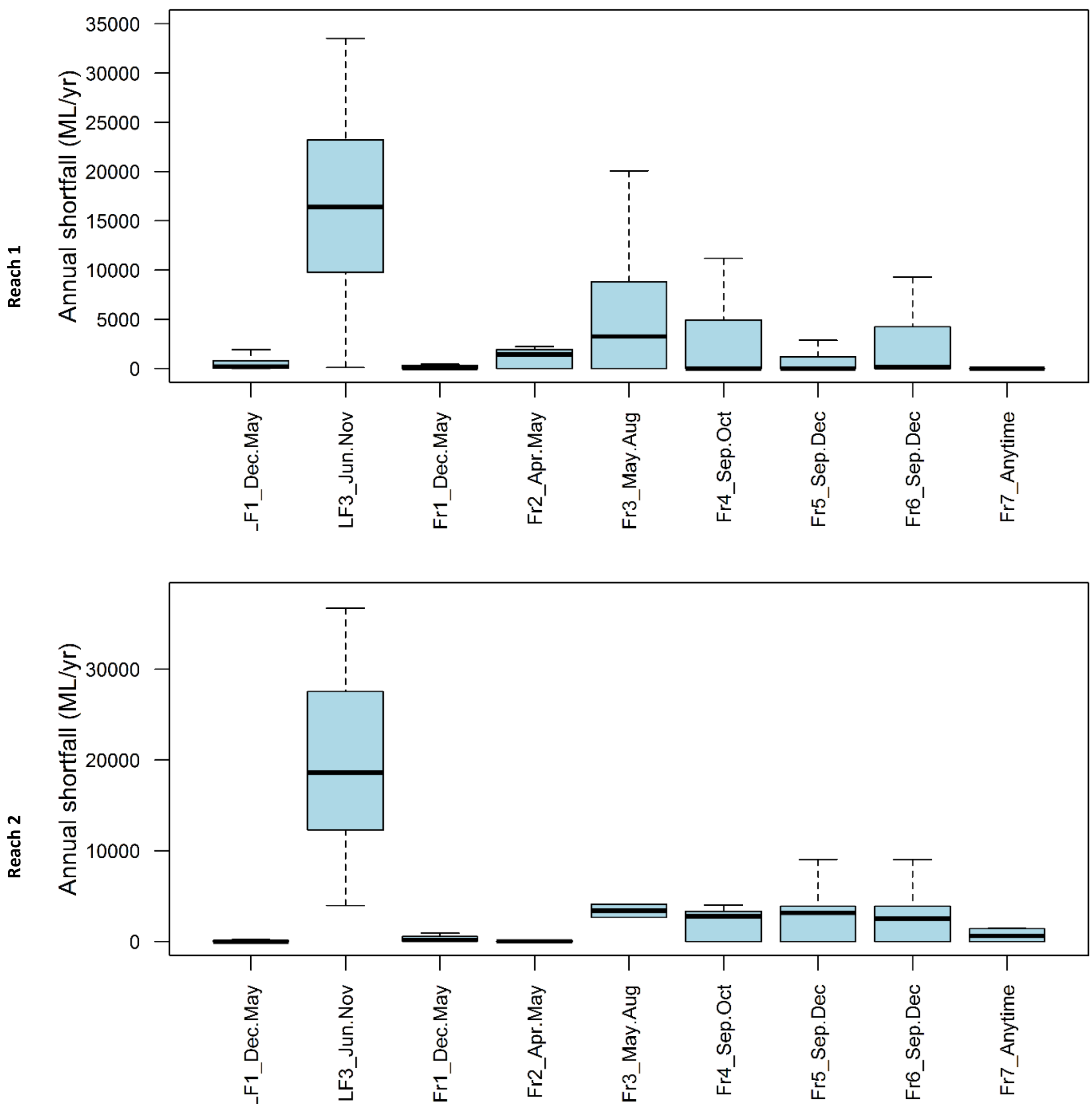


Figure 24. *Reach 1 and 2 – Total annual shortfall for each flow recommendation (each flow recommendation considered independently) – average shortfall by component labelled. Reach 1 shown on top chart, Reach 2 on bottom chart*

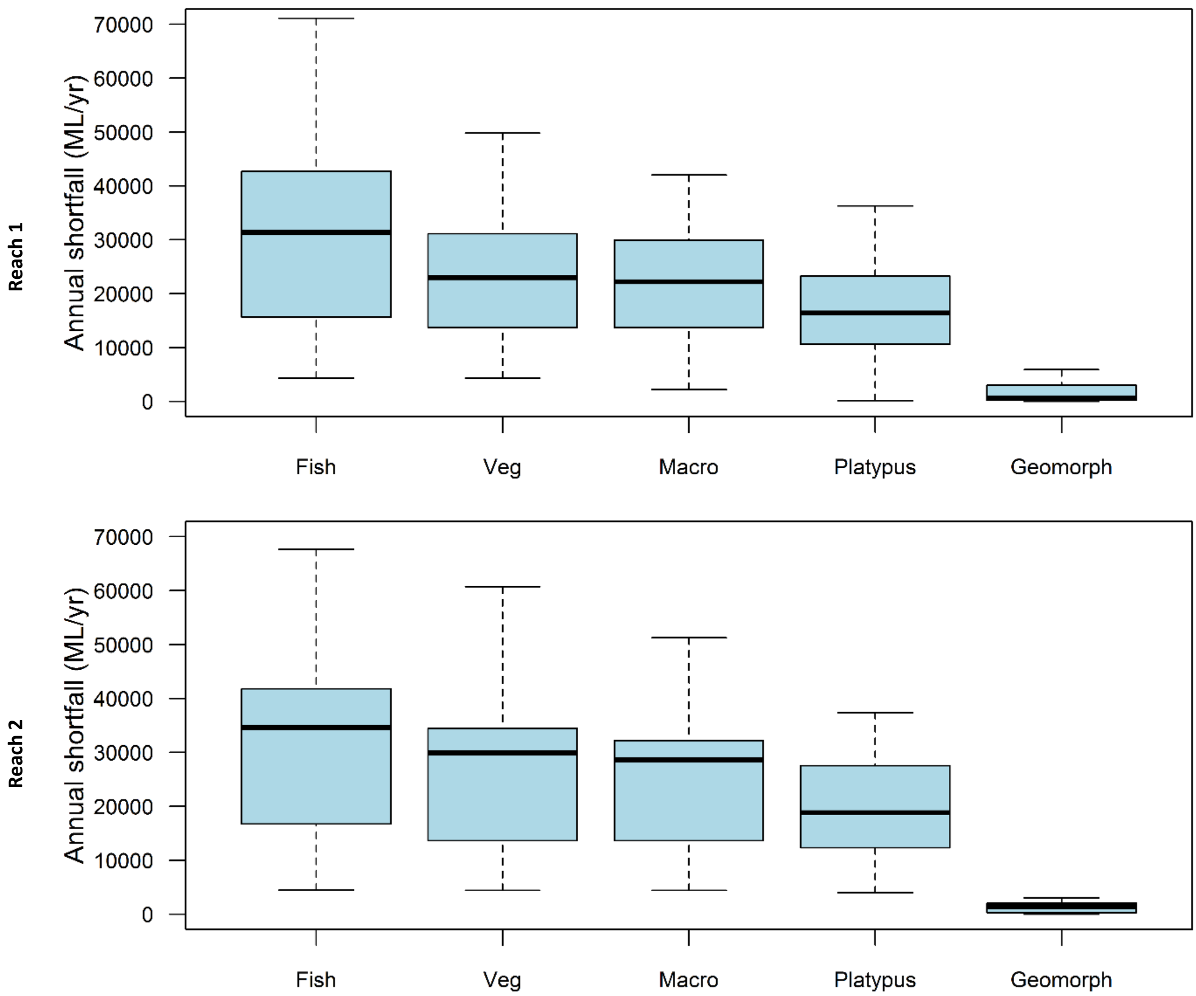


Figure 25. *Reach 1 and 2 –Total annual shortfall for each value (each value not considered exclusively). Reach 1 shown on top chart, Reach 2 on bottom chart*

Overall, the assessment found that:

- Long term average annual shortfall is 29 GL in Reach 1 and 31 GL in Reach 2.
- Median annual shortfalls vary in different climatic seasons – in reach 1 under drought conditions shortfall is 28 GL, dry conditions 23 GL, average conditions 33 GL, wet conditions 20 GL.
- The introduction of seasonally specific recommendations (i.e. different frequency and duration of events for drought, dry, average and wet years) has reduced the total environmental shortfall in comparison to implementation of the 2003 FLOWS study recommendations.
- June-November baseflows requires a significant volume of water. This large shortfall is a result of current system operations (i.e. filling Lake Glenmaggie) during the winter period.
- Freshes in the winter period require the greatest volume of ‘additional’ water to be provided. These freshes are important triggers for migratory fish movement and spawning (Tupong and Bass).

Based on value, the greatest shortfall can be attributed to fish, followed by vegetation and macroinvertebrates. However, it should be noted that each environmental flow delivered will typically support multiple values.

Part C: Macalister environmental water management

9 Risk assessment

The environmental flow recommendations provided in the Flow Recommendations Paper (Part B) assume that there is an adequate environmental entitlement available to deliver the desired flow regime. In practice, the existing environmental entitlement is not sufficient to deliver the full regime and the WGCMA along with VEWH must make decisions each year on which parts of the flow regime they deliver. Therefore, not all flow objectives may be met in a given year.

To assess the impact associated with not delivering all flow objectives over the long term, we have modelled the 'shortfall' associated with environmental condition as a result of non-delivery of environmental flow recommendations under the current regime. The assessment was undertaken using a habitat assessment approach using Eco Modeller (developed by eWater CRC), which is essentially a post-processor of daily time series data. It allows for the creation of different habitat preference curves to be assessed against different flow regimes.

9.1 Habitat preference curves

Environmental flows are delivered to support environmental values in the Macalister system. Sufficient magnitude, timing and frequency of flow components provide suitable habitat to support healthy populations of these environmental values. To assess the relative importance of different flow components for the environmental values, 'habitat' created through each environmental flow recommendation has been used as an indicator.

A 'habitat preference curve' describes the response of a habitat to certain flow conditions. Each curve describes a continuous function in relation to the magnitude, duration, or timing of a defined flow event. Whilst flow recommendations are essentially a binary definition of a flow requirement (it was either met or not), the preference curves allows the habitat value of partially successful events to be quantified. This allows a habitat condition score to be derived under different flow series (discussed below).

The habitat preference curves were developed with the Technical Panel based on an understanding of the current knowledge of flow requirements and life history stages of the environmental values, as well as the hydrology and hydraulics of the Macalister system. The process for developing each curves is provided in Figure 26. The full set of habitat preference curves are provided in Attachment 1.

To develop each curve a score of 1 is given to any condition that meets the flow recommendations. For values outside this range, an assessment is made whether it will provide some benefit to the habitat, and therefore a score between 0 and 1 is assigned, or whether it will provide minimal benefit and a score of 0 is assigned.

For any given flow event (from a daily time series), the score from the magnitude, frequency and timing graphs are combined (multiplied) to assign a condition score for that model on a given day. Therefore on a given day, an overall condition score of 1 can only be achieved if a score of **1** is achieved for magnitude, timing **and** duration. Similarly, if any of magnitude, timing **or** duration have a score of **0** for a given day, the overall condition score must also be 0, i.e. the flow requirements are not met. This process of multiplying the scores is shown for an example daily series across one year (Figure 27).

Each model represents a flow component, except where there are different functions and values driving the flow component, which will have different habitat preferences. In this case, multiple models will be used for each flow component.

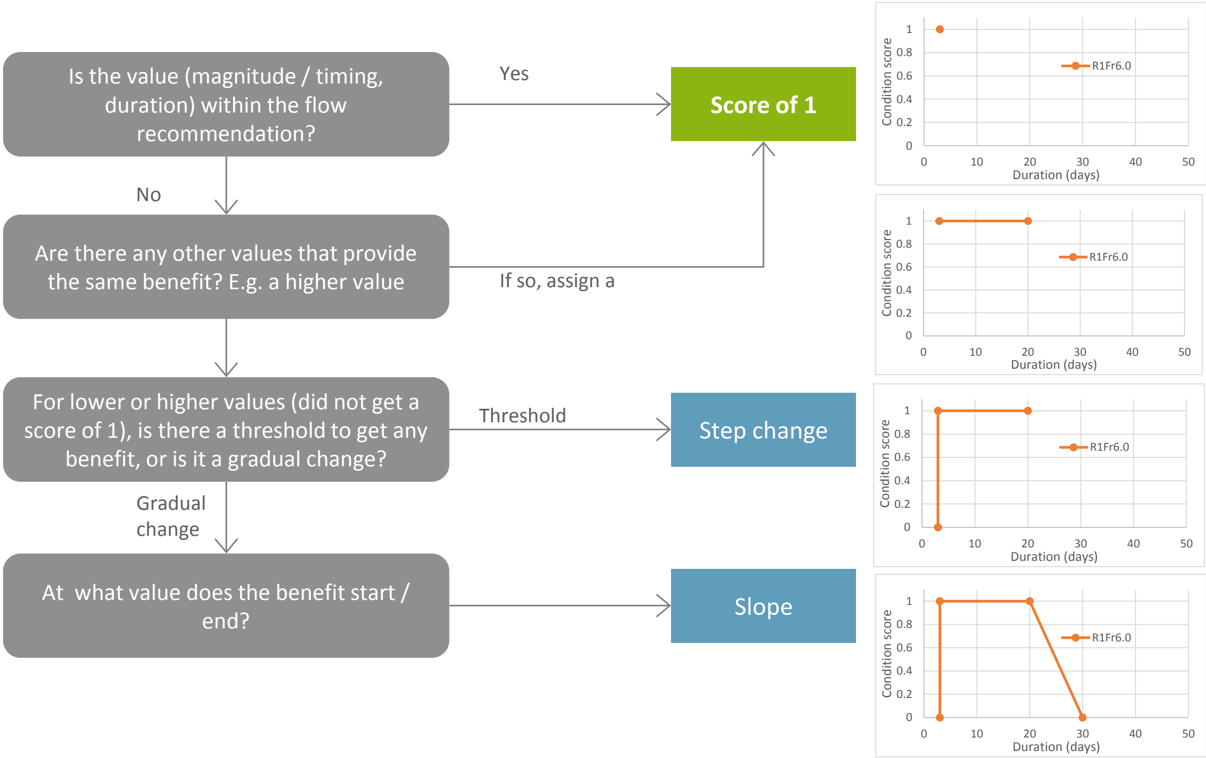


Figure 26. *Process for developing habitat preference curves*

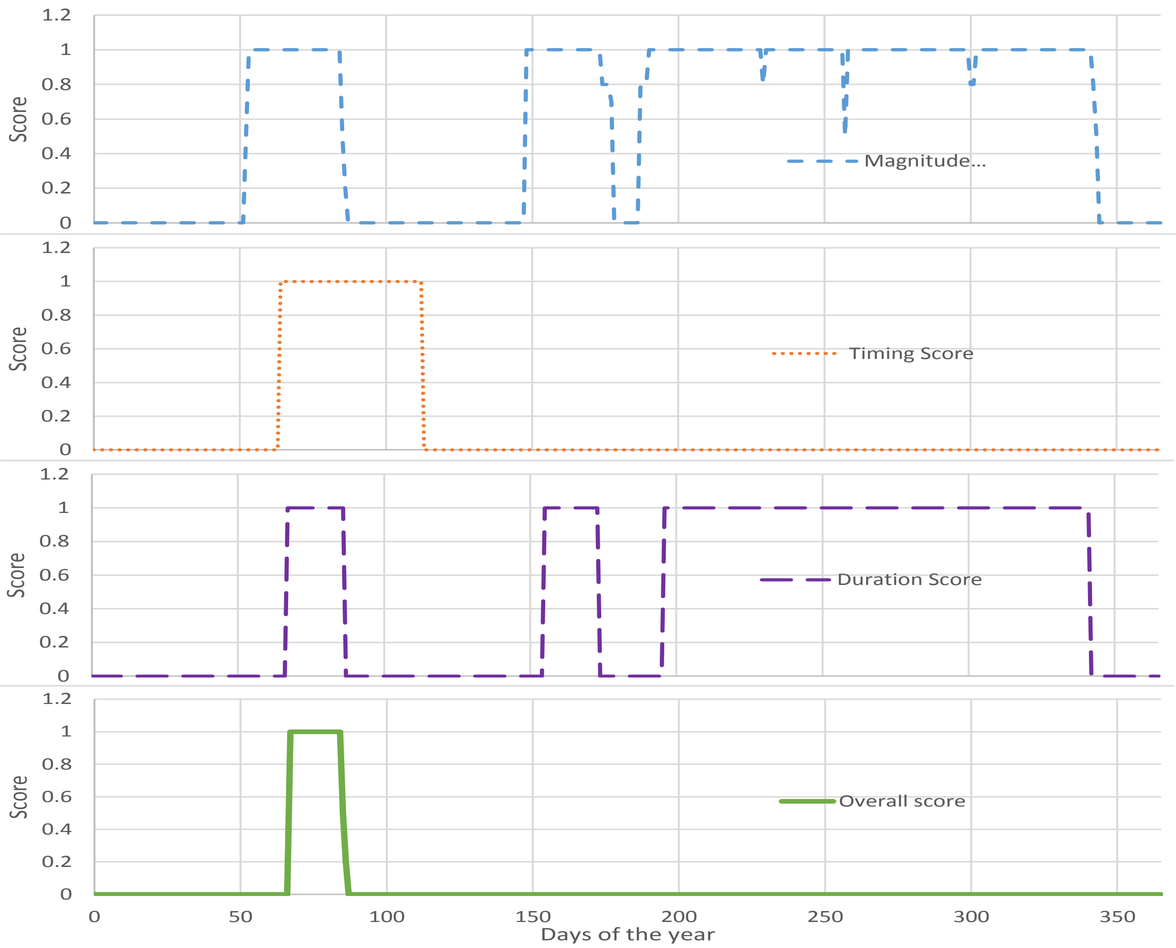


Figure 27. *Habitat preference curves: how the curves are combined to produce a score for a daily flow series.*

9.2 Method

Using the models based on the habitat preference curves, we have assessed the condition using the following flow regimes:

- Natural: the pre-development modelled flow series was used to test the validity of the ecological condition scores generated through Eco Modeller.
- Current: the gauge records (Riverslea and Maffra Weir) were used to represent the current flow regime
- Augmented: represents the current flow regime with all environmental flow recommendations delivered (if not achieved as part of the current regime). This scenario provides the ideal environmental scenario and minimises risk to the environment.

The model produces a daily condition score series for each flow regime. These condition scores can then be aggregated over the year. The aggregation approach depends on the type of flow. For a fresh, which is a single event, the maximum score over the year is adopted, i.e. is the fresh (or part thereof) provided at some point during the year. For a baseflow, the average score over the required period is adopted. This gives an annual condition score for each flow regime.

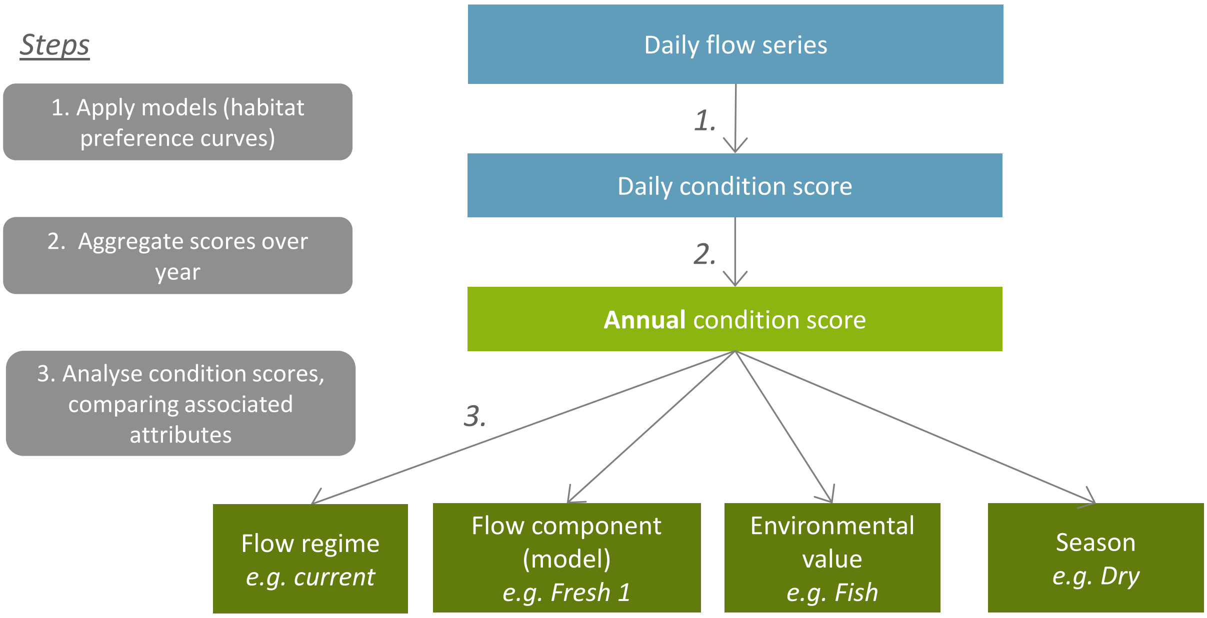


Figure 28. *Process for modelling condition scores*

The condition scores can then be analysed based on the following attributes associated with each score:

- Flow regime (augmented, current, natural)
- Flow component (i.e. the model, e.g. Fresh 1)
- Environmental value (Fish, Vegetation, Macroinvertebrates, Platypus, Geomorphology)
- Climate (drought, dry, average, wet)

Results for the natural flow regime are provided here (Figure 29). The graph demonstrates that the overall condition trend aligns with climate conditions, i.e. the condition decreases during dry and drought years, and increased during wet and average years. This illustrates that model is creating results we expected.

