Werribee River Environmental Flows Review

MELBOURNE WATER

Flow Recommendations Report

| Final

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Final	10/7/2014	Final report issued to Bill Moulden at Melbourne Water	Andrew Sharpe	Simon Treadwell	Simon Treadwell

Contents

Executive Summary

Ecological Associates (2005b) set environmental flow recommendations for the Werribee River and Coimadai Creek in 2005 and the Lerderderg River Environmental Flows Panel set recommendations for the Lerderderg River in 2003. Prolonged drought, a limited environmental water entitlement, operational and infrastructure constraints associated with irrigation and town supply demand, and the location of large dams and weirs have prevented Melbourne Water from delivering many of the recommended flows to date. However, better inflows in recent years, more secure environmental water entitlements and potential improvements to water delivery infrastructure mean that Melbourne Water is now, or will soon be, able to deliver environmental flows to some reaches of the Werribee River.

Even with higher storage inflows and an increased environmental entitlement, Melbourne Water will not be able to deliver all of the recommended flows to all reaches of the Werribee River and therefore needs to develop a plan to ensure it maximises the benefit of its environmental entitlement. Environmental flow recommendations are an important input to the planning process that Melbourne Water is going through. The existing environmental flow recommendations for the Werribee River and Lerderderg Rivers were determined using the FLOWS method, which is the approved method for determining environmental flow requirements for rivers and streams throughout Victoria. The FLOWS method has since been updated (in 2013) to improve the reliability of flow recommendations and to allow for different regimes in wet and dry years that will likely occur under our variable climate. Moreover, targeted monitoring in the Werribee River catchment, scientific research in other catchments and long-term studies such as the Victorian Environmental Flows Monitoring and Assessment Program have increased our understanding of the environmental water needs of particular species and biological communities that live in the Werribee River catchment. Melbourne Water engaged Jacobs to apply the updated FLOWS method and new scientific knowledge to review and, where necessary, update the original environmental flow recommendations for the Werribee River, Coimadai Creek and Lerderderg River.

This project focuses particularly on Coimdai Creek (Reach 6) and the lower Werribee River between the lower Diversion Weir and the Werribee Estuary (Reach 9) because those are the two reaches where Melbourne Water is most likely to be able to use environmental water to significantly improve the current flow regime. Melbourne Water has limited capacity to influence flows in other reaches in the near future either because it has little or no environmental entitlement in upstream storages or because the flow regimes are constrained by operation rules that are designed to meet the needs of irrigators and other groups that hold consumptive water entitlements.

Jacobs assembled an Environmental Flows Technical Panel to apply the updated FLOWS method to determine environmental flow objectives and set quantitative environmental flow recommendations for Coimadai Creek and the lower Werribee River. For these two reaches, the EFTP conducted a desktop review of available data and studies, conducted a detailed field assessment, and selected and surveyed new channel cross-sections to build new hydraulic models. This approach allowed us to review and where necessary revise the environmental flow objectives and recommend specific changes to the magnitude, timing, duration and frequency of flows that are needed to meet those objectives.

We qualitatively reviewed the environmental flow recommendations for the middle Werribee River between Pykes Creek and the Lerderderg River (Reaches 4 and 5) and the Lerderderg River. These assessments included a site inspection, review of the existing environmental flow objectives and a desktop review of the likely flow components that are needed to meet those objectives. We did not conducted detailed surveys, or build new hydraulic models for these reaches and therefore have not determined whether the magnitude of each of the flow components recommended in the two previous flow studies is appropriate.

The revised environmental flow recommendations for each reach and specific changes from the previous flow recommendations are summarised below:

Revised environmental flow recommendations for Coimadai Creek

Stream	Coimadai Creek downstream of Merrimu Reservoir		Climatic regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall**
Dry phase *	Cease-to-flow	Maintain natural ephemeral flow regime Prevent further expansion of *Phragmites* and *Typha* Prevent aquatic weeds and pest species that require perennial flow from establishing	Wet / Average	0 ML/day	All season	2-3 months	NA
			Dry	0 ML/day	All season	Up to 9 months	NA
Wet phase *	Low flow	Wet the width of the channel through the whole reach, fill pools and create riffle habitat for macroinvertebrates Allow fish to move between pools Promote the growth of seasonal aquatic plants such as *Triglochin* and *Myriophyllum* Recharge the hyporheic zone and local groundwater	Wet / Average	2 ML/day	All season	9-10 months	
			Dry	2 ML/day	All season	≥3 months	
	Fresh	Flush organic material and water that has accumulated in the channel during the dry phase Scour silt, biofilms and filamentous algae from substrata Water vegetation at the margin of the low flow channel	Wet / Average	30-40 ML/day	One at start of wet phase and then every 4-6 weeks from September until end of wet phase. Total number of events determined by duration of the wet phase.	1-2 days	
			Dry	30-40 ML/day	One at start of wet phase and then every 4-6 weeks from September until end of wet phase. Total number of events determined by duration of the wet phase.	1-2 days	
	High flow	Flush accumulated leaf litter and organic matter from benches and bars Promote the growth and recruitment of native riparian vegetation on benches and bars	Wet / Average	≥70 ML/day	At least one per year	1 day	
				≥130 ML/day	Every 1-2 years (to ensure 1 event every 3 years on average across wet, average and dry years).	2 days	
			Dry	≥70 ML/day	At least one per year	1 day	

* The timing and duration of the wet phase and dry phase will be determined by unregulated low flow in the Lerderderg River upstream of the confluence with Goodman Creek. In dry years the dry phase may last for up to 9 months, but in wet years it may only last for 2-3 months.

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Highlighted changes from the 2005 environmental flow recommendations

The revised environmental flow recommendations for Coimadai Creek differ markedly from those developed by Ecological Associates (2005b). The new recommendations recognise that Coimadai Creek is fundamentally an ephemeral system. It is now a much different system to what it would have been like prior to the construction of Merrimu Reservoir because bankfull or overbank flows are not going to occur under all but the most extreme circumstances. The loss of frequent high flows as caused the original river channel to narrow and has shifted riparian vegetation zones such that plants that cannot tolerate frequent or prolonged inundation now grow much closer to the channel.

Contrary to the original recommendations of 2005, the new recommendations do not include any large flows to scour established riparian vegetation or the stands of *Phragmites* and *Typha* that choke some sections of the channel. It is now recognized that only the most extreme high flows are capable of scouring large, rhizomatous macrophytes from streams: under most large flows, the emergent leaves and stems simply lay flat on the sediment as floodwaters pass over them, thus protecting the sediments from scour. Instead of the earlier emphasis on large flows, the revised recommendations focus on reinstating a prolonged cease-to-flow event each year to prevent further expansion of these plants. The new environmental flow recommendations have a dry phase that will last for 2-3 months in wet years and up to 9 months in dry years, and a wet phase that has a minimum low flow and numerous freshes of different magnitude to clean biofilms, silt and algae from the streambed, and to water riparian vegetation and flush organic material into the stream. The dry phase is not punctuated by summer freshes because they would not naturally occur in the system and are not needed to maintain permanent pools. Indeed, summer freshes would probably further encourage the growth of potentially troublesome *Phragmites* and *Typha* and would thus work against the potential for extended cease-to-flows to control this vegetation. Near-permanent pools in the system are probably maintained exclusively by groundwater during the dry phases and their level fluctuates according to changes in groundwater level. .

Revised environmental flow recommendations for the lower Werribee River

Stream	**Werribee River from Lower Diversion weir to the Werribee estuary**		**Climatic regime**	**Flow recommendations**			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec–May)	Low flow	Maintain pool and riffle habitats for fish, macroinvertebrates and submerged aquatic vegetation	All years	6 ML/day or natural	Whole season		
	Summer Fresh	Flush silt, and scour biofilms and algae from streambed Water fringing riparian vegetation Allow fish movement through the reach	Wet / Average	137-215 ML/day (at least 2 events ≥215 ML/day)	5 events (every 6-8 weeks) with at least 2 events in April-May, one of them on a full or new moon	1-2 days	
			Dry	137 ML/day	3 events with at least 1 in April-May	1-2 days	
Winter / Spring (Jun-Nov)	Low flow	Maintain clear flow path and control intrusions by terrestrial vegetation Allow fish movement throughout the reach	All years	81 ML/day	Whole season		

Stream	Werribee River from Lower Diversion weir to the Werribee estuary		Climatic regime	Flow recommendations			
Season	Flow	Objective	Wet/Average/Dry	Magnitude	Frequency and timing	Duration	Rise/Fall
	Winter fresh	Promote growth and recruitment of native riparian vegetation including woody shrubs and promote strong vegetation zonation on the banks Cue and facilitate fish movement Inundate depressions at margins of channel for frog breeding	Wet / Average	350 ML/day	4 events: - 2 between June-August - 2 between September-October	3 days	
			Dry	350 ML/day	2 events: - 1 between June-August - 1 between September-October	3 days	
	High / Bankfull flow	Inundate secondary channels and billabongs within main channel Scour pools and maintain channel form and dimensions	Wet / Average	≥3,000 ML/day	Every 2 years on average	2 days	
			Dry	Not expected			

Highlighted changes from the 2005 environmental flow recommendations

The main differences between the revised environmental flow recommendations and the 2005 recommendations are the length of the summer (low flow) period, the length of the winter (high flow) period, and the magnitude of the very large and bankfull flows. Many of the original objectives that aimed to maintain or improve native riparian vegetation and clear channel substrates remain valid, and the flows that aim to meet these objectives are still appropriate. However, the previous environmental flow study overly emphasised flows to allow River Blackfish to move throughout the Reach and to breed. It also placed a strong emphasis on the needs of some migratory fish. These have been revised, as River Blackfish do not currently occur in Reach 9 and even if they did, they do not need high flows or freshes to trigger movement or to provide appropriate breeding habitat. Also, many of the fish that are likely to migrate between the freshwater reaches of the Werribee River and its estuary are small-bodied and need moderate (rather than large) flow increases to trigger and facilitate their migration. Finally, the 2005 environmental flow recommendations do not consider potential risks to Platypus associated with delivering very high flows during their breeding season.

The 2005 environmental flow recommendations specified a low flow season from January to April that would have a minimum flow of 6 ML/day and three freshes of 137 ML/day. Our revised environmental flow recommendations extend the summer low flow period from December to May to better reflect natural seasonal flow patterns in the reach. We have retained the minimum flow recommendation of 6 ML/day for the summer period, but increased the recommended number of summer freshes from three to five in wet years to compensate for the longer low flow period and to ensure that the riparian vegetation flourishes in wet and average flow years. We think that increasing the number of freshes will deliver a greater benefit to the riparian vegetation and maintain the channel substrate better than having a slightly higher winter flow for a longer period. Moreover, we think that some summer freshes should go up to 215 ML/day in wet and average years to wet more of the riparian zone. There will naturally be fewer summer freshes in dry years and therefore we have retained the original recommendation for three events of 137 ML/day for dry years, but these are now spread over six months rather than four.

We have retained the winter low flow recommendation of 81 ML/day mainly because we could find no compelling evidence for a different flow magnitude. The recommended flow does fill the width of the low flow channel, and should be delivered for most of the winter period. It is, however, less important than some of the other flow recommendations and it can probably fall below 81 ML/day for a moderate proportion of the winter flow period without causing significant environmental harm. We have retained the recommended magnitude of 350 ML/day for the winter fresh to water riparian vegetation, scour the streambed and to facilitate fish movement, but have reduced the number of recommended events from five to four in wet years and reduced it further, to two, in dry years. We recognise that delivering only two winter freshes in dry years will place some stress on the environmental values in the reach, but those stresses are part of the natural cycle in streams in Mediterranean-type climates west of Melbourne and as long as adequate flows are provided in wet and average climate years to allow native flora and fauna to thrive, the biota should be able to cope with some hydrological stress in dry years. In summary, the changes recommended are in response to a fuller recognition that streams in to the west of Melbourne are inherently variable and often ephemeral. Attempting to make them into perennially flowing systems typical of wetter parts of the State is counter-indicated.

The new winter high/bankfull recommendation of at least 3,000 ML/day is half the flow recommended by Ecological Associates (2005b). The new and old flow recommendations have the same objective (i.e. to water secondary high flow channels), but the hydraulic model that we developed for the current project includes more of the high flow paths in the reach and therefore provides a more reliable estimate of the minimum flows needed to fill those channels and their associated wetlands. Flows of 3,000 ML/day are also less likely to flood Platypus burrows if they are delivered when juveniles, which are vulnerable to flooding and drowning, are present. We also recommend that these high/bankfull flows only occur on average in half of the wet or average climate years, and are not expected in dry years. Higher bankfull and overbank flows will still occur naturally when Melton Reservoir spills. Melbourne Water has no ability to control those events and we recognise they will deliver other environmental benefits when they occur.

Revised environmental flow recommendations for the Werribee River from Pykes Creek to the Lerderderg River

Based on our qualitative desktop review, we conclude that the existing environmental objectives for Reaches 4 and 5 of the Werribee River are sound and that most of the recommended environmental flows are adequate to meet those objectives. We recommend only two changes.

First, we can find no reason to provide a cease-to-flow period. Cease-to-flow events would probably not have occurred in most years under a natural flow regime and the recommended cease-to-flow period is too short to meet its stated objective of drying out the beds of *Typha* and *Phragmites* that are already growing in the channel and preventing further expansion of those plants. The growth form and life history of these large emergent plants is such that they readily maintain moist soils and a quiescent, shaded and damp microclimate within their canopy that enable them to easily withstand short periods of desiccation. The recommended cease-to-flow is unlikely to harm any of the values identified in the middle reaches of the Werribee, but given it will not deliver any specific benefits, we suggest that it be removed.

Second, the current environmental flow recommendations do not specifically consider the risk that high flows or floods may have on juvenile Platypus. Stabilising and increasing the Platypus population in the Werribee River is a very high management priority, but high flows during the breeding season can flood burrows and drown juveniles. We think the environmental flow recommendations for Reaches 4 and 5 should include several high freshes in July or August to encourage female Platypus to build their nests higher up the bank to reduce the risk of being flooded if higher flows are delivered in spring or summer.

Revised environmental flow recommendations for the Lerderderg River

Based on a qualitative desktop review, we conclude that the existing environmental flow recommendations for the Lerderderg River are generally sound and if implemented should maintain and in some cases improve the condition of flow-dependent values in the Lerderderg River. We suggest two revisions.

First, the environmental flow objective for Australian Grayling and the associated high flow recommendations in June and July to trigger their spawning and migration should be abandoned because Australian Grayling are not likely to use the Lerderderg River. The total number of recommended high flows should be retained to meet objectives for vegetation and geomorphology, but there is no need to deliver those flows in June and July. The timing of those high flows should therefore be determined by flow events in the upper Lerderderg River each year.

Second, the existing environmental flow recommendations do not specifically consider Platypus. The Healthy Waterways Strategy includes specific objectives to stabilise and then grow the Platypus population in the Werribee River (Melbourne Water, 2013). Flow throughout most of the Lerderderg River is too ephemeral to support resident Platypus populations, but animals that live in the Werribee River near Bacchus Marsh may move into the lower sections of the Lerderderg River to forage when there is sufficient flow. The existing recommendation to cease diverting water when flow in Reach 7 drops below 40 ML/day should allow Platypus to access parts of the Lerderderg River as often as they would under an unimpacted flow regime.

Complementary management actions

Environmental flows are an important way of improving the function of regulated rivers and the condition of the ecological values those rivers support. Even so, water harvesting, and associated changes to the flow regime are only two of the many anthropogenic factors that affect streams in Victoria, and other non-hydrological factors often have a critical role in degrading these systems (e.g. grazing by domesticated, feral or native animals, weed invasions and nutrient-enriched run-off). The recommended environmental flows described in this report will have limited effect unless other management actions – known widely as complementary works – are implemented to mitigate or minimise other non-flow related impacts. In the Werribee River, the main complementary works should address fish passage past artificial in-stream barriers, introduce more wood to the stream to provide habitat for native fish, weed control and include actions to reduce hydrological and water quality issues associated with historical and expanding agricultural and urban development.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to review the 2005 environmental flow recommendations for the Werribee River in accordance with the scope of services set out in the contract between Jacobs and Melbourne Water. That scope of services, as described in this report, was developed with Melbourne Water.

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

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

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

In preparing this report we have used the latest REALM model for the Werribee River, as well as hydraulic models and channel survey data for some sites that were developed as part of the original FLOWS study in 2005. A number of the assumptions made in developing the latest REALM model are flawed and Jacobs is not confident that the results of the model and therefore the estimates of current and unimpacted flows in different reaches of the Werribee River are reliable. At Melbourne Water's request, we have not conducted a full review of the REALM hydrology and have used the outputs of the model as provided. Any errors associated with the REALM model may affect the reliability of the environmental flow recommendations presented in this report.

Coimadai Creek was dry throughout the project. Some members of the EFTP have worked on the Coimadai Creek for several years and therefore have direct experience of different flows in the river, but other members of the panel have never seen the river with flow. The lack of flow also compromised the calibration of the hydraulic model for that reach.

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

1. Introduction and project overview

Ecological Associates (2005b) used the FLOWS method (DNRE, 2002) to specify flow components that would need to be delivered to meet objectives for geomorphology, water quality, fish, macroinvertebrates, vegetation and Platypus in six reaches of the Werribee River and three of its main tributaries. Ecological Associates (2005b) recommendations were based on available data for the Werribee River catchment and the environmental water requirements that were known for particular biota and ecological processes at that time.

Since 2005, the Werribee River has experienced prolonged drought, although catchment inflows have been closer to the long-term average in recent years. These climatic conditions have prevented many of the environmental flow recommendations being delivered naturally or through managed releases and have caused notable declines in the condition of many environmental values in the Werribee River catchment (Alluvium, 2011, CESAR, 2012, 2013, McGuckin, 2012). These environmental declines confirm the need for appropriate flow regimes, but four factors make it necessary to review the original flow recommendations. First Melbourne Water has made trial environmental flow releases in some reaches of the Werribee River over the last 3-4 years and monitoring associated with those trials has improved our understanding of how the catchment's ecological values respond to specific flow components and specific flow regimes. Second, targeted environmental flow monitoring programs across other parts of the State, such as the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP), have improved our general understanding of the environmental water requirements for many aquatic species and ecological processes. Third general environmental surveys throughout the Werribee River catchment has improved our understanding of the current distribution and condition of environmental values throughout the system, which can better inform the environmental flow objectives. Fourth, recent modifications to the FLOWS method (DEPI, 2013) improve the reliability of flow recommendations and consider how the recommended flow regimes should vary between wet and dry years that will likely occur under a variable climate.

Melbourne Water is responsible for managing the environmental water entitlement in the Werribee River catchment. It is currently meeting most of the current environmental flow recommendations in reaches that have relatively little extraction such as the Werribee River reaches upstream of Bacchus Marsh. However, the size of the environmental water entitlement, operational and infrastructure constraints associated with irrigation and town supply demand, and the location of large dams and weirs prevent many of the existing environmental flow recommendations being delivered in other reaches. Melbourne Water has commissioned Jacobs to review the existing environmental flow requirements for the Werribee River and its main tributaries, especially in those reaches where it has the capacity to manage flow releases (e.g. Coimadai Creek) to ensure they make best use of the available environmental entitlement.

1.1 Report structure

This Report has nine Chapters:

- Chapter 1 introduces the project objectives and purpose of this report.
- Chapter 2 describes the Werribee River catchment and the reaches targeted by the flows review.
- Chapter 3 gives a brief overview of the updated FLOWS method that was applied in the project.
- Chapter 4 is a literature review that describes the flow requirements of the main aquatic values in the Werribee River that environmental flows will aim to protect, maintain or improve.
- Chapter 5 presents a detailed review of the 2005 environmental flow recommendations for Coimadai Creek (between Merrimu Reservoir and the Werribee River) and updated environmental flow recommendations based on a full FLOWS assessment that included field survey and new hydraulic models.
- Chapter 6 presents a detailed review of the 2005 environmental flow recommendations for Werribee River downstream of the Lower Werribee Diversion Weir and updated environmental flow recommendations based on a full FLOWS assessment that included field survey and new hydraulic models.
- Chapter 7 presents a qualitative review of the 2005 environmental flow recommendations for the Werribee River between Pykes Creek and the Lerderderg River. A detailed FLOWS assessment was not conducted in the middle Werribee River for this project.

- Chapter 8 presents a qualitative review of the 2003 environmental recommendations for the Lerderderg River downstream of the Lerderderg Weir. A detailed FLOWS assessment was not conducted in the Lerderderg River for this project.
- Chapter 9 describes complementary management actions that will help to meet the environmental flow objectives for the Werribee River.

2. Study area

The Werribee River flows through the basalt plains region of western Melbourne and has a temperate-to-Mediterranean-type climate. The river rises on the Great Dividing Range near the Wombat State Forest and flows for ~110 km before flowing into north-western Port Phillip Bay near Werribee. Rainfall varies from ~1,000 mm per year in the headwaters to ~450 mm per year in the downstream reaches. The system includes perennial reaches, such as large sections of the Werribee River, as well as ephemeral reaches, such as the Lerderderg River and Coimadai Creek.

Ecological Associates (2005b) divided the Werribee River catchment into nine environmental flow reaches based on stream size, stream morphology, hydrology and stream operation. The reaches include six reaches in the main stem of the Werribee River from Ballan to the Werribee estuary and separate reaches in Pykes Creek, Coimadai Creek and Djerriwarrh Creek, which are the main regulated tributaries in the Werribee River (see Figure 2-1). Environmental flow requirements for the Lerderderg River were determined in an earlier study (LREFTP, 2003, 2002), and the flow requirements for the Werribee estuary were determined later (Lloyd *et al.*, 2008).

The current review focuses on Coimadai Creek (Reach 6) and the Werribee River downstream of the Lower Diversion Weir (Reach 9) because these are the two reaches where Melbourne Water has the greatest ability to influence flow releases. Melbourne Water is investigating options to purchase irrigation shares in the Werribee River, which will potentially allow them to release water from Pykes Creek Reservoir into the middle reaches of the Werribee River. The project therefore reviews the environmental flow requirements for the Werribee River between Pykes Creek and the confluence with the Lerderderg River (Reaches 4 and 5), but these reviews are less detailed than the review for Reaches 6 and 9. We also review the Lerderderg River passing-flow requirements.

Melbourne Water has little ability to adjust flows in the other environmental flow reaches of the Werribee River and therefore they are not addressed specifically in this review. The environmental flow requirements for the Werribee Estuary will be determined in a separate project and are not considered here.

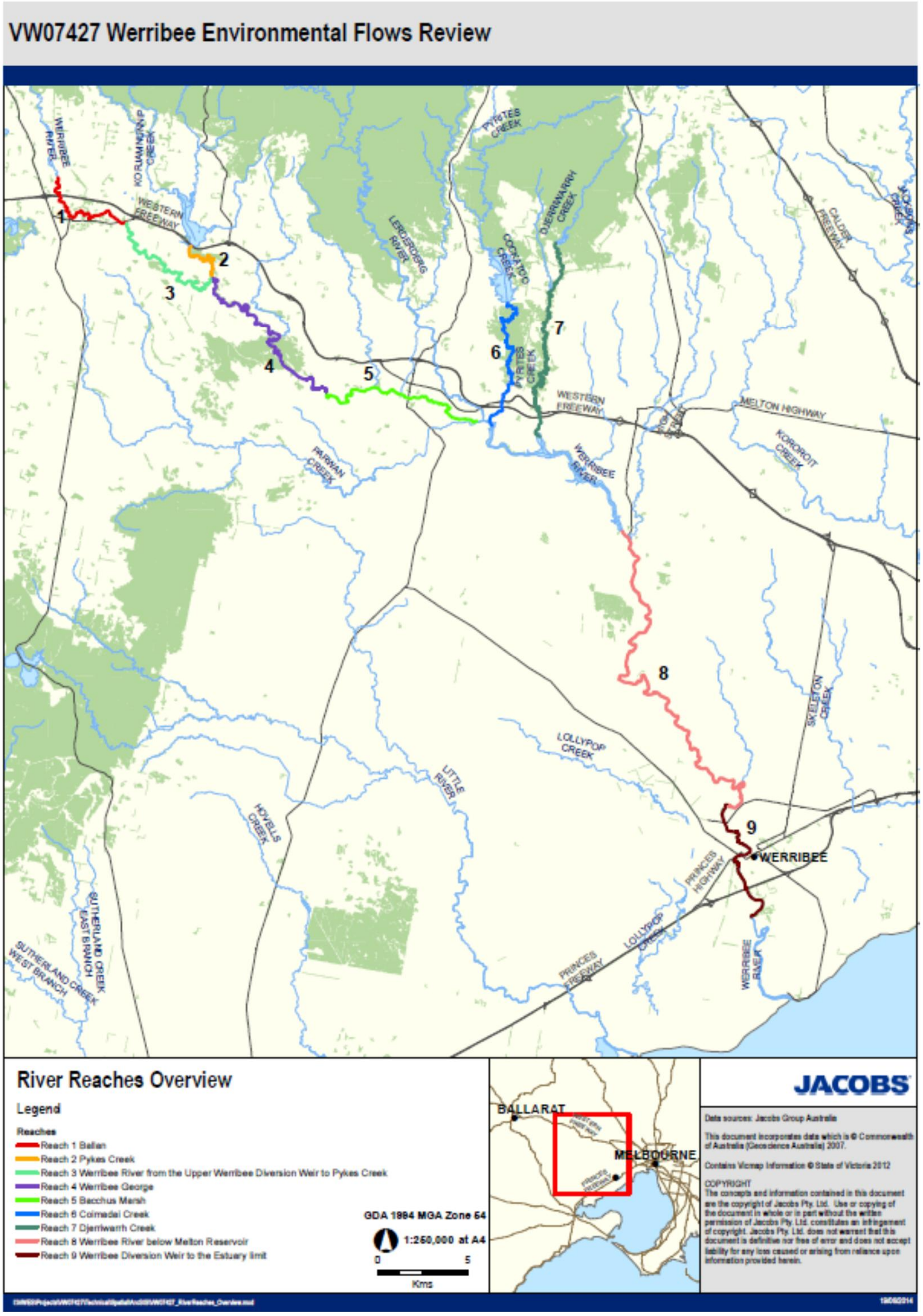


Figure 2-1: Environmental flow reaches of the Werribee River as determined by Ecological Associates (2005b).

3. Approach used to revise flow requirements

The approach used in this project generally follows the updated FLOWS method (DEPI, 2013). The main departures from that method relate to the use of existing data and models that Ecological Associates (2005b) developed for the 2005 study, which used the original FLOWS method (DNRE, 2002).