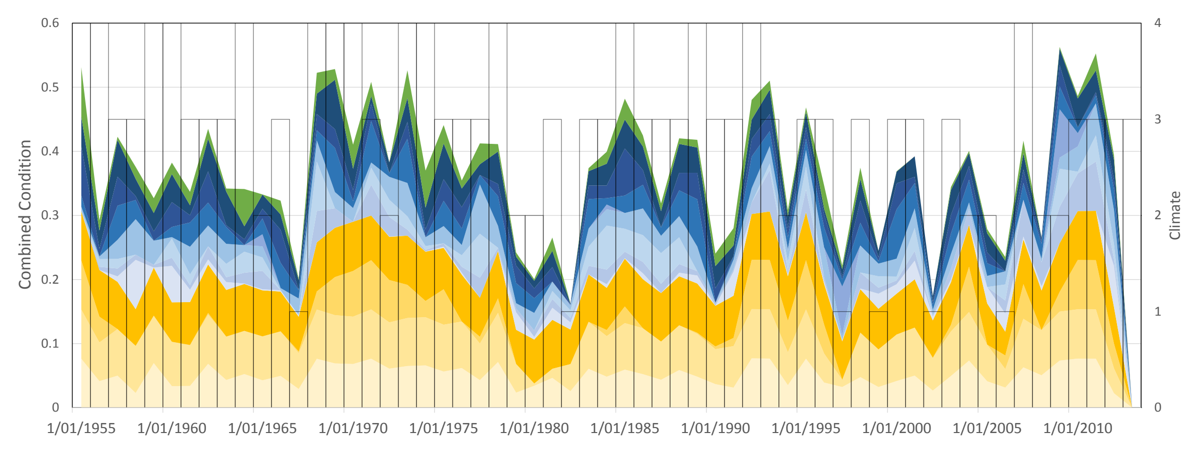


Figure 29. *Condition score for natural regime across time series, with climate shown on right axis; different colours represent different flow components, stacked to create the overall condition score*

9.3 Risk assessment results and discussion

The assessment of impact has been made for two flow regimes: augmented and current. As the condition scores are arbitrary values, it is the comparison of the results from different flow regimes that tells a story. Therefore results are provided for the difference between augmented and current (gauge).

Alongside the condition scores, the volumetric shortfall analysis results (from the Flow Recommendations Paper) are included here to understand the amount of water required to change the condition. Note that where volumetric shortfalls are presented for different flow components and different values, the results are not independent of each other. That is, the combined shortfall from each of these components will not add up to the total shortfall as they overlap in some instances.

The results are provided in the figures below (Figure 30 - Figure 35). Codes in the figures relate to flow components and habitat preference curves as described in Table 20 and Attachment 1. The data are presented below using boxplots.

Table 20. Model codes used in the risk assessment

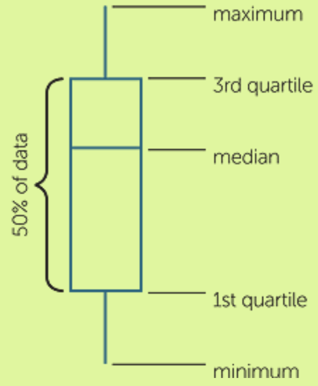
Code	Flow component	Function
LF1.0	Baseflow Dec – May	Physical habitat and vegetation
LF2.0	Baseflow All year	Habitat for fish, macroinvertebrate and platypus
LF2.1	Baseflow All year	Local movement of fish, macroinvertebrate and platypus values
LF3.0	Baseflow Jun-Nov	Vegetation
FR1.0	Fresh Dec – May	Water quality, macroinvertebrate and vegetation
FR1.1	Fresh Dec - May	Migration of eels
FR2.0	Fresh April - May	Grayling migration
FR3.0	Fresh May - Aug	Tupong and Bass migration
FR4.0	Fresh Sep – Oct	Vegetation
FR5.0	Fresh Sep – Oct	Fish recruitment
FR6.0	Fresh Sep – Dec	Vegetation and macroinvertebrate
FR7.0	Fresh anytime	Geomorphology and macroinvertebrate
BK1.0	Bankfull July - Oct	Vegetation, geomorphology, frog, bird and turtle

How to read a box plot:

A box plot consists of a 'box' and whiskers that extend either side of the box.

The **box** contains 50% of the data. The central line represents the median (50th percentile), the top represents the 25th percentile (or 1st quartile) and the bottom the 75th percentile (or third quartile).

The **whiskers** extend to the minimum and maximum value. In this case, they extend to the lowest and highest value that is within 1.5 × interquartile range and outliers are not shown



Results by flow component

The results by flow component are presented in Figure 30 and Figure 31. For this analysis, the discussion for each flow recommendation considers the following two questions:

- How much is the condition score improved in the augmented regime (compared to gauge)?
- How much additional water is required for that flow component in the augmented regime?

This allows for an assessment to be made on the impact of habitat condition relative to the amount of water required. The assessment found:

Low flow 1 (Dec-May):
There is a good improvement in condition in Reach 1 for the augmented flow, while there is only a minor improvement in Reach 2.

- The difference between the reaches may be due to the passing flow requirement under gauge conditions – this passing flow (60 ML/d) is lower than the Reach 1 LF1 requirement and higher than the Reach 2 LF1 requirement.
- There is only a small volumetric shortfall required to deliver this flow in both reaches.
- This flow should be delivered when not provided under current conditions.

Low flow 2 (All year):
There is some improvement in condition for both the habitat model (LF2.0) and movement model (LF2.1).

- There is more variability in the results for model 2.1 as it uses a step change in the habitat preference curve, whereas model 2.0 uses a slope change.
- There is no condition increase provided in Reach 2 as the passing flow requirement already meets the LF2 flow in the current regime.
- The volumetric shortfall for this flow component is part of the LF3 shortfall, which is significant.
- This flow should be delivered when not provided under current conditions.

Low flow 3 (Jun – Nov):
By implementing this recommendation, there is a significant improvement in habitat condition for vegetation.

- This flow requires a lot of water, however as identified in the habitat preference curves, any increase from the LF2 requirement will be valuable

Fresh 1 (Dec-May):
Fresh 1 is generally achieved in the gauge regime, and therefore there is a small condition (for model FR1.0) and volumetric shortfall.

- In model FR1.1 for eel movement, there is a greater increase in condition for the augmented regime and therefore it should be prioritised for delivery (at least one fresh to satisfy this requirement) when not provided under current conditions.

Fresh 2(Apr-May):
There is an improvement in condition for Grayling migration through provision of this flow recommendation. Delivery of this flow component does not require a significant volume of water and should be prioritised for delivery when not provided under current conditions.

Fresh 3 (May-Aug):
There is a small improvement in condition for Tupong and Bass migration. A significant amount of water is required for this fresh, particularly in Reach 1. Therefore, with only a small improvement in condition and a significant volume of water required, it is lower priority for regular delivery.

Fresh 4 (Sep-Oct):
Providing this fresh has limited impact on habitat condition (as a change from current to augmented) and a substantial amount of water is required to deliver the flow. This event should only be delivered if it hasn't occurred for many year, and should focus on reach 2.

Fresh 5 (Sep-Dec):
There is a small increase in condition for fish recruitment if this flow component is delivered. This flow event should be delivered where possible.

Fresh 6 (Sep-Dec):
There is a small increase in condition and a significant amount of water required. Where possible, allow this event to occur naturally.

Fresh 7 (anytime):
The assessment indicated little change between current and augmented conditions for this flow component. As Fresh 7 requires a significant amount of water, it should not be delivered as a priority.

Bankfull flow:
The bankfull flow provides minimal change in condition as it occurs under the current flow regime at the required frequency and duration. Protection of the current frequency of this flow is important for the long term habitat condition of the system.

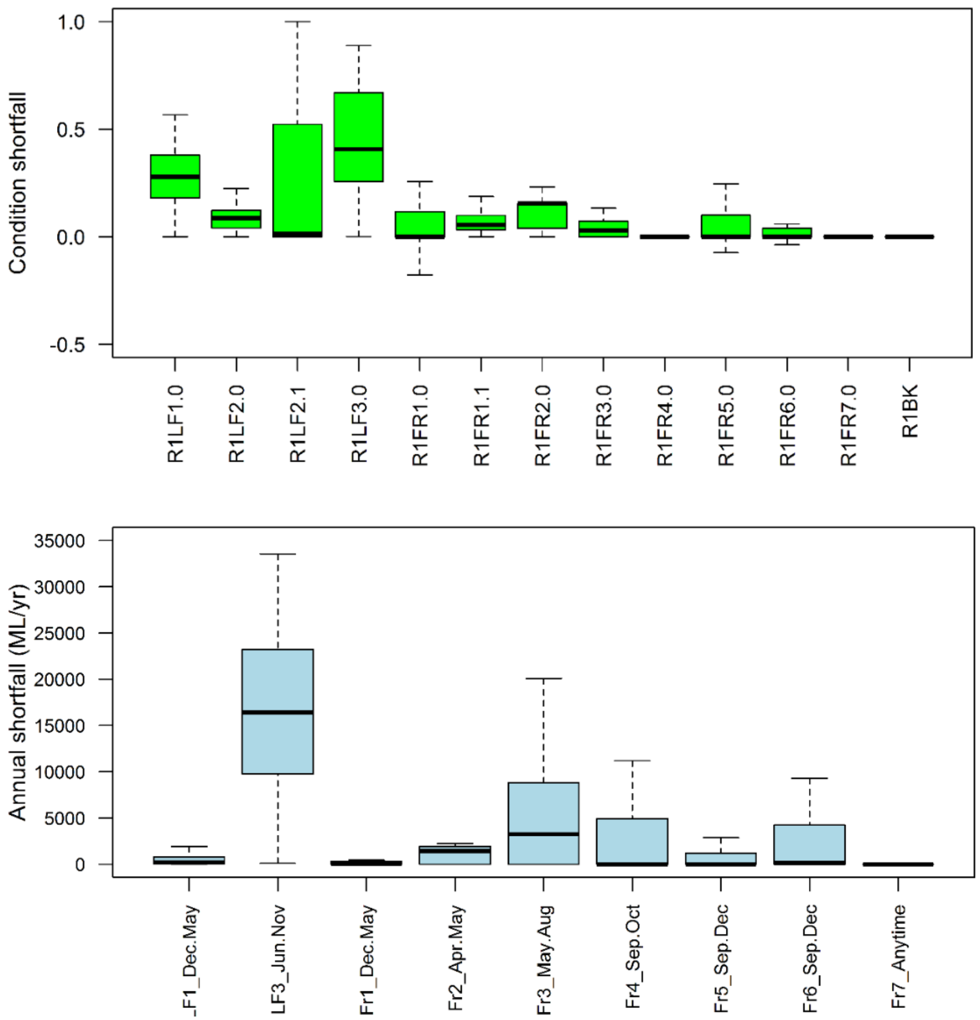


Figure 30. *Reach 1: Annual condition shortfall (top) and annual volume shortfall (bottom) by each flow component. Condition shortfall is calculated as the annual 'Augmented' score minus 'Current' score. Volume shortfall is calculated as the annual 'Augmented' volume minus 'Current' volume. Data shown is from 1960-2014 for each flow component.*

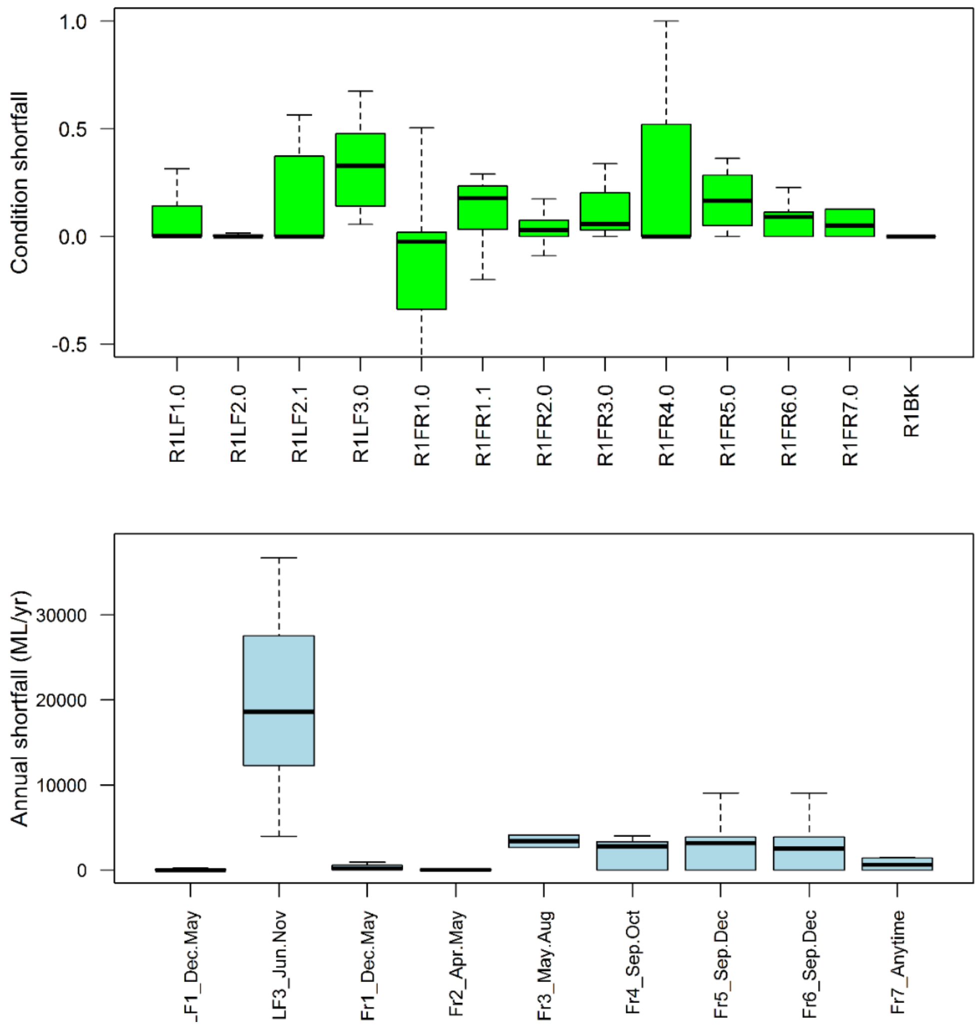


Figure 31. *Reach 2: Annual condition shortfall (top) and annual volume shortfall (bottom) by each flow component. Condition shortfall is calculated as the annual 'Augmented' score minus 'Current' score. Volume shortfall is calculated as the annual 'Augmented' volume minus 'Current' volume. Data shown is from 2001-2014 for each flow component.*

Results by climate

The results are presented below based on the different climate conditions. These graphs show that there is a similar change in condition across the four climate categories. This reflects the seasonal approach we have adopted for these flow recommendations. This provides confidence that the flow recommendations are realistic in their requirements under different climatic conditions.

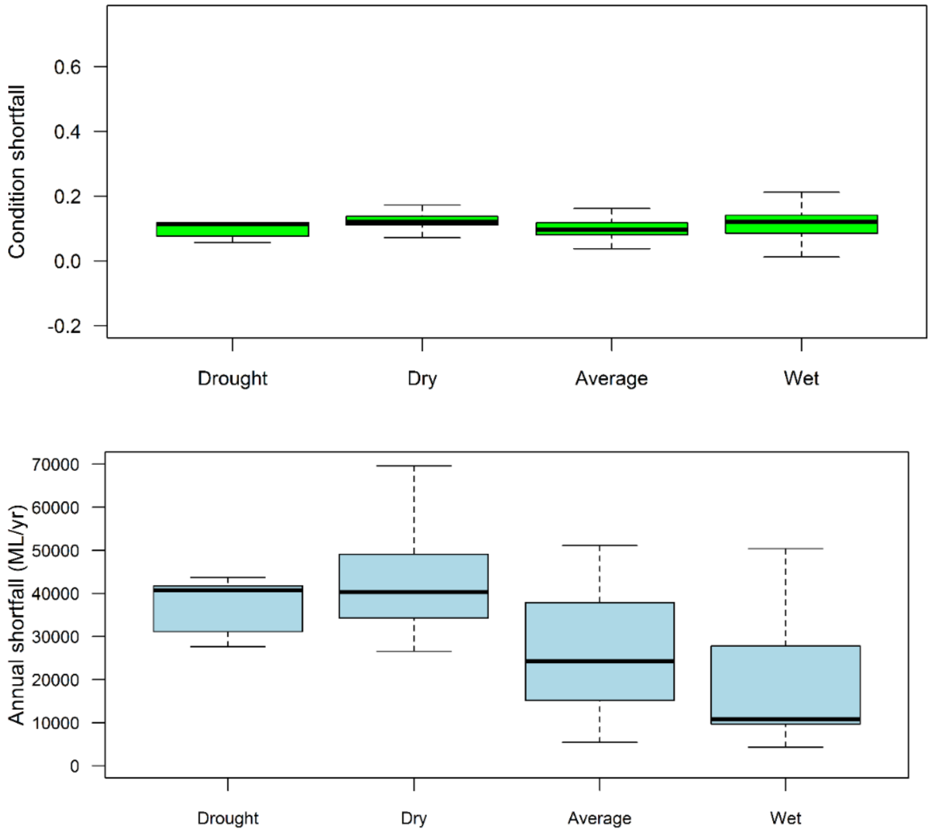


Figure 32. *Reach 1: Annual condition shortfall (top) and annual volume shortfall (bottom) for different climate conditions. Condition shortfall is calculated as the annual 'Augmented' score minus 'Current' score. Volume shortfall is calculated as the annual 'Augmented' volume minus 'Current' volume. Data shown is from 1960-2014.*

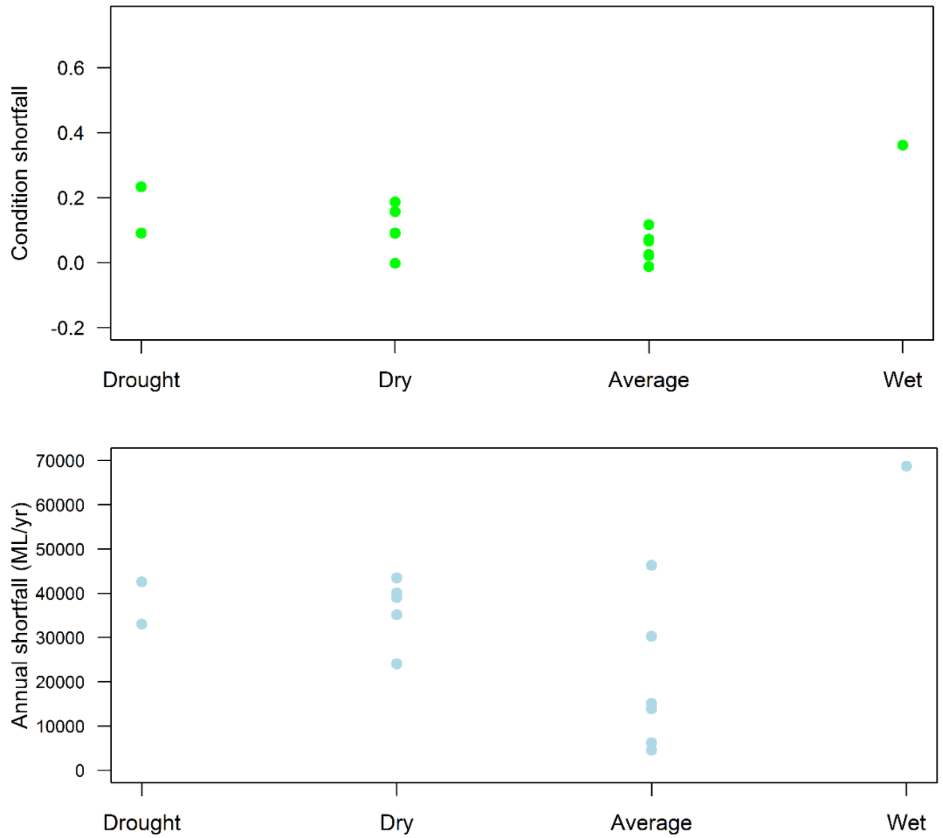


Figure 33. *Reach 2: Annual condition shortfall (top) and annual volume shortfall (bottom) for different climate conditions. Condition shortfall is calculated as the annual 'Augmented' score minus 'Current' score. Volume shortfall is calculated as the annual 'Augmented' volume minus 'Current' volume. Data shown is from 2001-2014.*

Results by environmental value
The change in condition for each value is presented below. These results help prioritise for each reach, where providing environmental flows can provide the biggest impact on habitat condition:

- Fish and vegetation are important in both reaches
- Platypus habitat condition is improved by the augmented regime in Reach 1
- Geomorphology and macroinvertebrates have limited change in condition under the augmented regime

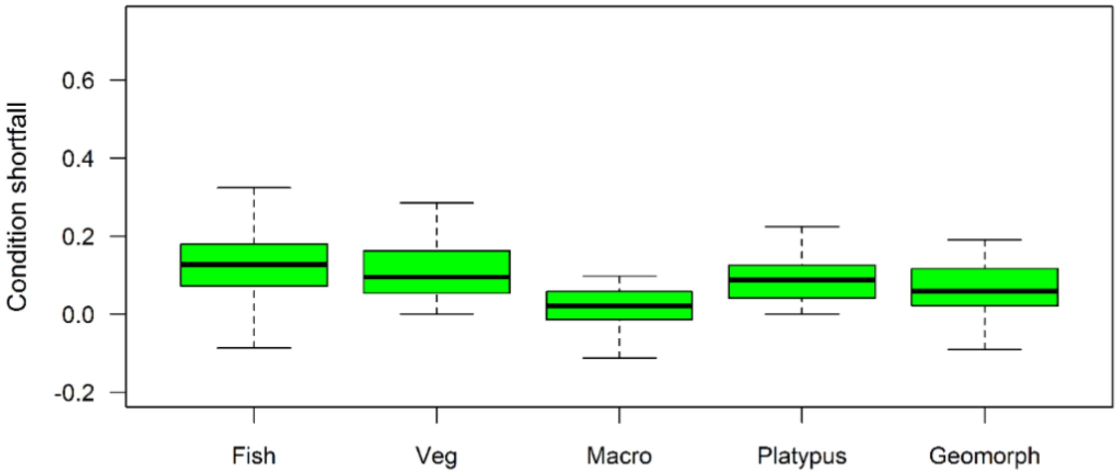


Figure 34. *Reach 1: Annual condition shortfall (top) and annual volume shortfall (bottom) by value. Condition shortfall is calculated as the annual 'Augmented' score minus 'Current' score. Data shown is from 1960-2014.*

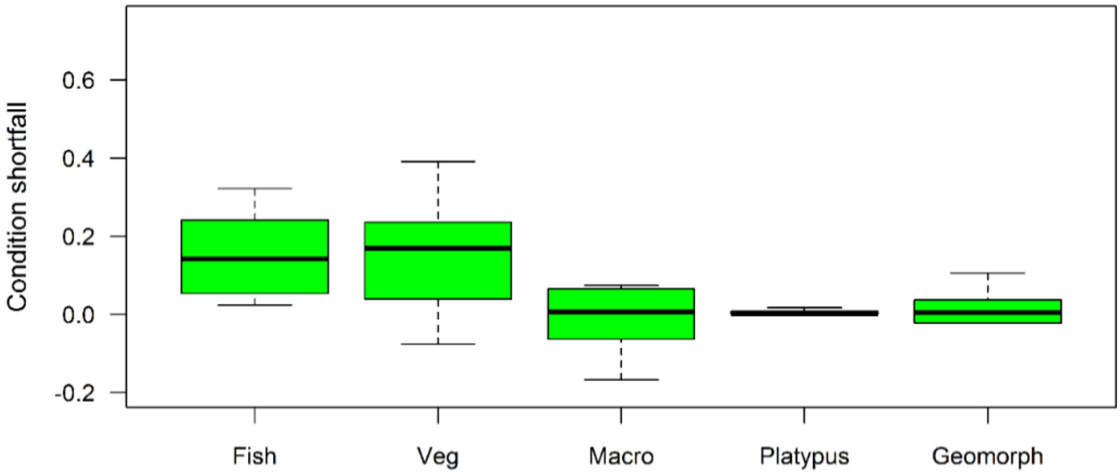


Figure 35. *Reach 2: Annual condition shortfall (top) and annual volume shortfall (bottom) by value. Condition shortfall is calculated as the annual 'Augmented' score minus 'Current' score. Data shown is from 2001-2014.*

10 Management objectives

10.1 Long term management goals for the Macalister River

A long-term management goal has been developed for the Macalister River, in conjunction with the community Project Advisory Group (PAG). This is an overarching goal which will guide the use of environmental water to achieve the desired ecological condition.