The original FLOWS method and the updated FLOWS method are applied by an Environmental Flows Technical Panel (EFTP) that comprises individuals with specific knowledge of the flow requirements of different physical processes or types of biota. The EFTP for the current project had six members who collectively have a detailed knowledge of nine flow related disciplines (see Table 3-1).

Table 3-1: Environmental Flows Technical Panel members and their respective technical discipline.

EFTP member	Technical discipline represented
Dr Andrew Sharpe (Jacobs)	Fish and macroinvertebrates
Dr Simon Treadwell (Jacobs)	Ecological processes and water quality
Prof. Paul Boon (Dodo Environmental)	Riparian and instream vegetation
Dr Peter Sandercock (Jacobs)	Geomorphology
Dr Josh Hale (Jacobs)	Amphibians
Amanda Woodman (Jacobs)	Hydrology and hydraulics

Members of the EFTP followed eight tasks (see Figure 3-1) to consider whether the existing environmental flow objectives for the Werribee River are appropriate and achievable, to revise those objectives where necessary and to determine the specific flows that are required to meet the confirmed and updated objectives. The review of objectives is probably the most critical stage of the project. It highlights what objectives can potentially be met with current entitlements and system infrastructure and uses input from a cross-section of relevant stakeholders to determine which environmental objectives are most important in each reach and what concessions may need to be made to meet them.

The EFTP met with invited stakeholders including members of the Werribee River Association, local landowners, Melbourne Water staff and Southern Rural Water staff on site at Riverbend Historical Park in Werribee on the 26th March 2014 and at Happy Valley on Coimadai Creek on 27th March 2014. Stakeholders described the changes that they have observed in the Werribee River over time and identified the values they would most like to see addressed by environmental flows. That information has been considered in all subsequent aspects of the project, but especially when determining the revised environmental flow recommendations for the Lower Werribee River and Coimadai Creek.

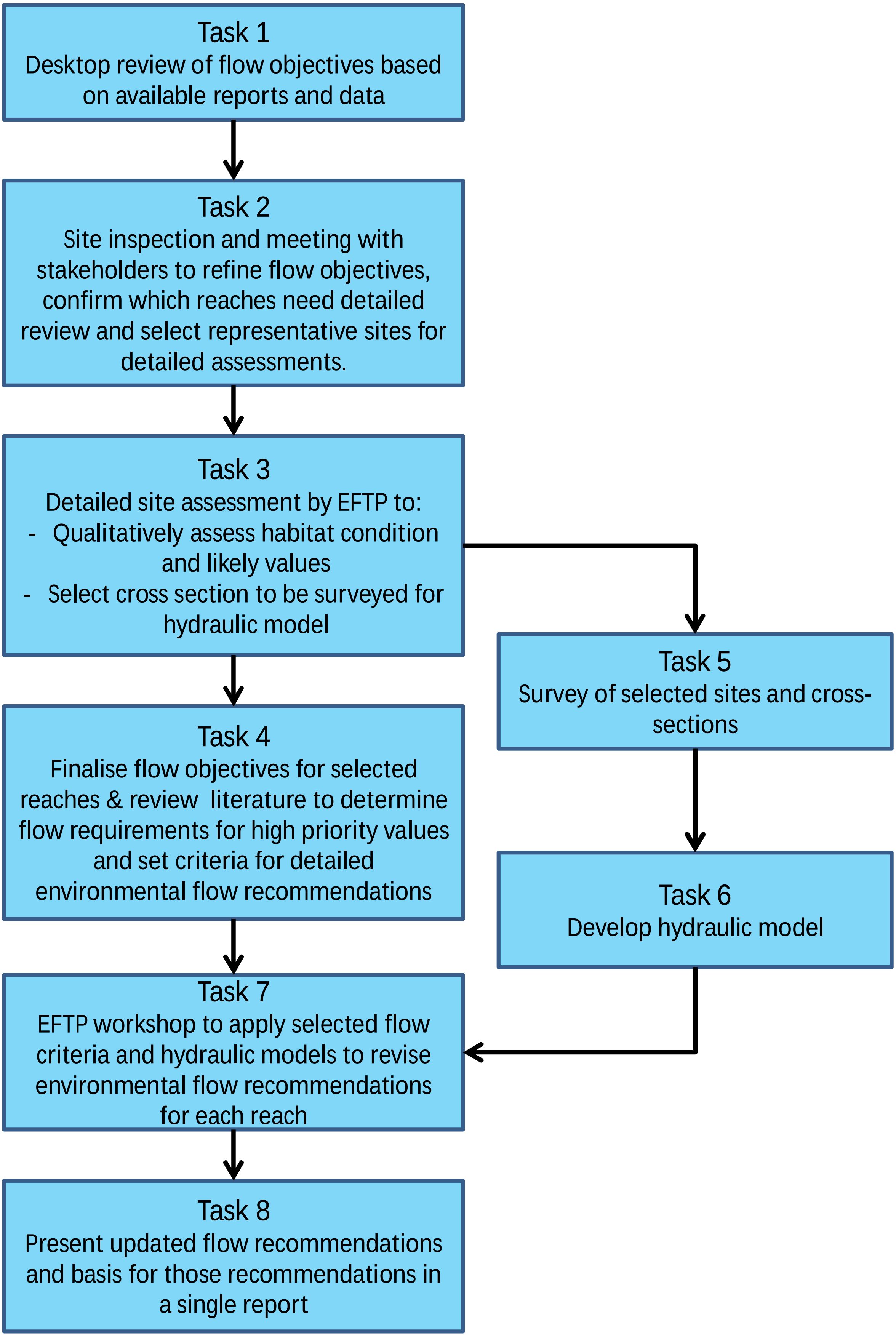


Figure 3-1: Flow diagram showing the tasks performed during the project and how each task relates to each other.

4. Review of the flow requirements of the Werribee River's main environmental values

4.1 Macroinvertebrates

Macroinvertebrate communities are affected more by indirect effects of flow reduction, such as increased electrical conductivity and increased water temperature, than they are by direct effects, such as reductions in water depth, water velocity, and wetted channel width (Miller *et al.*, 2007). Moreover, macroinvertebrate communities in systems that start out with poor or moderate water quality show very few if any responses to flow reduction, presumably because those communities are already dominated by low-flow tolerant taxa (Dewson *et al.*, 2007). Controlled experiments have shown that macroinvertebrates are generally resistant to short term severe reductions in flow as long as some water remains (James *et al.*, 2008). Temporal surveys have also shown that the greatest changes to macroinvertebrate communities occur when streams cease-to-flow and again when pools dry up (see Figure 4-1).

Macroinvertebrate communities show short term declines in abundance after very high flow disturbances that turn over substrate elements (McCabe and Gotelli, 2000, Lake, 2000, Doeg *et al.*, 1989), but these events are important for refreshing biofilm and algal communities (Hart *et al.*, 2013), and for distributing organic material through the streambed (Boulton and Foster, 1998). Moreover, macroinvertebrate communities generally recover from such disturbances relatively quickly as long as patches within the stream are less disturbed and can serve as refuges (Lake, 2000, Doeg *et al.*, 1989, Boulton and Lake, 1992a, b, Hart *et al.*, 2013). In these situations, the total abundance of macroinvertebrates within a site or stream reach may decrease, but some individuals from a wide variety of species will survive, and this means that overall species richness and diversity persist (McCabe and Gotelli, 2000, Doeg *et al.*, 1989) and that surviving individuals can subsequently recolonise disturbed habitats. Recovery from such disturbances is much quicker (i.e. 1-4 weeks) in summer than winter (4-8 weeks) because macroinvertebrates are more active and more abundant in the warmer months (Doeg *et al.*, 1989).

Longer term effects may occur if high flows carry large loads of fine sediment into a stream, which then smothers the streambed (Harrison *et al.*, 2007). That sediment can clog the gills of macroinvertebrates, causing them to suffocate, smother insects that construct cases, and can significantly reduce the quantity and quality of food that is available to grazing and filter feeding taxa. Plecoptera, Ephemeroptera and Trichoptera are most sensitive to smothering by fine sediment and affected communities are likely to see a reduction in the abundance and diversity of these groups and an increase in more tolerant taxa such as worms and chironomids (Harrison *et al.*, 2007).

The macroinvertebrate community in the Werribee River is currently in moderate condition and indirect effects of flow such as changes to water quality, are likely to be more important than direct flow effects such as increased water depth and wetted width. Taxa such as Plecoptera, Ephemeroptera and Trichoptera, which often dominate perennial upland streams in well forested areas, are not abundant in the Werribee system.

Given these factors, we believe that the environmental flow recommendations for macroinvertebrates should focus on the flows that are needed to maintain water quality, replenish food sources such as biofilms and to keep surfaces relatively free of fine silt and filamentous algae. Moreover, the environmental flow recommendations for macroinvertebrates in the perennial reaches of the Werribee River should focus on maintaining at least some permanent flow in riffle habitats and preventing excessive increases in electrical conductivity. In the main stem of the Werribee River this means that flows need to always be greater than 1 ML/day and probably greater than 4-5 ML/day. Higher flows that clean fine sediment and filamentous algae from substrate surfaces and reset biofilm communities are likely to benefit macroinvertebrate communities, but the magnitude and timing of those events will probably be more reliably set by considering the watering needs of riparian vegetation and other values.

In ephemeral reaches such as the Lerderderg River and Coimadai Creek, there is no need to provide permanent flow because the macroinvertebrate communities in those reaches are adapted to seasonal drying. In fact providing permanent flow in these reaches would change the macroinvertebrate community compared to what would have naturally occurred, and may create other ecological problems. The macroinvertebrate environmental flow recommendations for these ephemeral reaches should focus on maintaining permanent pools and providing sufficiently frequent flows to scour filamentous algae and sediment from substrate surfaces when flow is present. In Coimadai Creek, we have demonstrated that flows of around 30-40 ML/day can achieve this outcome and should be delivered approximately once every 4-8 weeks during spring and early summer.

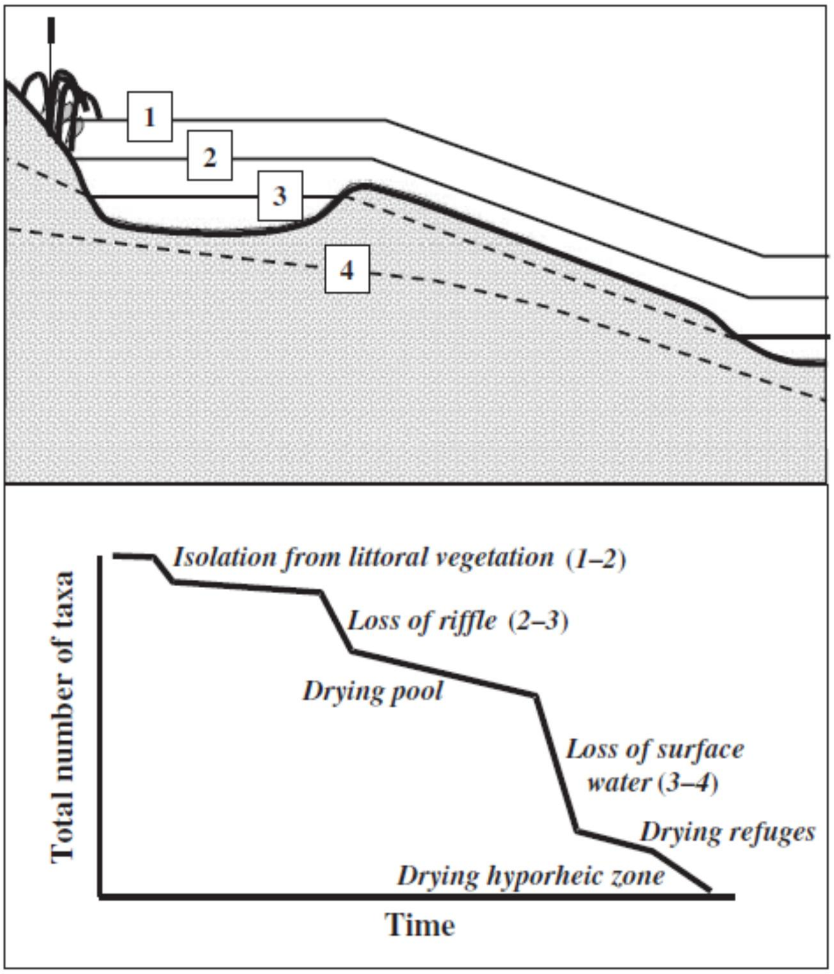


Figure 4-1 Changes in macroinvertebrate assemblage composition in a 'stepped' fashion during transitions across threshold discharges or water levels. During drying, total numbers of taxa are posited to decline sharply when submerged or trailing littoral vegetation is isolated from the free water (1 to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

4.2 Fish

The main focus for fish in the lower Werribee River is providing passage to allow diadromous species to move between the estuary and freshwater reaches and to maintain the quality and quantity of pool habitats for non-diadromous fish. (Diadromous fish species are those that need to migrate between freshwater and seawater to breed. They include anadromous fish, which migrate from the ocean to freshwater to spawn, and catadromous, fish, which migrate from freshwater to the ocean to spawn.)

4.2.1 Requirements for migratory fish

Fish passage throughout the Werribee River has been most affected by artificial barriers such as large dams, small weirs and road crossings. Reduced flow magnitudes throughout much of the year compound this problem by making it more difficult for fish to negotiate small artificial barriers and natural riffles and rock bars. As such, low flows can isolate sections of the stream network and thereby strand fish and restrict their spawning migration.

Common Galaxias, Tupong and Australian Smelt are the three diadromous species that are likely to be most affected by migration barriers in the Werribee River. Each species requires passage at slightly different times of the year. Common Galaxias migrate to the estuary to spawn on new or full moons in autumn and juveniles move from the estuary into freshwater reaches in spring (McDowall, 1996). There is some debate around the importance of high flows in triggering Common Galaxias migration. McDowall and Eldon (1980) reported peak catches of juvenile Common Galaxias entering freshwater shortly after high discharge events, but Hale *et al.* (2009) did not observe any relationships with catches of juvenile Common Galaxias in river mouths and flows. Australian Smelt can complete their life-cycle in freshwater environments (McDowall, 1996), but populations in coastal rivers are likely to move to estuaries to spawn in summer and autumn (Crook *et al.*, 2008). Female Tupong migrate to the estuary and sea during high flow events between May and August (Crook *et al.*, 2010), but do not move much at other times of the year (Crook *et al.*, 2010). Other diadromous species such as Short-finned Eel and Climbing Galaxias are unlikely to be affected by natural or artificial barriers. Short-finned Eel and Long-finned Eel can move short distances overland and Climbing Galaxias can move up near vertical rock faces and waterfalls as long as the surfaces are damp (McDowall, 1996). Australian Grayling is unlikely to occur in the Werribee River (McGuckin, 2006, 2012), and therefore its flow and migration requirements are not considered.

There is little empirical evidence to support the minimum water depth and flow conditions that fish need to facilitate upstream passage. In the absence of such information, most environmental flow studies base fish passage requirements on the body depth of target species, such that the depth of the shallowest channel cross section must be at least as deep as the caudal fin depth (i.e. the height of the fish) (Reinfelds *et al.*, 2010). These criteria typically suggest that tall-bodied fish such as Australian Bass, Golden Perch and Silver Perch need a minimum depth of at least 0.2 m for adult movement and 0.1 m for juvenile movement (Reinfelds *et al.*, 2010). By the same criteria smaller species such as Common Galaxias or Mountain Galaxias can probably move through riffles that are less than 0.1 m deep (Koehn and O'Connor, 1990). Arthington *et al.* (2003) estimated the minimum depth for passage for five fish species in a South African River system from frequency use curves. Their results suggest that the minimum depth for fish passage needs to be greater than the body depth and at least 0.07 m deep for juveniles of even small bodied species such as minnows (Arthington *et al.*, 2003). However, these criteria are relatively simplistic and do not take account of the channel form and associated flow characteristics. In general fish find it more difficult to move through wide-shallow, steep-turbulent and bifurcating riffle habitats under low flow conditions (Reinfelds *et al.*, 2010). Riffles with larger boulders and more variable depth provide a range of hydraulic habitats that will allow fish to move upstream in a series of short-distance bursts.

In the absence of empirical evidence, the minimum flow requirements to facilitate upstream fish passage should therefore be based on a qualitative assessment of the riffle morphology and a conservative estimate of the minimum depth for each species. For the purposes of this assessment we will set the minimum depth of 0.1 m to provide passage for Common Galaxids, Tupong and Australian Smelt, but will also consider the type of riffles present in each reach.

Riffles in the middle and lower reaches of the Werribee River are generally characterised by large rocks and boulders rather than small cobbles and gravel. Most of the fish species that occur or are expected to occur in the these reaches should be able to move through these rock riffles when the minimum depth is only 150-200 mm, because other parts of the riffle are likely to have deeper holes that will offer more cover.

Fast flow is an impediment to fish trying to move upstream, especially if they have to swim long distances in sustained high flow environments. The rocky riffles in the middle and lower reaches of the Werribee River are likely to assist upstream fish movement during high flow events because while higher flows will create very fast flow between individual rocks in the riffles, these fast flow sections will be very short (i.e. only 1-2 m long) and will be interspersed with areas of slower flow where fish can rest. Engineered fishways aim to reproduce this natural mix of fast and slow flow environments to facilitate upstream fish movement and empirical studies have shown that Common Galaxias and Spotted Galaxias both have improved upstream movement during high flows when there are baffles or resting areas to break up the flow (Macdonald and Davies, 2007). Where large rocks are not present to break up the flow, fish will generally move along the slower flowing margins of the channels during high flow events.

4.2.2 Non-migratory fish

Although there are a number of diadromous fish species in the Werribee River system, non-migratory species are also common and need to be considered. The main non-diadromous fish species in the Werribee River that need to be considered in the environmental flow assessment are River Blackfish, Southern Pygmy Perch, and Mountain Galaxias.

Hydrological variability has different effects on diadromous and non-diadromous fish. Diadromous fish generally require high flows to trigger or facilitate migration, but moreover their life history means they are probably better able to cope with and recover from flow related disturbance in any given year (Crow *et al.*, 2013). In contrast, high flows can have negative effects on non-diadromous fish by scouring their habitats or territories, or by flushing developing eggs and larvae out of the system. Moreover, because non-diadromous fish spend their whole life cycle in the one river system, populations may be less able to recover from a catchment-wide disturbance (Crow *et al.*, 2013).

River Blackfish prefer pool habitats with overhanging vegetation, abundant woody debris and flow velocity less than 0.2 m/s (Jackson *et al.*, 1996). They lay their eggs in submerged hollow logs to avoid high sheer forces and excessive sedimentation (Jackson *et al.*, 1996). Males tend the eggs and larvae to deter predators (Jackson *et al.*, 1996). Adult and juvenile River Blackfish can move into flooded riparian vegetation during high flow events to avoid high velocity conditions (Koster and Crook, 2008). However, managed high flows that are likely to scour pool habitats should be avoided from late spring to the middle of summer when eggs and larvae are developing (Jackson, 1978).

Koster and Crook (2008) observed that River Blackfish in Armstrong Creek in the upper Yarra River catchment move into cobble riffle habitats at night to forage. Sections of the Lerderderg River and Upper Werribee River have cobble riffle habitats that are similar to those found in Armstrong Creek and therefore sufficient flow should be provided in perennial reaches to ensure a depth of at least 0.15 m in riffle habitats (this depth is based on a figure of approximately 1.5 times the maximum body depth using the rules described in Section 4.2.1). River Blackfish have not been recorded in the Werribee River downstream of the lower Diversion Weir for many years, but there is an objective to restore the population in the lower reaches of the river. The larger rock riffles in the middle and lower reaches of the Werribee River are not likely to offer suitable foraging habitats for River Blackfish and therefore daily access to riffle habitats is probably not needed.

Environmental flows for River Blackfish in the Werribee River should primarily aim to maintain sufficient depth in pool habitats to inundate woody debris, especially hollow logs, and to maintain connections with fringing vegetation that will provide cover. Flows should also aim to prevent water quality problems. Adult River Blackfish can tolerate salinity levels up to 10,000 mg/L (i.e. approximately 16,000 EC) (Koehn and O'Connor, 1990, Tunbridge, 1988, Hart *et al.*, 1991), but larvae and juveniles can only tolerate salinity levels up to 6,000 mg/L (i.e. approximately 10,000 EC) (Bacher and Garnham, 1992). High flows that are likely to scour pools should be avoided during late spring and summer so as not to flush eggs and larvae out of the system.

Southern Pygmy Perch favour still or slow flowing, well vegetated habitats (Kuiter *et al.*, 1996). It is a poor swimmer and is rarely found in fast flowing parts of streams unless they have been displaced by floods (Kuiter *et al.*, 1996). It also doesn't disperse very far or very quickly (Dexter *et al.*, 2013), therefore populations are very dependent on flows that maintain its habitat from year to year. Environmental flow requirements for this species should aim to maintain water quality (Chessman and Williams, 1974 reported that River Blackfish can tolerate up to 6,000 EC) and aquatic vegetation in pools and avoid high scouring flows especially during the breeding season which extends from September to January when water temperature exceeds 16 °C (Kuiter *et al.*, 1996).

Mountain Galaxias occurs in small headwater streams where water temperatures remain cool during summer and water quality is good. It cannot tolerate electrical conductivity levels greater than 2,500 EC (Koehn and O'Connor, 1990). It does not undergo pre-spawning migration, but can move long distances in a relatively short time which helps it to find refuge when water quality in the stream deteriorate or the stream begins to dry up (Dexter *et al.*, 2013). Mountain Galaxias are often found in remnant pools in ephemeral headwater streams and their strong dispersal ability enables them to recolonise habitats when flows return or conditions improve (Dexter *et al.*, 2013). Females lay eggs among cobbles in riffle habitats during spring and summer (McDowall and Fulton, 1996). Mountain Galaxias is likely to have relatively simple flow requirements because of its ability to disperse to more favourable habitats as needed. Its shallow body depth means that it is able to move through very shallow water as streams dry, but it probably requires reasonable flow through riffle habitats during spring and at least into early summer to ensure successful breeding.

4.3 Water quality

It is a general principle of the FLOWS method that environmental flows should not be used to manage water quality problems that are due to non-flow related factors such as pollution from urban or agricultural sources. The exception is when it may be appropriate to augment flows to prevent extremely low dissolved oxygen concentrations or to prevent extremely high salinity. Both conditions can develop in remnant pools when streams naturally cease-to-flow, the first because of the respiration of trapped biota and the second because of intrusions of saline water when water levels in the pools are low or the evaporative concentration of existing salt. As the specific flow at which water quality begins to deteriorate will vary between rivers and between reaches within rivers, flow recommendations aimed at improving water quality should be based on a focussed analysis of flow and water quality data in each reach.

The only sites in the Werribee River that have adequate flow and water quality data are the gauging stations at Bacchus Marsh and the lower Diversion Weir. The results for the lower Diversion Weir are not very reliable, because the data relate to conditions in the Weir pool and do not indicate how water quality downstream of the weir pool varies under very low flow conditions. The environmental flow recommendations for water quality will therefore be based predominantly on the relationships established between flow and water quality at Bacchus Marsh.

The only water quality variable that should be addressed through environmental flows in the Werribee River is salinity. Dissolved oxygen concentrations did not drop to dangerous levels throughout the period of record at either site and although nutrient concentrations were well above the SEPP WoV trigger levels, the high concentrations are not due to altered flows and are not more pronounced under low than high flow conditions.

During the drought, the Werribee River at Bacchus Marsh almost stopped flowing. The gauged flow was less than 1-2 ML/day for eight or nine months of the year. During these periods, electrical conductivity rose up to 8,000 EC, which is too high for many plant, fish and macroinvertebrate species. Winter flows of 10-15 ML/day were sufficient to cause EC to drop back to around 2,000 EC and much higher flows reduced levels to around 500 EC.

Based on this pattern, we recommend that summer flows in the Werribee River should be at least 5 ML/day, and that if it drops below that level then freshes of at least 10-15 ML/day should be provided every 1-2 months to prevent river water salinity from becoming too high.

4.4 Frogs

Most Victorian frog species require surface water for foraging and/or breeding habitat at some stage during their life cycle. The flow requirements of the frogs of the Werribee River and Coimadai Creek are designed primarily to trigger and promote successful breeding. While an appropriate flow regime is important, it alone is not sufficient to ensure successful frog breeding and other factors such as suitable riparian vegetation must also be present.

Different frog species can breed in a variety of water bodies ranging from rain-fed ponds and small depressions to rivers and river-flow controlled wetlands. However, all breeding water bodies must satisfy three broad requirements:

1) Surface water must be available at the right time of year (i.e. during the breeding season). This is because the majority of Victorian frog species amplex (mate) in water and lay their eggs near, or attached to, fringing vegetation.

2) The water body (pool, pond, depression) needs to hold water long enough to allow tadpoles to develop into adult frogs (metamorphose). The required hydroperiod varies for different species, but also depends on water temperature, food availability and predation pressure (Anstis, 2007). The hydroperiod can be as short as 6 weeks for small, fast developing species, and up to 12 months for larger species (Wassens, 2011).

3) Still or very slow flowing conditions are maintained for as long as tadpoles are present in the waterbordy because tadpoles are not strong swimmers and can easily be washed out of suitable habitats if high flows occur at the wrong time (Wassens, 2011).

The frogs that are known to occur or that are likely to occur in the Werribee River catchment broadly fall into two categories: 1) those that use permanent pools and other in-stream habitats; 2) those that use off-stream habitats such as wetlands or rain filled depressions. Species in the first category include Growling Grass Frog and to a lesser extent the Pobblebonk Frog, Striped Marsh Frog, Spotted Marsh Frog and the Southern Brown Tree Frog (Cogger, 2000, Heard *et al.*, 2010, Pyke, 2002). These species predominantly use permanent pools or slow flowing channel habitats that have fringing vegetation that provide cover and substrates that mating frogs can call from (Cogger, 2000, Heard *et al.*, 2010, Pyke, 2002). They are also likely to use backwaters or anabranch channels that are filled during high flow events and then hold water for many months. Flows that maintain water and fringing vegetation in these habitats and that allow individuals to move between habitats will be critical to the continued survival of these frog species. Ecology Australia (2013) recommended relatively stable low flows from September to February would be most beneficial to the frogs that are likely to occur in Coimadai Creek and Djerriwarrh Creek because that is when the frogs that rely on instream habitats are most likely to breed. Species such as Bibrons Toadlet, Spadefoot Toad and Common Froglet that do not normally use in-channel habitats (Cogger, 2000, Hero *et al.*, 2004, Wassens, 2011), will be more affected by catchment rainfall and land use changes that affect the quality and quantity of off-stream habitats than any changes to the flow regime.