In partnership with the community we will preserve and enhance habitat to support water dependent plants, animals and the ecological character of the Macalister River and floodplains for current and future generations

10.2 Prioritised ecological objectives

Based on the discussion in Section 2, the ecological objectives have been prioritised in the table below into three groups: high, medium and low.

Table 21. Prioritised ecological objectives

High priority

- Improve spawning and recruitment opportunities for Australian Grayling
- Improve the distribution and abundance of Australian grayling

Medium priority

- Improve spawning and recruitment opportunities for Short-finned Eels, Australian Bass and Tupong
- Maintain the distribution and abundance of all expected native fish species
- Reinstate native submerged vegetation
- Improve abundance of platypus and rakali

Low priority

- Improve physical habitat
- Improve native emergent (non-woody) vegetation
- Maintain fringing native woody vegetation in the riparian zone
- Maintain the abundance and number of functional groups of macroinvertebrates

10.3 Prioritised hydrological objectives

Based on the discussion in Section 2, the hydrological objectives have been prioritised in the table below into three groups: high, medium and low. The priorities below are based on fish passage being provided at Maffra Weir. It is important to note that providing flows for migratory fish in Reach 1 under current conditions (with a fish barrier at Maffra Weir) will only have a limited impact.

Table 22. Prioritised hydrologic objectives

Priority	Flow ID	Description	Values	Reach Prioritisation
High	LF 1	Low flow, Dec- May	Vegetation, Physical habitat	Focus on reach 1
	FR 1	Fresh, Dec- May	Fish, Macroinvertebrates, Vegetation, Physical habitat	Both important
	FR 2	Fresh, April- May	Fish	Focus on reach 1
Medium	LF 2	Low flow, all year	Fish, Macroinvertebrates, Platypus	Focus on reach 1
	LF 3	Low flow, June – Nov	Vegetation	Both important
	FR 3	Fresh, May - Aug	Fish	Both important
	FR 5	Fresh, Sep - Dec	Fish	Both important
Low	FR 4	Fresh, Sep - Oct	Vegetation	Focus on Reach 2
	FR 6	Fresh, Sep - Dec	Macroinvertebrates, Vegetation	Focus on Reach 2
	FR 7	Fresh, Anytime	Macroinvertebrates, Physical habitat	Focus on Reach 2
	BK 1	Bankfull flow, Anytime	Vegetation, Physical habitat, Birds, Turtles and Frogs	Same recommendation

It is recommended that as well as delivering these hydrologic objectives, where possible, environmental water should be managed to avoid significant risk to platypus and rakali. These risks are outlined in the Issues Paper and include:

- Avoid bankfull (or similar) flows during breeding season (October to March)
- Avoid extended high flow events

These should be considered in particular when delivering FR 5, F 6, FR 7 and BK 1.

11 Testing success: monitoring requirements

Monitoring is required to measure progress towards achieving objectives. Monitoring is critical to:

- ensure **accountability** by enabling environmental water managers to report on the use of environmental water
- ensure **transparency** by investigating (and communicating) the ecological benefits of environmental watering
- improve **efficiency** by facilitating learning and improved management.

The information gained from each type of monitoring is shared between organisations and communities to build a comprehensive picture of the ecological benefits of environmental watering.

There are three different types of monitoring that operate over different temporal scales: operational, intervention and condition. Operational monitoring reports on the delivery of environmental water and whether **hydrologic objectives** are achieved. Intervention monitoring looks at the achievement of **ecological objectives** in the medium term, and condition monitoring looks at the overall health of the river, and the achievement of the **long term management goal**.

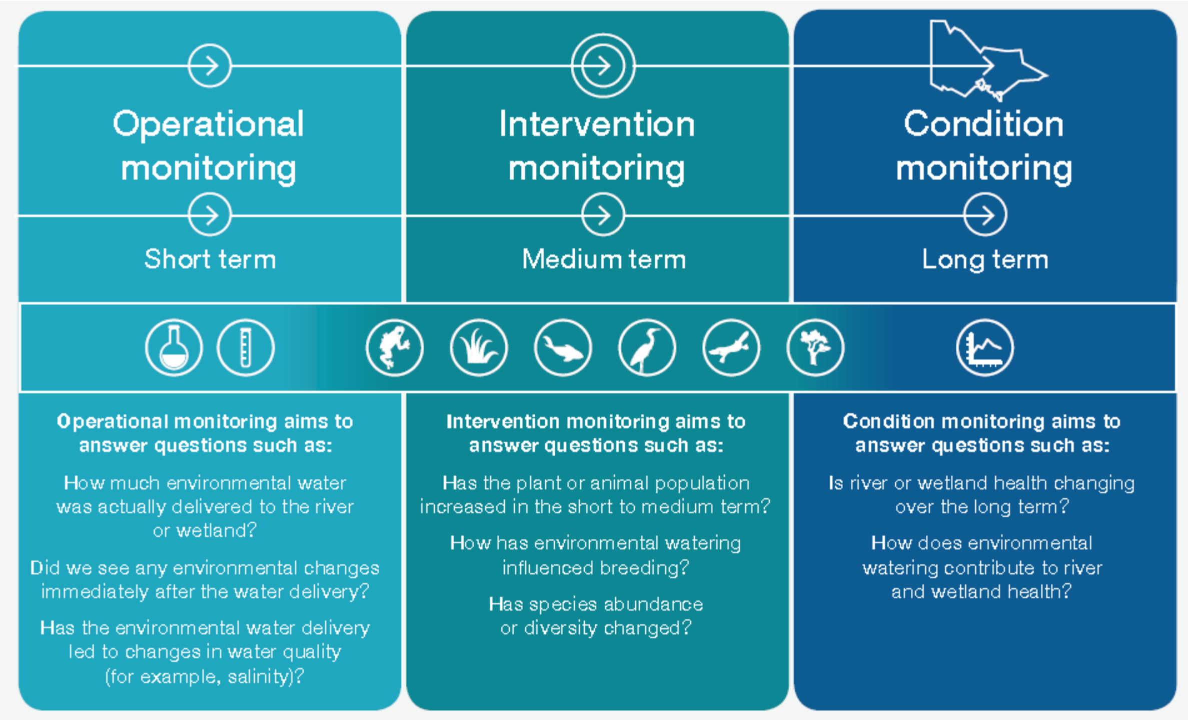


Figure 36. *Types of monitoring (VEWH 2015)*

This section outlines the key monitoring requirements for the Macalister River flow recommendations.

11.1 Operational monitoring

Compliance monitoring should be performed by the WGCMA to measure and report on the flow recommendations. This includes events that are delivered with environmental water, and events that occur due to the operation of Lake Glenmaggie and supply of consumptive water. This should be done at the two compliance point gauges: Macalister River at Lake Glenmaggie (tail gauge) for Reach 1 and Macalister River at Maffra weir for Reach 2.

Hydraulic modelling
A critical aspect of the hydraulic criteria used to determine flow recommendations is around minimum depth over riffles for fish passage. While the hydraulic models help us to understand minimum depths over riffles, there are limitations in these modelled results. Further information could be obtained from observing riffle sites during low flow events to ensure that adequate depth for fish passage is provided.

11.2 Intervention monitoring

Specific monitoring activities will depend on the monitoring question that is being asked. Some main areas for monitoring of the ecological objectives are described below.

Fish
Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) fish surveys provide suitable monitoring to understand abundance of fish species. To understand movement of fish for spawning and recruitment, telemetry (tagging) techniques are required in combination with analysis of hydrological and hydraulic aspects of flow.

Vegetation
There are three key areas for intervention monitoring vegetation in the Macalister system. Monitoring should be undertaken to determine:

- Whether submerged vegetation re-establishes in the main channel of the river.
- If re-establishment does not occur, what factors might be responsible for the lack of success. Water clarity (e.g. turbidity) would be the first water quality variable to monitor. This should be monitored in real-time in Reach 1 and in Reach 2 over an entire year, and the results linked with flow and with weather patterns.
- The effectiveness of complementary works including fencing, control of stock access, and weed control. Complementary works are directed at both submerged vegetation and at fringing (riparian) vegetation. Monitoring vegetation responses in areas along the river that have complementary works implemented should be compared with areas that do not; e.g. fringing vegetation in riparian areas with free stock access versus that in areas that have been fenced or where stock access is otherwise controlled. This program would allow the beneficial effects of an improved flow regime to be compared with the beneficial effects of the proposed complementary works.

Macroinvertebrates
Monitoring requirements for macroinvertebrates are well established. The EPA rapid bioassessment live sorting method (EPA 2003) must be used to collect the data which are to be compared against the biological objectives or previous data which utilized the same methods. Samples need to be collected from two consecutive seasons - autumn (March – May) and spring (October – December) - and the data combined for assessment against the biological objectives.

While two stream habitats– riffles and edges (including aquatic macrophytes) – are specified in the standard sampling protocols, only edge habitats are in sufficient abundance in the Macalister River for sampling.

Platypus
The understanding of the presence of platypuses and Rakali in the system could be improved by a targeted population study, or building on online databases with more current sightings. Monitoring efforts could focus on the instances where significant threats occur, specifically:

- Bankfull flows during breeding season
- Extended periods of high flow
- Poor water quality
- Areas with poor riparian vegetation

Birds, Reptiles and Frogs
Monitoring for the Common Long-necked Turtle and for Growling Grass Frog may be valuable in consideration of effects of flow regimes. For both species initial baseline surveys for their presence and abundance would be necessary.

For Common Long-necked Turtles a 'snapshot' of the population's age structure can be obtained by a trapping session to determine whether a range of ages are present. If the population sampled is skewed toward aged individuals with few younger age-class animals this may indicate previous years of low recruitment. It will be difficult to absolutely determine a cause, but subsequent surveys after flow manipulations would be instructive. Common Long-necked Turtles can be effectively trapped using appropriately set fyke nets.

Methods for survey of Growling Grass Frog are detailed in EPBC Act Policy Statement 3.14 Significant impact guidelines for the vulnerable growling grass frog (Litoria raniformis) (Department of the Environment, Water, Heritage and the Arts, 2009). Standard methods entail monitoring for calling of breeding males during night time surveys. Call playback may be used to elicit responses from frogs. Ideal survey conditions include warm and windless nights in spring and summer. An initial baseline investigation for the presence of the species across suitable habitat within the lower Macalister River will be required to ascertain whether any populations currently exist. If key elements of breeding habitat, such as requisite density of aquatic vegetation are presently missing, it would be informative to re-survey following re-establishment of required habitat components.

11.3 Condition monitoring

The WGCMA can use river health monitoring and other long-term ecological surveys to understand the overall condition of the Macalister River. Some examples include Index of Stream Condition (ISC), and the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP).

12 Knowledge gaps

This study has been undertaken based on the best available science for the Macalister system. The science underpinning environmental water management will continue to evolve with more monitoring, research and management experience. This section outlines the main knowledge gaps relating to the environmental values, ecological objectives and flow recommendations outlined in Papers A and B. The knowledge gaps are discussed in terms of ecological and hydrological topics below.

12.1 Ecological knowledge gaps

One of the main knowledge gaps for this system in the absence of data on the current distribution, abundance, or status of platypus and Rakali in the system.

Platypus and Rakali

There is little information on the population trends, or the current distribution, abundance, or status of platypuses and Rakali in the Macalister system. There have been no targeted population studies in the Macalister River on either species, and there is some data from online databases (Atlas of Living Australia, Victorian Biodiversity Atlas; accessed 10th March 2015) indicate the species' are widely distributed throughout the Macalister River and its tributaries. However, the distribution data from these sources is generally sparse, derived from anecdotal sightings, and more than 20 years old.

Unfortunately, there is also very little empirical data on the flow requirements for platypuses (*Ornithorhynchus anatinus*) and Rakali (*Hydromys chrysogaster*). Much of the knowledge is extrapolated from anecdotal evidence, understanding of their behaviour and habitat requirements, and expert opinions formed from experience in the field. Although platypuses and Rakali are known to inhabit many regulated waterways, it is largely unknown how altered flow regimes may impact populations. Such changes to flow regimes may include increased frequency and duration of low flow or cease to flow events, increased 'flashiness' of floods (higher peaks, shorter duration) in urban areas, or altered seasonality of flows. However, further research is required to verify these hypotheses and understand the long-term impacts of river regulation on platypus and Rakali populations. Probably of most importance are the impacts of altered flow regimes on the benthic macroinvertebrates that constitute the majority of the diet for both species.

Therefore the following research priorities are recommended:

- Improve resolution of platypus and Rakali distribution and abundance to understand trajectory of populations in regulated and unregulated rivers.
- Understand the response of platypuses and Rakali to variable flow regimes with particular focus on very low and very high flows.
- Determine optimal flow regimes by quantifying habitat availability and benthic productivity at different flows.
- Identify environmental factors that influence timing of reproduction and reproductive success.
- Identify drought refuges and determine minimum flows required to maintain these refuges.
- Determine minimum flows required to maintain longitudinal habitat connectivity along the river.

Fish

Recommendations for the provision of environmental flows in autumn/winter have been made to trigger downstream spawning migrations of adult diadromous fish (i.e. fish that move between freshwater and marine habitats at some stage during their life cycle). While recent work has provided significant new information on the migration ecology and links with flow for diadromous species such as Australian Grayling, Tupong, Short-finned Eel and Australian Bass (Crook et al. 2010; Walsh et al. 2012; Koster et al. 2013; Crook et al. 2014), the specific mechanisms for how flow affects movement require further exploration. For example, aside from eliciting direct behavioural responses, flow also affects the physical habitat in terms of the hydraulic characteristics (e.g. velocity, turbulence, depth), which may influence the swimming ability of fishes. These knowledge gaps could be addressed using telemetry (tagging) techniques combined with detailed statistical analyses that incorporate hydrological and hydraulic aspects of flow.

There is also a knowledge gap around the specific mechanism of how flows influence spawning success of Bass. Where spawning freshes during Autumn/Winter in the Macalister River are timed with freshes in the Thomson, movement of Australian Bass into the estuary may occur. These high flows may also improve conditions for spawning by stimulating primary productivity and increasing food sources of larval bass. This area requires further research.

High flow freshes in Spring/Summer have also been recommended to trigger upstream migration of juvenile catadromous (e.g. Common Galaxias) and amphidromous (e.g. Australian Grayling) fish and adult anadromous (e.g. Lamprey) fish. However, our understanding of the influence of flow on the upstream migration of these diadromous fishes is limited at present. Relationships between upstream migration of diadromous fish and river flow are currently being investigated using microstructural and microchemical analyses of the otoliths (earstones) in various coastal streams in southern Victoria as part of research conducted by the Arthur Rylah Institute. Preliminary results indicate a trend towards increased numbers of migrating fish shortly after high flow events in spring for some species, but further work on migratory characteristics and links with hydrology is needed.

Vegetation

Two knowledge gaps regarding vegetation in the Macalister River system stand out. The first is why the river does not support extensive beds of submerged aquatic vegetation. Anecdotal information suggests such vegetation was present in the past. Factors antagonistic to submerged aquatic vegetation include the steep-sided channel and the concentration of flows arising from the prior building of levees. On the other hand, the channel does have benches that provide micro-topographic relief, pools are abundant in which submerged plants might grow, and water-column turbidity is generally low because of the low sediment load and the interception of suspended particles in Lake Glenmaggie upstream. River water salinity is low (generally <500 EC) and is not likely to be a limiting factor. Sediments are mostly coarse and are probably suitable for plant establishment. Whilst parts of the river are open to grazing, many others are not. This would suggest that grazing is not the direct cause. It may be that there are insufficient propagules coming from upstream to allow submerged plants to establish downstream; perhaps they are trapped in Lake Glenmaggie.

The second is the way fringing vegetation has changed over time, especially over past decades. Abundant and healthy beds of Common Reed are now rare in the river. It is not known when they disappeared, or what caused the loss. Historical documents (e.g. aerial photographs covering the period since World War 2, complemented by oblique or repeat landscape photographs provided by local community members, and their individual recollections) could be analysed to determine where and when riparian vegetation changed. Such information is not of merely academic interest; it is vital to providing a visual template and a guiding image from which a vision can be built of what the river 'should' look like (Willby 2011). Repeat photography has proven useful in describing vegetation change (Boon et al. 2008) and there is now good information on how such images might be interpreted (e.g. Pickard 2002).

Macroinvertebrates

The current status of the macroinvertebrate community in the Macalister River is unknown. The most recent data were from 2005-6, but in 2006-7, upstream bushfires and floods have altered the structure of the river (possibly resulting in a loss of aquatic and fringing vegetation). Further fires in 2013 may also have had an impact. These events may have had a significant impact on the macroinvertebrate community, reducing abundance and the diversity of functional groups.

While the stated objective for macroinvertebrates is to “Maintain the abundance and number of functional groups of macroinvertebrates”, it is assumed that this refers to the pre-fire/flood community recorded in 2006-7, not the unknown current community at the time that the objective was set. However, the data from

2006-7 suggests that few of the sample met the EPA objectives for edge habitats in Cleared Hills and Coastal Plains segments for AUSRIVAS (Band A), SIGNAL (5.5) and Total number of Families (26)[8].

It is unlikely that the failure to meet EPA objectives is due solely to an inadequate flow regime, and catchment issues (e.g. stock access, exotic vegetation) played an important part. Crowther and Papas (2006) attributed the low diversity to "…poor riparian and instream habitat and impaired water quality." (p. 22). The relative contributions of flow and catchment issues to the current macroinvertebrate community remains the major knowledge gap in the system (as it is in many Victorian rivers).

Hence, an environmental flow objective to rehabilitate macroinvertebrate communities to meet the EPA objectives would seem to be doomed to failure without additional complementary actions, and the objective to maintain the 2006-7 abundance and number of functional groups can be seen as meaning that no further decline should occur (while not discounting the possibility of improvement to EPA standards).

Birds, Reptiles and Frogs

Baseline data for most populations of birds, reptiles and frogs of the lower Macalister River are insufficient to permit investigation that would allow responses to flow adjustments to be validly measured. Whilst this represents a knowledge gap, the great majority of bird, reptile and frog species of the Macalister River floodplain are secure in much wider distributions and, as such they are not solely – or even substantially - reliant on the Macalister River.

The waterbird species whose ecologies are intrinsically linked to wetlands and to variables of wetting and drying are all highly mobile species with capacity to naturally move within the broader landscape and many of them can routinely move at the continental scale. Only studies with extremely long time spans (multiple decades) have capacity to detect real population trends for the majority of birds and such investigations would not appear to be warranted for birds in the lower Macalister River.

With one exception, reptiles of the lower Macalister River are also not reliant in an obligatory fashion to the river or are likely to be affected by flows. The exception is the Common Long-necked Turtle Chelodina longicollis. This species is listed as data deficient on the Advisory List of Threatened Vertebrate Fauna of Victoria (DEPI 2013). During watering events that fill billabongs the turtles respond by moving into these highly productive environments and then retreat to permanent water of the river as billabongs dry. Access to highly productive environments is likely to improve subsequent breeding success. The female turtles lay eggs in soil above the waterline during late spring/early summer and eggs will drown if flooding was to occur at this time of year. Populations of some freshwater turtles in the Murray Valley have been shown to be under intense pressure from fox predation of eggs. This leads to very low recruitment of juveniles into the populations. As adult turtles are long-lived the effect may not be immediately apparent, but without recruitment a population will ultimately age and may go into rapid decline as aged animals die. The age-structure and health of the Common Long-necked Turtle population of the lower Macalister River has not been investigated and this represents a knowledge gap that could be addressed (as discussed in section 11.2). At one location on the nearby Avon River where dozens of adult turtles were documented in the early 1980s, only two individuals were found during similar survey effort in 2003 (I. Smales pers. obs.).

The Growling Grass Frog Litoria raniformis is the only frog species of the lower Macalister River that is threatened and may be affected by the flow regime. It is listed as vulnerable under the Environment Protection and Biodiversity Conservation Act 1999; it is also listed as threatened under the Flora and Fauna Guarantee Act 1988 and as endangered on the Advisory List of Threatened Vertebrate Fauna of Victoria (DSE 2013). The species occupies a variety of permanent and semi-permanent water bodies generally containing abundant submerged and emergent vegetation. If it is present in the lower Macalister River floodplain, it is likely to have highest densities in billabongs with abundant aquatic vegetation. The species requires still, or slow-flowing waterbodies for breeding and successful tadpole development. Adult Growling Grass Frogs may retreat to the river corridor or permanent channels during prolonged drought but a population would be likely to be negatively impacted by very high flow rates.

[8] Objectives also include the number of key families, but this is a combined riffle-edge number and riffles are not sampled in the Macalister River.

The lack of recent local records of Growling Grass Frog, despite possibly suitable habitat, may reflect modification of habitats, such as those leading to little aquatic vegetation, or may reflect a lack of targeted survey for the species.

12.2 Hydrological knowledge gaps

Data

A major hydrological knowledge gap is the availability of accurate flow measurement devices in the system. The Riverslea gauge in the downstream section of Reach 2 is not considered highly accurate due to potential backwater influences from the Thomson River, and therefore is not used for monitoring compliance with environmental flow requirements. We are also aware of issues regarding the reliability of readings at Maffra Weir. Investigation into locations to reliably measure flow in the system would help current system understanding and future investigations.

Floodplain billabongs

There are many floodplain billabongs throughout the Macalister system that support bird, turtle and frog values. Under the current operating arrangement, these billabongs only receive water during overbank event that also flood significant areas of productive land. An investigation into alternative ways of getting water into these billabongs could assist in the use of environmental water entitlements to support these values.

Water quality

The relationship between environmental flows and water quality is not well understood. There have been observations of high turbidity in the Macalister River, and this is also known to impact treatability of raw water for potable water supply. This issue could assist in the management of environmental flows for multiple benefits in the Macalister system.

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Appendix A
Groundwater data

Figure 1: Alluvium monitoring bores- Macalister River from Lake Glenmaggie to Thomson River

Key

- Localities
- Watercourse lines
- Watercourse areas

Groundwater monitoring locations

- No hydrograph presented
- Hydrograph presented

0 1,450 2,900
Metres
GDA 1994 MGA Zone 54

DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Data Source:

CDM Smith
listen. think. deliver.