4.5 In-stream, fringing and riparian vegetation

Water-dependent vegetation includes a wide range of growth forms and of plant species. The distribution of different taxa is controlled by two competing sets of pressures: i) their relative resistance to inundation or waterlogging and to desiccation; and ii) competitive interactions among the different species. Responses to this combination of physico-chemical conditions and to inter-species competition often results in clear zonation of different taxa along an elevation gradient from the stream bed.

The taxa most tolerant of inundation occur in-stream and typically include submerged angiosperms such as Water Ribbon (*Triglochin procera*) and semi-emergent angiosperms such as milfoils (*Myriophyllum* spp.) and pondweeds (*Potamogeton* spp.). Macophytic algae, such as charophytes, are also often present in ephemeral streams in western Victoria. Although these plants are most tolerant of permanent inundation, many have adaptations that allow them to withstand episodic desiccation and thus survive in temporary water bodies: Water Ribbons, for example, can lay-down drought-resistant buds known as turions in the sediments. Turions are packed with storage compounds such as starch and sugars, and can remain dormant, sometimes for years, until the sediments are flooded. Upon re-wetting, turions sprout into new plants which, if there is a sufficiently long wet phase, complete their vegetation growth, flower and set seed, and lay down another set of seeds and turions to allow survival over the next dry phase. Turions are only one set of adaptations to episodic drying: other species of submerged plants can generate copious seedbanks in the sediments (Brock, 1997). The longevity of sediment-based seedbanks is, however, variable: some taxa, such as *Myriophyllum* spp. have long-lived seed whereas others (e.g. *Vallisneria*) have short-lived seed. Many submerged taxa are clonal and thus capable of asexual reproduction, meaning they can colonize newly wetted areas if plant fragments are imported from upstream.

Emergent non-woody macrophytes commonly fringe the channel at slightly higher elevations. The main macrophytes in the Werribee River system include rushes such as *Juncus bufonius*, *Juncus pallidus*, and *Juncus usitatus*, the exotic and weedy Spiny Rush (*Juncus acutus*) as well as club-rushes (e.g. River Club-rush *Schoenoplectus tabernaemontani* (syn. *S. validus*), native sedges such as Tall Sedge (*Carex appresa*) and Leafy Flat-sedge (*Cyperus lucidus*). Common Reed (*Phragmites australis*) and Cumbungi (*Typha* spp.) are often placed in this category, despite the former actually being a grass. These are all large, rhizomatous taxa, often clonal, and with the capacity to form extensive beds along the channel margins. They are broadly intolerant of permanent inundation or of permanent dry conditions, but the tolerance of wetting and dying varies across taxa. Some taxa produce prolific numbers of seed, but are also often clonal. Clonality confers a number of advantages, including the ability to share resources among ramets and to reproduce asexually (Hatton *et al*., 2008).

The Werribee River system is unusual in having a diverse and dense band of woody shrubs and trees growing along the channel margins, often interspersed with beds of rushes, reeds and sedges. Many of these shrubs and trees are in the family Myrtaceae: examples include River Bottlebrush (*Callistemon sieberi*), Woolly Teatree and River Teatree (*Leptospermum lanigerum* and *L. obovatum*, respectively). These taxa tend not to be clonal, and their seed bank is held in aerial capsules on their branches, rather than in the sediment. They rely on the longevity of adult specimens and on the production of copious amounts of small, short-lived seed to survive episodic desiccation.

At the highest elevations, flooded only rarely and for short periods, is the slightly flood-tolerant grass *Poa labillardierei* (Common Tussock-grass). It was observed along in Coimadai Creek, in Long Forest Nature Reserve, growing in a narrow band ~30 cm above stream level.

Riparian vegetation at higher elevations than these *Poa* grasslands includes almost fully terrestrial plants such as wattles (e.g. Blackwood *Acacia melanoxylon* and Lightwood *Acacia implexa*) and occasional eucalypts (e.g. Manna Gum *Eucalyptus viminalis*) as well as a diverse shrub and ground-layer. These taxa require relatively moist conditions, but cannot tolerate even short-term inundation, as their roots cannot survive in waterlogged soil. The riparian flora of Coimadai Creek includes the spatially limited Werribee Blue Box, *Eucalyptus bauerianna* subsp. *thalassina*, which occurs in elevated areas. It is not thought to require periodic inundation.

The water-regime requirements of only some of the semi-aquatic and riparian plant groups found in the Werribee River catchment is well understood (Rogers, 2011, Roberts and Marston, 2011, VEAC, 2006). Submerged taxa require annual inundation for up to 12 months, typically to a depth of 50−100 cm. They can, however, survive periodic drying if the subsequent wet period is long enough for them to complete their vegetative life cycle and to lay down desiccation-resistant organs and/or to flower and set seed. If the wet phase is too short, vegetative growth will occur but the ability to recolonise the area after a prolonged dry period will be compromised as they plants will not have had time to set seed.

The water requirements of rushes, reed and sedges are well understood. In broad terms, they require annual inundation to a depth of ~ 20 cm for 2−4 months over spring or summer. Fluctuating water levels advantage some species over others (e.g. *Phragmites australis* over *Typha* spp.) and facilitate the development of a complex zonation of different taxa along an elevation gradient according to slight variations in their responses to wetting and drying. Rogers (2011) provides the most detailed description of the wetting and drying requirements of emergent non-woody vegetation, but like all such collations her summaries are heavily biased towards vegetation in the Murray-Darling River system. It is not clear how readily they can be transferred to aquatic systems outside the Basin and with quite different climates and river conditions.

The least well understood of all water-dependent plant taxa are the woody trees and shrubs. Good information is available only for a small number of species, including River Red Gum *Eucalyptus camaldulensis*, Black Box *Eucalyptus largiflorens*, Coolibah *Eucalyptus coolabah*, and River Cooba *Acacia stenophylla*. Wetting and drying regimes needed to maintain adult bottlebrushes and teatrees are poorly, if at all, described in the literature and we rely on the position of these plants in the landscape (e.g. occurring at high or low elevations along river banks) to infer their likely water-regime requirements. The wetting and drying regimes required by grasses are also often poorly understood, with the exception of Cane *Grass Eragrostis australasica*, Water Couch *Paspalum distichlum*, Spiny Mud Grass *Pseudorhapis spinescens* and, Common Reed *Phragmites australis* (Roberts and Marston, 2011). The position of *Poa labillardierei* in the landscape informs our prescriptions for its optimal wetting and drying cycles.

4.6 Platypus

Platypus feed mainly on aquatic macroinvertebrates and except when tending their young, spend up to 10-12 hours per day foraging for food. Females with young only spend short periods away from the nest during the first three weeks after laying their eggs (Holland and Jackson, 2002, Serena, 1994), but will spend a full day foraging once their young are around six weeks old (Holland and Jackson, 2002). Late lactating females need to consume their equivalent body weight in food each day and therefore need an abundant supply of macroinvertebrates such as insect larvae and shrimp (Holland and Jackson, 2002).

Their ideal foraging habitat is pools that are at least 0.5 m deep to provide cover, but not too deep as they expend more energy diving to the bottom of deep pools (Serena *et al.*, 2001, Bethge *et al.*, 2003). They generally favour slow flowing environments and will forage in submerged backwater habitats during high flow events (Gust and Handasyde, 1995). Serena *et al.* (2001) radio tracked platypus in the Yarra River catchment and noted that they were more abundant and active in sections of the stream that had large Eucalyptus, Acacia and Populus trees growing on the bank; a mix of gravel, pebble, cobble, large rocks and coarse particulate matter in the substrate; abundant riffle habitats, large woody debris and undercut banks. They were less common in reaches that had large numbers of willow trees, silt and solid clay substrates and a dominance of very deep pool habitats (Serena *et al.*, 2001). They spend on average approximately 30-40 s underwater during each dive and 10-15 s on the surface between dives (Kruuk, 1993, Bethge *et al.*, 2003, Gust and Handasyde, 1995). Moreover, they will tend to spend longer underwater and cover more distance in each dive in habitats that have more abundant food (Kruuk, 1993, Bethge *et al.*, 2003).

Platypus commonly forage over 2.9 - 7.3 km (mean 4.6 km) home ranges and need continuous sections of aquatic habitat because they are susceptible to predators such as foxes if they are forced to leave the stream and move over exposed ground (Serena *et al.*, 1998). Animals that only use stream channel habitats tend to have a longer home range than individuals that forage in channel habitats as well as associated pond habitats (Serena, 1994).

Platypus build burrows on steep or undercut banks that are generally at least 1 m high and have a cover of dense vegetation or tree roots that allow animals to safely move from the burrow to the water and that also protect the burrow from erosion (Serena *et al.*, 1998). Individual animals have multiple burrows within their territory (Serena, 1994), but females will select a single burrow to raise their young. The burrow opening is usually at least 0.5 m above the normal water level to reduce the risk of flooding and can extend into the bank for up to 3.7 m (Serena *et al.*, 1998).

Females lay their eggs in late winter and juveniles remain in the burrows for at least 3-4 months until they are ready to swim and forage (Holland and Jackson, 2002). Juveniles learn to forage on their own from February to April and then disperse from their natal home range to fill gaps in local or other nearby populations (Serena and Williams, 2008). Females build their burrows at least 0.5 m above the normal winter high water mark and although they can plug the entrance to their burrows, very high flows during spring or summer can flood their burrows and drown the developing young. Females probably use winter water levels to determine likely water levels later in the year and therefore one way of reducing the likelihood of high flows drowning juvenile platypus is to provide high flows in winter to encourage females to build their nests higher up the bank.

The two biggest flow related threats to platypus are:

1. low flows that limit the amount of available food and that force animals to move overland where they are susceptible to predators, and

2. high flows that flood burrows and drown juvenile animals.

Environmental flows should therefore aim to maintain connecting flow throughout entire reaches and a minimum depth of 0.5 m through pool and run habitats, although a depth of 0.3 m may be sufficient in small streams that are less than 3 m wide (Serena and Williams, 2008). Also if high spring or summer flows are recommended for other values such as riparian vegetation or native fish, then it will be important to deliver flows of a similar magnitude prior to the nesting period to encourage females to build their nesting burrows higher up the bank. Very high flows that drown juvenile platypus will naturally occur at some stage in most rivers, but as long as there is good recruitment in the population every 2-3 years the population will persist. Males and females reach sexual maturity at around age two and females generally live for more than 10 years, but less than half the mature females in a population will breed in any given year (Grant *et al.*, 2004). Males tend not to live as long as females and predators and drought can significantly reduce lifespans in some river systems.

5. Review of environmental flow recommendations for Reach 6 – Coimadai Creek downstream of Merrimu Reservoir

5.1 Reach description

Coimadai Creek flows south from Bullengarook (south west of Gisborne) to join the Werribee River at Melton Reservoir. The upper half of Coimadai Creek flows through the Pyrite State Forest and is unregulated, but flow in the lower half of the catchment has been significantly altered by the construction and operation of Merrimu Reservoir, which is in the middle of the catchment and captures all inflows from the upper catchment as well as transfer flows from Lerderderg River and Goodman Creek. Environmental flow Reach 6 is defined as the section of Coimadai Creek between Merrimu Reservoir and the Melton Reservoir. Much of this reach flows through an incised valley in the Long Forest Nature Reserve. The channel is bound by bedrock in the upper section and flows through an alluvial plain in the downstream sections. The active flow channel through this reach is approximately 3-5 m wide (Ecological Associates, 2005a), although it would have been wider prior to the construction of Merrimu Reservoir. The most downstream section of the reach flows through cleared agricultural land on the Werribee River floodplain and under the Western Highway downstream of Bacchus Marsh.

Prior to regulation, Coimadai Creek would have been an open, rocky stream with shallow pools, rocky riffles and stands of vegetation (riparian shrubs and some emergent macrophytes) (Ecological Associates 2005). The natural flow regime for Coimadai Creek is very flashy. It would have dried completely for long periods during summer and autumn, but the steep rocky catchment would have delivered very high flows in most years (Ecological Associates 2005).

The section of Coimadai Creek upstream of Merrimu Reservoir has retained the natural flow regime and is characterised by a relatively open channel with a distinct riffle and run morphology. Regular high flow and bankfull flow events help to maintain the channel structure and habitat diversity in this upstream reach.

The environmental flow reach downstream of Merrimu Reservoir has a very different flow regime and altered channel form. Merrimu Reservoir has reduced annual discharge in Reach 6 by approximately 50% and has also altered the seasonal flow patterns (GHD, 2014 and verified by comparing flow data from Gauge #231222 upstream of Merrimu Reservoir and Gauge #231223 downstream of Merrimu Reservoir). The main flow changes include the loss of high flows (these are now all captured in Merrimu Reservoir) and the introduction of a near permanent trickle flow (due to intended leakage to maintain the integrity of the dam wall) in the first approximately 3 km of stream immediately downstream of the Reservoir. The water logged conditions and lack of regular scouring flows have allowed dense stands of macrophytes (particularly *Typha* and *Phragmites*) to become established in the main channel downstream of the Reservoir (Ecological Associates, 2005b). Bottlebrush and tea tree have also encroached further on the channel than they would naturally and reduced the effective width of the streambed and the diversity of stream habitats.

The current environmental flow objectives for Coimadai Creek relate to reversing some of the vegetation and associated geomorphological changes that have occurred as a result of flow regulation. Specific recommendations from the 2005 FLOWS study include re-instating cease-to-flow events to reduce the dominance by large rhizomatous emergent macrophytes such as *Typha* and *Phragmites*, and delivering high flows and freshes to scour some established vegetation and reverse the encroachment of terrestrial plant species on the lower banks (Ecological Associates, 2005b).

Figure 5-1: Map of Coimadai Creek, Reach 6 showing 2005 FLOWS site at Long Point and the current FLOWS site at Happy Valley.

5.2 Hydrology of Coimadai Creek

Merrimu Reservoir was constructed in three stages between 1969 and 1986 and has significantly reduced flow in Coimadai Creek (see Figure 5-2). The river channel and aquatic values of Coimadai Creek have adapted to a much drier flow regime and the environmental flow recommendations for this reach should aim to maintain current values and values that can persist in a drier than natural system. While the difference in unimpacted and current flows in Coimadai Creek is interesting and is described here, the magnitude, timing, frequency and duration of events that would have occurred in Coimadai Creek if Merrimu Reservoir was not built, have little relevance to the new flow regime. Moreover, the hydrological model that estimates unimpacted flow in Coimadai Creek is unreliable. For those reasons we have not used hydrological spells statistics to set the revised environmental flow recommendations for this reach.

Coimadai Creek would have naturally ceased-to-flow in most if not all years, but Merrimu Reservoir has increased the duration of cease-to-flow events downstream of the reservoir and also significantly reduced the magnitude of flows. The main flow gauges in Coimadai Creek are in the unregulated section upstream of Merrimu Reservoir, and at the Western Highway at the downstream end of Reach 6. These flow gauges have only been operating continuously since 2011 and therefore the flow record does not necessarily reflect long term patterns. Nevertheless, a comparison of flow at these two gauges does provide an estimate of the effect (albeit an underestimate given flow would normally increase further downstream) that Merrimu Reservoir has on flow in Coimadai Creek. From the flow data, we see that Coimadai Creek upstream of Merrimu Reservoir has had a mean daily flow of 4.1 ML/day and ceased-to-flow for approximately 25% of the time since 2011, while the downstream reach of Coimadai Creek had a mean daily flow of 2.6 ML/day and ceased-to-flow for 42% of the time over the same period (Figure 5-3). The only large flows in Coimadai Creek downstream of Merrimu Reservoir over the last three years have been trial environmental flows that Melbourne Water has released for monitoring purposes (Figure 5-4). Southern Rural Water can use Coimadai Creek to transfer water from Merrimu Reservoir to Melton Reservoir. Such flows would create a prolonged high flow at a time when the river would normally have little or no flow.

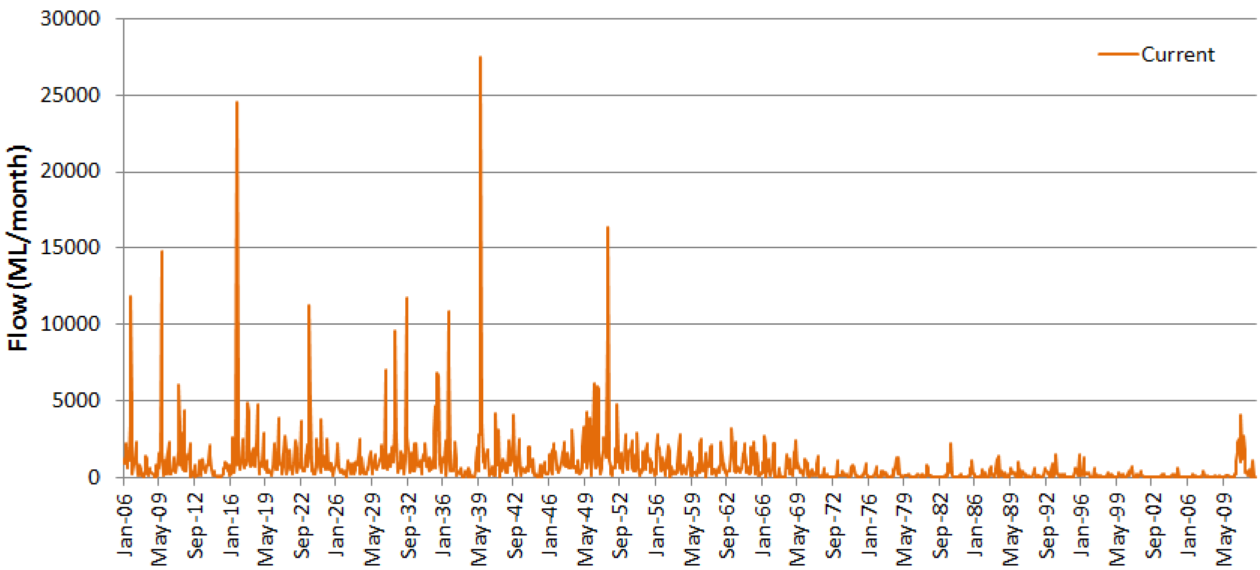


Figure 5-2 Monthly flow time series in Reach 6 showing estimated flows downstream of Merrimu Reservoir from 2006 to 2010.

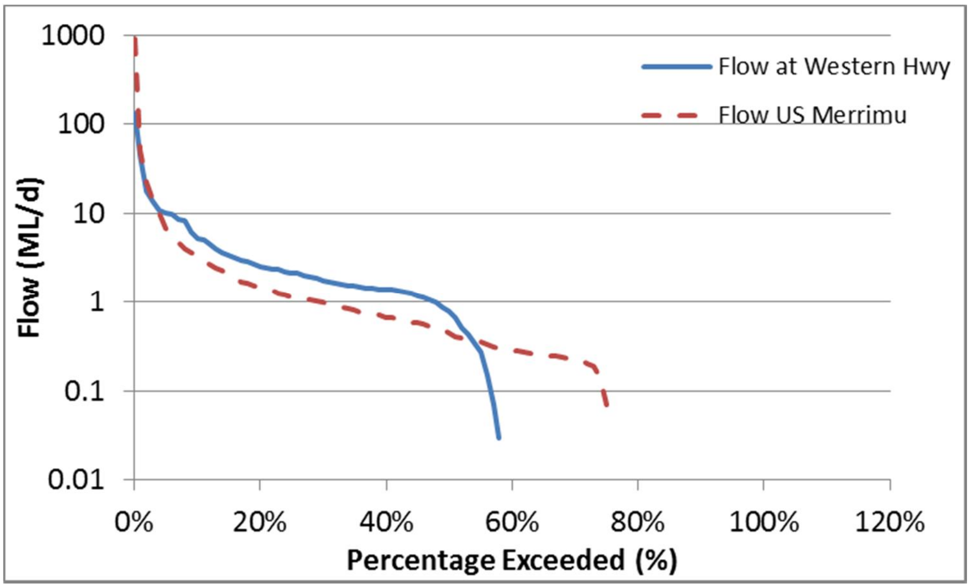


Figure 5-3 Flow duration curve for Coimadai Creek upstream and downstream Merrimu Reservoir between 2011 and 2014. The available flow record is extremely short and contains a lot of missing data. This flow duration curve should be used as an indication of flows, and not a representation of the long term flow record.

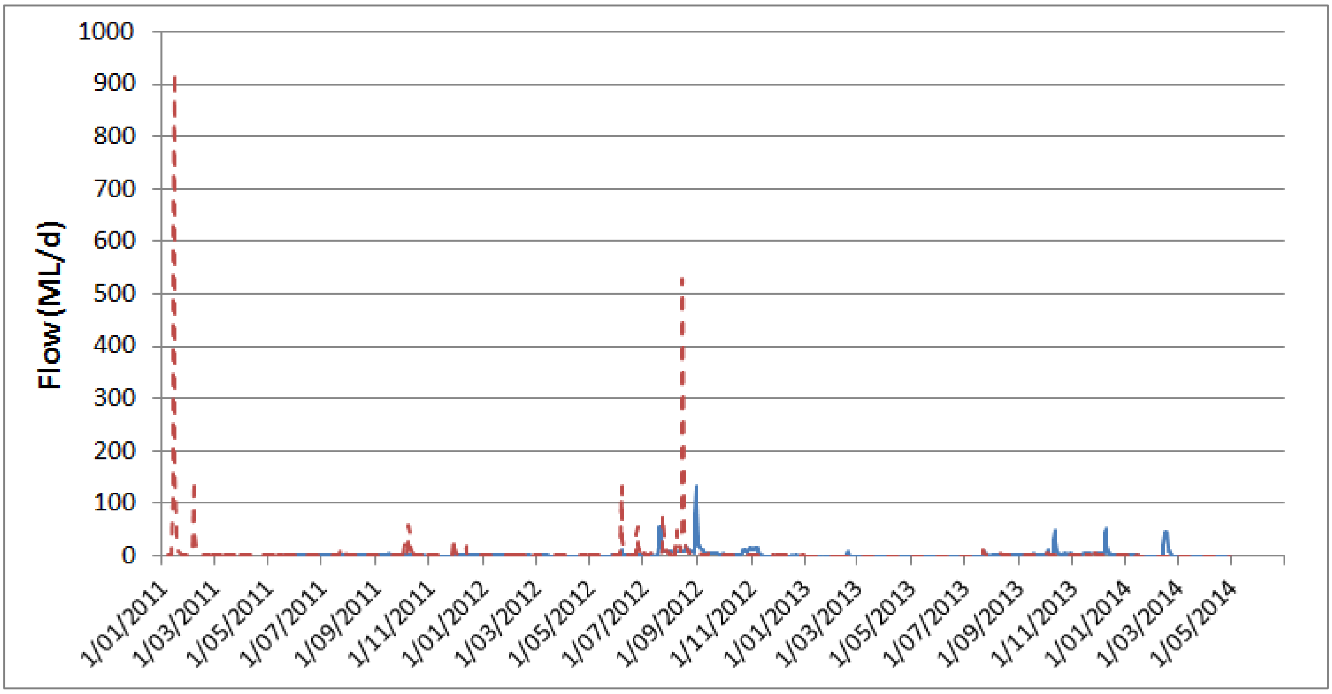


Figure 5-4 Daily flow time series for Coimadai Creek upstream of Merrimu Reservoir (red line) and downstream of Merrimu Reservoir (blue line) from 2011 to 2014. Note there are some missing data periods in the record.

5.3 Conceptual understanding of flow regime and aquatic ecosystems in Coimadai Creek

Coimadai Creek is a relatively steep catchment that lies in a rain shadow and has a distinct dry and wet period each year. The dry period varies in length from two to nine months each year depending on climatic conditions. During the dry period, long sections of Coimadai Creek downstream of Merrimu Reservoir contract to a small number of deep pools, short sections with trickle flows and other sections where the streambed completely dries.

The two sections with constant or near constant periods of trickle flow are between the Merrimu Reservoir Dam wall and Long Point, and near the Old Homestead site at the downstream end of the Long Forest Nature Reserve. The constant flow immediately downstream of the Merrimu Reservoir is most likely due to the 0.5 ML/day flow that is deliberately allowed to seep through the dam wall to maintain its structural integrity. However, recent water quality testing demonstrated that the trickle flow had an electrical conductivity of approximately 1000 EC, which suggests that it either includes some groundwater or is leaching salts from the material that was used to construct the dam wall. If the flow immediately downstream of the dam wall contains groundwater then it is likely that the hydraulic pressure exerted by the water held in Merrimu Reservoir is re-charging the groundwater at this point or forcing groundwater into the stream. The Old Homestead site is near a break in slope in the catchment. The trickle flow at this site is less reliable than the flow immediately downstream of Merrimu Reservoir and is almost certainly a surface expression of groundwater.

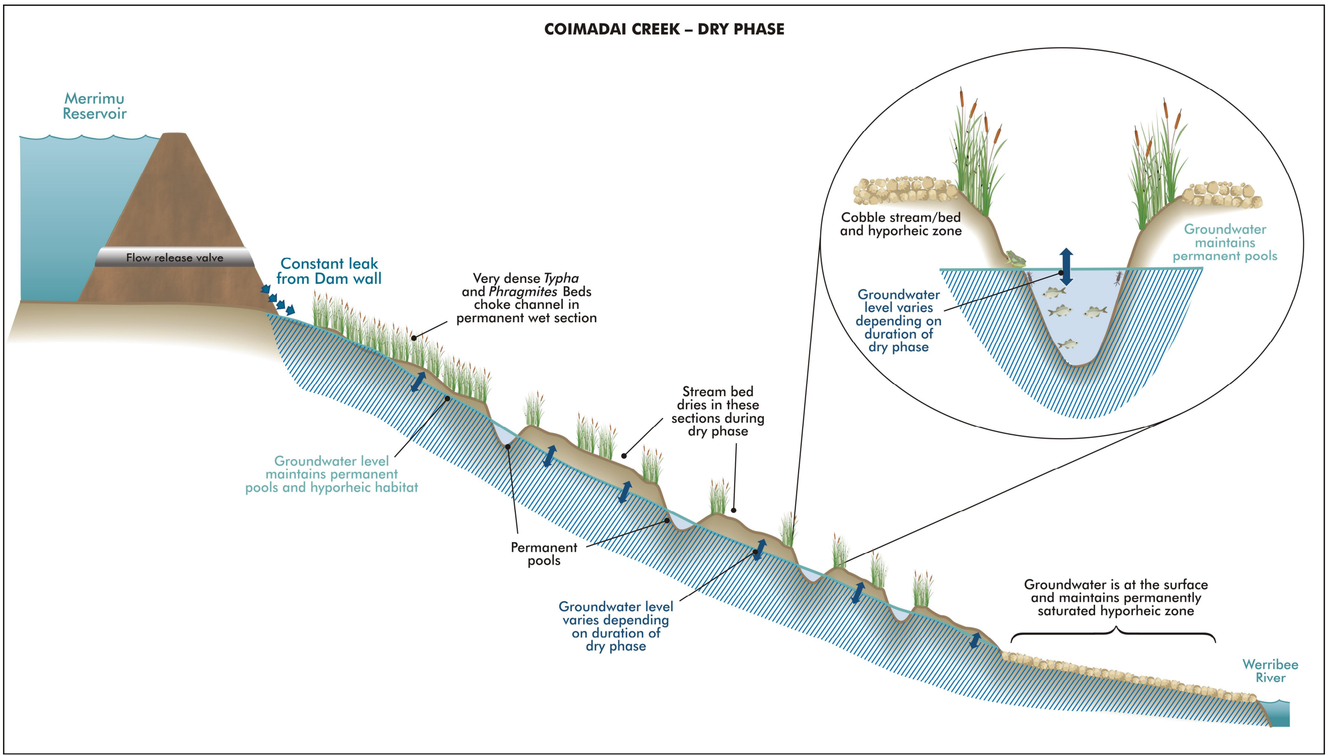
The FLOWS assessment site at Happy Valley has no flow during the annual dry period, but it does have several pools that are maintained by groundwater and are likely to be important refuge habitats for aquatic biota. The bottom of these pools is 4-5 m below the level of the surrounding streambed and the water level in the pools varies with the level of the underlying water table. In very dry years, the water level in these pools may be more than 2 m below the level of the surrounding streambed, yet still maintain a pool depth of at least 2 m. The hyporheic zone is likely to be an important refuge for macroinvertebrates during cease-to-flow periods and groundwater and summer rainfall are critical to maintaining some moisture in those environments.

A conceptual model of the relationship between groundwater and surface water in Coimadai Creek is shown in Figure 5-5. The geology and steep topography of Coimadai Creek has been determined by a large fault line (Rowsley Fault). Uplifting along the Rowsley Fault more than one million years ago resulted in the down cutting of the Werribee River and connected streams including Coimadai Creek. Valley wall springs in the catchment recharge the groundwater and contribute to stream flow and permanent pools. Valley wall springs do not have large storage capacity and therefore there is little lag time between catchment rainfall and groundwater recharge. Moreover, groundwater recharge rates will vary considerably between years. They will be high during wet years and low during dry years. This variation in groundwater level determines the duration of the dry period, the depth of remnant pools and the extent of hyporheic drying throughout Coimadai Creek. These factors in turn determine the type of aquatic and semi-aquatic plants and animals that can persist in Coimadai Creek and the condition of those biota in any given year or climatic period.

Long dry periods mean that Coimadai Creek is unlikely to support many fish, platypus or a diverse macroinvertebrate community. Some small-bodied fish may persist in refuge pools during cease-to-flow periods and move to other sections of the stream when flows return, but abundances are likely to be very low. The macroinvertebrate community will most likely consist of taxa that can tolerate poor water quality (i.e. moderate to high EC, and low dissolved oxygen) and taxa that either have a short life cycle that enables them to take advantage of flow when it is present, or that can seek refuge in remnant pools or hyporheic zones. Riffle dwelling specialists are not expected to occur in Coimadai Creek.

The main channel of Coimadai Creek is likely to maintain a mix of aquatic and semi-aquatic plants. The permanent pools are likely to be fringed by plants that require permanent or near permanent inundation (e.g. water Ribbons, milfoils and pondweeds), while shallower sections of the channel will mainly support plants that become less active or even die back during dry periods and grow rapidly when water is present (e.g. rushes, reed and sedges). The riparian vegetation will most likely consist of woody species such as bottlebrush and teatrees that can access groundwater below the surface and do not rely on inundation during summer and autumn, but can tolerate or benefit from flooding during winter or spring.

The other factor that is likely to influence riparian and aquatic vegetation in Coimadai Creek is the frequency and magnitude of high flow events. The steep terrain and geology that have already been described can create significant run-off. Rain events during the dry period when the groundwater level is low, are likely to infiltrate the soil and streambed without creating flow in the stream. However, heavy rain events when the groundwater level is high and the catchment soils are saturated can cause very sudden increases in streamflow. Pyrites Creek upstream of Merrimu Reservoir and other nearby streams such as Goodmans Creek and the Lerderderg River still experience large flows every few years that turn over the streambed and scour vegetation from within the river channel. Merrimu Reservoir prevents these high flows in Coimadai Creek and as a result there is no mechanism to remove vegetation from the channel. This has become a particular problem in the reach immediately downstream of the dam wall, where the constant trickle flow has allowed *Typha* to proliferate to such an extent that it now chokes most of the channel for several kilometres downstream of the Reservoir. Studies in the Murray-Darling Basin and elsewhere in the world (e.g. the USA) have shown convincingly that *Typha* grows best under relatively stable water regimes, with shallow water present over the summer months (e.g. Rogers, 2011, Roberts and Marston, 2011). *Typha* is less of a problem in the sections of the channel that completely dry each year because the plant cannot tolerate extended dry periods.



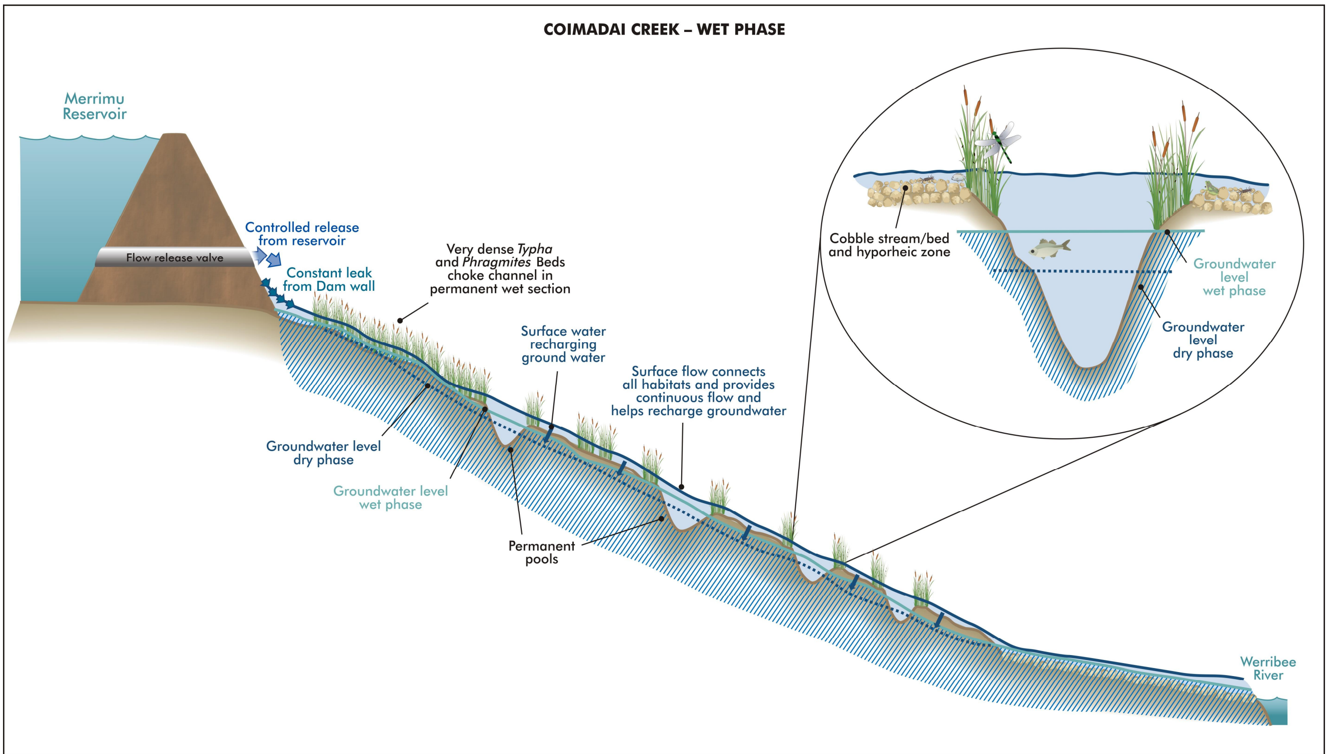


Figure 5-5: Conceptual model showing the role of managed releases and leaks from Merrimu Reservoir and groundwater on streamflow and the distribution of aquatic habitats in Coimadai Creek during the dry phase and wet phase.

5.3.1 What is needed to test this model?

There are no groundwater monitoring bores along Coimadai Creek and therefore the conceptual model presented above cannot be verified, let alone quantified. We recommend a detailed monitoring program should be designed and implemented to answer the following questions:

1. Does groundwater maintain refuge pools, the hyporheic zone and the water-dependent biota that rely on those habitats during prolonged cease-to-flow periods in Coimadai Creek?

2. How do groundwater levels vary between seasons and between wet and dry years and how do those changes affect the distribution and quality of refuge pools, hyporheic zones and sections of stream that have perennial trickle flows?

3. How responsive are groundwater levels to catchment rainfall (i.e. what is the time lag between individual rain events and detectable changes in groundwater level?) and do these responses vary between wet and dry periods?

4. How important are the following factors to groundwater level in Coimadai Creek?

    a. Stream flow during the annual wet period (normally mid-winter to mid-summer).

    b. Local catchment rainfall

    c. Storage levels in Merrimu Reservoir

    d. Leakage from the Merrimu Reservoir Dam wall.

Determining the extent to which groundwater levels throughout the year rely on stream flow during the wet period has important implications for environmental flow management. If monitoring demonstrates that stream flow during the wet period re-charges the groundwater and determines groundwater levels in the following dry period then it may be necessary to make specific environmental flow releases during winter and spring to help maintain pools and hyporheic habitats through summer and autumn.

Designing and implementing a monitoring program to answer these questions is beyond the scope of the current study, but addressing these knowledge gaps will improve environmental water management in Coimadai Creek in the future.

5.4 Summary and review of existing flow objectives and flow recommendations

Ecological Associates (2005b) recommended an environmental flow regime with high-flow components to specifically reduce the encroachment of terrestrial and emergent vegetation in the channel, promote a greater diversity of in-stream vegetation, maintain channel dimensions, re-work and mobilise sediments in the streambed, maintain permanent pool habitats for Southern Pygmy Perch and aquatic macroinvertebrates and access to riffle and run habitats for part of the year. These flow recommendations are summarised in Table 5-1 and evaluated in detail below.

Table 5-1: Current environmental flow recommendations and objectives for Coimadai Creek (modified from Ecological Associates, 2005b).

Flow recommendations					Rationale / objective
Season	Component	Magnitude	Frequency	Duration	
Dec-Feb	Cease-to-flow	0 ML/day	annual	1 month *	Curtail growing season of in-channel emergent macrophytes
Mar-Jun	Cease-to-flow	0 ML/day	annual	1 month *	Curtail growing season of in-channel emergent macrophytes
Dec-Jun	Low flow freshes	5 ML/day*	4 per year ^ with a minimum separation of 20 days	3 days	Maintain pool habitat for Southern Pygmy Perch and macroinvertebrates
Jul-Dec	Baseflow	0.5 ML/day*	Not in low rainfall years	Commence after first winter runoff event	Maintain pool habitat for Southern Pygmy Perch and macroinvertebrates
Jul-Nov	Small fresh	10 ML/day*	10 per year * with a minimum separation of 7 days	5 days	Sustain the growth of in-channel vegetation Allow Southern Pygmy Perch to access emergent vegetation in the streambed Mobilise silts and sands from riffles and pools to maintain structure and macroinvertebrate habitat
Jul-Nov	Large fresh	93 ML/day*	2 per year with a minimum separation of 14 days	2 days	Disturb instream emergent macrophytes to limit vegetation encroachment
Anytime	Bankfull flow	1,900 ML/day	Natural (1 in 5 years)	1 day	Rework sediment including gravels to maintain channel dimensions Disturb instream emergent macrophytes to limit vegetation encroachment (reported that 217 ML/day would disturb macrophytes at all cross sections)
Anytime	Overbank flow	3,000 ML/day	Natural (1 in 10 years)	1 day	Disturb shrubby vegetation on the benches

* Or natural if the natural magnitude or duration is less than what is specified.

^ or natural if the natural frequency is greater than what is specified.

5.4.1 Evaluation of vegetation objectives

The loss of regular high, bankfull or overbank flows in Coimadai Creek downstream of Merrimu Reservoir and the introduction of a constant trickle flow from the dam wall have allowed *Phragmites* and *Typha* to dominate the main channel and allowed terrestrial vegetation to colonise the lower sections of the river banks. These changes have resulted in sediment accumulation within the channel and constricted flow paths, which have reduced the quality and diversity of in-stream habitat for other biota. Ecological Associates (2005b) identified removing or reducing the amount of emergent in-stream vegetation as one of the main environmental flow objectives for this reach. They recommended a combination of cease-to-flow events in summer and autumn to curtail the growth of *Phragmites* and *Typha*, and periodic high flows to scour existing plants and maintain a clear flow path in the middle of the channel (Ecological Associates, 2005b). The concept behind those recommendations is sound, but the duration of the proposed cease-to-flow event and magnitude of the recommended high flows are not likely to be adequate to meet those objectives.

Once established, *Phragmites* and *Typha* plants should easily tolerate the one month cease-to-flow periods that Ecological Associates (2005b) recommended for this reach, especially if those cease-to-flow events are interspersed with freshes that connect all habitats and prevent the plants from completely drying. Indeed, *Phragmites australis* has one of the widest hydrological niches of any native emergent aquatic plant and it can thrive under a wide range of flow conditions (e.g. see Ganf *et al.*, 2010), even in situations where the groundwater is 4 m below the surface (Haslam, 1972). *Typha* is less tolerant of prolonged desiccation, but is not likely to dry out during a relatively short cease-to-flow period. Photos taken before and after some trial flow releases that Melbourne Water made to test some of the 2005 environmental flow recommendations indicate that summer freshes probably facilitate *Typha* growth and recruitment in previously clear sections of the channel near Happy Valley (see Figure 5-6). In order for cease-to-flow events to be effective they need to last for many months during summer and autumn to ensure the substrate around the plants completely dries (Rogers, 2011). Moreover, particularly long cease-to-flow events should occur over three or more consecutive years to compound the stress on established plants and prevent new recruits from becoming established.

In principle, high flows can remove established *Phragmites* or *Typha* plants by one of two ways. First, they may generate enough sheer stress to physically scour the plants from the channel. Second, they may completely inundate the whole plant for long enough to drown the plants. High flow events in Coimadai Creek are likely to have a relatively short duration, but very high velocities and are therefore more likely to physically scour rather than drown *Phragmites* and *Typha*. Ecological Associates (2005b) estimated that freshes of 93 ML/day would disturb some macrophytes in the middle of the channel and that flows greater than 217 ML/day would be sufficient to disturb established macrophytes at all of the channel cross-sections they surveyed at their FLOWS assessment site at Long Point. Melbourne Water delivered several environmental flows up to 160 ML/day in 2012 to try and scour emergent macrophytes in the reach immediately downstream of the Merrimu Dam wall. Those flows temporarily flattened some reed beds, but they quickly 'stood up' again once the flows passed (SKM, 2012). Only flows that are large enough to undermine the rhizomes and roots, and completely 'dig out' the sediments will remove established plants. Less severe flows merely wet the sediments and temporarily disturb the existing adult plants. The established reed beds are so dense that they are now very resistant to high sheer forces and only bankfull or overbank flows are likely to have enough force to scour them.

Southern Rural Water will not deliberately allow Merrimu Reservoir to spill and therefore Coimadai Creek downstream of the reservoir will not receive enough bankfull and overbank flows to remove the established *Phragmites* and *Typha*. We suggest that a better objective is to prevent further expansion of existing *Phragmites* and *Typha* beds and more importantly prevent emergent macrophytes from colonising sections of the reach that currently have clear flow paths. Given the available information, we propose that the most effective way of achieving this outcome will be to ensure prolonged cease-to-flow periods, particularly in dry years. Such conditions are likely to be detrimental to *Typha* in particular; although the more adaptable *Phragmites australis* could probably survive extended desiccation, its further expansion is likely to be checked by prolonged cease-to-flow events. Variable low flows and frequent high flow events in winter and spring can then be used to promote the growth of more diverse aquatic plants in the main channel and riparian communities on the adjacent benches and river bank. The sections of channel that are relatively free of dense stands of *Phragmites* and *Typha* have three distinct zones of riparian vegetation. The first zone is at the edge of the low flow channel and includes some aquatic plants such as *Triglochin* and some sparse *Typha* and *Phragmites*. As noted in Section 4.5, the second vegetation zone is approximately 10-20 cm higher up the bank and is characterised by sedges (e.g. *Carex appressa*), rushes (e.g. *Juncus pallidus, J. usitatus, J. acutus*) and woody shrubs such as River Bottlebrush (*Callistemon sieberi*) Woolly Tea Tree (*Leptospermum lanigerum*) and River Tea Tree (*L. obovatum*). Melbourne Water has sprayed Spiny Rush (*J. acutus*) on the banks at the Happy Valley FLOWS site. The third zone is approximately 30 cm higher than the low flow channel and is characterised by *Poa* grasses and eucalypt species such as River Red Gum (*Eucalyptus camaldulensis*), Brown Stringybark (*E. baxteri*), Manna Gum (*E. viminalis*) and Werribee Blue Box (*Eucalyptus bauerianna* subsp. *Thalassina*). The revised environmental flow recommendations for Coimadai Creek should aim to maintain the diversity of vegetation in each of these three zones.

Figure 5-6: Photos of Coimadai Creek at Happy Valley showing increased growth of *Typha* from September 2012 (left photograph) to February 2013 (right photograph). Photograph taken by Bill Moulden Melbourne Water.

5.4.2 Evaluation of geomorphological objectives

Freshes are important to flush silt and fine sediment from the surface of the streambed and maintain feeding habitat for macroinvertebrates and higher flows that overturn the streambed are important for redistributing organic material throughout the hyporheic zone and for maintaining pool depth and channel width. Ecological Associates (2005b) recommended small freshes of 10 ML/day to flush silt and sand from riffles and pools to improve the quality of macroinvertebrate habitat and bankfull flows of 1,900 ML/day to maintain channel form, although they reported that flows of 960 ML/day would be sufficient to mobilise gravel and re-work the streambed throughout most of the Long Point flow assessment site. These flow objectives are still relevant, and the recommended high flows may be sufficient to turn over the streambed, but the recommended small freshes are probably too small to have much effect on macroinvertebrate habitat. Melbourne Water released a range of small flows up to 40 ML/day during spring 2013. Monitoring associated with those releases demonstrated that flows of 10 ML/day slightly reduced the amount of biofilm and filamentous algae from sections of the streambed in the fastest section of the channel, and that flows closer to 40 ML/day were required to clean the surfaces of rocks and cobbles across at least half of the channel width (SKM, 2012). Other objectives to wash organic material from adjacent benches should also be considered for this reach as that material is important for driving ecological processes in the stream.

5.4.3 Evaluation of fish objectives

Prior to regulation, Coimadai Creek would have potentially supported populations of Southern Pygmy Perch, Common Galaxias, Mountain Galaxias, Flathead Gudgeon, Short-finned Eel and possibly Dwarf Galaxias. Melton Reservoir and Merrimu Reservoir have effectively isolated fish populations in Coimadai Creek from nearby reaches, which means that populations in Coimadai Creek are unlikely to recover from local impacts or severe stresses such as the Millennium Drought. Recent surveys have failed to record any fish in Coimadai

Creek (McGuckin, 2006, 2012), although we have observed movement in some of the permanent pools, which suggests that some fish may be present. Eels have been observed in the pool immediately downstream of Merrimu Reservoir and in the scour valve that is used to release water from the reservoir (Tim Kitchen, Pers. Comm.).

The only current fish related objective for Coimadai Creek concerns Southern Pygmy Perch, but the flow requirements for Southern Pygmy Perch are likely to favour the other small-bodied native fish that would have naturally inhabited the creek. Ecological Associates (2005b) recommended summer freshes and a baseflow of 0.5 ML/day between July and December to maintain the pool habitats where Southern Pygmy Perch are likely to live and to provide up to 10 freshes of 10 ML/day between July and November to provide regular access to vegetation at the margin of the channel.

There is no objective to re-introduce any fish species to Coimadai Creek, and providing flows that will favour more fish is most likely to allow alien species such as Gambusia to colonise the reach. However, the objective to maintain the quality and quantity of refuge pools for any native fish that currently exist in Coimadai Creek is sound. As indicated in the conceptual model in Section 5.3, most of the permanent pools in Coimadai Creek are probably maintained by groundwater and do not require freshes to keep them 'topped up' during summer and autumn. The electrical conductivity of that groundwater is approximately 1500 EC (based on measurements taken from the pools in autumn 2014), and therefore is not too saline for Southern Pygmy Perch and any other small-bodied native fish that are adapted to living in remnant pools in ephemeral streams. Southern Pygmy Perch live among submerged or emergent vegetation in pools or slow flowing rivers and as long as there is adequate cover from predators can probably tolerate relatively low dissolved oxygen conditions by remaining close to the water surface. For these reasons, summer freshes are also not needed to maintain water quality in refuge pools.

We recommend that the original objective to maintain suitable conditions for Southern Pygmy Perch should be retained, but the recommended flows to achieve that objective should be changed. There is no need for summer freshes to periodically top up, or improve the water quality in permanent pools, especially since doing so is likely to promote the expansion of unwanted vegetation (see Section 5.4.1). The winter low flow should however, be increased from 0.5 ML/day to provide more opportunities for Southern Pygmy Perch and other small-bodied native fish to disperse throughout the reach and forage in riffle and run habitats during the wet period each year.

5.4.4 Evaluation of macroinvertebrate objectives

Because Coimadai Creek is ephemeral, it would have naturally supported macroinvertebrate species that have one or more of the following characteristics:

- They can live in isolated pools that experience relatively high temperatures, moderate to high salinity and relatively low dissolved oxygen;
- They have short life cycles, and possibly mobile adult life stages, that enable them to colonise new habitats and complete their aquatic stages when water is present;
- They can seek refuge in the hyporheic zone when the stream ceases to flow and pools dry up.

These characteristics typify the macroinvertebrate communities that are found in nearby streams such as the Lerderderg River (Boulton and Lake, 1990, 1992a, b).

It is highly unlikely that Coimadai Creek would have supported macroinvertebrates that rely only on fast flowing riffle habitats or that are intolerant of variable flow and variable water quality.

Ecological Associates (2005b) recommended summer freshes to maintain permanent pools during cease-to-flow periods, a baseflow of 0.5 ML/day to provide other habitat between July and December and regular freshes of 10 ML/day to mobilise silts and sands to clean substrates that macroinvertebrates are likely to forage on. The objective to maintain habitats and suitable flow conditions for tolerant macroinvertebrate fauna in Coimadai Creek is still valid, but the specific flow recommendations should be revised.

It is unlikely that even high rainfall events in summer would have caused Coimadai Creek to flow and therefore the recommended summer freshes to top up permanent pools during the cease-to-flow period should be abandoned. The recommended baseflow of 0.5 ML/day may not be sufficient to wet much of the channel width or provide flow throughout the entire reach and therefore a higher baseflow is recommended to wet more channel habitat. Finally, recent monitoring has shown that flows of 10 ML/day are not sufficient to clean large portions of the streambed (SKM, 2012). Substrates in Coimadai Creek become smothered with a dense biofilm and filamentous algae during low flow conditions in late spring and early summer when water temperatures rise. While these biofilms and algae provide food for macroinvertebrates if they become too dense or too homogeneous they will reduce feeding opportunities and habitat quality for many macrorinvertebrate species. Monitoring associated with trial flow releases demonstrated that flows up to 40 ML/day scoured algae, biofilms and sediment from large proportions of the river channel and created a more heterogeneous habitat that is likely to suit more macroinvertebrates (SKM, 2012). Based on those studies, we recommend that the flow recommendations for macroinvertebrates in Coimadai Creek should be revised.

5.4.5 Relevant objectives that were not considered in the 2005 FLOWS study

The 2005 FLOWS study did not include any flow objectives or flow recommendations for platypus. Ephemeral streams such as Coimadai Creek are generally not suitable for platypus and recent surveys have not recorded any platypus in the region (CESAR, 2012, 2013). There is no need to include platypus objectives for this reach in the current flow review.

The 2005 FLOWS study did not include specific environmental flow objectives for frogs, but Coimadai Creek does support several native frog species including Bibrons Toadlet, Pobblebonk Frog, Striped Marsh Frog, Spotted Marsh Frog, Spadefoot Toad, Common Froglet, Southern Brown Tree Frog, Verreaux's Tree Frog and possibly the EPBC listed Growling Grass Frog (Ecology Australia, 2013). Growling Grass Frog, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog and the Southern Brown Tree Frog may use permanent pools with fringing vegetation and benefit from higher flows that allow individuals to move between habitats (Cogger, 2000, Heard *et al.*, 2010, Pyke, 2002), but Growling Grass Frog is the only species that relies on permanent in-stream habitats (Heard *et al.*, 2010, Pyke, 2002). Bibrons Toadlet, Spadefoot Toad and Common Froglet rely on rainfall to inundate depressions in the landscape and do not specifically use in-stream habitats (Cogger, 2000, Hero *et al.*, 2004, Wassens, 2011). In general flow regimes that help to maintain permanent pools and fringing vegetation, or that inundate depressions near the channel will probably benefit the frog populations in Coimadai Creek.

5.5 Revised flow objectives for Coimadai Creek

Environmental flows in Coimadai Creek should aim to prevent the further expansion of emergent vegetation such as *Phragmites* and *Typha*, improve the diversity of native streamline and riparian vegetation, and maintain permanent pools that will act as refuges for small-bodied native fish, macroinvertebrates and breeding habitats for native frogs. Existing stands of emergent vegetation will not be removed without delivering very large bank-full or overbank flows and since these flows are unlikely to occur under the current operation of Merrimu Reservoir, objectives to remove that vegetation have not been included. There is no intention to provide near continuous flow to riffle habitats throughout the year for macroinvertebrates because such flows would change the naturally ephemeral nature of Coimadai Creek and potentially favour the expansion of unwanted emergent vegetation and allow exotic pests such as *Gambusia* greater access to existing pools. The updated environmental flow objectives for Coimadai Creek are summarised in Table 5-2.