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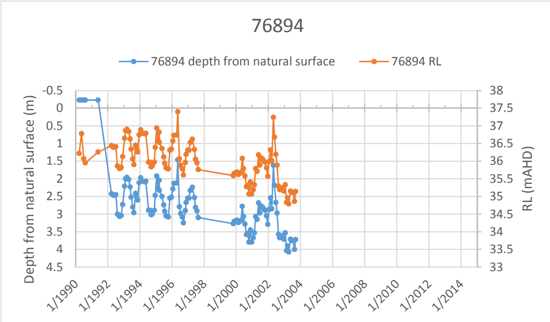
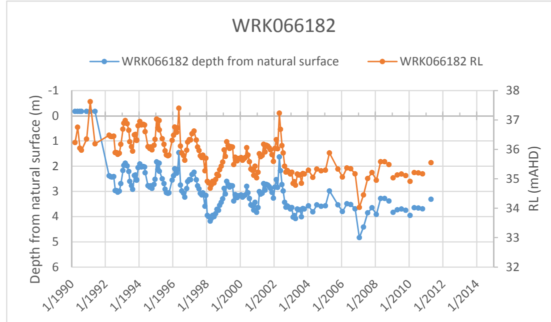
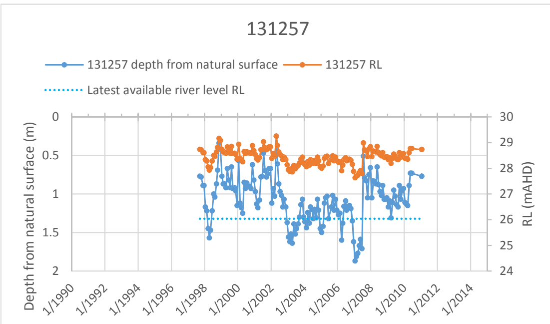
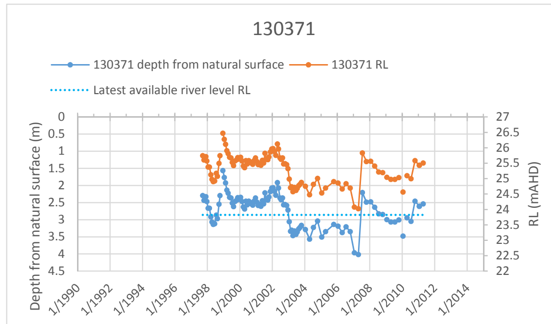
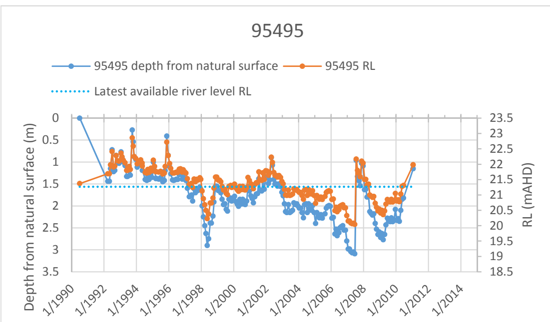
Wetlands

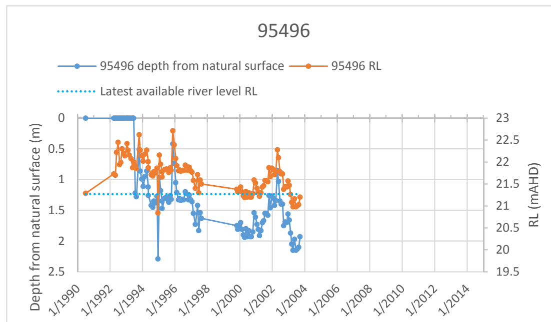












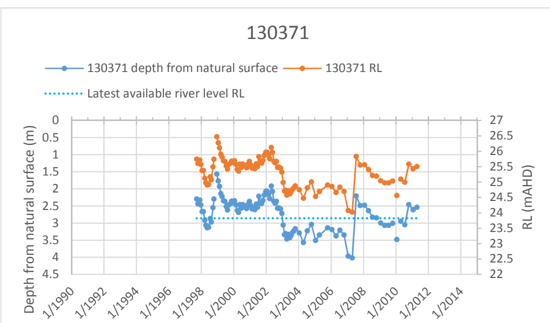
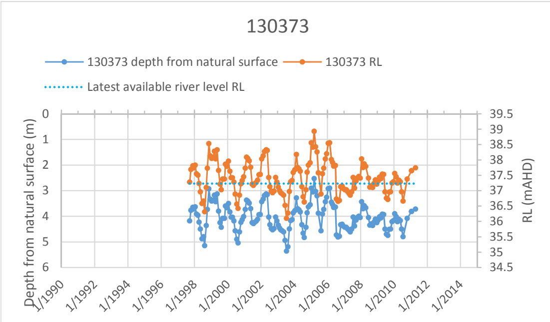
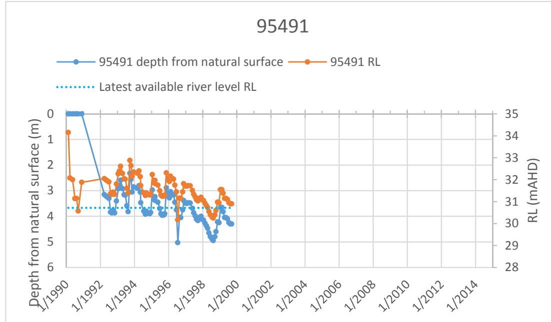
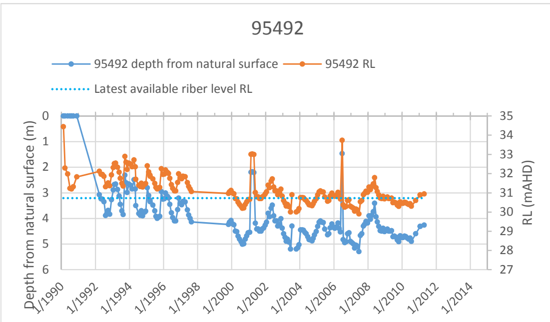


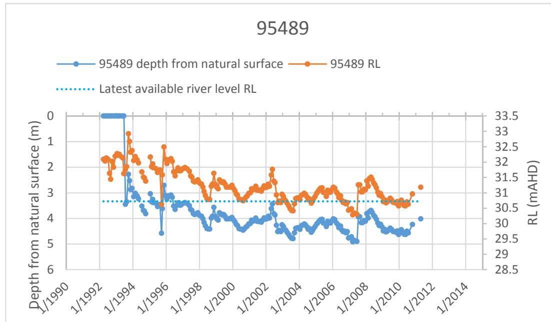
Figure 3
Hydrographs
Alluvium Monitoring Bores - Macalister River to Thomson River

Macalister River

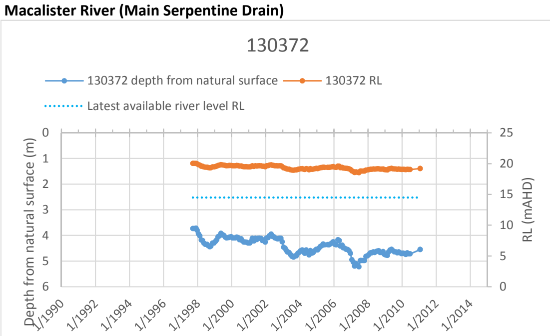


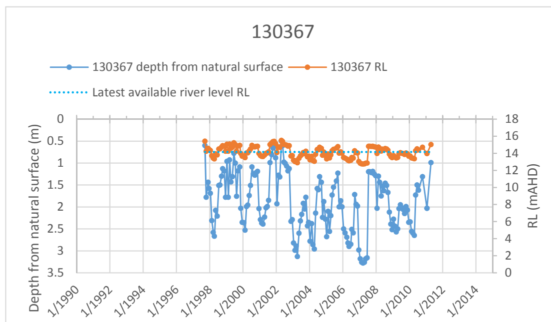






Macalister River (Main Serpentine Drain)





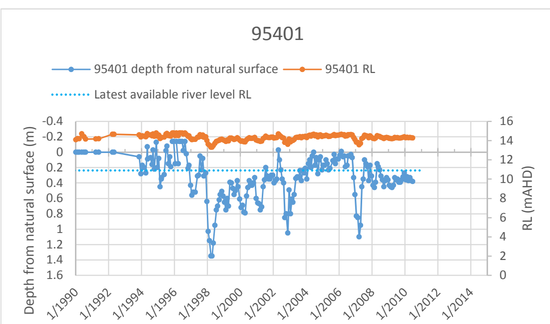


Figure 3
Hydrographs
Alluvium Monitoring Bores -
Macalister River to Thomson River

Appendix B
Water dependent values

Water dependent fauna of the Macalister River

Table 23. Water dependent fauna

Group	Common name	Scientific name
Fish	River blackfish	Gadopsis marmoratus
	Southern pygmy perch	Nannoperca australis
	Flat-headed gudgeon	Philypnodon grandiceps
	Dwarf flat-headed gudgeon	
	Australian smelt	Retropinna sp. 2
	Short-finned eel	Anguilla australis
	Long-finned eel	Anguilla reinhardtii
	Short-headed lamprey	Mordacia mordax
	Common galaxias	Galaxias maculatus
	Australian grayling	Prototroctes maraena
	Australian bass	Percalates novemaculeata
	Tupong	Pseudaphritis urvillii
	Estuary perch	Percalates colonorum
	Flinders pygmy perch	Nannoperca sp. 1
Frogs	Victorian smooth froglet	Geocrinia victoriana
	Common froglet	Crinia signifera
Reptiles	Gippsland water dragon	Physignathus lesueurii howitii
	Common long-necked turtle	Chelodina longicollis
Birds	Masked lapwing	Vanellus miles
	Red-kneed dotterel	Erythrogonys cinctus
	Black-fronted dotterel	Elyseyornic melanops
	Grey teal	Anas gracilis
	Little black cormorant	Phalacrocorax sulcirostris
	Little pied cormorant	Microcarbo melanoleucos
	White faced heron	Egretta novaehollandiae
	Australian shelduck	Tadorna tadornoides
	Purple swamphen	Porrphyrio porphyrio
	Black swan	Cygnus atratus
	Dusky moorhen	Gallinula tenebrosa
	Australian white ibis	Threskiornis molucca
	Australian wood duck	Chenonetta jubata
	Australian pelican	Pelecanus conspicillatus
	Eurasian coot	Fulica atra
	Pacific black duck	Anas superciliosa
	Royal spoonbill	Platalea regia
	Australasian shoveler	Anas rhynchotis
	Magpie goose	Anseranas semipalmata
	Eastern great egret	Ardea modesta
	Australasian bittern	Botaurus poiciloptilus
	White-bellied sea eagle	Haliaeetus leucogaster

Group	Common name	Scientific name
	Pied cormorant	Phalacrocorax varius
	Great cormorant	Phalacrocorax carbo
	Hoary headed grebe	Poliocephalus poliocephalus
	Musk duck	Biziura lobata
	Yellow-billed spoonbill	Platalea flavipes
	Chestnut teal	Anas castanea
	Hardhead	Aythya australis
	Australiasian grebe	Tachybaptus novaehollandiae
	Straw-necked ibis	Threskiornis spinicollis
	White-necked heron	Ardea pacifica
	Cattle egret	Ardea ibis
	Pink-eared duck	Malacorhynchus membranaceus
	Blue-billed duck	Oxyura australis
	Swamp harrier	Circus approximans
	Intermediate egret	Ardea intermedia
	Latham's snipe	Gallinago hardwickii
Mammals	Grey-headed flying fox	Pteropus poliocephalus
	Southern myotis	Myotis macropus
	Common bent-wing bat	Miniopterus schreibersii
Macroinvertebrates	Waterboatmen	Micronecta
	Stick caddis	Triplectides
		Notalina
	Non-biting midges	Chironominae
	Mayflies	Atalophlebia
	Water treaders	Microvelia
	Freshwater shrimp	Paratya australiensis
	Baetids	Baetidaw Genus 1
	Sleeping bag caddis	Anisocentropus

Water dependent flora of the Macalister River

Table 24. Water dependent flora

Common name	Scientific name
	Acacia dealbata
	Acacia floribunda
	Acacia implexa
	Acacia longifolia
	Acacia mearnsii
	Acacia melanoxylon
	Acacia mucronata
	Acacia spp.
Southern Varnist Wattle	Acacia verniciflua
	Acaena novae-zelandiae
	Acaena ovina
	Adiantum aethiopicum
	Alisma plantago-aquatica
	Alisma spp.
	Allocasuarina littoralis
	Allocasuarina spp.
	Alternanthera denticulata s.l
Joyweed	Alternanthera spp.
Mistletoe	Amyema spp.
	Asteraceae spp.
	Atriplex prostrata
	Atriplex semibaccata
	Atriplex spp.
Wallaby grass	Austrodanthonia caespitosa
	Austrodanthonia racemosa var. racemosa
	Austrodanthonia setacea
	Austrodanthonia spp.
	Austrostipa scabra subsp. falcata
Veined spear-grass	Austrostipa rudis subsp.nervosa
Spear-grass	Austrostripa spp.
Tall club-sedge	Bolboschoenus fluviatilis
	Boraginaeceae spp.
Daisy	Brachyscome spp.
	Bursaria spinosa
	Callistemon paludosus
	Callistemon rugulosus
	Callistemon sieberi
	Callistemon spp.
	Calochlaena dubia
	Calystegia spp.
	Calystegia marginata
	Calystegia silvatica
	Calytrix tetragona
	Carex appressa
	Carex breviculmis
	Carex fascicularis
	Carex gaudichaudiana
	Carex spp.
	Cassinia aculeata
	Cassinia longifolia
	Cassinia spp.
	Centipeda cunninghamii
	Centrolepis spp.
	Cheilanthes austrotenuifolia
	Chenopodium glaucum
	Chloris sp.
	Chrysocephalum semipapposum
	Clematis aristata
	Clematis spp.
	Convolvulus erubescens
	Coprosma hirtella
	Coprosma quadrifida
	Crassula helmsii
	Crassula sieberiana s.l.
	Crassula spp.
	Crepis spp.
	Cyperus ludicus
	Daviesia leptophylla
	Daviesia spp.
	Derwentia derwentiana
	Dianella caerulea s.l.
	Dichanthium sericeum subsp. sericeum
	Dichondra repens
	Dipodium spp.
	Dodnaea spp.

Common name	Scientific name
	Einadia nutans
	Einadia nutans subsp. nutans
	Einadia trigonos subsp. trigonos
	Eleocharis sphacelata
	Elymus scabrus
	Elymus scaber var. scaber
Upright Panic	*Entolasia stricta*
	Eragrostis brownii
	Eragrostis sp.
	Eucalyptus camaldulensis
	Eucalyptus cypellocarpa
	Eucalyptus globulus
	Eucalyptus ovata
	Eucalyptus radiata s.l.
	Eucalyptus tereticornis subsp. mediana
	Eucalyptus viminalis subsp. viminalis
	Eucalyptus spp.
	Euchiton involucratus s.l.
	Euchiton sphaericus
	Euchiton spp.
	Exocarpos cupressiformis
	Exocarpos spp.
	Glycine clandestina
	Glycine tabacina
	Glycine tabacina s.l.
	Glycine spp.
	Gonocarpus humilis
	Goodenia ovata
	Goodenia spp.
	Goodia lotifolia
	Gratolia peruviana
Gippsland hemp bush	*Gynatrix macrophylla*
	Gynatrix pulchella s.l.
	Gynatrix spp.
	Heichrysum luteoalbum
	Helichrysum leucopsideum
	Hemarthria uncinata var. uncinata
Pennywort	*Hydrocotyle spp.*
	Hypericum gramineum
	Indigofera australis
	Isachne globosa
	Isolepis inundata

Common name	Scientific name
	Juncus amabilis
	Juncus articulatus
	Juncus australis
	Juncus flavidus
	Juncus gregiflorus
	Juncus holoschoenus
	Juncus spp.
	Kunzea ericoides spp. agg.
	Lachnagrostis filiformis
	Lachnagrostis filiformis var. 1
	Lepidosperma laterale
	Lepidosperma spp.
	Leptospermum brevipe
	Leptospermum grandifolium
	Leptospermum laniger
	Leptospermum lanigerum
	Leptospermum spp.
	Lomandra filiformis
	Lomandra longifolia
	Luzula meridionalis var. flaccida
	Lycopus australis
	Melaleuca ericifolia
	Melaleuca spp.
Tree violet	*Melicytus dentatus s.l.*
	Mentha X rotundifolia
	Microlaena stipoides
	Microlaena stipoides var. stipoides
	Oxalis exilis
	Oxalis perennans
	Pandorea pandorana
	Panicum spp.
	Paspalidium spp.
	Pelargonium spp.
	Persicaria decipiens
	Persicaria hydropiper
	Persicaria praetermissa
	Persicaria prostrata
	Persicaria subsessilis
	Persicaria spp.
	Phragmites australis
	Phyllanthus gunnii
	Pimelea axiflora
	Pimelea linifolia ssp. linifolia
	Pittosporum undulatum

Common name	Scientific name
	Plantago debilis
	Plantago major
	Poa labillardierei
	Poa spp.
	Pomaderris aspera
	Poranthera microphylla
	Prostanthera rotundifolia
	Prostanthera spp.
	Pseudognaphalium luteoalbum
	Pteridium esculentum
	Pterostylis nutans
	Pulternaea sp.
	Rubus parvifolius
	Rumex brownii
	Schoenoplectus tabernaemontani
	Schoenoplectus validus
	Schoenus maschalinus
	Schoenus spp.
	Senecio glomeratus
	Senecio hispidulus s.l.
	Senecio minimus
	Senecio quadridentat
	Senecio quadridentatus

Common name	Scientific name
	Senecio spp.
	Sigesbeckia orientalis subsp.
	Solanum aviculare
	Solanum linearifolium
	Solanum prinophyllum
	Stellaria flaccida
	Stylidium spp.
	Stypandra glauca
	Themeda triandra
	Triglochin procera s.l.
	Typha domingensis
	Urtica incisa
	Vallisnera americana var. americana
	Veronica calycina
	Veronica plebeia
	Veronica spp.
	Viola hederacea sensu Entwisle (1996)
	Vittadinia sp.
	Wahlenbergia gracilis
	Wahlenbergia spp.
	Wahlenbergia stricta subsp.

Appendix C
Analysis of 2D model results for flow recommendations

Memo

Subject	2D Modelling of Macalister River between Lake Glenmaggie and the Thomson River confluence
Distribution	Minna Tom, David Stork (WGCMA)
Date	6 July 2015
Project	Macalister River environmental flows review

As part of the Macalister River environmental flows review, the West Gippsland Catchment Management Authority (WGCMA) has engaged Alluvium to undertake 2D hydrodynamic modelling of the system to enhance the understanding of environmental flows in the system. Hydraulic modelling undertaken in previous environmental flows work is limited by both spatial extent and simplification of hydraulic processes. The 2D modelling documented in this memo covers the entire study area and provides a fuller understanding of relationships between flow and ecological and geomorphic processes.

This memo outlines the approach to the modelling and the analysis used to assist in determining the environmental flow recommendations.

1 Aims of modelling

The modelling was undertaken to answer the following questions:

- What discharge generates shear stress above an erosion threshold to scour sediment through pools? This geomorphic process is required to meet the following objectives:
    - Improve geomorphic habitat
        - Scour of sediment [G4]
    - Maintain the abundance of macroinvertebrate communities
        - Scour of sediment and disturbance of biofilm [M2]
- What discharges move organic matter into the channel provide a variable watering regime for fringing woody vegetation? This is required to meet the following objectives:
    - Maintain the abundance of macroinvertebrate communities
        - Move organic material into channel to [M3]
    - Improve fringing woody vegetation in the riparian zone
        - Wetting tea tree and paperbark vegetation. Provide variability in water levels [V4]
        - Maintain woody vegetation higher up the streamside zone. Provide variability in water levels [V5]
- What discharge achieves bankfull flow and some inundation of floodplain areas? This is required to meet the following objectives:
    - Improve geomorphic habitat
        - Channel form, sediment transport, organic matter transport [G5]
    - Improve fringing woody vegetation in the riparian zone
        - Disturbance and resetting (some removal) of aquatic and riparian veg [V6]
    - Increase abundance of frog, turtle and waterbird communities
        - Wetting of low lying areas on floodplain [B1}

- For the 10 and 20 year average recurrence interval (ARI) events, which areas have high erosion potential?
    - This aim is not related to the environmental flow recommendations, it was included to provide useful planning advice to the WGCMA

2 Approach to modelling

The 2D hydrodynamic model of the Macalister system was developed in XPSWMM. There were three primary inputs to the XPSWMM model:

- Channel geometry (from LiDAR data)
- Downstream boundary condition (from flow gauges and bed slope)
- Hydraulic roughness (Manning's *n*).

The model was then calibrated to two flow gauges:

- Reach 1 – Macalister River at Lake Glenmaggie (225205)
- Reach 2 – Macalister River at Riverslea (225247)

Table 1 lists the boundary conditions and hydraulic roughness adopted for each model. These parameters were adopted on the basis of the calibration, field observations and aerial photography.

Table 1. Hydraulic parameters adopted in XPSWMM model

Hydraulic parameter	Reach 1	Reach 2
Manning's roughness - channel	0.02	0.06
Manning's roughness - trees	0.08	0.12
Manning's roughness - floodplain	0.035	0.045
Downstream boundary	Slope = 0.001	Stage discharge curve from downstream gauge (Thomson River @ Bundalaguah)

LiDAR data has transformed hydraulic modelling since its availability has become widespread over the last ten years, but one of its central limitations is its inability to penetrate water. The implications for this study are that the 2D model can only provide information on hydraulics above the water level in the river at the time the LiDAR data were collected.

The digital elevation model (DEM) developed for the model includes the flat water surface consistent with the flow at the time the LiDAR data were captured: 350 ML/d for Reach 1 and 160 ML/d for Reach 2. Therefore only flows above these levels can be analysed using the 2D model.

A number of flows were selected to be analysed using the 2D model. The selection of the flows was guided by the understanding of channel hydraulics provided by the by the 1D HEC-RAS models used in the study.

The following discharges were run for the model:

- 350 Ml/d (Reach 2 only)
- 700 ML/d
- 1,500 ML/d
- 2,500 ML/d
- 3,000 ML/d
- 3,500 ML/d
- 10,000 ML/d
- 16,000 Ml/d
- 25,000 ML/d

The modelling results include water depth, water surface elevation, velocity and shear stress, in a raster grid format with 4 m by 4m cells.

In addition to the XPSWMM model, Water Technology were engaged to produce the 10 and 20 year ARI results. Water Technology developed a 2D flood model in Mike 21 for Southern Rural Water and WGCMA in 2011. This model was rerun to estimate shear stress distribution in floodplain areas.

3 Analysis for flow recommendations

3.1 Shear stress analysis

This section outlines the analysis to determine the discharge that generates shear stress above an erosion threshold to scour sediment through pools. As part of the overall flow regime, this will be a **fresh**.