Table 5-2: Updated environmental flow objectives for Coimadai Creek and the flow components that they require

Asset	Environmental flow objective	Function	Required flow component(s)	Timing	Expected response
Vegetation	Prevent further encroachment of *Phragmites* and *Typha*	Dry out existing plants growing in marginal habitats and kill new recruits to prevent them becoming established	Prolonged cease-to-flow	3-6+ months per year	No further expansion of *Phargmites* and *Typha*
	Promote growth of seasonal aquatic vegetation such as *Triglochin* and *Myriophyllum*	Inundate streambed for significant period to allow aquatic and semi-aquatic plants to grow	Low flow	From mid-winter to early summer or longer	Annual growth of submerged aquatic vegetation that dies back in dry period.
	Limit the spread of terrestrial vegetation and promote recruitment of native water-dependent emergent species such as rushes, reed, sedges and grasses as well as woody riparian taxa such as bottlebrushes and teatrees on the banks of the stream and adjacent benches.	Drown terrestrial species that cannot tolerate being inundated and increase the growth and recruitment of woody and non-woody taxa of plants that require periodic inundation for germination and survival.	Low flow	From mid-winter to early summer or longer	Reduction of terrestrial vegetation in and adjacent to the channel, increase in growth and clear zonation of water dependent riparian plants
			Periodic freshes and high flows	Spring	
Geomorphology	Clean substrate on streambed	Flush silt and scour algae and biofilms from substrates on the streambed	Regular freshes	Late spring and early summer	Substrate will be periodically cleared of filamentous algae and silt, and biofilms will be reset
	Flush organic material from low lying benches	Provide carbon to drive aquatic food webs and to clear benches beside the channel to prevent blackwater events if a large event occurs later in the season	High flows	Winter or spring	Carbon supplied to stream to drive ecological foodwebs and no blackwater events
Fish	Maintain any existing populations of small-bodied native fish species such as Southern Pygmy Perch, Flathead Gudgeon, Mountain Galaxias, Short-finned Eel.	Maintain permanent pools that fish may use as a refuge during the dry period	Adequate flow to re-charge groundwater	Anytime	Existing fish populations will be maintained. Due to migration barriers we do not expect species to recolonise Coimadai Creek
		Provide access to other channel habitats and dispersal opportunities during the wet period	Low flows and freshes	Winter, spring and early summer	

Asset	Environmental flow objective	Function	Required flow component(s)	Timing	Expected response
Macroinvertebrates	Maintain tolerant macroinvertebrate community	Maintain permanent pools and hyporheic zones	Adequate flow to re-charge groundwater	Anytime	Existing macroinvertebrate community will be retained. The community is typical of an ephemeral stream in this region.
		Provide access to riffle and run habitats	Low flow	Winter to early or late summer	
		Scour silt, biofilms and filamentous algae from substrate to maintain quality and quantity of food and habitat	Regular freshes	Spring and early summer	
Frogs	Maintain populations of Growling Grass Frog, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog and the Southern Brown Tree Frog	Maintain permanent pools with fringing vegetation	Adequate flow to re-charge groundwater	Anytime	Existing frog populations persist in current condition
		Provide connecting flows to allow frogs to use channel habitats and allow GGF to move to mix with other metapopulations	Low flow	Winter to early or late summer	Increased resilience of GGF population because there is greater exchange between metapopulations
		Inundate depressions adjacent to stream that frogs can use for breeding	High flows	Spring	Increased breeding by species that do not rely on in-stream habitats.

5.6 Revised flow recommendations

The flow regime for Coimadai Creek has two distinct phases. The first is a dry phase, which may last for 3-9 months in any given year and has no reliable surface flow, including an absence of any freshes. The second is a wet phase that lasts for the rest of the year and is characterised by a constant low flow and a combination of multiple freshes and high flows. The duration of each phase and number and magnitude of freshes and high flows will vary between wet and dry years.

The updated environmental flow recommendations for Coimadai Creek are summarised in Table 5-3 and discussed in more detail in the following text.

Table 5-3: Updated environmental flow recommendations for Reach 6: Coimadai Creek downstream of Merrimu Reservoir

Stream	**Coimadai Creek downstream of Merrimu Reservoir**		**Climatic regime**	**Flow recommendations**			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall**
Dry phase *	Cease-to-flow	Maintain natural ephemeral flow regime Prevent further expansion of *Phragmites* and *Typha* Prevent aquatic weeds and pest species that require perennial flow from establishing	Wet / Average	0 ML/day	All season	2-3 months	NA
			Dry	0 ML/day	All season	Up to 9 months	NA
Wet phase *	Low flow	Wet the width of the channel through the whole reach, fill pools and create riffle habitat for macroinvertebrates Allow fish to move between pools Promote the growth of seasonal aquatic plants such as *Triglochin* and *Myriophyllum* Recharge the hyporheic zone and local groundwater	Wet / Average	2 ML/day	All season	9-10 months	
			Dry	2 ML/day	All season	≥3 months	
	Fresh	Flush organic material and water that has accumulated in the channel during the dry phase Scour silt, biofilms and filamentous algae from the substrate Water vegetation at the margin of the low flow channel	Wet / Average	30-40 ML/day	One at start of wet phase and then every 4-6 weeks from September until end of wet phase. Total number of events determined by duration of the wet phase.	1-2 days	
			Dry	30-40 ML/day	One at start of wet phase and then every 4-6 weeks from September until end of wet phase. Total number of events determined by duration of the wet phase.	1-2 days	
	High flow	Flush accumulated leaf litter and organic matter from benches and bars Promote the growth and recruitment of native riparian vegetation on benches and bars	Wet / Average	≥70 ML/day	At least one per year	1 day	
				≥130 ML/day	Every 1-2 years (to ensure 1 event every 3 years on average across wet, average and dry years).	2 days	
			Dry	≥70 ML/day	At least one per year	1 day	

* The timing and duration of the wet phase and dry phase will be determined by unregulated low flow in the Lerderderg River upstream of the confluence with Goodman Creek. In dry years the dry phase may last for up to 9 months, but in wet years it may only last for 2-3 months.

5.6.1 Cease-to-flow

Coimadai Creek should have a prolonged cease-to-flow from early summer to autumn or early winter each year to allow sections of the channel to dry out and thereby prevent further growth and expansion of *Phragmites* and *Typha*, maintain biota that are adapted to ephemeral systems, and prevent weeds and pest animals that require perennial flow from becoming established. The duration of the cease-to-flow event is likely to vary from 2-3 months in wet years to up to nine months in dry years. Rather than specify in advance when the cease-to-flow event should commence and end, we suggest that Melbourne Water match the timing of cease-to-flow events in Coimadai Creek with cease-to-flow events in the Lerderderg River immediately upstream of Goodmans Creek (Flow Gauge 231211), shown in Figure 5-7. Over the period of record at this gauge (1978 to current), the stream ceases to flow 28% of the time (Figure 5-8). Low flows in the Lerderderg River are not affected by current water extraction practices and therefore the lower reaches of the Lerderderg River are expected to indicate when flows would naturally cease and commence in the lower reaches of other nearby tributaries in any given year. The stream gauge in the Lerderderg River upstream of Goodmans Creek is considered a more reliable indicator of cease-to-flow and commence to flow times in Coimadai Creek downstream of Merrimu than the flow gauge in Pyrites Creek upstream of Merrimu Reservoir, because of its relative position in the catchment. The cease-to-flow period in Pyrites Creek upstream of Merrimu Reservoir is usually much longer than the cease-to-flow period in the Lerderderg River upstream of Goodmans Creek and imposing the Pyrites Creek cease-to-flow period in Coimadai Creek downstream of Merrimu Reservoir is likely to threaten existing values such as frogs and some desirable riparian vegetation.

Cease-to-flow periods in Coimadai Creek would not naturally be punctuated by low flows or summer freshes and therefore there is no need to release any water from Merrimu Reservoir into Coimadai Creek during the dry phase. If the conceptual model of groundwater and surface water interactions in Coimadai Creek presented in Section 5.3 is correct then groundwater inflows will maintain refuge pools and hyporheic zone habitats during the cease-to-flow period. The duration of the cease-to-flow period and groundwater levels will determine the depth and quality of refuge pools and distribution of refuge hyporheic habitats and sections of stream with near permanent trickle flows in any given year. Other flows are not needed during the dry phase and delivering them may promote further nuisance growth of *Phragmites* and *Typha*, or allow species such as Gambusia to colonise the reach and hence do more harm than good.

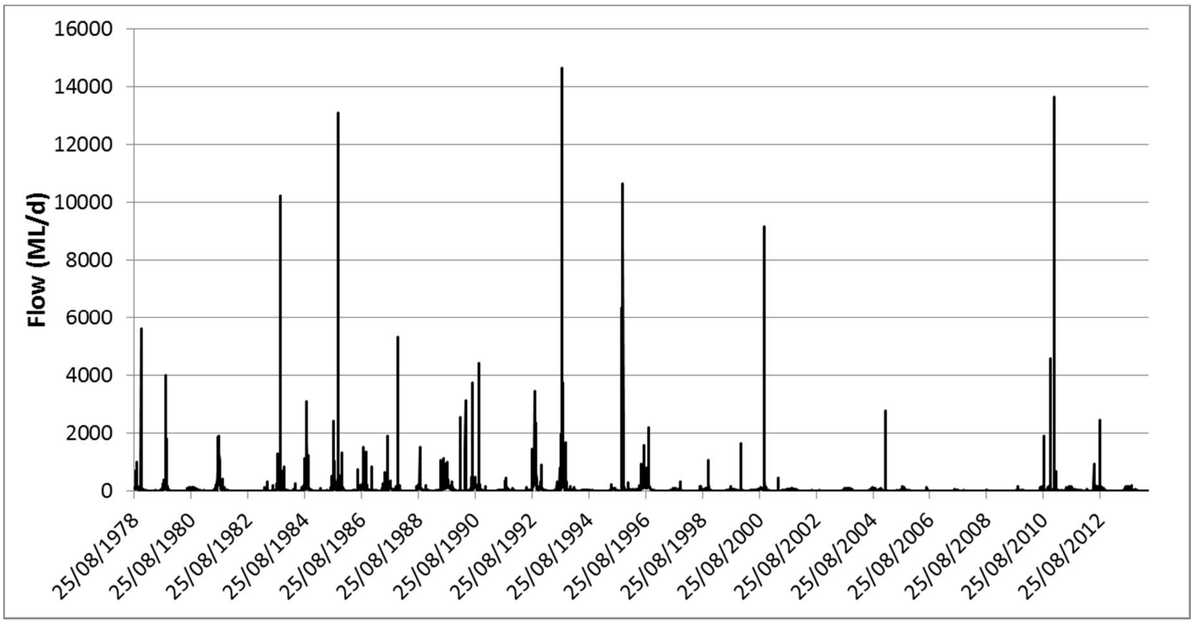


Figure 5-7 Daily flow time series of Lerderderg River upstream of Goodman Creek Junction (231211) as a surrogate for cease to flow conditions to be adopted in Reach 6

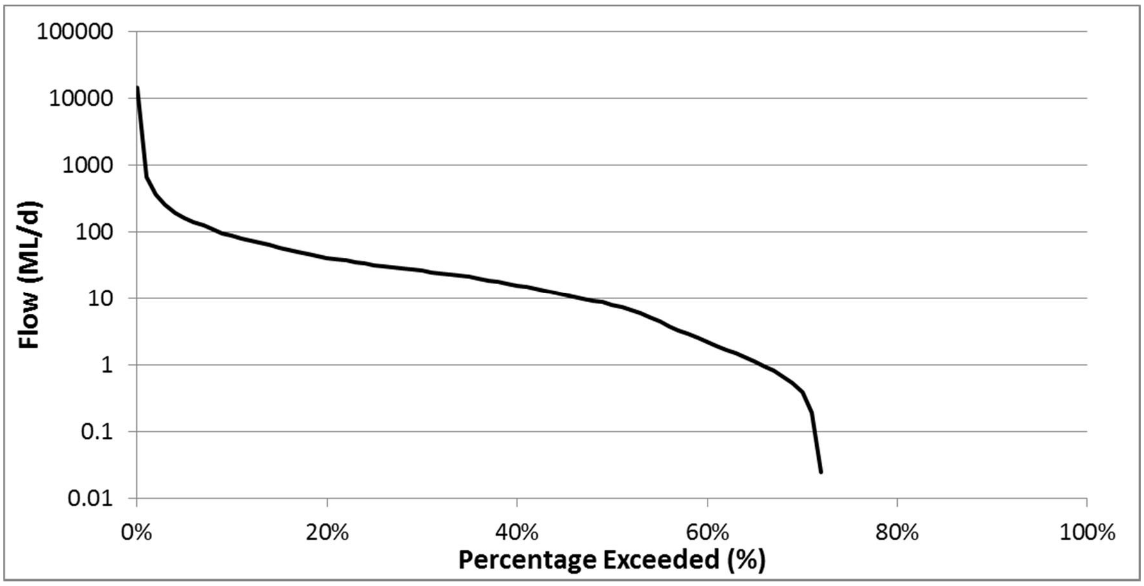


Figure 5-8 Flow duration curve of Lerderderg River upstream of Goodman Creek Junction (231211) as a surrogate for cease to flow conditions to be adopted in Reach 6

5.6.2 Low flow

Coimadai Creek should have a minimum low flow of 2 ML/day throughout the wet phase to wet the width of the low flow channel along the whole reach. The flow will fill all of the pools throughout the reach and provide a minimum depth of 5 cm through riffles (Figure 5-9 and Figure 5-10). The low flows will inundate riffle and run habitats that macroinvertebrates can colonise, allow small-bodied fish and macroinvertebrates to move between pools or move out of refuge pools and wet substrates to allow biofilm growth. Delivering the low flow in late winter, spring and early summer will also allow seasonal water plants such as *Triglochin* and *Myriophyllum* to grow in the low flow channel and sedges such as *Carex* to grow at the margins of the channel. *Triglochin* and *Myriophyllum* will die back during the dry phase, but as long as they are inundated for several months through late winter, spring and into summer each year, they will have new vegetative growth and lay down desiccation resistant organs (turions) that enable them to cope with extended drying and therefore persist in the reach.

Low flows during the wet phase may also re-charge the groundwater and therefore influence the duration of the next cease-to-flow period and the quality and quantity of groundwater fed refuge habitats during the next dry phase. Targeted monitoring is needed to determine how much low flows in Coimadai Creek contribute to groundwater re-charge and groundwater-surface water interactions in subsequent dry phases.

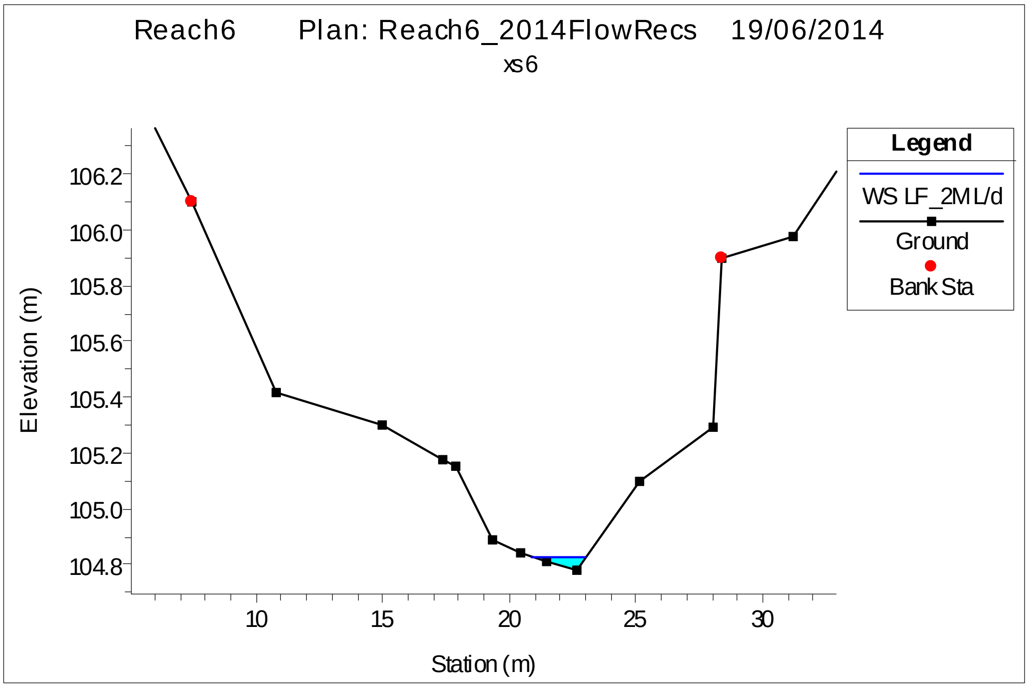


Figure 5-9 Low flow of 2 ML/day at cross section 6, the shallowest cross section within the flows site. 2 ML/day inundates the riffle by 5 cm at this cross section.

Figure 5-10 Photo of cross section 6, the shallowest cross section within the flows site, showing 1 ML/day. The low flow recommended will produce a larger wetted area.

5.6.3 Fresh

We recommend delivering 3-5 freshes of 30-40 ML/day throughout the wet phase. Each fresh should last for 1-2 days and the total number of freshes in any given year will be determined by the duration of the wet phase.

The first event should occur at or near the start of the wet phase to flush organic material that has accumulated in the channel over the dry phase and through the system, flush poor quality water out of the refuge pools and provide an early opportunity for fish and frogs to disperse from the refuge pools. Flows of 40 ML/day provide a minimum depth of 33 cm through the shallowest riffle habitats at Happy Valley, which will allow small-bodied fish to readily disperse; and also wets the lowest edges of benches beside the low flow channel (Figure 5-11 and Figure 5-12). A secondary benefit of the first fresh will be to water vegetation at the margin of the low flow channel and saturate soils and the roots of trees just beyond the channel margins. Under natural flow conditions the wet phase would probably start with a small fresh that is triggered by a heavy rain event once the groundwater has risen to a level where it is at or very close to the streambed. Delivering a managed fresh at the start of the wet phase replicates this natural event and effectively cleans the stream.

The subsequent freshes are mainly intended to scour biofilms and filamentous algae from the streambed to maintain the quality and diversity of macroinvertebrate habitats and food sources. Under low flow conditions, biofilms and filamentous algae grow on the rock and cobble streambed in open sections of Coimadai Creek, such as the Happy Valley FLOWS site. These biofilms and algae play an important role in stream function and are a particularly important food source for macroinvertebrates. However, if they become too dense they can smother the substrate and make it unsuitable for many macroinvertebrates and fish. Biofilms and filamentous algae grow relatively slowly in winter, due to cold water temperature and short day length, but from September onwards they can grow prolifically and freshes are needed every 4-6 weeks to reduce their biomass. Monitoring associated with trial flow releases in Coimadai Creek demonstrated that freshes of 10 ML/day clean the surfaces of only a small proportion of rocks and cobbles in the fastest flowing sections of the channel and that flows closer to 40 ML/day are needed to scour biofilms and filamentous algae from at least 50% of the streambed (SKM, 2014) (see also Figure 5-13). These observations are supported by the modelled shear forces associated with the different flow magnitudes in riffle and run habitats at the Happy Valley site (Table 5-4), which frequently exceed 10 N/m^2 and are therefore sufficient to move normal settled bed particles up to 5 mm diameter (Ecological Associates, 2005a).

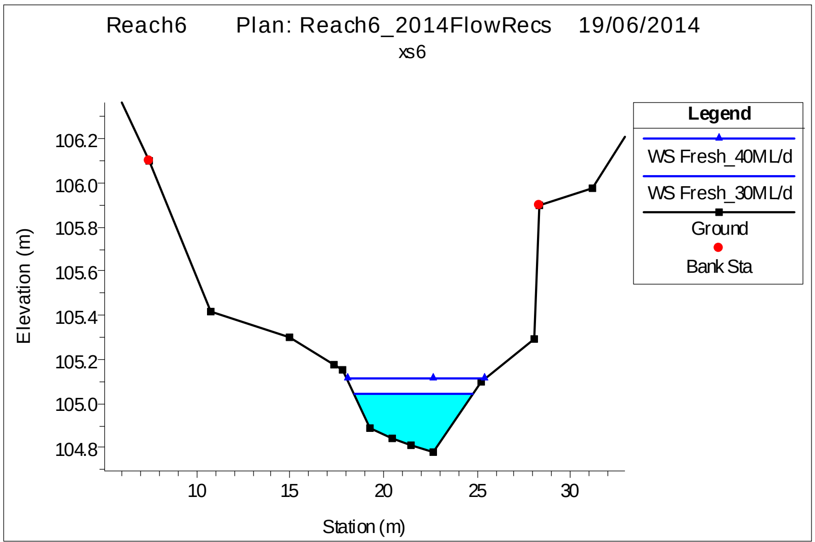


Figure 5-11 Fresh flow of 30 ML/day and 40 ML/day at cross section 6, the shallowest cross section within this flows site.

Figure 5-12 Photo of 30 ML/day at cross section 6 wetting the low edge of the bench

Figure 5-13: Photographs of the streambed in Coimadai Creek showing moderate cover of filamentous algae on 26 September 2013 (left photo), clear of algae on 14 October 2013 (middle photo) following a 50 ML/day fresh and with a dense cover of filamentous algae on 25 November 2013 (right photo) following seven weeks of low flow.

Table 5-4 Sheer Stress and Velocity for flows of 10 ML/day, 30 ML/day and 40 ML/day

Cross section	Flow	Shear Stress (N/m^2)	Velocity (m/s)
XS1	10 ML/d	0.16	0.06
	30 ML/d	0.62	0.13
	40 ML/d	0.86	0.16
XS2	10 ML/d	10.37	0.53
	30 ML/d	18.3	0.74
	40 ML/d	18.21	0.74
XS3	10 ML/d	10.12	0.43
	30 ML/d	23.87	0.69
	40 ML/d	24.92	0.71
XS4	10 ML/d	3.15	0.39
	30 ML/d	6.61	0.58
	40 ML/d	6.95	0.61
XS5	10 ML/d	0.14	0.09
	30 ML/d	0.43	0.16
	40 ML/d	0.54	0.18
XS6	10 ML/d	15.4	0.68
	30 ML/d	2.2	0.32
	40 ML/d	1.86	0.3
XS7	10 ML/d	2.72	0.14
	30 ML/d	12.47	0.3
	40 ML/d	17.55	0.36
XS8	10 ML/d	1.76	0.11
	30 ML/d	5.36	0.22
	40 ML/d	6.61	0.25
XS9	10 ML/d	1.2	0.2
	30 ML/d	2.61	0.31
	40 ML/d	2.97	0.33

5.6.4 High flows – variable

A high flow event of between 70 and 130 ML/day is required during spring (preferably between mid-September and the end of October) to flush accumulated leaf litter and other organic matter from benches and bars beside the low flow channel and to promote the growth and recruitment of true riparian plant species on these habitats. One event of at least 70 ML/day is needed each year to inundate the low lying benches beside the main channel. Approximately once every three years on average, the high flow event should be at least 130 ML/day to inundate the full width of the channel and high backwaters such as those shown in Figure 5-14, Figure 5-15 and Figure 5-16.

Delivering high flows of different magnitude will help to promote a diverse riparian vegetation community with distinct elevation zones that reflect different inundation frequency. The lowest zone at the edge of the low flow channel will support semi-aquatic plants such as *Triglochin*, *Phragmites* and some *Typha* at desirable densities. The second zone approximately 10-20 cm above the low flow channel will be inundated at least once every year and will support various sedges and rushes as well as some native and desirable woody shrubs in the family Myrtaceae. The third zone that extends more than 30 cm above the low flow channel will only be inundated approximately once every three years on average and mostly during wet years and will support *Poa* grasslands and various Eucalypt species.

All of the high flows and some of the freshes will inundate different backwater habitats beside the channel. Water should remain in these backwaters and depressions after the high flows and freshes recede, which will provide temporary habitats for frogs. Small aquatic herbs and forbs are also likely to grow in these temporary habitats, especially if they hold water from September to November when conditions favour rapid plant growth.

High flows of 70 ML/day may only stay above their target flow magnitude for one day, but flows of 130 ML/day should last for two days if possible. All high flows can be ramped up within a day from the low flow level, but they should have a slower rate of fall. We recommend that at the end of the delivered peak flow, SRW should continue to deliver flow through the riparian valve at its maximum rate for approximately two days.