This is required to meet the following objectives:

- Improve geomorphic habitat: Scour of sediment [G4]
- Maintain the abundance of macroinvertebrate communities: Scour of sediment and disturbance of biofilm [M2]

Scour of sediment and transport downstream is an important part of a healthy waterway as it provides geomorphic habitat and supports macroinvertebrate communities. Shear stress represents the force exerted by flowing water on the bed of the river. Shear stress of 1.1 N/m^2 is required to mobilise coarse sand sediments (Fischenich 2001). This shear stress threshold must be exceeded throughout the majority of the reach, otherwise sediment will be deposited in areas of low shear stress.

Two approaches have been used for the analysis of shear stress results: visual interpretation of the raster and quantitative analysis of the distribution of shear stress throughout the study reach. Shear stress data along the centreline of the channel were extracted and analysed in this way.

Shear stress is typically inversely related to sinuosity. Therefore, in the centreline assessment, the two study reaches have been broken up into a total of five subreaches to represent the changes in sinuosity through the system. Reach 1C and Reach 2B are the most sinuous reaches in the system.

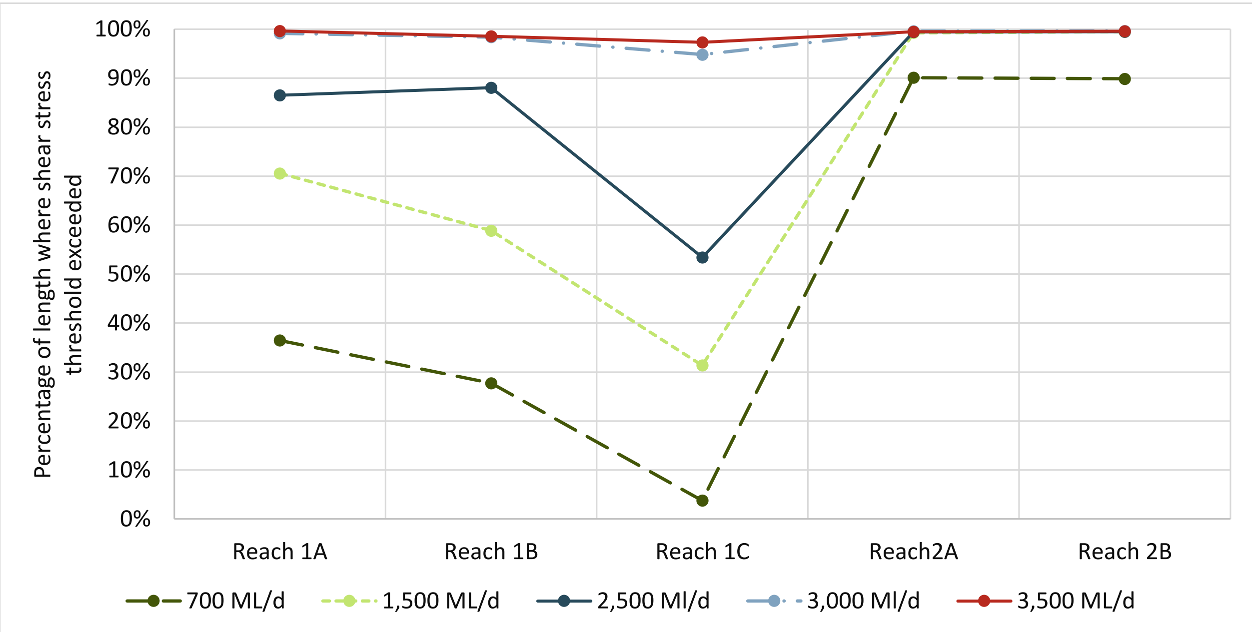


Figure 1. *Centreline assessment for shear stress criteria: subreaches range from upstream extent on the left to downstream extent on the right.*

For Reach 1, a discharge of 2,500 ML/d is required to achieve consistently high shear stress results through the mid and upper sections. Subreach 1C, which has a high sinuosity and is influenced by the backwater from Maffra weir downstream and experiences lower shear stresses than the upstream part of reach 1. Subeach 1C requires flows of 3,000 ML/d to exceed the shear stress threshold of 1.1 N/m^2 over more than 90% the reach length.

This conclusion is confirmed by the visual analysis. In the side by side images of Reach 1C below (Figure 2), the locations where shear stress is exceeding the sediment scour threshold (1.1 N/m^2, shown in red) increases significantly from the 2,500 ML/d flow on the left to the 3,000 ML/d on the right. This pattern is repeated across the reach, and the flow of 3,000 ML/d will provide sufficient shear stress to scour sediment across the channel. The centreline assessment suggests that there would be only minor benefit achieved from increasing the flow up to 3,500 ML/d.

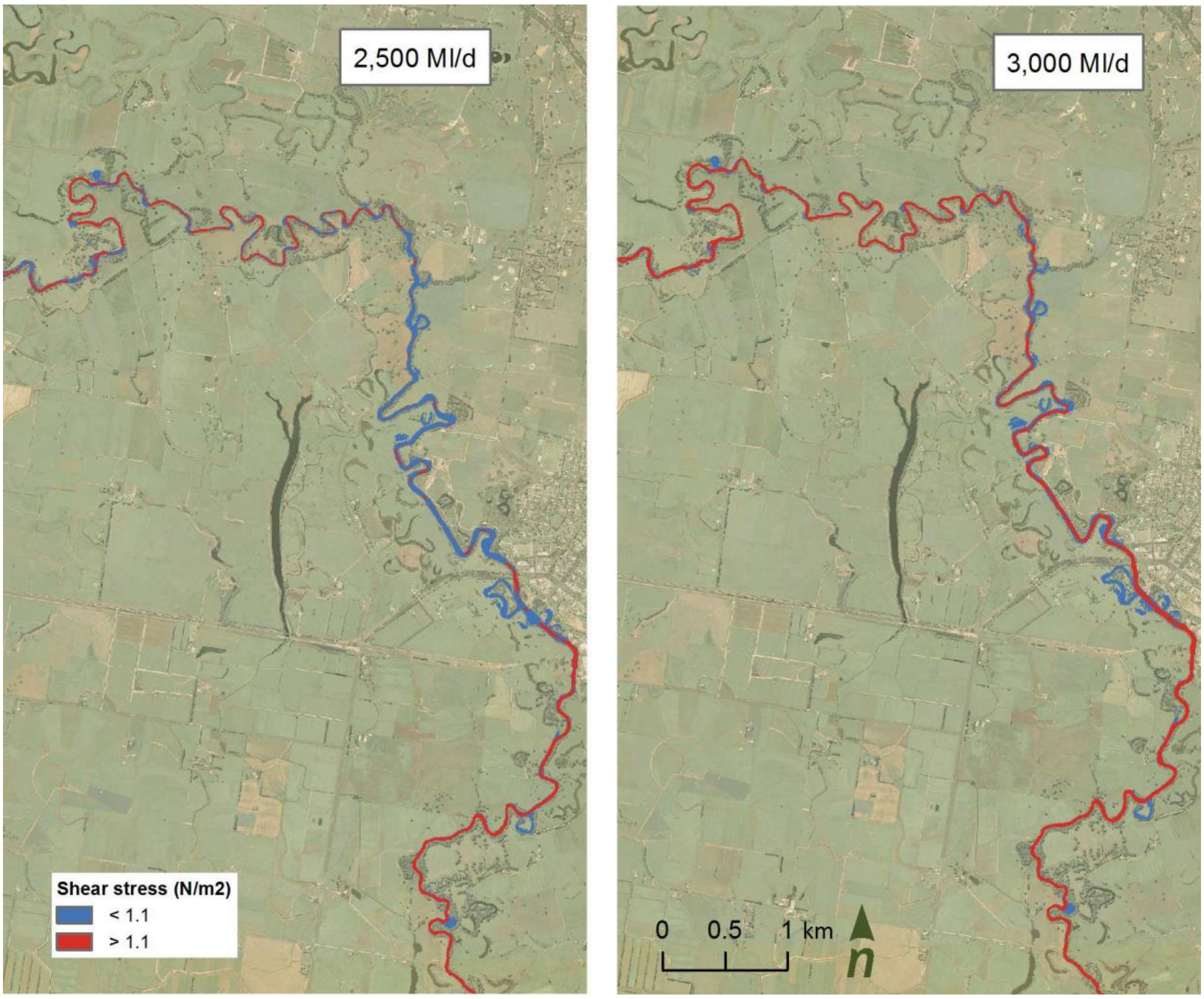


Figure 2. *Example of visual assessment for shear stress criteria: Reach 1C*

At a discharge of 700 ML/d the shear stress threshold is exceeded along 90 % of the length of reach 2 (Figure 1). To ensure sediment scour occurs throughout the entire reach, without any areas of large-scale deposition, a flow of 1,500 Ml/d is recommended. This is supported by the visual assessment, as shown in Figure 3.

Therefore, the flow magnitudes recommended for sediment scour are:

- 3,000 ML/d for reach 1
- 1,500 ML/d for reach 2

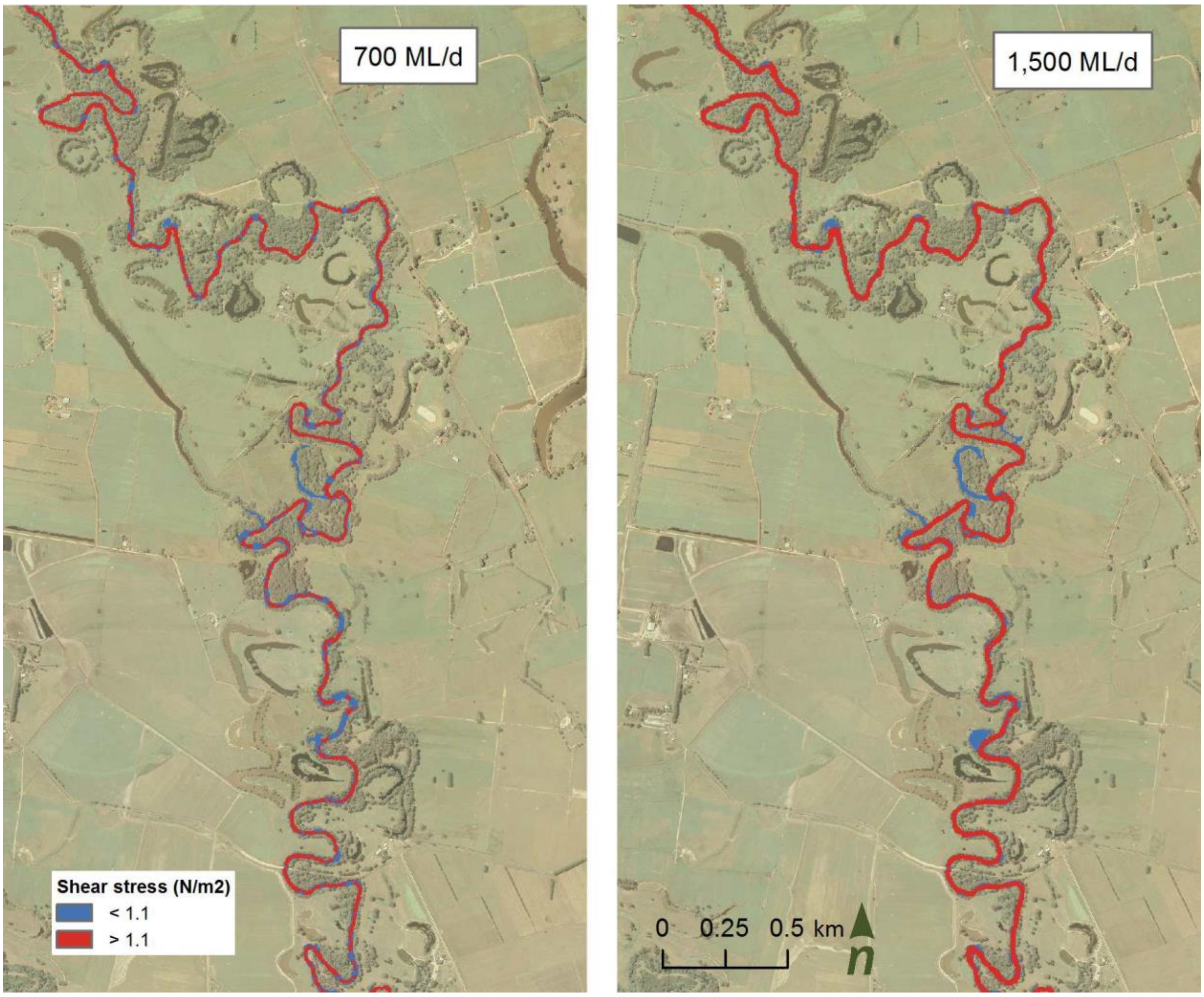


Figure 3. *Example of visual assessment for shear stress criteria: Reach 2B*

3.2 Water level for vegetation

This section outlines the analysis to determine the discharge that move organic matter into the channel and provides a variable watering regime for fringing woody vegetation. As part of the overall flow regime, this will be a **fresh**. This is required to meet the following objectives:

- Maintain the abundance of macroinvertebrate communities
    - Move organic material into channel to [M3]
    - Improve fringing woody vegetation in the riparian zone
- Wetting tea tree and paperbark vegetation. Provide variability in water levels [V4]
    - Maintain woody vegetation higher up the streamside zone. Provide variability in water levels [V5]

The recommendation is for two flow magnitudes that will be delivered as freshes during September to December. The intent of these flows is to provide variability in the flow regime, wet the roots of the fringing woody vegetation across the streamside zone and move organic material from benches into the channel.

We have analysed these hydraulic criteria in a number of ways:

- Analysis of water level compared to bank height
- Inundation of benches (visual, cross-section analysis)
- Comparison between flows for variability

- Water elevation / depth
- Inundation extent

The following sections describe these analyses in more detail.

Water level compared to bank height
The water level has been compared to bank height as a long-section (Figure 4 and Figure 5) has also been expressed as the water level as percentage of bank height (Table 2).

For this analysis, the bed elevation and top of bank was sourced from the Index of stream Condition (ISC) data in 100 m sections. The average water surface elevation for each flow was then extracted from the raster results for these 100 m sections.

Table 2. Median water level as a percentage of bank height for in-channel flows

Flow	Reach 1	Reach 2
350 ML/d	-	26 %
700 ML/d	15 %	39 %
1,500 ML/d	26 %	59 %
2,500 ML/d	35 %	87 %
3,000 ML/d	39 %	95 %
3,500 ML/d	43 %	104 %

The water elevation analysis reveals the following features:

- At the upstream extent of reach 1, the banks are high as the river is confined and the flows do not exceed 20 % of the bank height
- The mid-section of Reach 1 (Ch. 10,000- 25,000) has low water levels compared to the bank height
    - Through this area, there is little increase in water level from 2,500 to 3,000 Ml/d
    - This will be analysed further with the inundation analysis
- The downstream section of reach 1 has higher water levels relative to bank height, this is likely due to the backwater effect from Maffra weir
- For reach 2, the water level compared to bank height is fairly consistent through the reach, and 1,500 ML/d is the first flow to have a water level exceeding the 50% of bank height

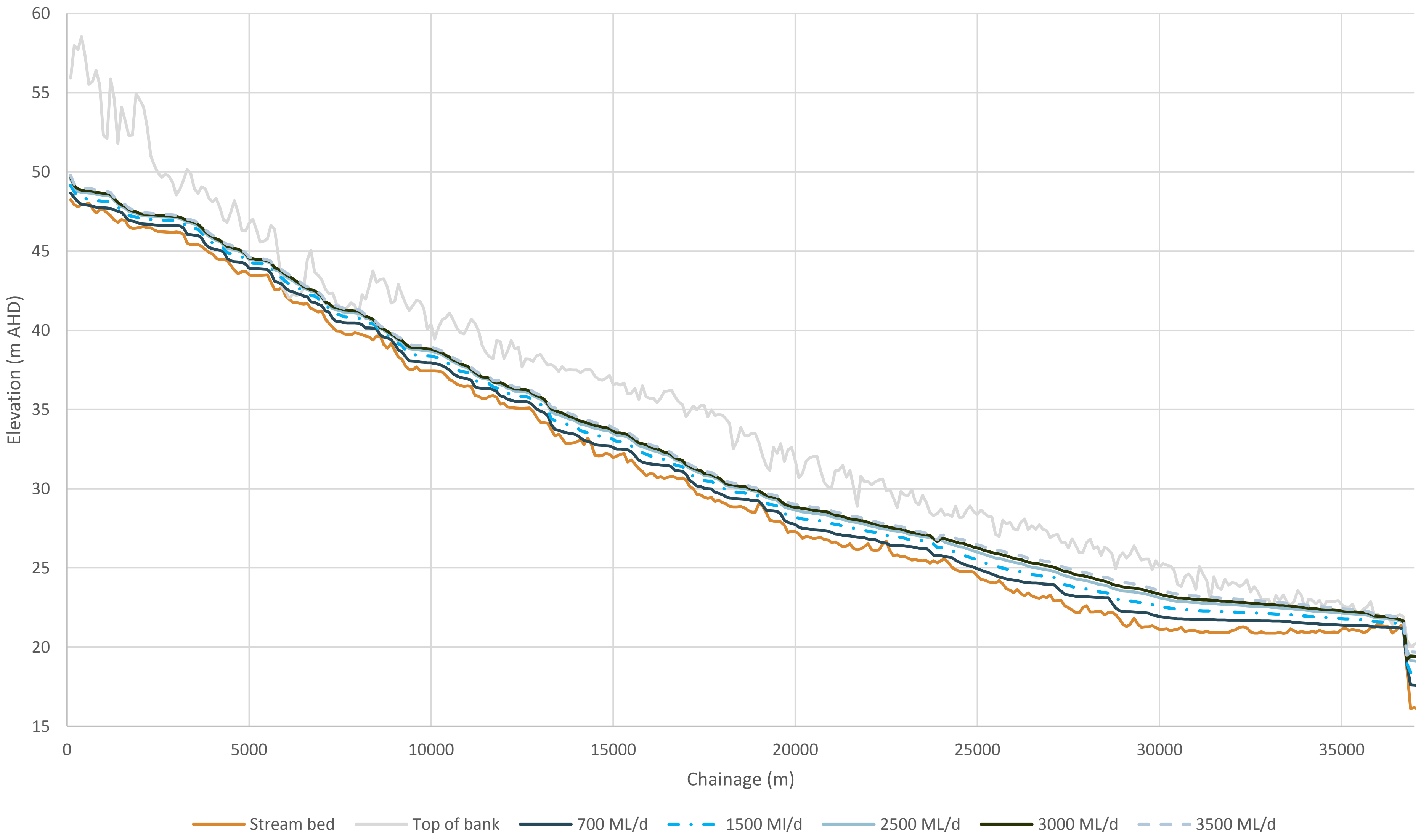


Figure 4. *Long-section of Reach 1 showing bed and bank elevations with water surface elevation: upstream at Lake Glenmaggie on left to downstream at Maffra weir on right*

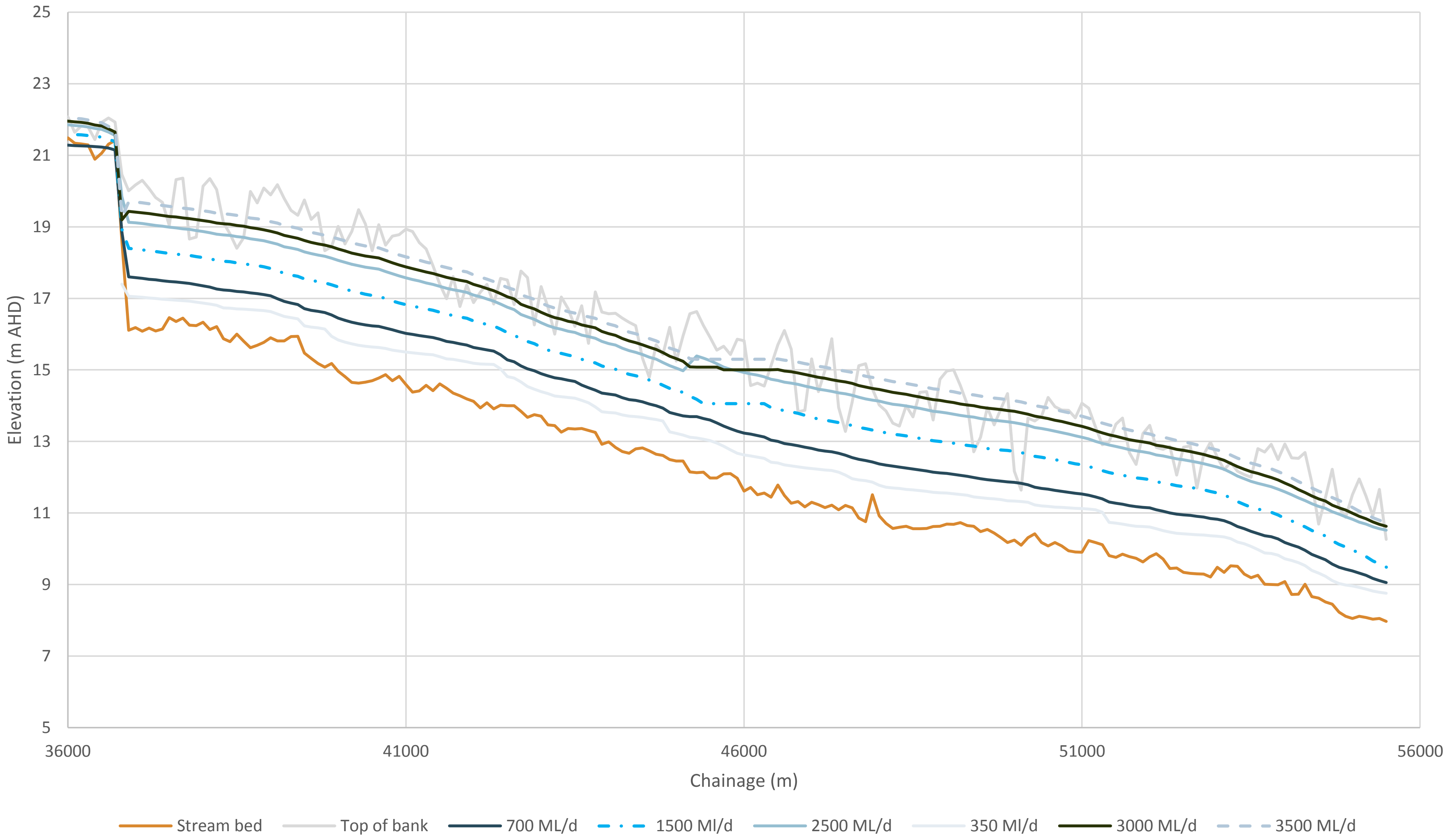


Figure 5. *Long-section of Reach 2 showing bed and bank elevations with water surface elevation: upstream at Maffra weir on left to downstream at right*

Bench inundation

While the long-section analysis provides useful information on the water level, it is important to complement this with a plan view analysis of the benches to check they are being inundated. In this study the term *bench* is used to describe horizontal surfaces within the bankfull channel, acknowledging there is a large body of literature on the difference between different types of benches and bars. In environmental flows studies horizontal surfaces are particularly important as they provide important habitat for vegetation. Benches in the system can be identified using the LiDAR and aerial imagery.