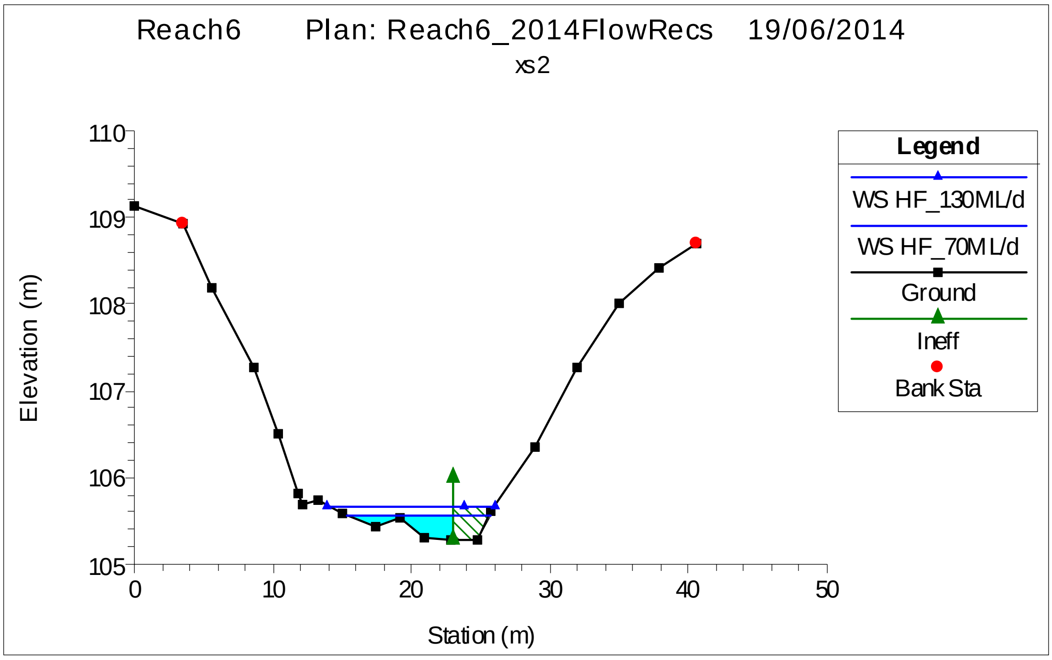


Figure 5-14: High flows of 70 ML/day and 130 ML/day at cross section 2

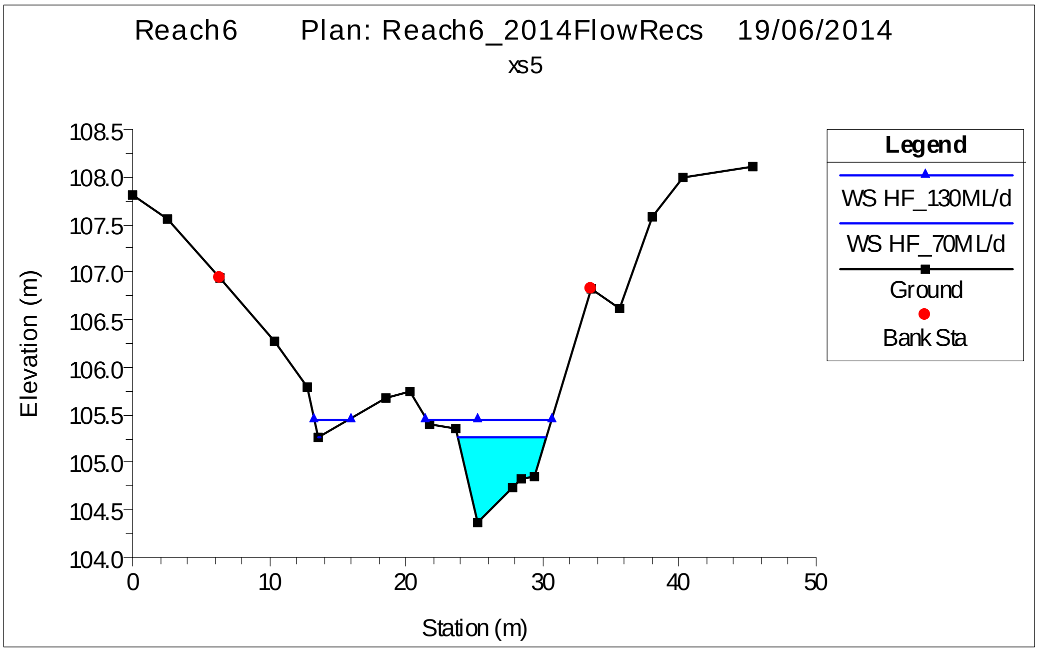


Figure 5-15: High flows of 70 ML/day and 130 ML/day at cross section 5, with the backwater inundated for flows of 130 ML/d

Figure 5-16: High flow of 130 ML/day near cross section 6, filling the whole width of the channel, including inundating backwaters in cross section 5 as seen at the right of the photo

5.6.5 Bankfull and overbank flows

Bankfull and overbank flows have not been specified for Coimadai Creek because they can only occur if Merrimu Reservoir spills. Current operating arrangements mean that SRW will not deliberately allow Merrimu Reservoir to spill and therefore these events are not likely to be delivered.

If Merrimu Reservoir does spill, it is likely to scour at least some of the established *Phragmites* and *Typha* in Coimadai Creek and open up currently choked sections of stream channel, which would significantly change the current condition and potential management options for the system. Under those circumstances, we recommend that Melbourne Water assess the new condition of the stream, review the management and flow objectives and if necessary revise the flow recommendations to better meet any new objectives.

5.7 Compliance

The recommended environmental flows are compared to the current flow regime to determine how well the flow recommendations for Reach 6 are currently met (Table 5-5). These assessments include an ‘or natural’ clause, which considers the flows that would have occurred in Reach 6 under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

For this reach, care needs to be taken when reporting on compliance due to the unspecified change between the dry and wet phase each year. The change in the wet and dry phase will be influenced by flow in the Lerderderg River catchment. Moreover, the compliance assessment is based on a the flow record downstream of Merrimu Reservoir over the last three years. Melbourne Water has made trial environmental flow releases over that period, and so the level of compliance will inevitably be higher than it would if those trial releases had not been made. If the assessment was based on flows prior to 2011 then the level of compliance would have been much lower. Several assumptions have been made when completing this compliance:

- Cease to flow is not assessed because the number of months that it should occur will change each year depending on the natural flow regime in the Lerderderg River.
- The fresh flows compliance is based on 30 ML/day, not 40 ML/d

All flow recommendations are met well, but none comply 100% of the time. The low flow complies 100% of the time under the current flow regime.

The high flow of 70 ML/day and 130 ML/day comply 94% and 92% of the time, respectively, but these are based on trial flow releases over the last two years rather than the flows that have occurred over a longer period. The high flow of 130 ML/day was assessed as 1 every 2 years, although the recommendation states that 1 event every 1-2 years is required, but as a minimum 1 event in 3 years is required, particularly during ongoing dry periods.

The fresh flow recommendation was met 83% of the time over the last three years. There may be fewer events in dryer years where the wet phase may only occur for 3 months of the year, when the number of freshes would reduce to 2-3 per year, rather than 4-6 events if the conditions are wet.

Table 5-5 Compliance of environmental flow recommendations to the current flow regime for Reach 6 for the wet phase

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance
Low Flow	Jan - Dec	**1**	**12**	Magnitude	**2**	ML/d	**Yes**	*99%*
Fresh	Jan - Dec	**1**	**12**	Magnitude	**30**	ML/d	**Yes**	*83%*
				Frequency	**5**	per year		
				Duration	**1**	days		
High Flow 1	Jan - Dec	**1**	**12**	Magnitude	**70**	ML/d	**Yes**	*94%*
				Frequency	**1**	per year		
				Duration	**1**	days		
High Flow 2	Jun - Nov	**6**	**11**	Magnitude	**130**	ML/d	**Yes**	*92%*
				Frequency	**1**	in **2** years		
				Duration	**2**	days		

Table 5-6: Compliance colour codes for Table 5-5

Mostly complies	
Frequently complies	
Often complies	
Occasionally complies	
Rarely complies	
Never complies	

6. Review of environmental flow recommendations for Reach 9 – Werribee River downstream of lower diversion weir

6.1 Reach description and main flow objectives

Reach 9 of the Werribee River flows for approximately 9 km from the Werribee Diversion Weir to the top of the estuary (nominally the ford immediately downstream of the Werribee Mansion). The reach has an extensive alluvial floodplain and the main channel (which is approximately 10 m wide on average) is deeply incised (i.e. approximately 6 m) (Ecological Associates, 2005a). There are some bedrock outcrops and the main in-channel habitats include large rocky riffles and long, shallow pools, which are generally 0.5 – 2.0 m deep at baseflow (Ecological Associates, 2005a). However, Bungey's Hole, which is behind the recreation reserve at Chirnside Park and approximately half way along the reach, is estimated to be 30 m deep and is fed by a freshwater spring at its downstream end (Hickman, 2014).

Flow in Reach 9 is highly modified due to diversion and capture for agricultural, urban and industrial demands at the Werribee Diversion Weir or further upstream. Annual discharge has been reduced by approximately 42%, the median daily discharge has been reduced by approximately 80% and the natural seasonal flow pattern has been lost (Ecological Associates, 2005a). Except when the Diversion Weir spills, flow in Reach 9 is restricted to a constant year round flow of approximately 1 ML/day.

The current environmental flow objectives for Reach 9 aim to provide suitable habitat for River Blackfish (even though they have not been recorded in the reach), facilitate the movement of migratory fish such as Tupong, Common Galaxias, Australian Smelt, Short-finned Eel, Pouched Lamprey and Shortheaded Lamprey, maintain resident platypus populations and improve habitat and water quality to support a more diverse macroinvertebrate community. Other objectives relate to maintaining or improving the diversity and condition of riparian vegetation.

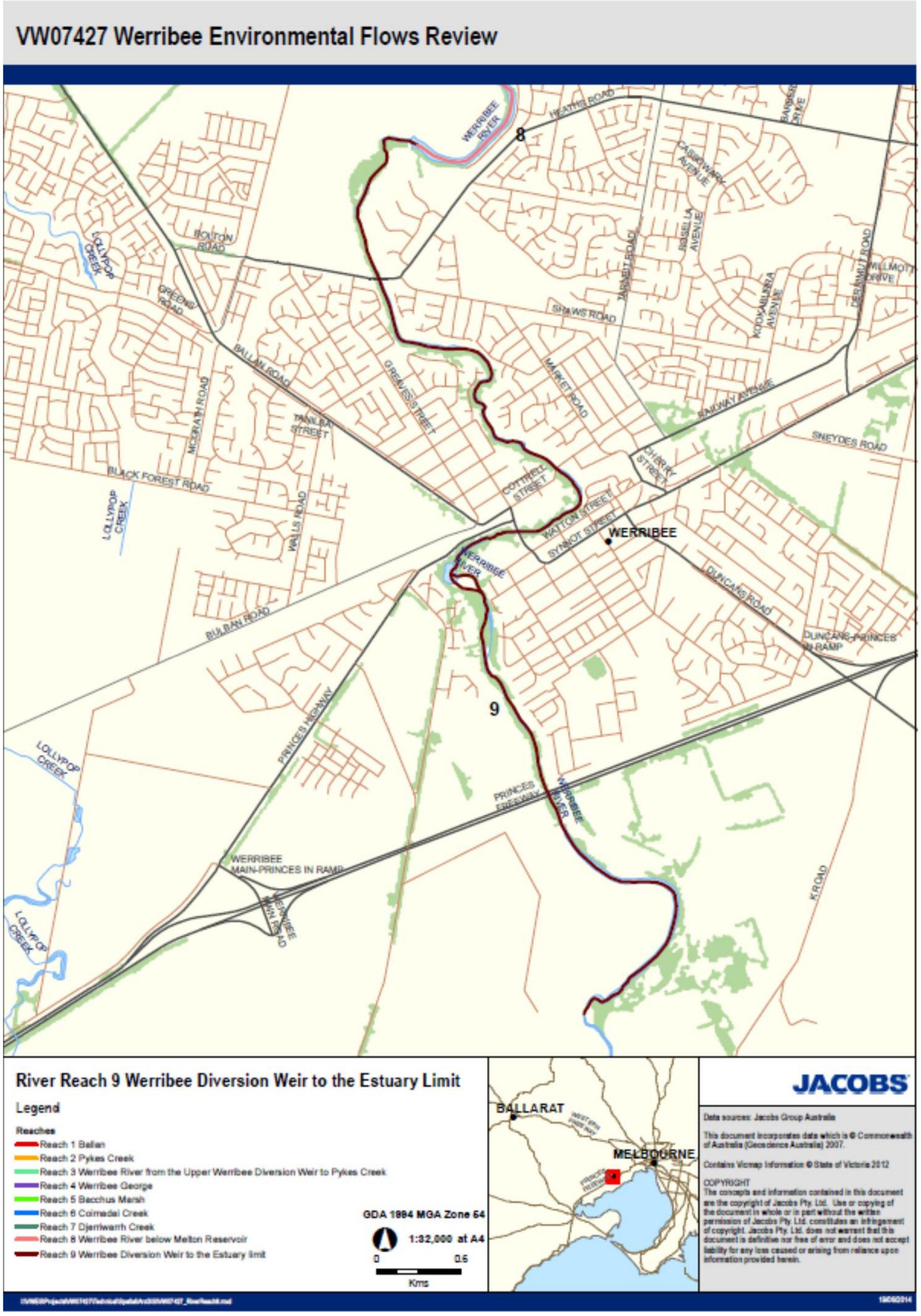


Figure 6-1: Map of Werribee River at Reach 9

6.2 Hydrology of the lower Werribee River

Melton Reservoir and the operation of the lower Diversion Weir largely determine flow in the lower Werribee River. The current flow regime in this reach retains the natural seasonal pattern of higher flow in winter and low flow through summer (Figure 6-2), but the mean annual flow is 33% lower than it be under unimpacted conditions (Table 6-1 and Figure 6-3). Most of the flow reduction is during low flow periods, as large freshes, high flows and bankfull flows will spill over the Diversion Weir and flow through Reach 9. Under unimpacted conditions, flow in the lower Werribee River would have exceeded 10 ML/day 80% of the time, but under current operating rules, flow is 1 ML/day or less for 50% of the time and greater than 10 ML/day about 45% of the time (Figure 6-4). Frequent cease-to-flow events also occur in the lower Werribee River under the current flow regime, but would have been rare under unimpacted conditions.

It should be noted that the hydrological assessment for this reach is based on the latest REALM model for the Werribee River. Some of the assumptions used in that model are not valid and therefore aspects of the estimated current and unimpacted flow regimes may be inaccurate. For example, the model significantly overestimates the current flow regime; gauged data suggests that the stream has lower flow and more days of no flow than described by the model (see Figure 6-5). These errors may have a bearing on the recommendations made in this chapter.

Summary flow statistics for Reach 9 of the Werribee River are presented in Table 6-1.

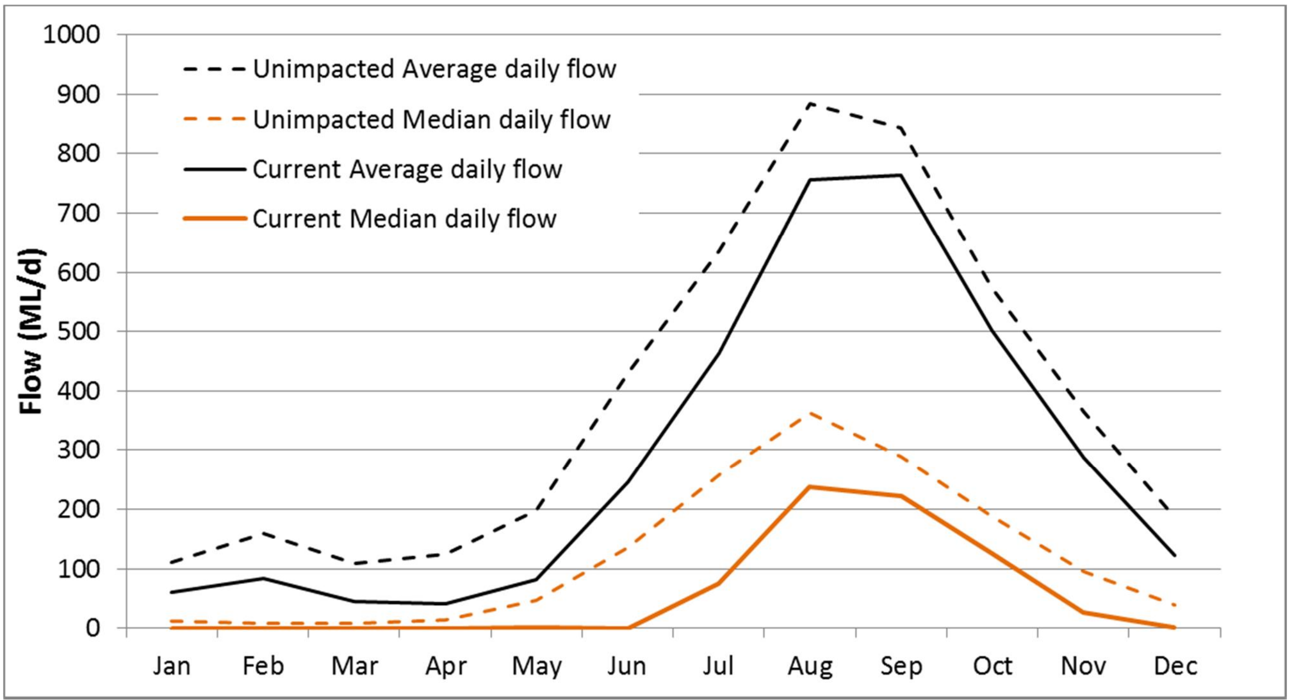


Figure 6-2 Average and Median daily flows in Reach 9 for unimpacted and current flows

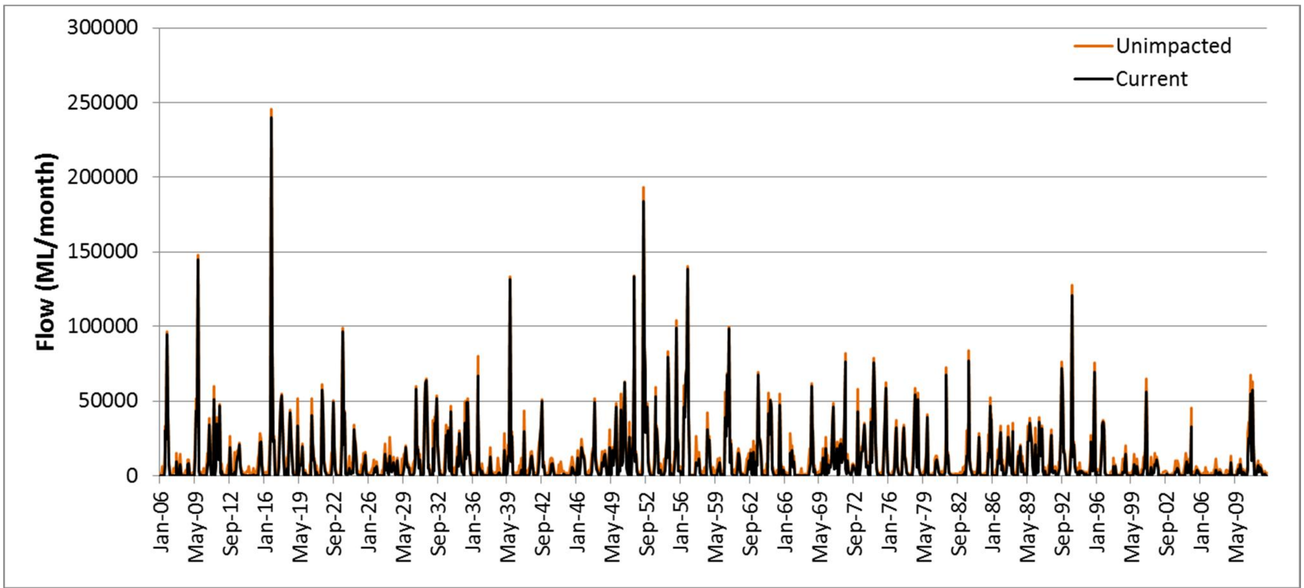


Figure 6-3 Monthly flow time series in Reach 9 for unimpacted and current flows

Table 6-1 Summary flow statistics in Reach 9 for current and unimpacted flows

Statistic	Unimpacted	Current
Mean Daily Flow (ML/d)	385.3	287.9
Median Daily Flow (ML/d)	74.0	2.0
Standard Deviation	1551.0	1459.1
Coefficient of Variation	4.0	5.1
Low Flow (80th Percentile) (ML/d)	8.0	0.0
High Flow (20th Percentile) (ML/d)	389.0	219.0
Mean Annual Flow (ML/y)	140,627.2	105,098.7

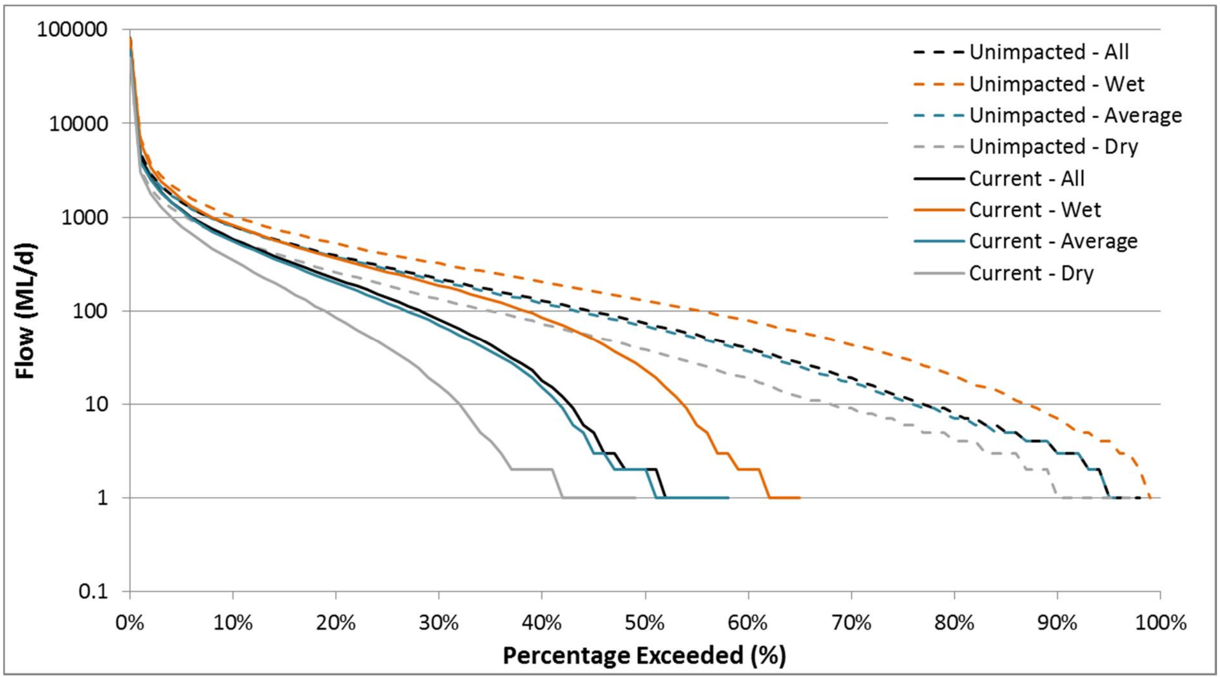


Figure 6-4 Flow duration curve for current and unimpacted flows in Reach 9. The record has been split to present wet, average and dry climate conditions.

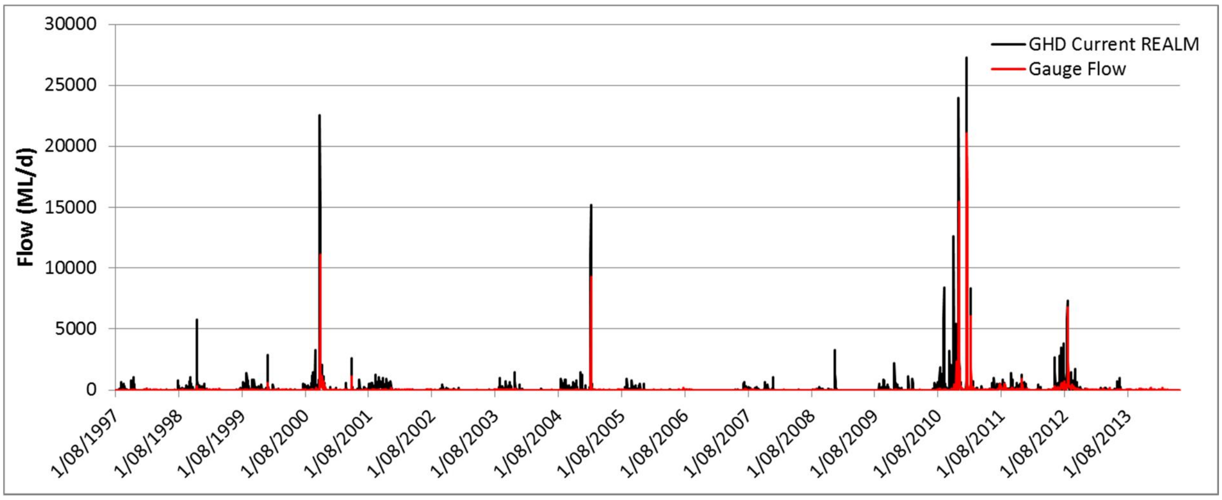


Figure 6-5 Flow timeseries of recorded and modelled current flows in the Werribee River downstream of the lower Diversion Weir. Modelled flow based on the GHD REALM model is shown in black and the recorded flow at Werribee Weir (Gauge 231204) + 1 ML/day passing flow that is not detected at the gauge is shown in red.

6.3 Conceptual understanding of flow regime and aquatic ecosystems in lower Werribee River

The lower reaches of the Werribee River, including Reach 9 and the Werribee estuary are located in the Parwan Trough sub-basin, but the main geological influence is the Quaternary deposits of the Werribee Delta, which include coarse gravel to clay particles that overlie Newer Volcanics. Sand and gravel are deposited along former river channels and the finer materials are deposited over former floodplains. The geology beneath the lower reaches of the Werribee River comprises the Tertiary aged Melbourne Formation, which is overlayed by Tertiary rocks including the Werribee Formation, Older Volcanics, Fyansford Formation, Brighton Group and Newer Volcanics. The Werribee Delta deposits overlays the New Volcanics except along the coastline where it is in direct contact with the Tertiary aged Brighton Group. The Werribee River is incised into the Werribee Delta deposits. There are a number of plant species (e.g. *Phragmites,* and River Red Gum) located along the lower Werribee River, Estuary and floodplain that use and probably rely on groundwater.

6.4 Groundwater Surface Water Interaction

6.4.1 Groundwater surface water interaction in the Lower Werribee River catchment

The main aquifer system below the lower reaches of the Werribee River is the Werribee Delta aquifer. The lower Werribee River is incised into the Werribee Delta deposits it is therefore highly connected to the Werribee Delta aquifer.

The groundwater gradient in Werribee Delta aquifer is generally to the south towards Port Phillip Bay, however there is also a vertical groundwater gradient which alternates between the Newer Volcanic aquifer and the Werribee Delta aquifer, such that groundwater can flow up in some places and discharge into the Werribee River. The freshwater spring described at the downstream end of Bungey's Hole (Hickman, 2014) is probably an example of such flow. Local groundwater also flows within the estuarine sediments adjacent to the Werribee Estuary with localised discharge to the Estuary during wet periods. It is likely that groundwater contributes to the baseflow of the lower Werribee River (gaining) and Werribee Estuary. Moreover, groundwater is likely to support a number of permanent pools in Reach 9 in the vicinity of Werribee Zoo and contribute a significant proportion of the freshwater in the Estuary. Groundwater will also help sustain River Red Gums and *Phragmites* during low flow periods.

The lower Werribee River is under continued pressure from river regulation to provide customers along the Werribee River and increase groundwater extraction to supplement surface water for irrigation. If groundwater extraction lowers the water table below the river stage, the groundwater component of baseflow would be reduced and there is potential that the lower reaches of the Werribee River will shift from a gaining to a losing stream. Such changes will reduce the volume and quality of permanent refuge pools in Reach 9.