For Reach 1, a variety of benches have been analysed with a particular focus on chainages 10,000- 25,000, where the water surface is relatively low compared to the bank height. Figure 6 shows two benches within this section. For each bench, 1,500 ML/d starts to inundate the bench, while a higher flow of 2,500 ML/d is required to fully inundate the bench area. There is limited additional inundation extent provided by the higher 3,000 ML/d flow (shown by the dark blue cells).

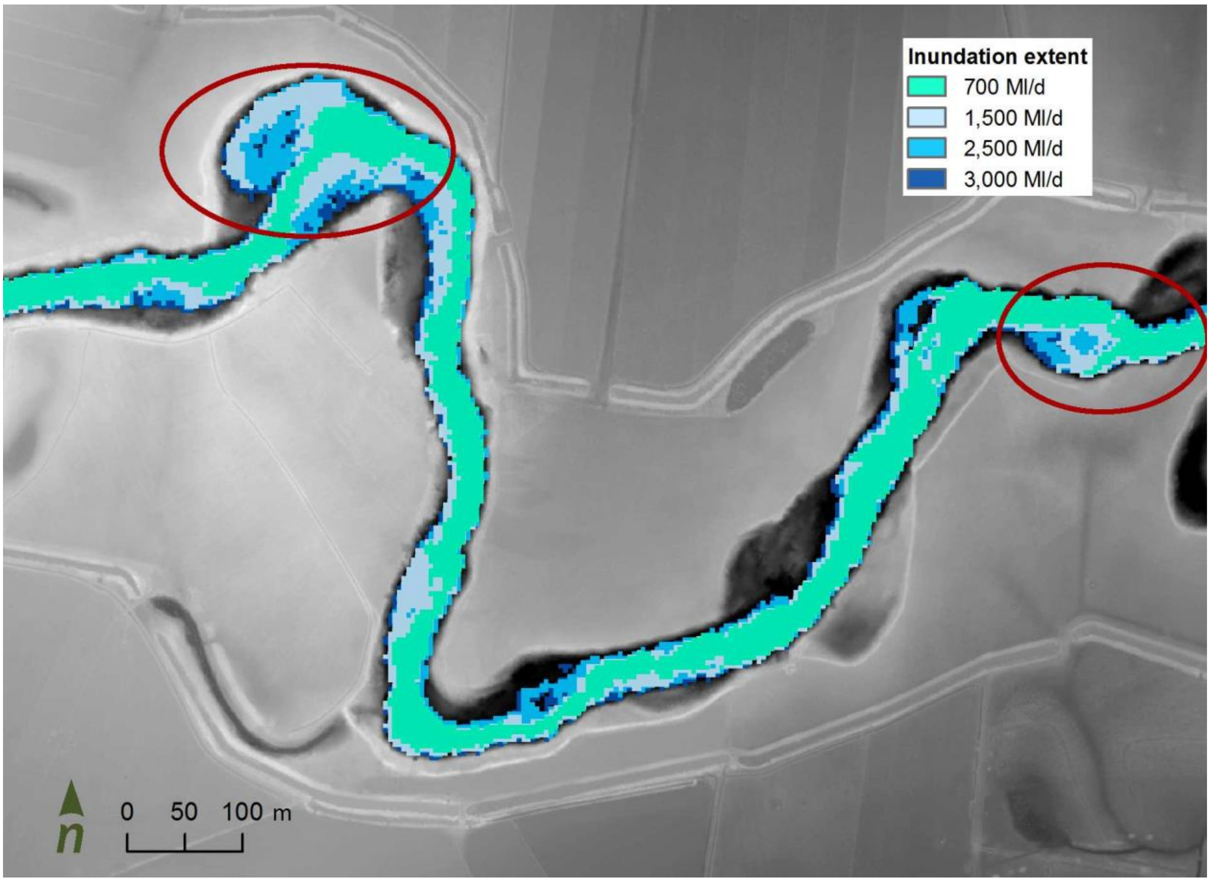


Figure 6. *Example of visual assessment for inundation criteria: Reach 1 – red circles show bench inundation*

An example cross-section (Figure 7) has been extracted for the eastern bench shown above. The right bank bench is wetted in some places by the 1,500 ML/d discharge, and is completely inundated by the 2,500 ML/d flow by at least 0.1 m of water.

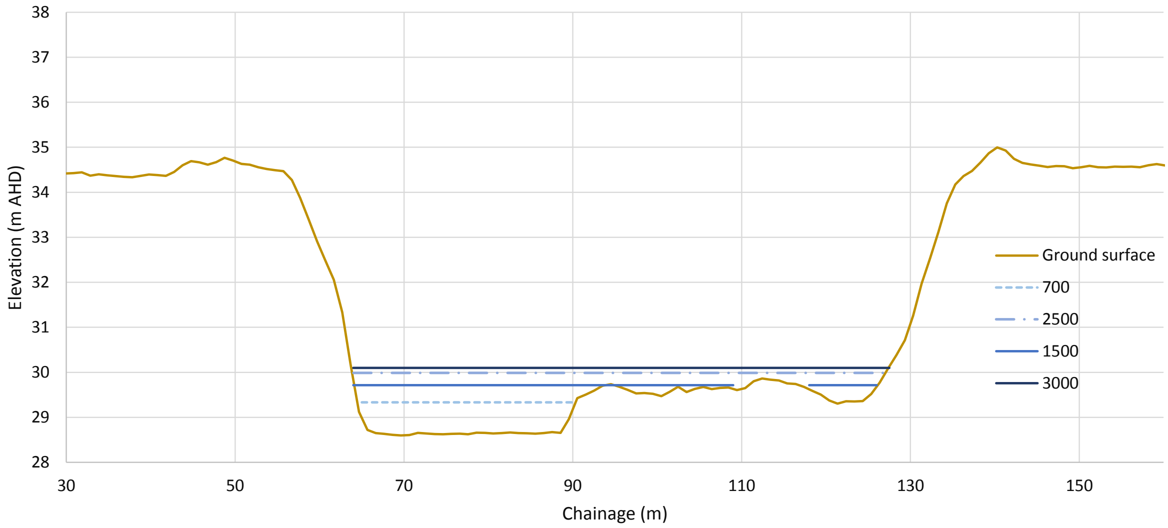


Figure 7. *Example cross-section through bench in Reach 1*

For reach 2, there are some lower benches inundated by 700 Ml/d flows (Figure 8, right) while some higher, larger benches require 1,500 ML/d for inundation of the benches (Figure 8, left).

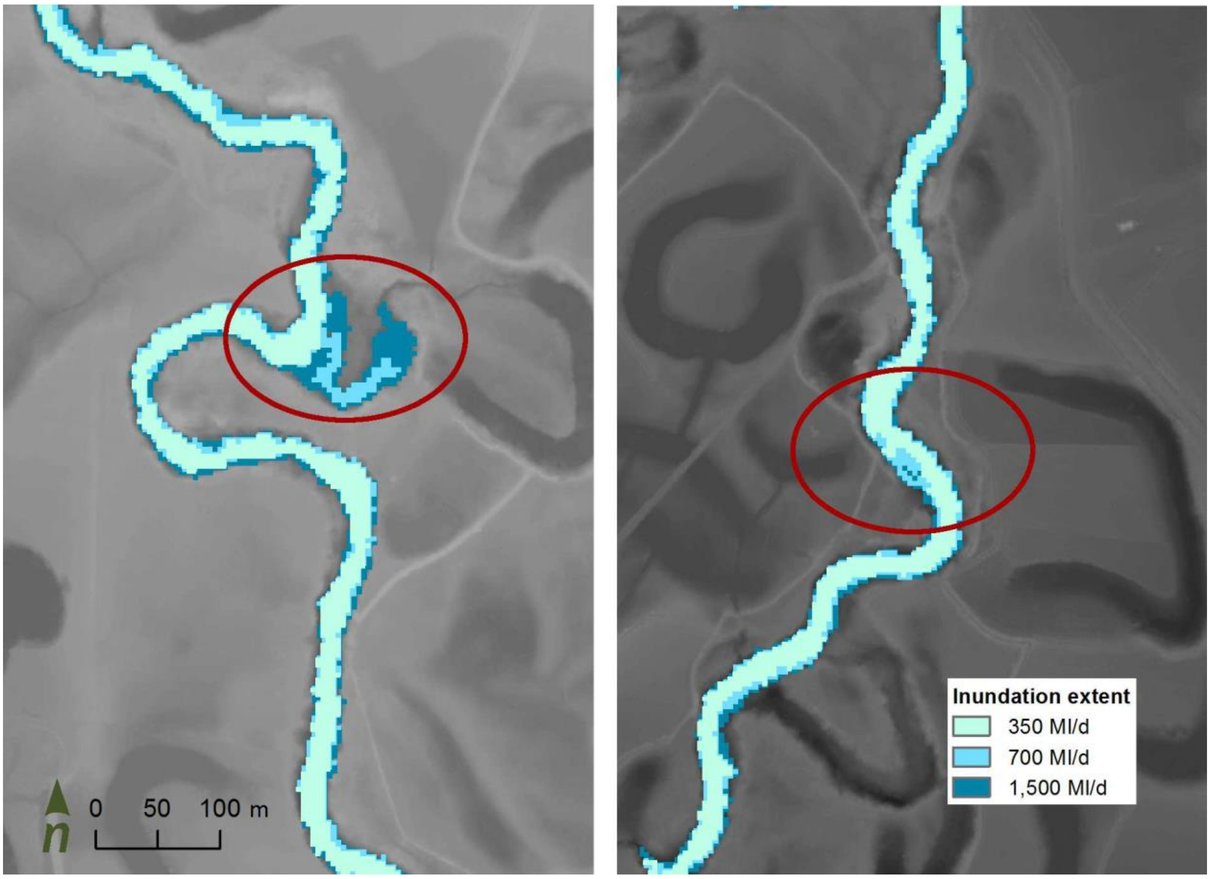


Figure 8. *Example of visual assessment for inundation criteria: Reach 2*

Depth and inundation variability

Part of the criteria for fringing vegetation inundation is to provide variability in the water level and area inundated. This variability should be provided between the two freshes and also between the freshes and the baseflow. Table 3 provides the increase in water level and inundated area for each of the modelled flows in reach 1 and 2. The proposed magnitudes for the freshes (shown in green) will provide a significant increase in depth (greater than 0.3 m) and inundated area (over 14%).

Table 3. Variability in depth and inundation

	Reach 1		Reach 2	
Change in flow	**Increase in water level (m)**	**Increase in inundated area**	**Increase in water level (m)**	**Increase in inundated area**
350 ML/d to 700 ML/d	-	-	0.50	16%
700 ML/d to 1,500 ML/d	0.45	28%	0.72	21%
1,500 ML/d to 2,500 ML/d	0.37	14%	0.71	21%
2,500 ML/d to 3,000 ML/d	0.16	6%	-	-
3,000 ML/d to 3,500 ML/d	0.15	6%	-	-

Based on the above analysis, the flow magnitudes recommended for fringing vegetation inundation and moving organic matter into the channel are:

- 1,500 and 2,500 ML/d for reach 1
- 700 Ml/d and 1,500 ML/d for reach 2

3.3 Bankfull flow recommendation

This section outlines the analysis to determine the discharge that achieves bankfull flow and some inundation of floodplain areas. This is required to meet the following objectives:

- Improve geomorphic habitat: channel form, sediment transport, organic matter transport [G5]
- Improve fringing woody vegetation in the riparian zone: disturbance and resetting (some removal) of aquatic and riparian veg [V6]
- Increase abundance of frog, turtle and waterbird communities: wetting of low lying areas on floodplain [B1]

Firstly, the flows are assessed as to whether they achieve a water level at the top of bank along the reaches, therefore meeting the geomorphic and vegetation criteria. This varies throughout the length of the study area as the channel flow capacity changes, and there are points at which the way breaks out onto the floodplain. The 'bankfull' criteria is assessed by comparing the water level to the bank height in the long-section analysis shown in Figure 9. The water level is fairly consistent between the three flows for Reach 2 and the downstream part of Reach 1, delivering water levels at or around the top of bank.

Throughout the mid and upper sections of Reach 1, there is more variability in the water level between the different flow magnitudes, with differences in water level of up to 1.7 m. This occurs as the flow is largely in-channel rather than spilling over the banks. The water level for all flows in this section is around the bank height and therefore meeting the bankfull criteria. The 3 km immediately downstream of Lake Glenmaggie (upstream extent of Reach1) is in a confined gorge and therefore bankfull flows are not achieved.

Across the entire study areas, all three flows provide adequate water level for the bankfull criteria, as shown in Figure 9 and Table 4.

Table 4. Median water level as a percentage of bank height for bankfull flows

Flow	Reach 1	Reach 2
10,000 ML/d	96 %	125 %
16,000 ML/d	108 %	129 %
25,000 ML/d	113 %	140 %

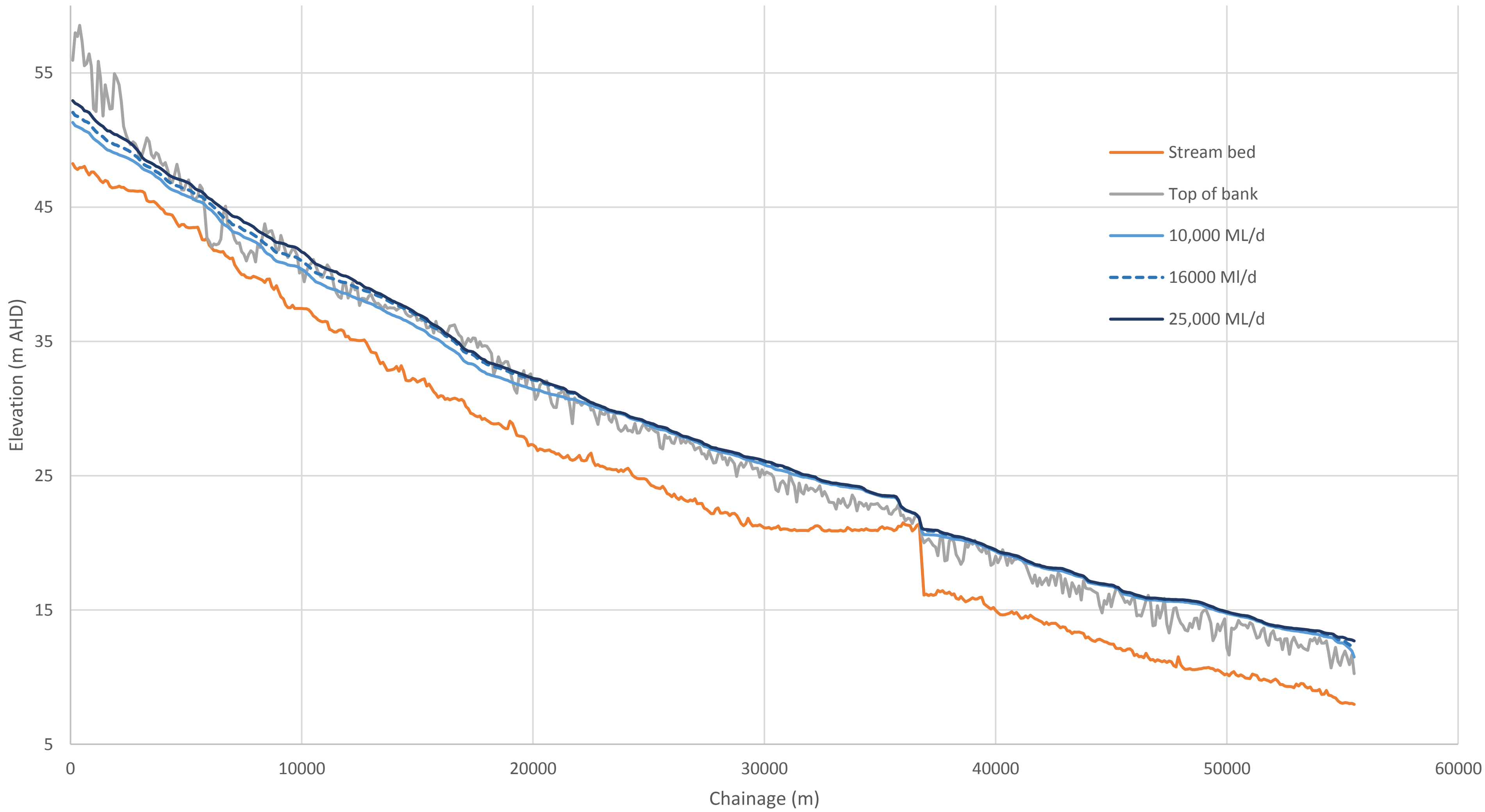


Figure 9. *Long-section of Reach 1 and 2 showing bed and bank elevations with water surface elevation: upstream at Lake Glenmaggie on left to downstream at confluence with Thomson on right*

Part of the bankfull flow criteria is to inundate low lying floodplain areas. These areas are generally located around Reach 2 and the downstream part of Reach 1. Figure 10 shows the inundation extent of the three flows. All three flows inundate the low lying areas in the floodplain of Reach 2. The higher flows (16,000 and 25,000 ML/d) also break out from the upper – mid section of Reach 1 and inundate some land south of the Macalister River. These flows provide additional inundation area, increasing the overall inundated land from 19 km^2 at 10,000 ML/d to 29 km^2 and 40 km^2 for the 16,000 ML/d and 25,000 Ml/d flows respectively. This additional inundated land is mostly agricultural land with few environmental values.

Therefore as the 10,000 Ml/d discharge provides a water level at bank height and inundates environmentally valuable floodplain land without excessive inundation other land, it is the appropriate flow recommendation.

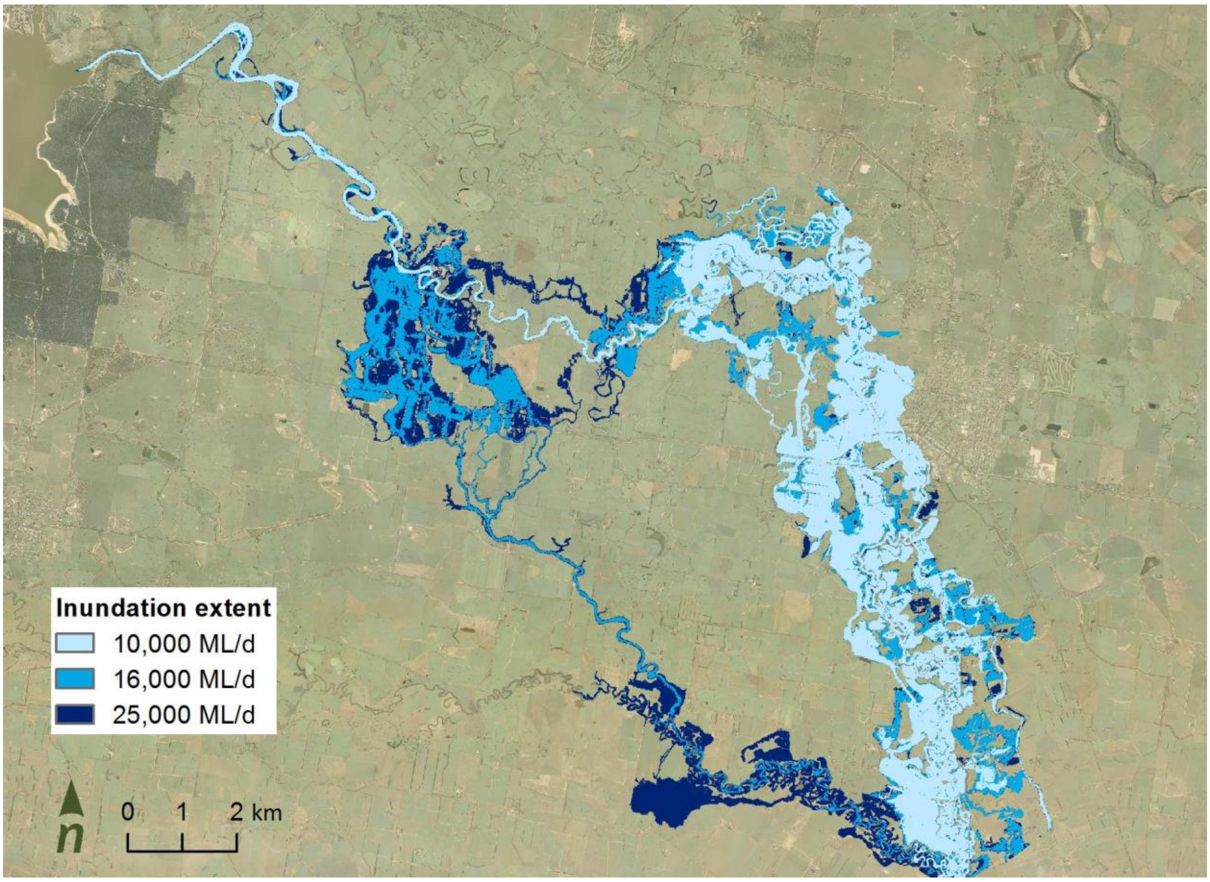


Figure 10. *Inundation extent for bankfull flow runs*

3.4 Summary of results for flow recommendations

Based on the analysis outlined in the preceding sections, the following flow recommendations can be adopted for the Macalister River Environmental Flows Review.

Table 5. Flow recommendations based on 2D modelling results

Hydraulic criteria	Objectives	Reach 1	Reach 2
Scour of sediment and disturbance of biofilms	G4, M2	3,000 ML/d	1,500 ML/d
Inundation of benches, wetting fringing vegetation	V4	1,500 ML/d	700 ML/d
Inundation of higher benches, increase in wetted area	V5, M3	2,500 ML/d	1,500 ML/d
Bankfull flow and some inundation of floodplains	B1, G5, V6	10,000 ML/d	10,000 ML/d

4 Analysis for river planning

This section examines the shear stress results for the 10 and 20 year average recurrence interval (ARI) events, to identify which areas have high erosion potential. This is not related to the environmental flow recommendations, it has been included to provide useful planning advice to the WGCMA. The comments provided here are based on the modelling results and do not substitute a dull geomorphic review of the system.

Shear stress

Shear stress represents the force of the water against the watercourse and floodplain. The equation for determining shear stress is γRS_f, where γ is the specific weight of water, R is the hydraulic radius (cross-sectional area divided by wetted perimeter), and S_f is the friction slope. Therefore the shear stress generated at a location is determined by the slope, depth of water, and width of the channel.

Shear resistance

A range of shear stress categories have been identified in the literature and defined for the purpose of this investigation to assist with the interpretation of the model results (Table 6). These shear stress categories are based on consideration of similar values in the literature, and past field experience of the project team.