Reduced groundwater contributions to the Werribee Estuary as a result of groundwater extraction may cause the salt water wedge to move further upstream and potentially allow salt water to extend into the downstream end of Reach 9, where it could influence aquatic and riparian vegetation and aquatic fauna. A change in groundwater flow and flux within the Werribee Estuary will also cause saline water to enter and contaminate the underlying aquifer (DEPI, 2011). Associated changes in water quality may lead to temporary or permanent loss of individual species that rely on the groundwater or the loss of some groundwater dependent ecosystems. Surface water flows from upstream reaches will also influence the position of the salt wedge and therefore it may be necessary to minimum flows through Reach 9 to prevent upstream migration of salt and contamination of the aquifer.

6.5 Summary and review of existing flow objectives and flow recommendations

Ecological Associates (2005b) recommended an environmental flow regime for Reach 9 to specifically maintain riffle habitats and the quality of pool habitats throughout the year to support macroinvertebrate, River Blackfish and Platypus populations, sustain in-channel and riparian vegetation and provide passage for migrating fish such as Tupong. These flow recommendations are summarised in Table 6-2 and evaluated in detail below.

Table 6-2: Current environmental flow recommendations and objectives for Reach 9 – Werribee River from the Lower Werribee Diversion Weir to the Estuary Limit (modified from Ecological Associates, 2005b).

Flow recommendations					Rationale / objective
Season	Component	Magnitude	Frequency	Duration	
Jan-April	Low flow	6 ML/day*	annual	Residual time after other flows	Wet the perimeter of riffles to provide habitat for macroinvertebrates Maintain pool habitats for fish, macroinvertebrates and platypus
Jan-April	Freshes	137 ML/day*	3 per year with a minimum separation of 14 days	1 day	Flush silt from riffle, run and some pool habitats to improve the quality of macroinvertebrate habitats Maintain water quality in pools and provide enough depth for fish to disperse through riffle habitats.
May-Dec	Low flow	81 ML/day*	annual	Residual time after other flows	Provide spawning habitat in pools for River Blackfish and adequate depth through riffles to allow River Blackfish to disperse between pools Sustain macrophytes in the channel and at the channel margins
Jul-Dec	Freshes	350 ML/day*	5 in Jul-Sep 2 in Oct-Dec with a minimum separation of 5 days	5 days	Disturb in-stream emergent macrophytes to limit vegetation encroachment Inundate benches frequently in winter and spring and less frequently towards summer to promote the growth of riparian shrubs and macrophytes Mobilise gravels on the streambed Drown in-stream barriers to allow Tupong to move from the estuary to the lower Werribee Diversion Weir
Anytime	Bankfull flow	6,000 ML/day	Natural (1 in 2 years)	1 day	Rework sediment including gravels to maintain channel dimensions Disturb shrub vegetation on channel benches and emergent macrophytes in the channel
Anytime	Overbank flow	13,600 ML/day	Natural (1 in 5 years)	1 day	Fully inundate high flow channels and rework gravel sediments throughout the whole reach to maintain channel dimensions.

* Or natural if the natural magnitude or duration is less than what is specified.

6.5.1 Evaluation of vegetation objectives

Sections of the Reach 9 floodplain that have not been cleared for agricultural or urban development support mature River Red Gum and the endangered Werribee Blue Box as well as an understorey of native and terrestrial shrubs and grasses. Pools and runs within the channel support submerged aquatic plants such as *Triglochin*, and *Myriophyllum*, and the pool and channel margins are fringed by *Phragmites* and River Club-rush (Ecological Associates, 2005a). Woody riparian shrub taxa are also common, including various species of water-dependent bottlebrush (*Callistemon* spp.) and teatree (*Leptospermum* sp.) The condition of this in-stream and riparian vegetation varies considerably throughout the reach. Melbourne Water, the Wyndham Shire and Werribee River Association have implemented various weed control and revegetation programs in the section immediately downstream of the lower Diversion Weir and the riparian vegetation in that section is diverse and in good condition. The relatively still, long, shallow pools through this section also support a healthy community of submerged aquatic plants. Bungey's Hole supports a diverse community of submerged and emergent macrophytes, but the network of braided stream channels downstream of Bungey's Hole are choked with *Phragmites* and the banks are overgrown with weeds (see Figure 6-6). The dominance of *Phragmites* and weeds is probably due to a combination of disturbance associated with urban development, nutrient enrichment (e.g. via stormwater and diffuse runoff) and the lack of a variable flow regime that would prevent terrestrial weeds from persisting on the low lying benches next to the stream.

Ecological Associates (2005b) recommended summer and winter low flows to sustain submerged aquatic plants, high flows and freshes to inundate low lying benches and promote the growth of native riparian species and a combination of high flows and bankfull flows to limit encroachment by terrestrial species and prevent excessive growth of *Phragmites* and River Club Rush. They also recommended bankfull and overbank flows to disturb shrubby vegetation on some benches and to deliver flow through high flow channels at the FLOWS assessment site just downstream of the Lower Diversion Weir.

The condition of riparian and in-stream vegetation in Reach 9 does not appear to have changed much since 2005 and the vegetation objectives set by Ecological Associates (2005b) are still valid. The current environmental flow study has used the same assessment site as the 2005 study, but we have extended the length of stream included in the hydraulic model to better understand the flows that are required to inundate the complex series of secondary channels and billabongs upstream of the 2005 FLOWS site. These channels have different elevations and will therefore be inundated by different flows. Providing a range of flows through those channels will help promote the growth of different plants in each channel and therefore a diverse mix of vegetation across the site. We have not surveyed the braided channels downstream of Bungey's Hole, but do specifically consider the flows that are needed to reduce the dominance of weeds in that part of the reach.

Figure 6-6: One of the narrow channels in the braided section downstream of Bungey's Hole showing weeds in riparian zone.

6.5.2 Evaluation of geomorphological objectives

The Werribee River downstream of the lower Diversion weir retains its natural form, although there has been some modification to the floodplain through urban development such as housing, road construction and recreational parks and facilities, as well as agriculture, predominantly market gardens. Flow regulation has reduced the frequency at which the Werribee River inundates its floodplain and the urban and agricultural development has disrupted many of the ecological processes that are normally associated with those events. Moreover, the man-made catchment disturbance and more efficient drainage networks carry more sediment into the Werribee River than would have naturally been the case and lower baseflows prevent that sediment from being transported out of the system. As a result, some sections of the streambed are susceptible to being clogged or smothered by fine sediment, which in turn reduces the amount of biofilms and algae that can grow, increases turbidity in the water and reduces habitat and food for macroinvertebrates and fish. Finally, lower flows mean that the stream substrate is not turned over as often as it would have before regulation and hence there are fewer opportunities to re-distribute organic material through the streambed.

Ecological Associates (2005b) recommended regular freshes every year to flush fine sediment and turn over gravel and sand on the streambed as well as bankfull flows every two years and overbank flows at least once every five years to scour pools and prevent emergent macrophytes from consolidating new benches and bars within the channel. The geomorphological objectives and associated flow recommendations set in 2005 are still valid and should be retained. The current project will use the updated hydraulic model for the FLOWS site to review the required magnitude of the recommended flow components.

6.5.3 Evaluation of fish objectives

The main fish objectives for Reach 9 in the 2005 FLOWS study relate to re-establishing a River Blackfish population and providing opportunities for Tupong to migrate into freshwater reaches from the estuary (Ecological Associates, 2005b). At the time, River Blackfish were known to occur upstream of the Lower Diversion Weir and were most abundant in the Werribee Gorge and other reaches upstream of Melton Reservoir. Ecological Associates (2005b) argued that River Blackfish would have naturally occurred in the lower Werribee River and that a lack of flow, which limits the quality of instream habitat, and migration barriers (McGuckin and Borg, 2013 identified 10 natural and artificial barriers to fish movement through this reach) are the main factors excluding them.

McGuckin (2006, 2012) extensively surveyed the fish communities throughout the Werribee River in the middle of the Millennium Drought and two years after the drought. He caught Short-finned Eel, Common Galaxias, Spotted Galaxias, Flathead Gudgeon, Australian Smelt and Tupong in the lower Werribee River in both surveys and detected no change in the composition or condition of any population (McGuckin, 2006, 2012). He did not catch any River Blackfish in the lower Werribee River and noted that the abundance of River Blackfish in the reaches upstream of Melton Reservoir declined during the drought (McGuckin, 2006, 2012). The Werribee River immediately downstream of the lower Diversion Weir potentially provides good habitat for River Blackfish. There are long shallow pools, with submerged vegetation, submerged logs and undercut banks that River Blackfish can use for cover and for nesting sites. River Blackfish may also use some of the fringing habitat around Bungey's Hole. However, the braided channel section downstream of Bungey's Hole is likely to be too shallow for River Blackfish and given River Blackfish do not need to access the Werribee estuary we question whether restoring River Blackfish populations to a few pools in a short reach with lots of barriers between it and more viable upstream populations should be a high priority.

During our field assessment, we observed several schools of Galaxiids (we did not attempt to catch any individuals and assume they were Common Galaxias). Melbourne Water's Healthy Waterways Strategy has a stated aim to increase the proportion and abundance of native fish in the Lower Werribee River (Melbourne Water, 2013). The Strategy does not specifically mention River Blackfish and we suggest that instead of trying to re-establish populations of River Blackfish a better environmental flow objective will be to improve the abundance and diversity of migratory species such as Common Galaxias, Spotted Galaxias, Short-finned Eel, Pouched Lampreys, Australian Smelt and Tupong that use Reach 9 as a corridor between Port Phillip Bay, the Werribee Estuary and freshwater reaches further upstream. Improving flow and in-stream habitat throughout Reach 9 to meet other environmental flow objectives may allow River Blackfish to re-colonise some of the pools in the upstream half of Reach 9, but such an outcome should be considered a bonus rather than a primary flow objective.

Most of the native fish that will occur in Reach 9 are small-bodied species that favour habitats with abundant vegetation for cover. They can generally negotiate most barriers as long as there is 100-200 mm of water depth over them, the vertical drop is not too great and there are plenty of resting habitats (Macdonald and Davies, 2007). There are more than 10 potential migration barriers between the Lower Diversion Weir and the Werribee Estuary (McGuckin and Borg, 2013). Melbourne Water is currently investigating options to improve fish passage across the artificial barriers in the reach (Stefanie Wabnik, Melbourne Water Pers. Comm.), but higher flows will also be needed at critical times to trigger and facilitate migration for different species. Female tupong migrate to the estuary and sea during high flow events between May and August (Crook *et al.*, 2010). Common Galaxias migrate downstream to the estuary to spawn on the full moon or new moon in autumn and high flows in spring may or may not encourage juveniles to migrate upstream to freshwater reaches in spring (McDowall and Eldon, 1980, Hale *et al.*, 2009). Australian Smelt in coastal rivers are likely to move to estuaries to spawn in summer and autumn (Crook *et al.*, 2008), and therefore need passage at that time.

Non-flow related factors such as habitat degradation due to urban and agricultural development and competition from or predation by exotic fish such as Carp, Redfin, Goldfish, Tench, Gambusia and Brown Trout are also likely to affect the native fish community in Reach 9. Delivering the right flow regime will not be sufficient to meet the fish related objectives in the Healthy Waterways Strategy.

Ecological Associates (2005b) recommended a minimum summer low flow of 6 ML/day to maintain pool habitat for River Blackfish, multiple summer freshes to allow River Blackfish to move between pools during summer and a winter low flow of 81 ML/day to allow River Blackfish to move between pools and to provide suitable nesting habitats. They also recommended high winter freshes that would drown out the lower Diversion Weir and allow Tupong to move further upstream (Ecological Associates, 2005b). The recommended flows are probably more than what is needed for River Blackfish, especially since there is a low likelihood that they will re-colonise Reach 9, but setting flows to maintain the quality and quantity of pool habitats and providing opportunities for migratory fish to move through and beyond the reach are valid for all of the fish that are likely to use Reach 9. The current flow study, will review the magnitude, timing and frequency of high flows and freshes in particular to ensure they meet the needs of migratory fish rather than River Blackfish.

6.5.4 Evaluation of macroinvertebrate objectives

The macroinvertebrate community in the lower Werribee River is below reference condition and indicative of mild pollution. Poor water quality due to run-off from urban and agricultural activities within the reach and further upstream contribute to elevated nutrient levels and increased inputs of fine sediment, which can significantly reduce the abundance and diversity of pollution sensitive macroinvertebrate groups such as Ephemeroptera, Plecoptera and Trichoptera (Harrison *et al.*, 2007).. A combination of high nutrient concentrations and lower than natural flow allow thick mats of filamentous algae to grow in summer, which further reduces habitat and feeding opportunities for macroinvertebrates. Given the type of land-use in the catchment, it is probably unrealistic to expect that the macroinvertebrate community in Reach 9 will ever be equivalent to an unimpacted reference condition and Melbourne Water’s target to improve the condition of the macroinvertebrate community from moderate to high over more than 20 years (Melbourne Water, 2013) is more appropriate.

Ecological Associates (2005b) recommended the summer minimum flow should be increased to 6 ML/day to wet a greater proportion of riffle habitats throughout Reach 9 and that three summer freshes of 137 ML/day should be delivered each year to flush fine sediment from macroinvertebrate habitat. The macroinvertebrate objectives and associated flow recommendations for Reach 9 are still valid, however more regular summer freshes may be warranted to limit the density of filamentous algae. Recent monitoring in Coimadai Creek has demonstrated that biofilms and filamentous algae can grow very rapidly in the warmer months and large freshes that exert a shear stress of at least 10 N/m^2 on the streambed are needed every 4-8 weeks from the end of September through until early autumn to scour the attached algae and maintain suitable habitat for macroinvertebrates (SKM, 2012, 2014). The recommended flows will probably also help to maintain water quality throughout the year, which in turn will help improve the condition of the macroinvertebrate community. Specific water quality objectives are described in Section 6.5.5.

6.5.5 Evaluation of water quality objectives

Water quality in the lower Werribee River is moderate to poor. Total nitrogen concentration and total phosphorus concentration in the Lower Werribee Diversion Weir frequently exceed the SEPP WoV trigger levels (see Figure 6-7 and Figure 6-8). Environmental flows should not be used to treat pollution associated with run-off from urban and agricultural land. However, unnaturally low flows (especially prolonged periods of very low flow such as occurred during the Millennium Drought) are likely to contribute to low dissolved oxygen levels and high salinity in summer (see Figure 6-9 and Figure 6-10). Dissolved oxygen levels at the monitoring site are generally above 6 mg/L, and are therefore not considered a threat to aquatic life, but electrical conductivity during the middle of the drought rose above 4,000 µS/cm, which is higher than some macroinvertebrates and fish can tolerate. Higher flows throughout summer are needed to either reduce saline groundwater intrusions to the river or to dilute any saline groundwater that flows into the stream. As discussed in Section 6.4, higher surface flows are probably also needed to control the salt wedge in the Werribee estuary and therefore prevent sea water from contaminating the underlying aquifer, but the exact flow requirements for the estuary are not known and are beyond the scope of the current study.

Ecological Associates (2005b) recommended a minimum summer flow of 6 ML/day and three summer freshes of 137 ML/day to maintain and mix pool habitats throughout Reach 9. Those flow objectives remain valid and the recommended flows are likely to increase current flows by a sufficient amount to improve water quality and reduce the risk of adverse water quality outcomes.

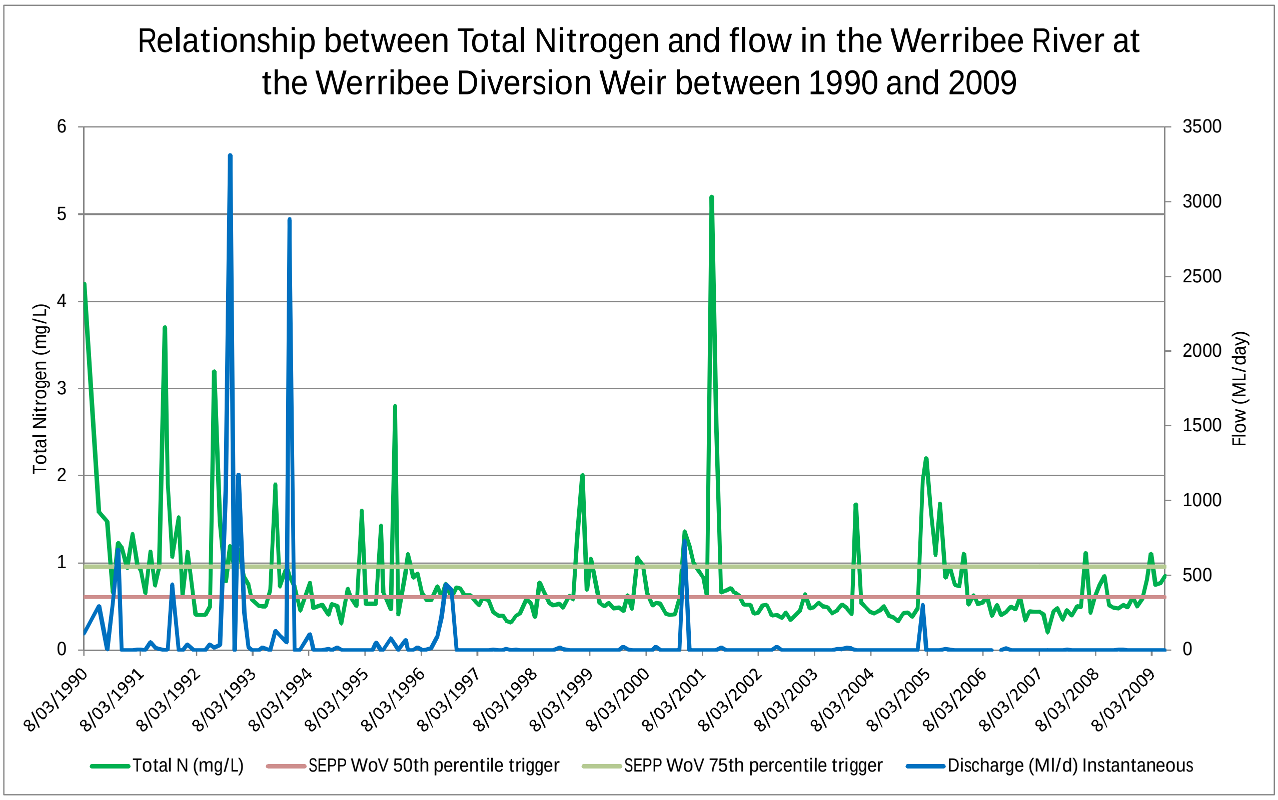


Figure 6-7: Relationship between total nitrogen and flow in the lower Werribee Diversion Weir between 1990 and 2009.

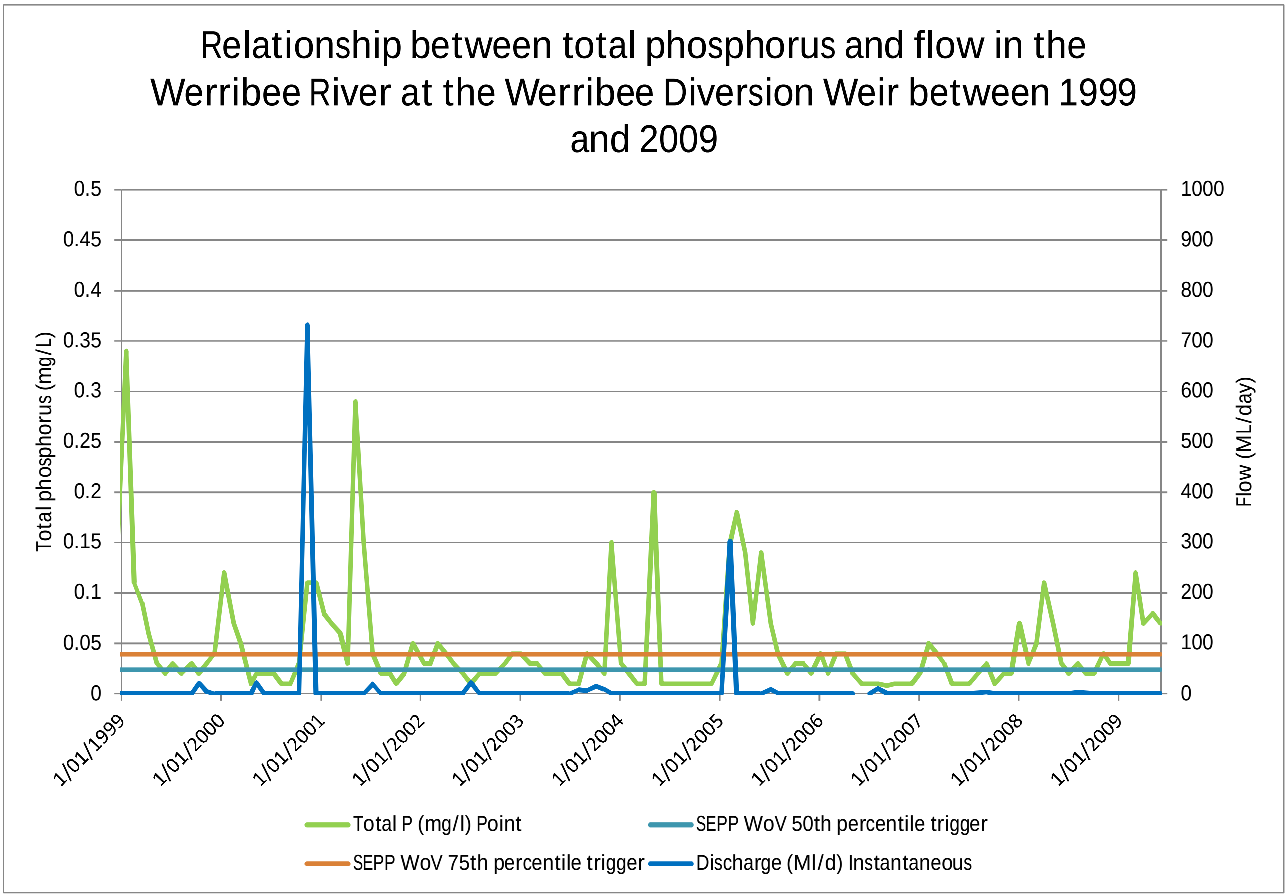


Figure 6-8: Relationship between total phosphorus and flow in the lower Werribee Diversion Weir between 1999 and 2009.

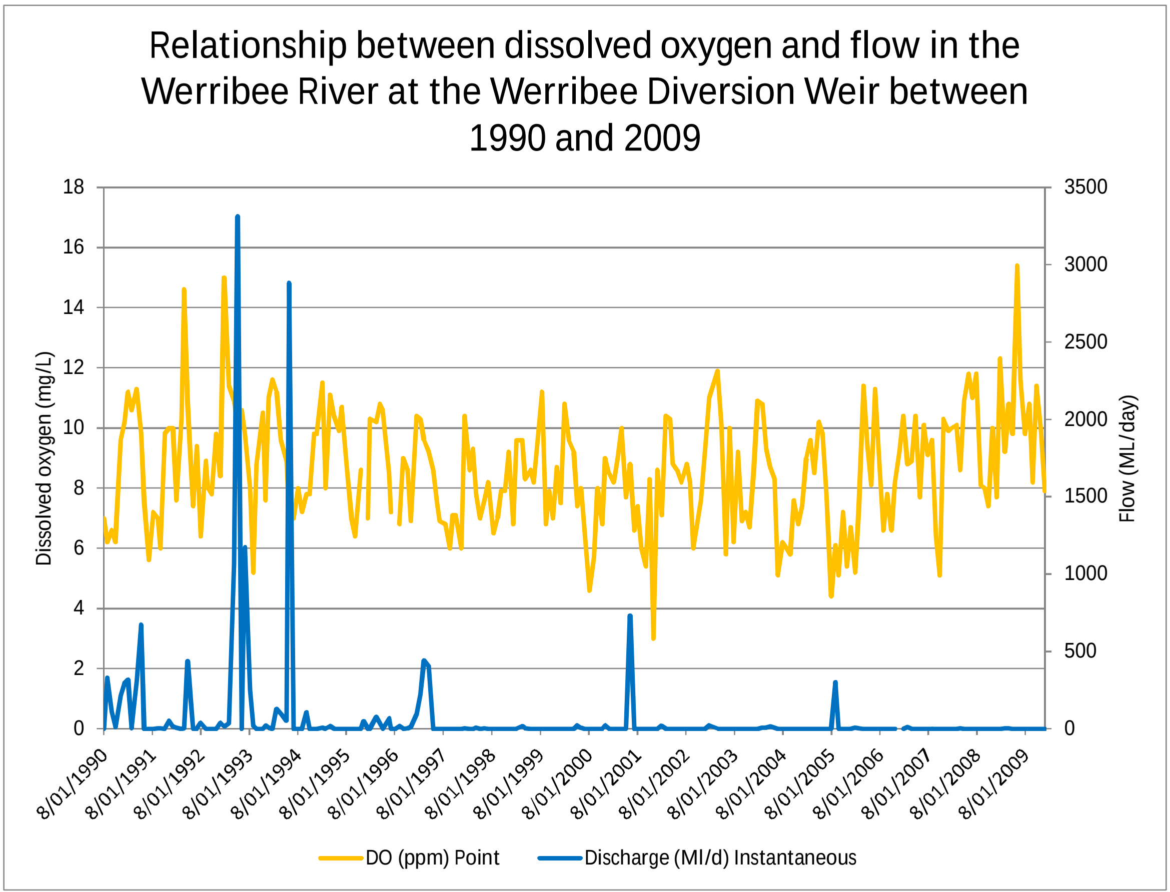


Figure 6-9: Relationship between dissolved oxygen and flow in the lower Werribee Diversion Weir between 1990 and 2009

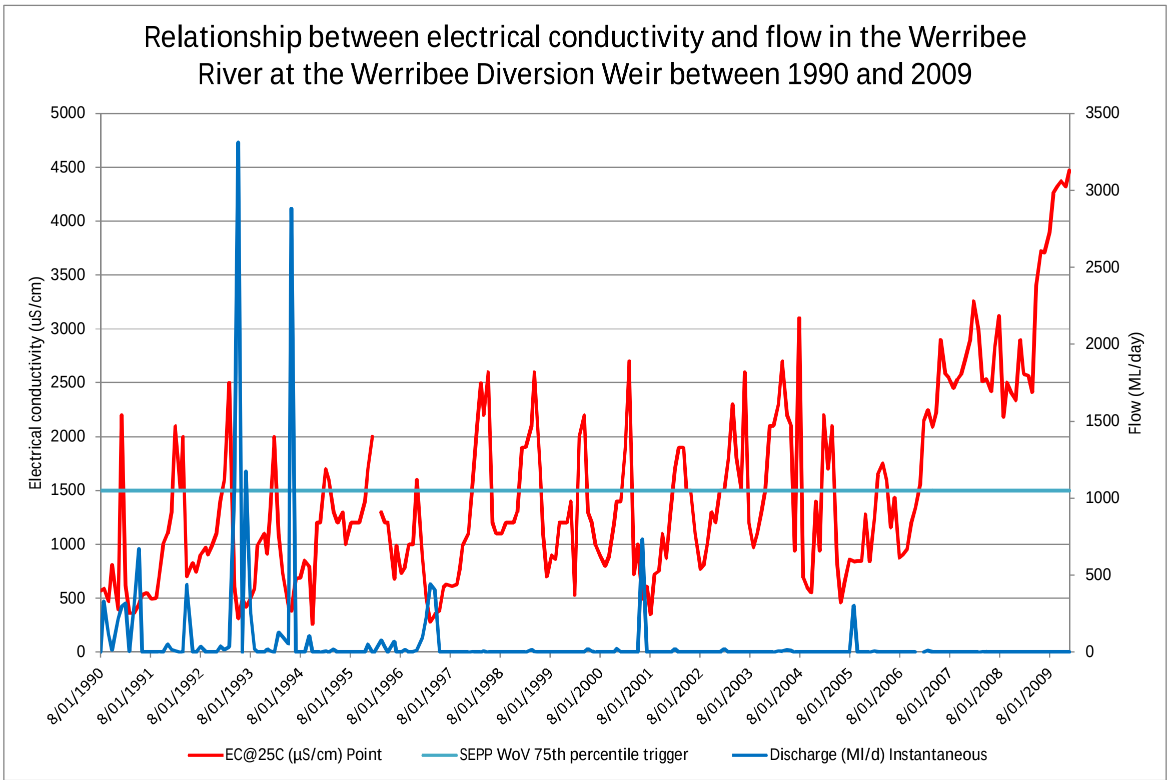


Figure 6-10: Relationship between electrical conductivity and flow in the lower Werribee Diversion Weir between 1990 and 2009

6.5.6 Evaluation of platypus objectives

The lower Werribee River supports suitable habitat for Platypus. Serena and Williams (2008) recorded numerous Platypus in the reach, but as with other parts of the Werribee River, Platypus numbers in Reach 9 declined considerably during the drought (Alluvium, 2011, CESAR, 2012, 2013) and the population in the lower Werribee River is now considered to be critically low. Melbourne Water's Healthy Waterways Strategy classifies the current platypus population in the lower Werribee River as very low, but has a long-term target to stabilise and then increase the population so that they are common throughout the reach (Melbourne Water, 2013).