Table 6. Critical shear stress thresholds adopted for this study

Category	Boundary type	Critical shear stress (N/m^2)	Reference
Soils	Coarse sand	1.1	Fischenich 2001
	Alluvial silt (non-colloidal to colloidal – includes gravels, loams)	2.2 - 12.5	Fischenich 2001
Vegetation	Short grass	40	Adapted from Fischenich 2001
	Long grass	70	Adapted from Fischenich 2001
	Mix of shrubs and trees	120 -150	Fischenich 2001, Alluvium 2014

The shear stress results are provided in Figure 11 and Figure 12 below and coloured based on the categories above. The areas of orange and red may be susceptible to erosion if they are not stabilised by vegetation or other means. There are particularly high shear stresses in the Macalister River immediately downstream of Lake Glenmaggie. This is expected and is not of concern as it is a confined gorge area with a stable bed. There are some areas of high shear stress within the channel of mid-reach 1, localised areas in Reach 2 and within Boggy creek.

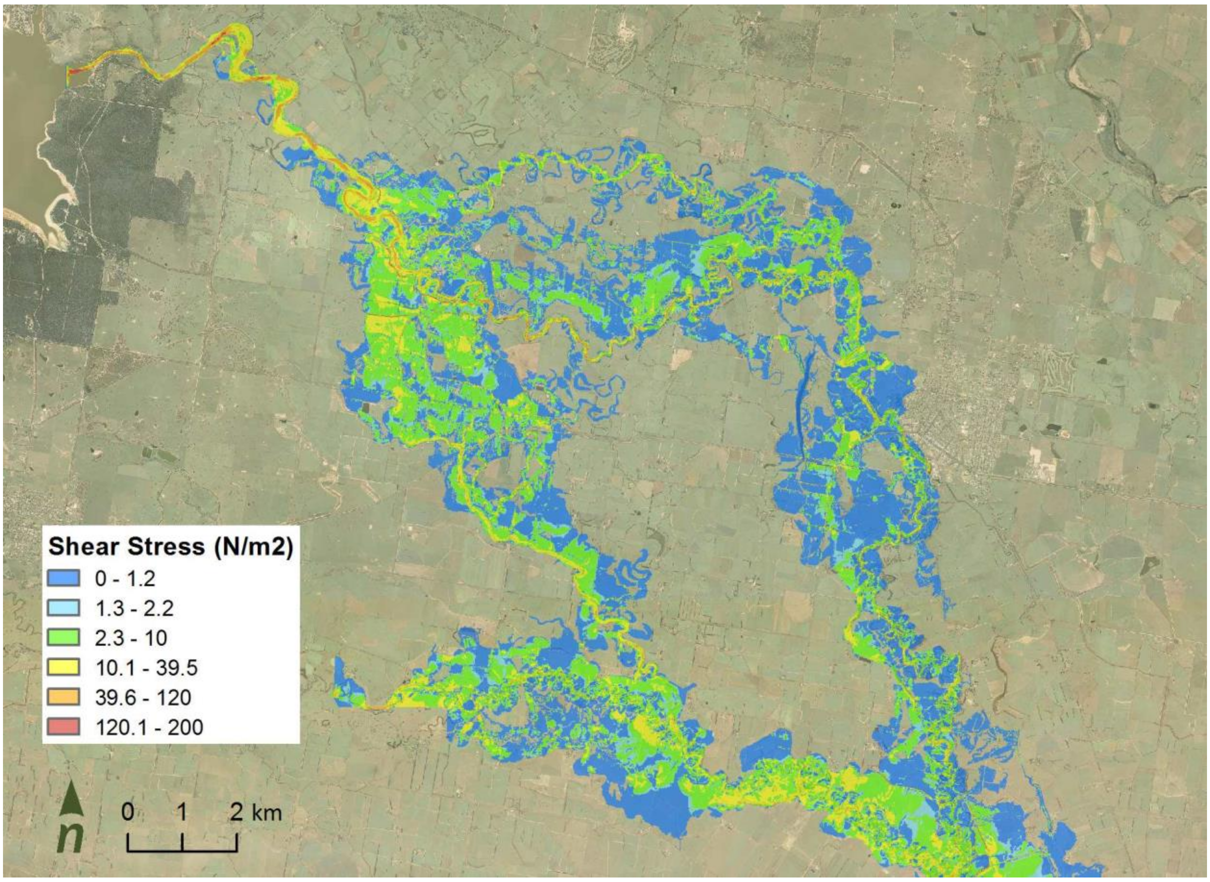


Figure 11. *Shear stress results for 10 year ARI event*

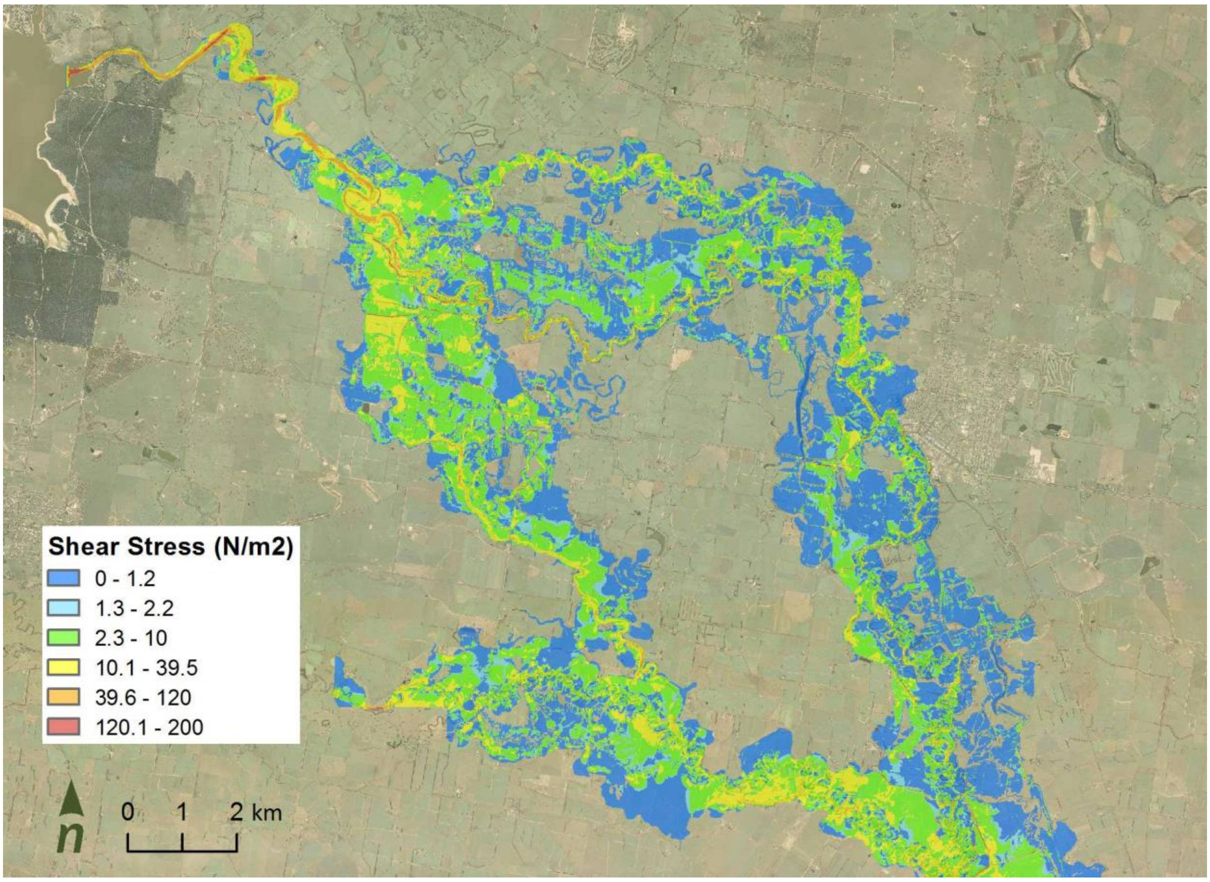


Figure 12. *Shear stress results for 20 year ARI event*

Shear exceeded (excess)
In addition to looking at the shear stress results, further analysis has been undertaken to take into consideration the land use in each location and the implications for the ability to withstand high shear stresses. The applied shear stress has been divided by the existing shear resistance of the ground material (see below), to give the shear exceeded at any given location. The shear exceeded value provides a good indication of the potential for erosion to occur.

Based on the recommended thresholds above and the land use classifications for the study area (provided by Water Technology) shear resistance values have been assigned to the main land use components.

Table 7. Shear resistance adopted for this study

Component	Description	Shear resistance adopted (N/m2)
Channels	Assume unvegetated banks	30
Pasture	Short grass	45
Roads, houses	Non-erodible	300

The shear exceeded results are provided in Figure 13 and Figure 14. In areas within the range '0.75 – 1.25', the modelling shows that the shear resistance of the land use is likely to withstand the applied shear stress by the flood event. There are some areas where the shear exceeded is greater than 1.25, which suggests the shear applied is greater than 125% of the shear resistance and there is potential for erosion to occur. These areas are through the upper sections of Reach 1 within the channel. Note that it is assumed in this analysis that the channel is relatively unvegetated.

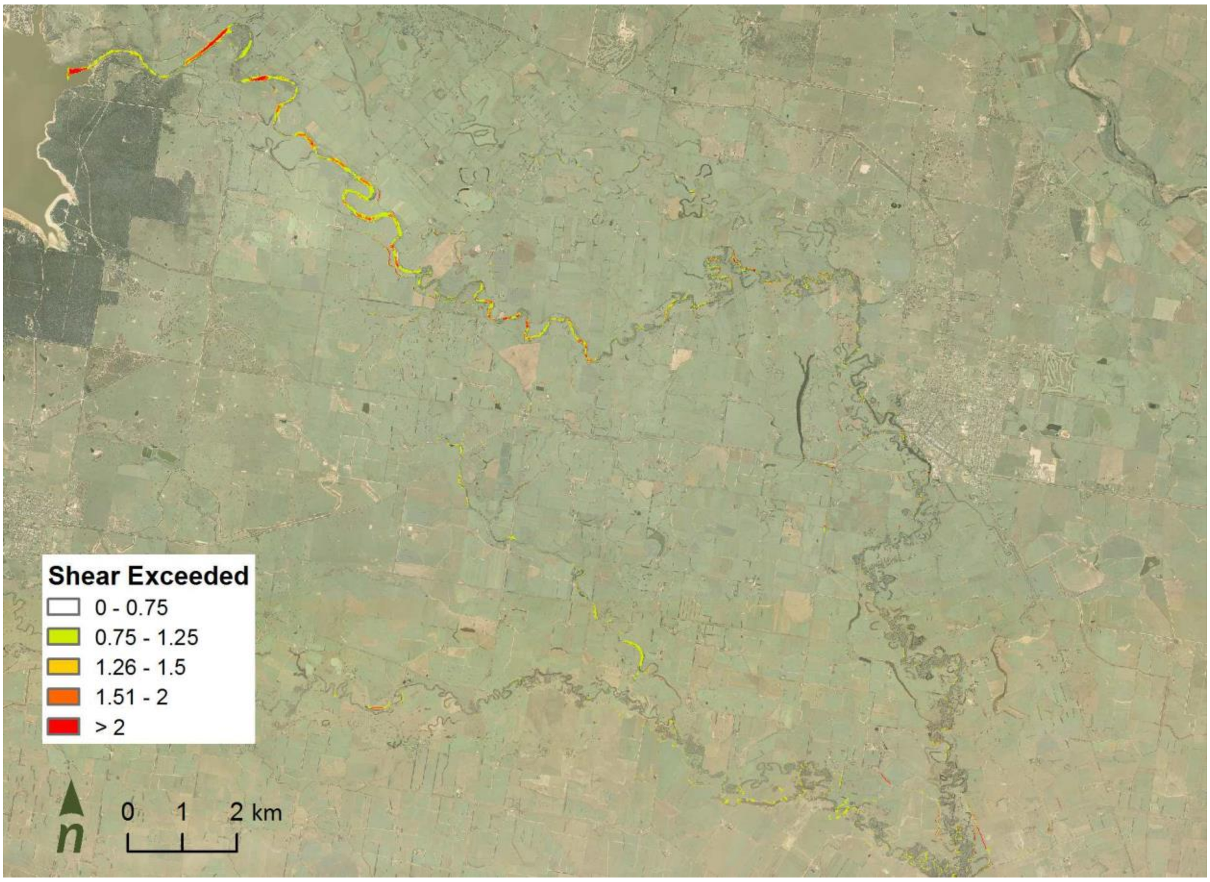


Figure 13. *Shear stress exceeded results for 10 year ARI event*

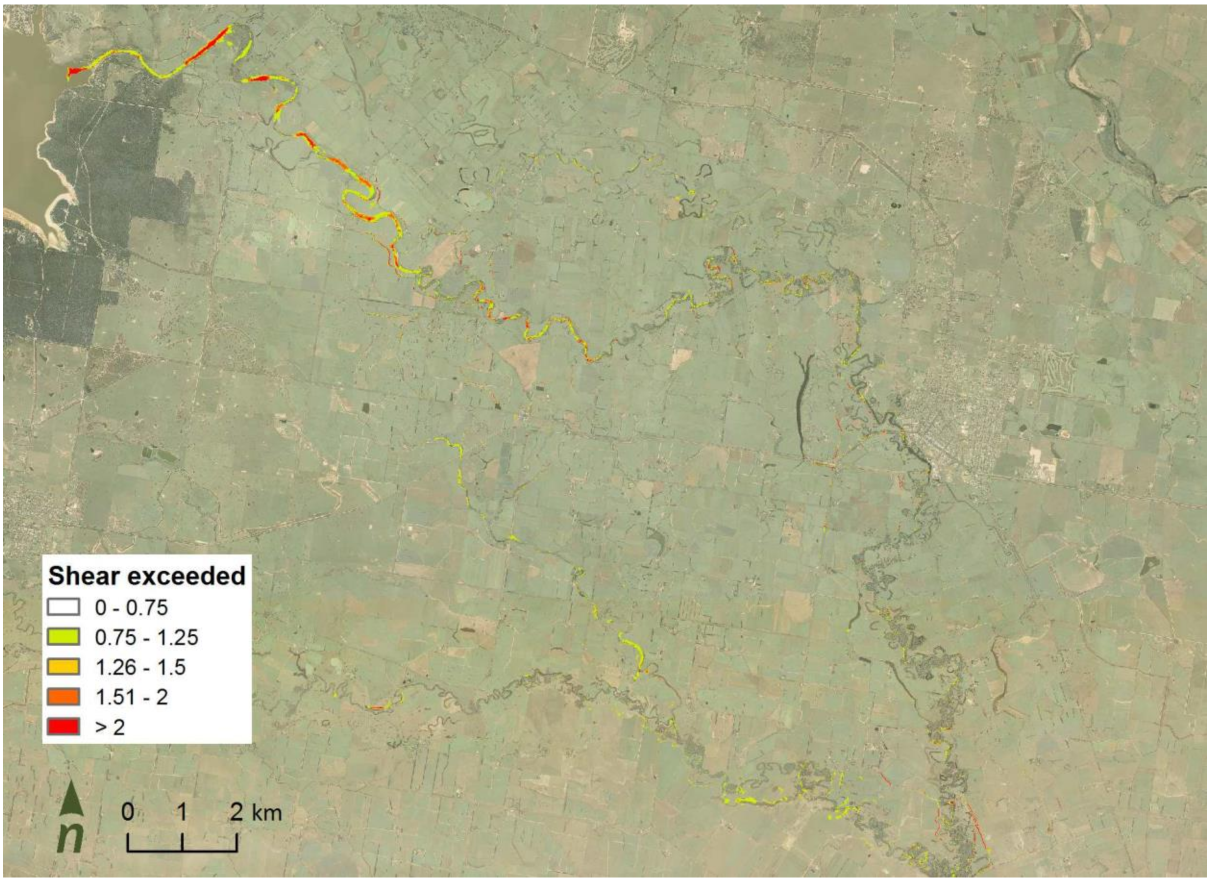


Figure 14. *Shear stress exceeded results for 20 year ARI event*

Appendix D
Habitat preference curves

Reach 1 – Habitat preference curves

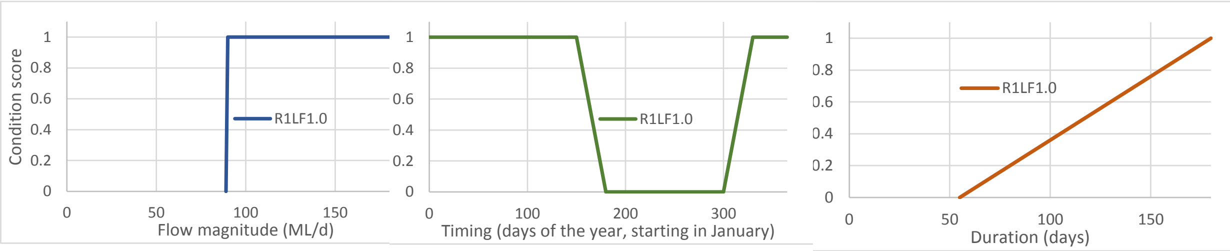


Figure 37. *Habitat preference curves for model R1L1.0 (low flow Dec – May for physical habitat and vegetation values)*

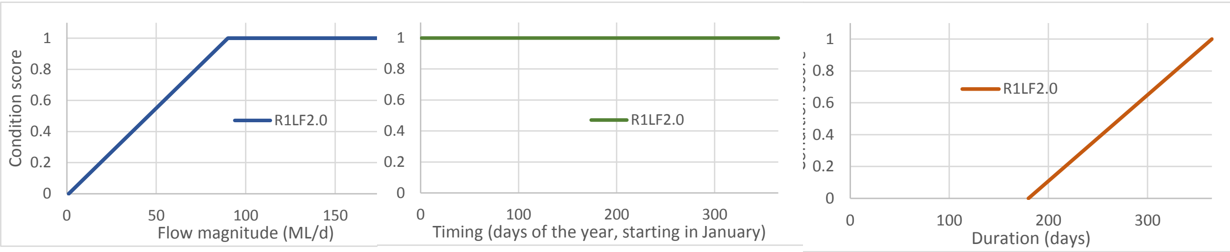


Figure 38. *Habitat preference curves for model R1L2.0 (Low flow required all year for habitat for fish, macroinvertebrate and platypus values*

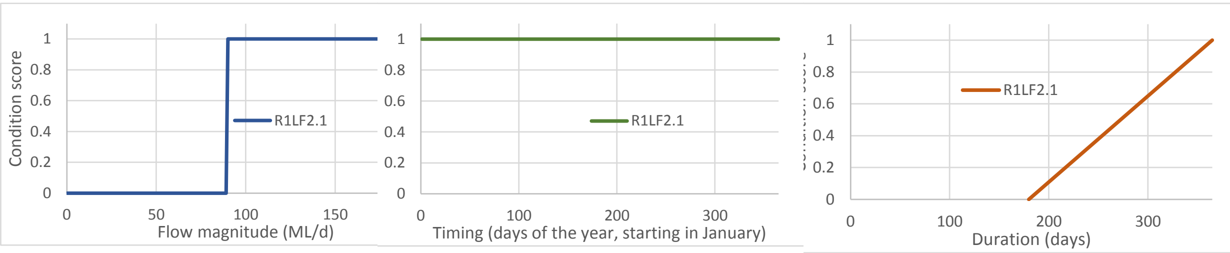


Figure 39. *Habitat preference curves for model R1L2.1 (low flow all year for local movement of fish, macroinvertebrate and platypus values)*

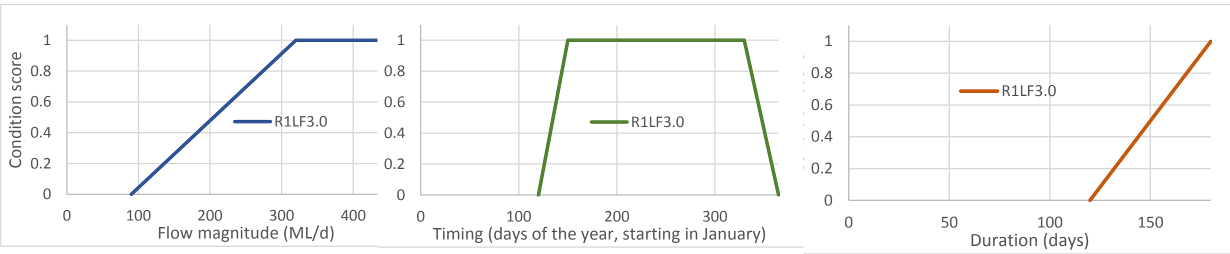


Figure 40. *Habitat preference curves for model R1LF3.0 (low flow Jun-Nov for vegetation values)*

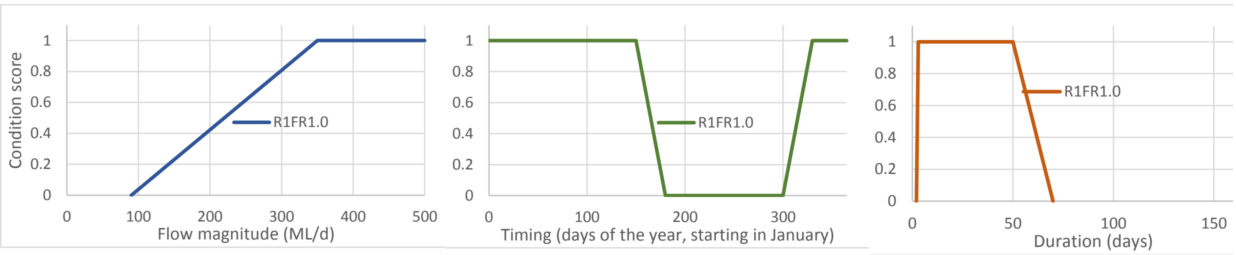


Figure 41. *Habitat preference curves for model R1FR1.0 (fresh Dec - May for water quality, macroinvertebrate and vegetation values)*

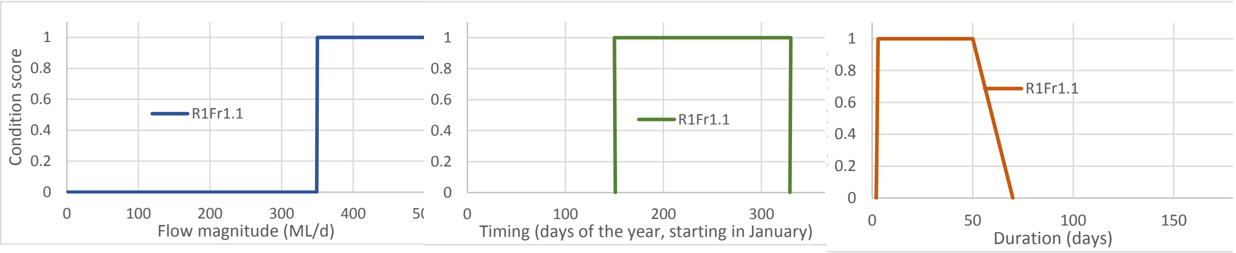


Figure 42. *Habitat preference curves for model R1FR1.1 (fresh Dec - May for migration of eels)*

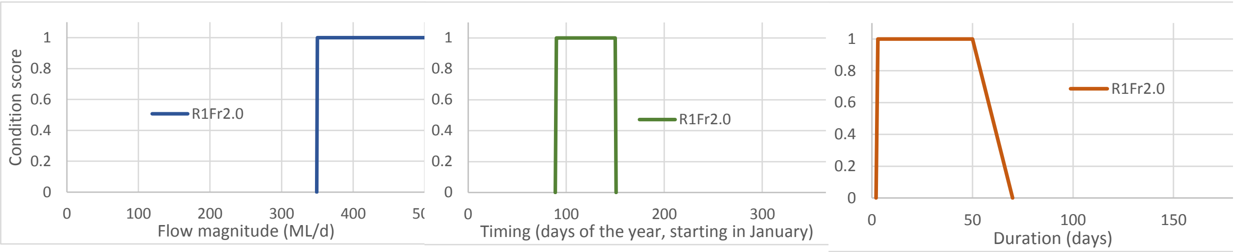


Figure 43. *Habitat preference curves for model R1FR2.0 (fresh April - May for grayling migration)*

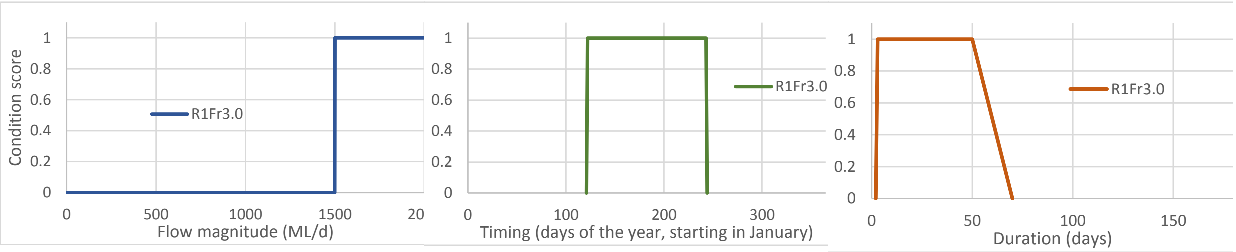


Figure 44. *Habitat preference curves for model R1FR3.0 (fresh May - Aug for tupong and bass migration)*

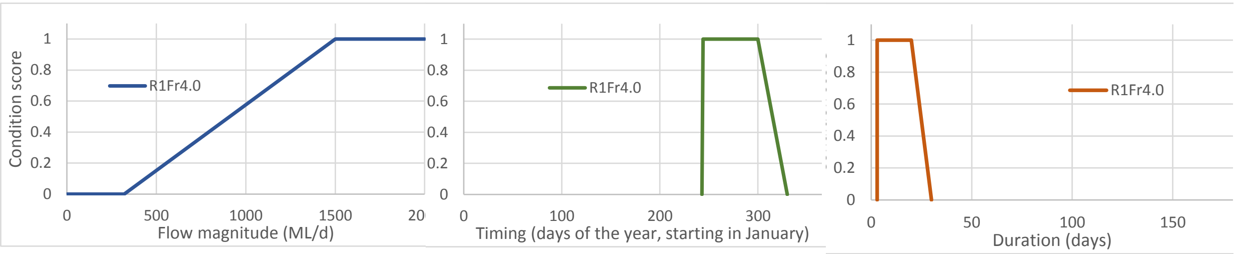


Figure 45. *Habitat preference curves for model R1FR4.0 (fresh Sep – Oct for vegetation values)*

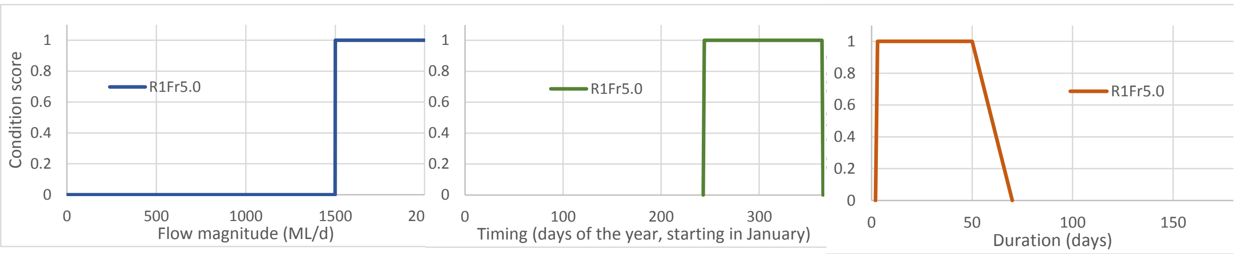


Figure 46. *Habitat preference curves for model R1FR5.0 (fresh Sep – Dec for fish recruitment)*

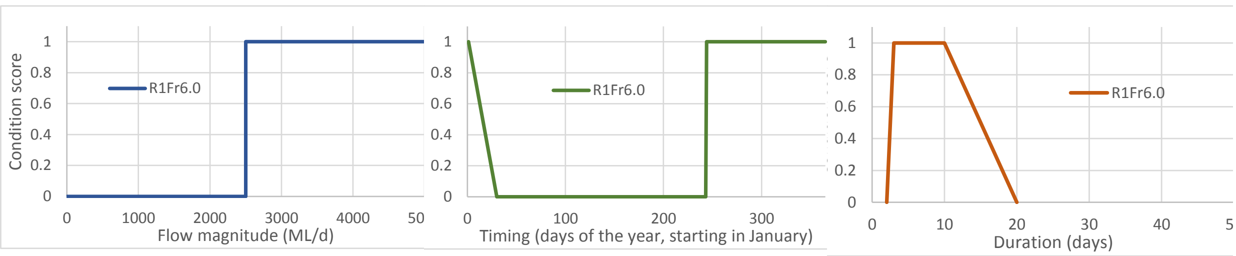


Figure 47. *Habitat preference curves for model R1FR6.0 (fresh Sep – Dec for vegetation and macroinvertebrate values)*

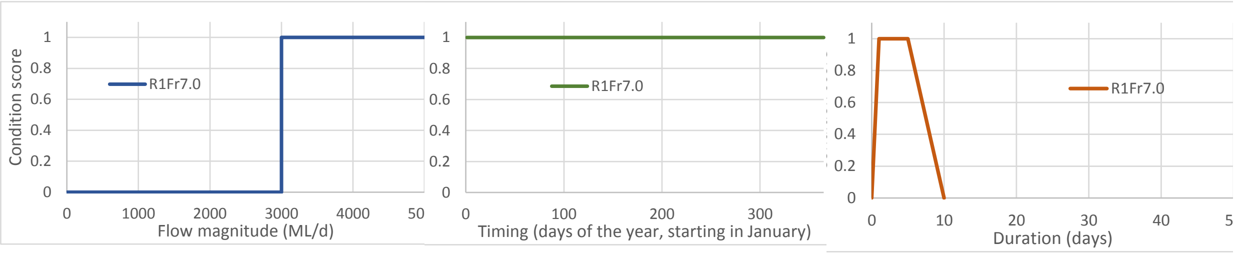


Figure 48. *Habitat preference curves for model R1FR7.0 (fresh anytime for geomorphology and macroinvertebrate values)*

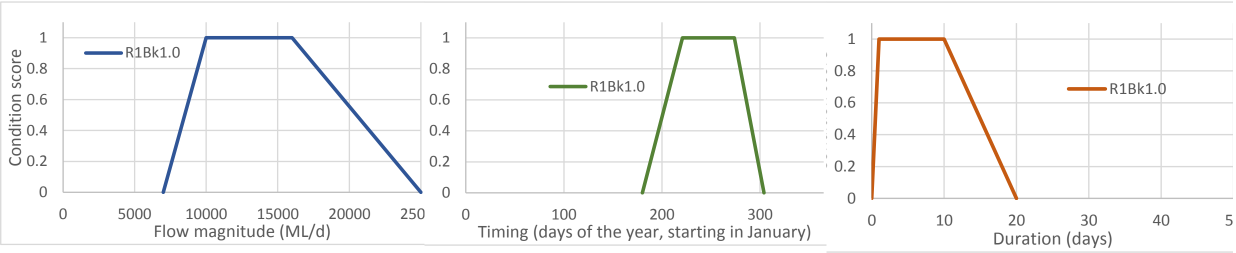


Figure 49. *Habitat preference curves for model R1BK1.0 (bankfull July - Oct for vegetation, geomorphology, frog, bird and turtle values)*

Reach 2 – Habitat preference curves

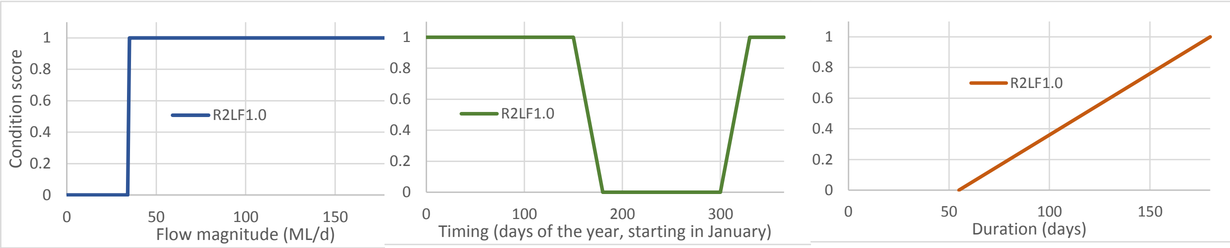


Figure 50. *Habitat preference curves for model R2L1.0 (low flow Dec – May for physical habitat and vegetation values)*

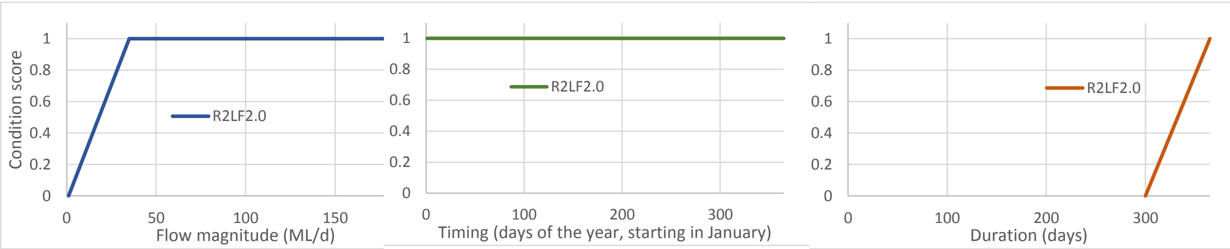


Figure 51. *Habitat preference curves for model R2L2.0 (Low flow required all year for habitat for fish, macroinvertebrate and platypus values*

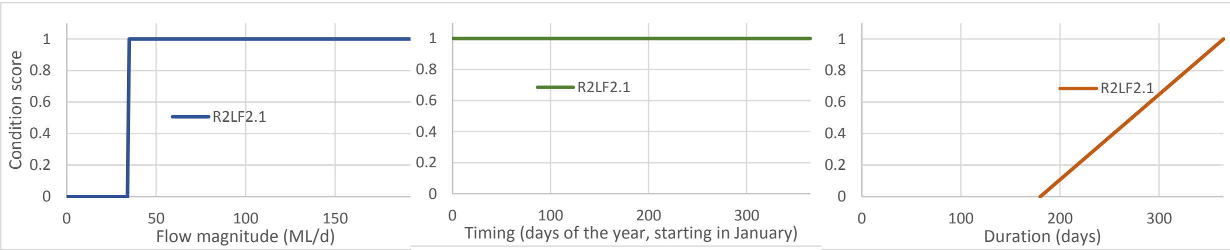


Figure 52. *Habitat preference curves for model R2L2.1 (low flow all year for local movement of fish, macroinvertebrate and platypus values)*

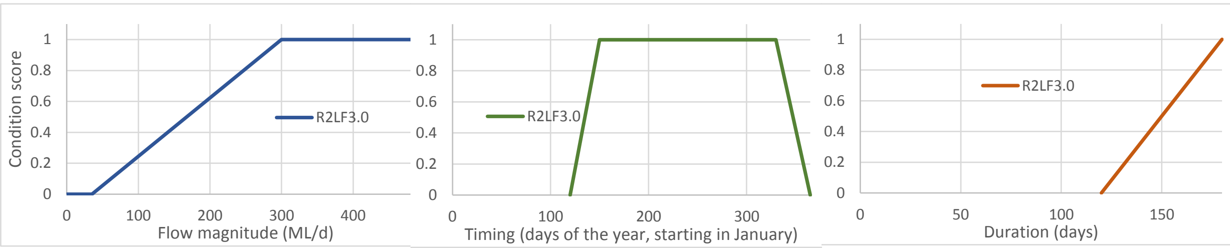


Figure 53. *Habitat preference curves for model R2LF3.0 (low flow Jun-Nov for vegetation values)*

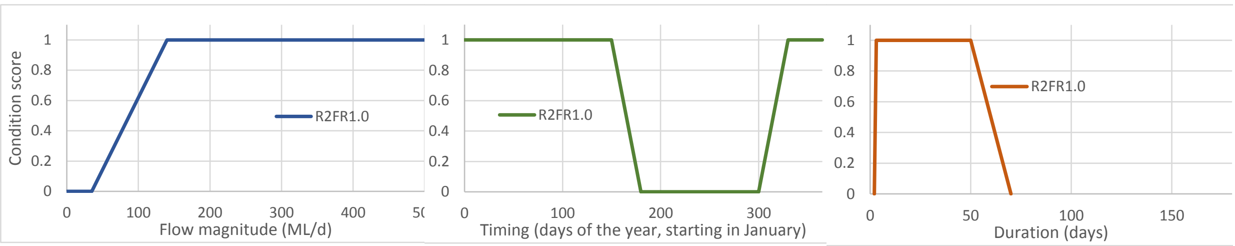


Figure 54. *Habitat preference curves for model R2FR1.0 (fresh Dec - May for water quality, macroinvertebrate and vegetation values)*

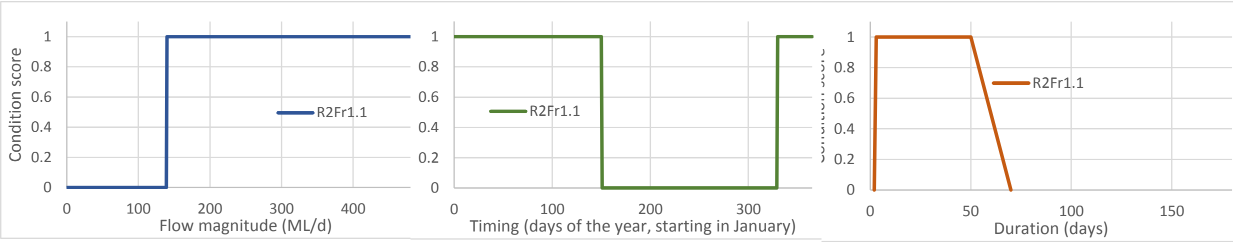


Figure 55. *Habitat preference curves for model R2FR1.1 (fresh Dec - May for migration of eels)*

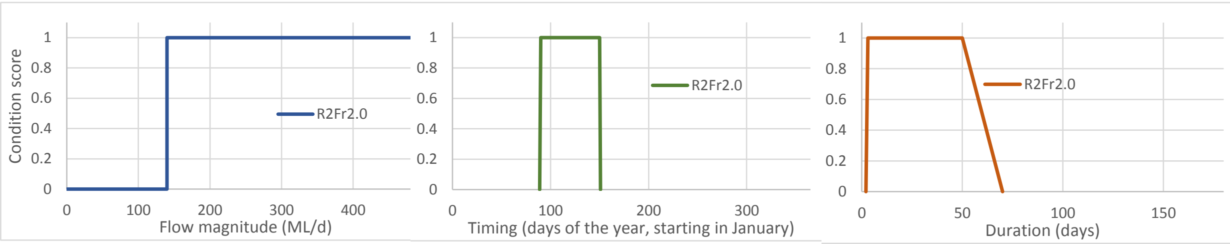


Figure 56. *Habitat preference curves for model R2FR2.0 (fresh April - May for grayling migration)*

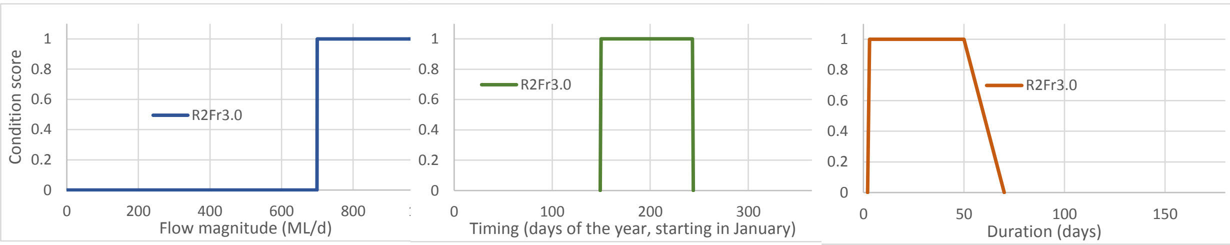


Figure 57. *Habitat preference curves for model R2FR3.0 (fresh May - Aug for tupong and bass migration)*

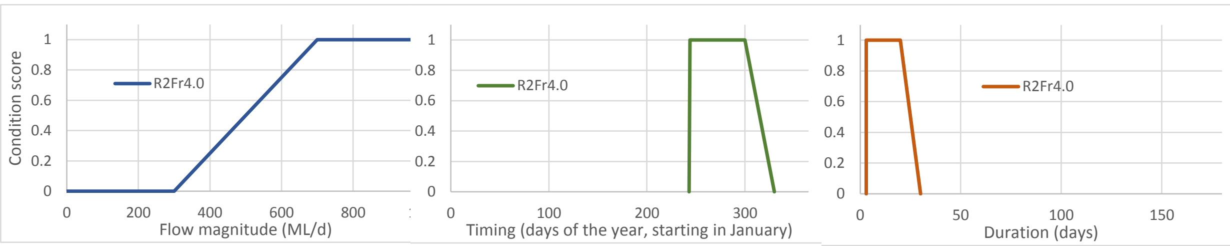


Figure 58. *Habitat preference curves for model R2FR4.0 (fresh Sep – Oct for vegetation values)*

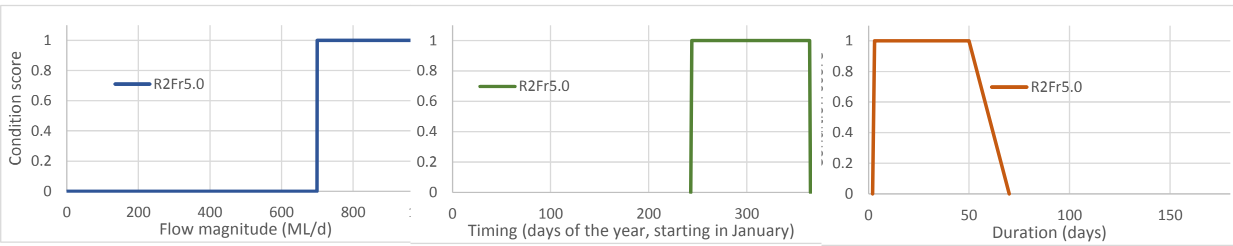


Figure 59. *Habitat preference curves for model R2FR5.0 (fresh Sep – Dec for fish recruitment)*

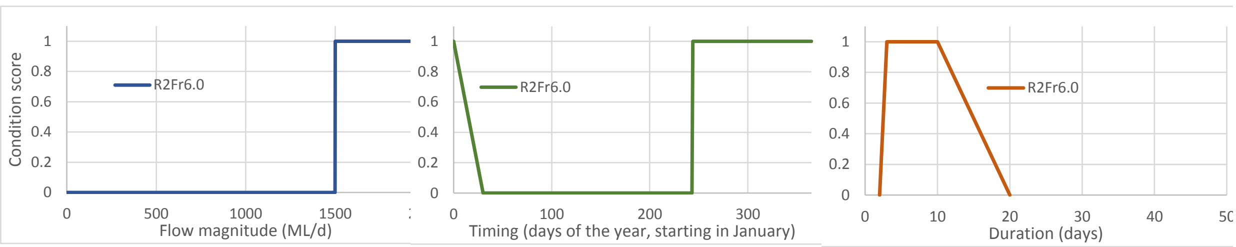


Figure 60. *Habitat preference curves for model R2FR6.0 (fresh Sep – Dec for vegetation and macroinvertebrate values)*

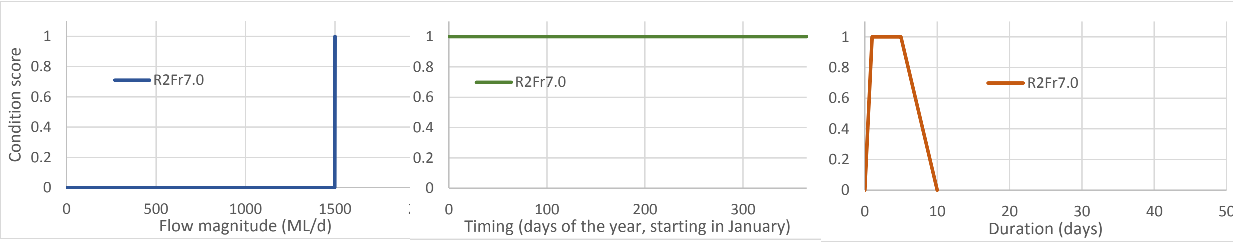


Figure 61. *Habitat preference curves for model R2FR7.0 (fresh anytime for geomorphology and macroinvertebrate values)*

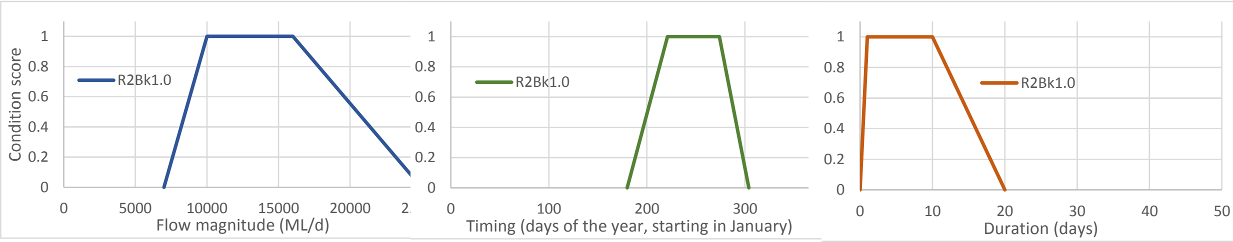


Figure 62. *Habitat preference curves for model R2BK1.0 (bankfull July - Oct for vegetation, geomorphology, frog, bird and turtle values)*