Platypus rely on an abundant supply of macroinvertebrates (their main food), suitable foraging habitats (generally pools greater than 0.5 m deep, with plenty of cover), and well vegetated banks where they can construct and access burrows (Serena and Williams, 2008). Litter, predation by foxes, dogs and cats and degradation of riparian habitats through clearing, weed infestation or willows are considered the main threats to Platypus in the Werribee River (Serena and Williams, 2008). However, very large flows during the breeding season can flood the burrows of nesting platypus and drown the juveniles.

Ecological Associates (2005b) set flow objectives to maintain the Platypus population in Reach 9 and recommended flows that aimed to maintain an abundant macroinvertebrate community and therefore food for the Platypus. They did not specifically consider the minimum flows that would be required to maintain adequate depth in pools or sufficient flow through riffles to minimise the occasions when Platypus would need to leave the water while foraging. This latter point is particularly important because Platypus are most susceptible to predators when they are out of the water. Ecological Associates (2005b) also did not explicitly consider whether their recommended high flows would be delivered at a time or at a magnitude that would inundate nesting burrows. The current FLOWS study does consider these factors.

6.5.7 Relevant objectives that were not considered in the 2005 FLOWS study

The lower Werribee System supports nine out of the 16 frog species that would have naturally occurred in the region including Bibrons Toadlet and Growling Grass Frog (Melbourne Water, 2013). Melbourne Water's Healthy Waterways Strategy aims to increase the number of represented species over the next 20 years and beyond (Melbourne Water, 2013). Most of the frogs recorded and expected in the lower Werribee System will use off stream habitats such as wetlands and flooded depressions; and only a small proportion will rely specifically on in-stream habitats and therefore environmental flows. The diversity of large pools, shallow slow flowing channels, and secondary channels that only fill occasionally provides a good mix of habitats that will support a variety of different frogs and therefore flows that maintain or improve those habitats at times when frogs are likely to use them may improve the abundance and richness of the frog community.

Growling Grass Frogs may use some of the smaller backwaters on the main channel and some of the rain filled depressions on the island at the Reach 9 assessment site. However, the main risk in these flowing habitats are the presence of fish and potentially frequent high flows that could flush developing tadpoles downstream.

Pobblebonks, Southern Brown Tree Frogs and Common Froglets possibly use the margins of the main channel and some of the well vegetated backwaters near the islands. However, the billabongs and secondary flow channels that are filled during very high flows and then draw down over several months are likely to provide the best habitat for these three frog species and possibly Verraux's Tree Frog, Striped Marsh Frog and Spotted Marsh Frog. All of these frogs have long breeding seasons and are able to take advantage of newly inundated habitats therefore the timing of events that inundate these channels and billabongs is not critical as long as the billabongs hold water for long enough to allow tadpoles to complete their development and the events are not so frequent that they wash developing tadpoles out of the system.

Some individuals from all the listed frog species are likely to persist in and around the lower reaches of the Werribee River all of the time and therefore the frequency of large events that fill billabongs is probably not critical to ensuring these populations persist. However, events every 2-3 years should ensure numbers remain high and may allow some frog species to recolonise the reach.

6.6 Revised flow objectives for Reach 9

Environmental flows in Reach 9 of the Werribee River should aim to maintain pool habitats for fish, aquatic macroinvertebrates and aquatic vegetation; increase the extent of riffle habitats for macroinvertebrates and to improve passage for migratory fish; improve the diversity of native riparian vegetation and reduce the dominance of terrestrial weeds in the braided section of the reach; and reduce flood and predation risks for Platypus. More frequent high flows should also be provided to deliver water to secondary channels and billabongs, which are likely to support frogs and other riparian plants.

Environmental flows may need to be delivered through Reach 9 to prevent the upstream migration of the salt wedge in the Estuary and to help achieve other environmental objectives in the Estuary. Melbourne Water is planning a separate project to review the environmental flow requirements of the Werribee Estuary and the environmental flow recommendations for Reach 9 may need to be further revised once the specific flow requirements of the estuary are known.

The revised environmental flow objectives for Reach 9 of the Werribee River are presented in Table 6-3.

Table 6-3: Updated environmental flow objectives for Reach 9 (Werribee River from lower Diversion Weir to the estuary) and the flow components that they require

Asset	Environmental flow objective	Function	Required flow component(s)	Timing	Expected response
Vegetation	Maintain diverse community of submerged aquatic vegetation	Maintain pool habitats year round	Low flows	Year round	Maintain or potentially increase the abundance and diversity of aquatic vegetation in pool habitats.
	Limit the spread of terrestrial vegetation especially in the braided channel section and promote recruitment of native riparian species such as non-woody rushes, reeds, sedges and woody shrubs such as bottlebrush and tea tree on the banks of the stream and adjacent benches.	Drown terrestrial species that cannot tolerate being inundated and increase the growth and recruitment of plants that require periodic inundation for germination and survival.	Low flow	Winter/Spring	Reduced terrestrial vegetation in and adjacent to the channel (especially in the braided channel section downstream of Bungey's Hole, increased growth and clear zonation of water dependent riparian plants
			Periodic freshes and high flows	Spring	
	Promote growth of native riparian vegetation in secondary channels and billabongs	Periodically water secondary channels and fill billabongs at the channel margins	Bankfull flows	Winter or spring every 2-3 years	Increased growth of native riparian species and reduced terrestrial vegetation in secondary channels; growth of seasonal aquatic species such as *Triglochin* and *Myriophyllum* when channels inundated
	Reduce or prevent excessive encroachment by *Phragmites* and other undesirable emergent macrophytes	Periodic flows to scour unwanted vegetation and maintain a clear flow path	Bankfull flows	Winter or spring every 2-3 years	Reduced cover of *Phragmites* in the channel and clear flow paths maintained.
Geomorphology	Clean substrate on streambed	Flush silt and scour algae and biofilms from substrates on the streambed	Regular freshes	Year round	Substrate will be periodically cleared of fine silt and filamentous algae and biofilms will be reset in warmer months
	Maintain channel dimensions	Mobilise and re-work sand and gravel on streambed to maintain pools and channel dimensions	High flows	Winter/spring	Sand and fine gravel turned over
			Bankfull flows	Anytime	Pools scoured and benches replenished
	Maintain secondary flow paths and billabongs	Inundate secondary flow paths and billabongs within the main channel	Bankfull flows	Winter/spring once every 2-5 years	Maintain benches and pools and turn over substrate in secondary flow paths and billabongs
Fish	Maintain existing populations of diadromous fish	Maintain water quality and food in pool habitats	Low flows	All year	Current populations of native migratory fish are maintained or increased. Richness may also increase

Asset	Environmental flow objective	Function	Required flow component(s)	Timing	Expected response
	Allow Common Galaxias, Tupong and other species to migrate to estuary or sea in autumn	Provide enough flow for fish to move downstream past natural or artificial barriers	Freshes	Autumn	Target species are able to migrate downstream to spawn.
	Allow juvenile Common Galaxias, Tupong and other diadromous species to migrate into freshwater reaches	Provide movement cues and enough flow for fish to move upstream past natural and artificial barriers.	Freshes	Spring	Fish are able to migrate into Reach 9
			High flows	Spring	Fish are able to migrate upstream past the Lower Diversion Weir.
Macroinvertebrates	Maintain tolerant macroinvertebrate community	Maintain permanent pools and increase extent of riffle habitats	Low flows	All year	Increase quality and quantity of available habitat should increase abundance of macroinvertebrate fauna
		Scour silt, biofilms and filamentous algae from substrate to maintain quality and quantity of food and habitat	Regular freshes	Spring and early summer	
Water quality	Maintain dissolved oxygen levels above 4 mg/L and prevent electrical conductivity exceeding 3,000 EC	Maintain flow through pool habitats to allow mixing and to either suppress or dilute saline groundwater intrusion	Low flows	All year	Dissolved oxygen and electrical conductivity levels are maintained at a level that is suitable for aquatic biota
Platypus	Increase abundance of resident Platypus population	Maintain foraging habitat and abundant food supply	Low flows	All year round	Adequate habitat and food that allows Platypus to forage safely and access enough food
		Avoid flooding burrows during the breeding and rearing seasons	Avoid high flows that increase water depth by >1m compared to winter flows	September - January	Greater recruitment of Platypus
Frogs	Maintain populations of Growling Grass Frog, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog and the Southern Brown Tree Frog	Maintain pools with fringing vegetation	Low flows	All year	Existing frog populations persist in current condition
		Inundate depressions adjacent to stream that frogs can use for breeding	High flows	Spring	Increased breeding by species that do not rely on in-stream habitats.
		Inundate secondary channels and billabongs	Bankfull	Every 2-5 years	Increased abundance and diversity of native frogs

6.7 Revised flow recommendations for Reach 9

The flow regime for Reach 9 has two seasons that are based on the wet and dry phases of the natural flow regime in the catchment (see Figure 6-11). The first season is referred to as winter; it extends from June to November and is characterised by higher magnitude low flows and larger freshes, high flows and bankfull flows. The second season is referred to as summer; it extends from December to May and is characterised by lower magnitude low flows and occasional freshes. The winter season is shorter than the high flow season and the summer season is longer than the low flow season specified in the 2005 environmental flow study, but in our view they better reflect the duration of the wet period and dry period under both current and unimpacted flow regimes.

The revised environmental flow recommendations reflect the changed objectives described in Section 6.5. Where the objectives from 2005 are still valid, we have generally kept the same flow recommendations except where new information suggests that a particular objective requires different flow components or where updated hydraulic modelling indicates that a different flow magnitude is needed.

The revised environmental flow recommendations for Reach 9 are summarised in Table 6-4.

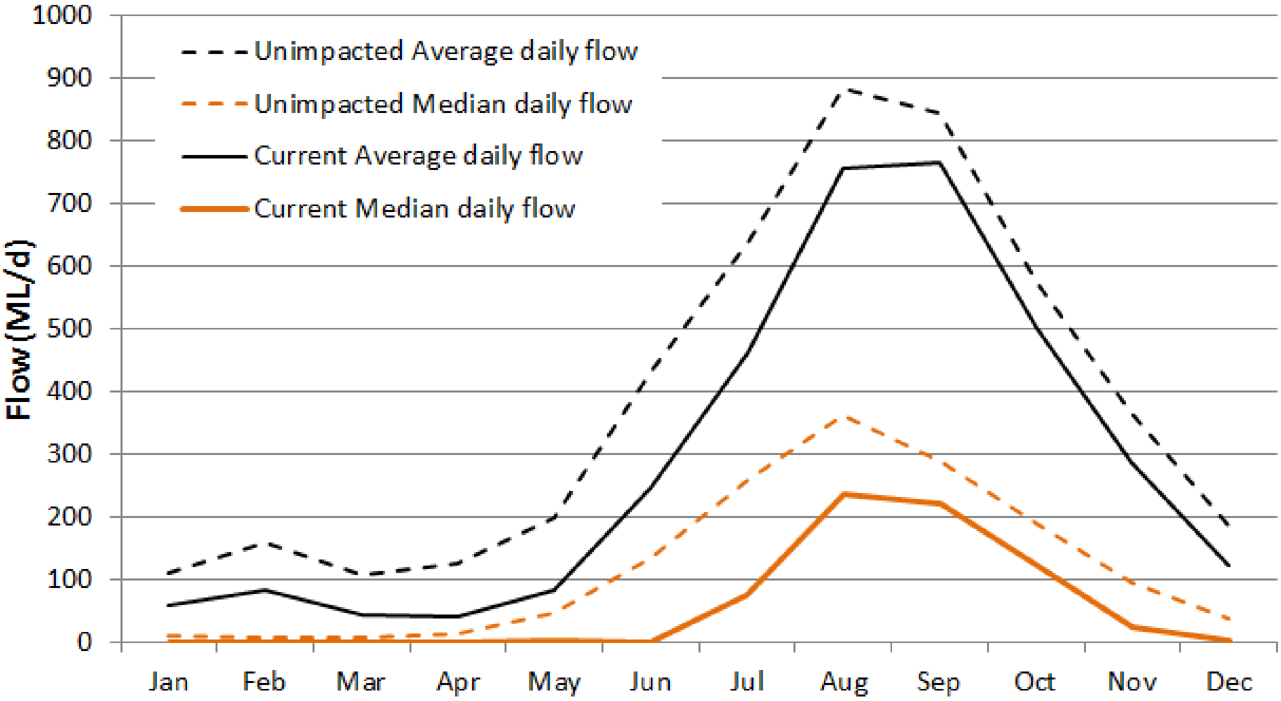


Figure 6-11: Plot of seasonal changes in average and median daily flow in the Werribee River downstream of the lower Diversion Weir under current and unimpacted flow regimes.

Table 6-4: Updated environmental flow recommendations for Reach 9: Werribee River between Lower Diversion Weir and Werribee Estuary

Stream	Werribee River from Lower Diversion weir to the Werribee estuary		Climatic regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec–May)	Low flow	Maintain pool and riffle habitats for fish, macroinvertebrates and submerged aquatic vegetation	All years	6 ML/day or natural	Whole season		
	Summer Fresh	Flush silt, and scour biofilms and algae from streambed Water fringing riparian vegetation Allow fish movement through the reach	Wet / Average	137-215 ML/day (at least 2 events ≥215 ML/day)	5 events (every 6-8 weeks) with at least 2 events in April-May, one of them on a full or new moon	1-2 days	
			Dry	137 ML/day	3 events with at least 1 in April-May	1-2 days	
Winter / Spring (Jun-Nov)	Low flow	Maintain clear flow path and control intrusions by terrestrial vegetation Allow fish movement throughout the reach	All years	81 ML/day	Whole season		
	Winter fresh	Promote growth and recruitment of native riparian vegetation including woody shrubs and promote strong vegetation zonation on the banks Cue and facilitate fish movement Inundate depressions at margins of channel for frog breeding	Wet / Average	350 ML/day	4 events: - 2 between June-August - 2 between September-October	3 days	
			Dry	350 ML/day (but some events could be slightly less)	2 events: - 1 between June-August - 1 between September-October	3 days	
	High / Bankfull flow	Inundate secondary channels and billabongs within main channel Scour pools and maintain channel form and dimensions	Wet / Average	≥3,000 ML/day	Every 2 years on average	2 days	
			Dry	Not expected			

6.7.1 Summer low flow

The lower Werribee River downstream of the lower Diversion Weir should have a minimum low flow to maintain pool and riffle habitats and to maintain water quality throughout the reach. Southern Rural Water currently release a constant low flow of 1 ML/day, which is not enough to wet the full width of riffle habitats throughout the reach and could fail to adequately mix pools and maintain water quality in pools during summer. Increasing the wetted width of riffle habitats will increase the quality, diversity and quantity of habitat that macroinvertebrates can colonise and therefore increase the available food for fish and platypus.

Ecological Associates (2005b) recommended a minimum summer low flow of 6 ML/day or natural. We do not have any water quality monitoring data to confirm whether that flow is sufficient to maintain water quality, but hydraulic modelling does show that a flow of 6 ML/day will provide greater wetted width in riffle habitats and increase the depth through riffle habitats by 5 cm compared to a flow of 1 ML/day (see Figure 6-12). For these reasons we retain the recommended minimum summer low flow at 6 ML/day.

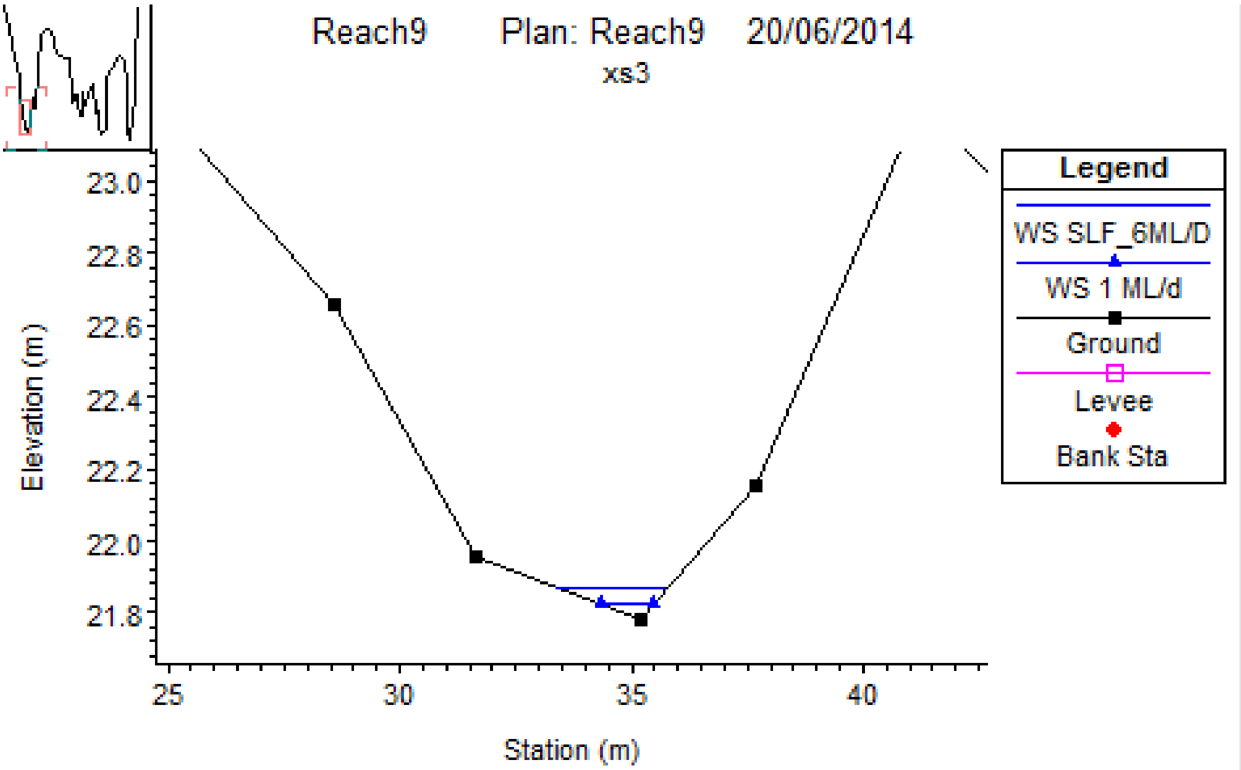


Figure 6-12: Cross section of main flow path at left hand side of the channel showing inundation under 1 ML/day and 6 ML/day flows.

6.7.2 Summer fresh

We recommend delivering 3-5 freshes of 137 - 215 ML/day over the summer period to flush fine sediment and scour biofilms and filamentous algae from the streambed; provide opportunities for migratory fish such as Tupong, Common Galaxias, and Australian Smelt to move between pools and to wet littoral vegetation on low lying benches. The recommended freshes will partially inundate the low channel benches (see Figure 6-13) and provide a depth of at least 31 cm through the shallowest riffle habitat at the assessment site (see Figure 6-14). They will also provide an average sheer stress of 20.3 N/m^2 through riffle and run habitats at the FLOWS site, which based on monitoring in Coimadai Creek is enough to clean accumulated biofilms and filamentous algae from a large proportion of the streambed.

In average or wet years, the freshes should be delivered every 6-8 weeks throughout summer and autumn to prevent excessive growth of biofilms and filamentous algae. A total of five freshes should be delivered and at least two of them should exceed 215 ML/day. At least two freshes should be delivered in autumn, with at least one preferably occurring during a new moon, to help Common Galaxias migrate to spawning sites in the estuary. Each fresh should last for 1-2 days. The frequency that these flows occur under unimpacted and current flow regimes are presented in Figure 6-15 and Figure 6-16.

Fewer freshes will occur in dry years and they may be smaller. As a result biofilms and algae are likely to become more prolific and macroinvertebrate abundance may drop. In dry years, Melbourne Water should aim to deliver three freshes of at least 137 ML/day and at least one of them should be in April or May to facilitate fish migration.

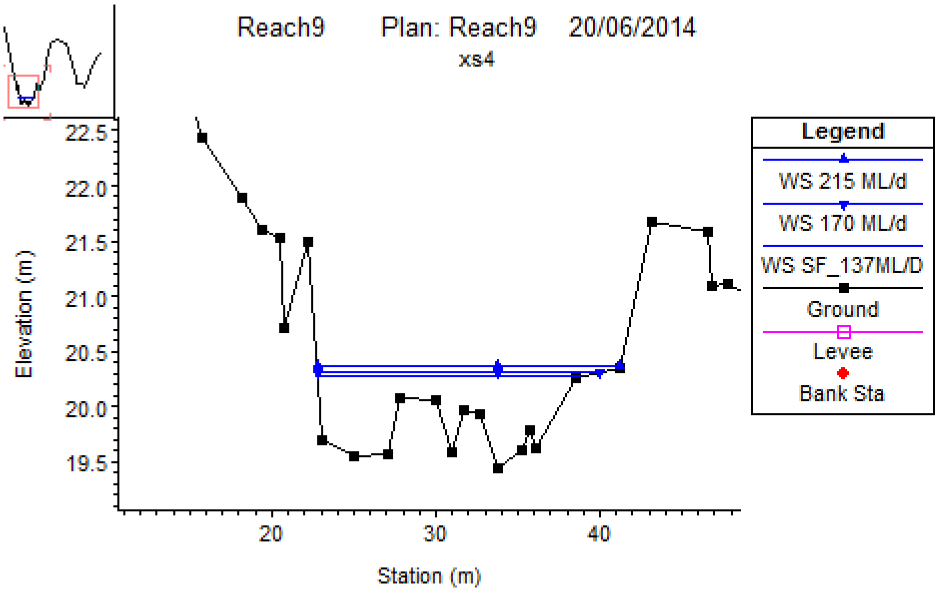


Figure 6-13: Summer fresh flow of between 137 ML/day and 215 ML/day at cross section 4. 137 ML/day inundates the leading edge of the bench, 170 ML/day inundates to the middle of the bench and 215 ML/day inundates the whole bench at this cross section.

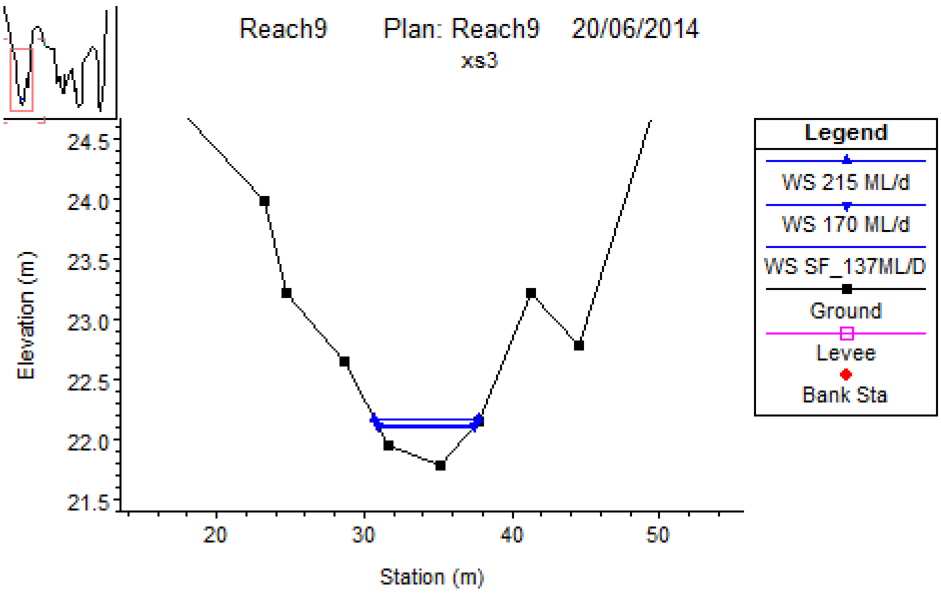


Figure 6-14: Summer fresh flow of between 137 ML/day and 215 ML/day at cross section 4, the shallowest riffle

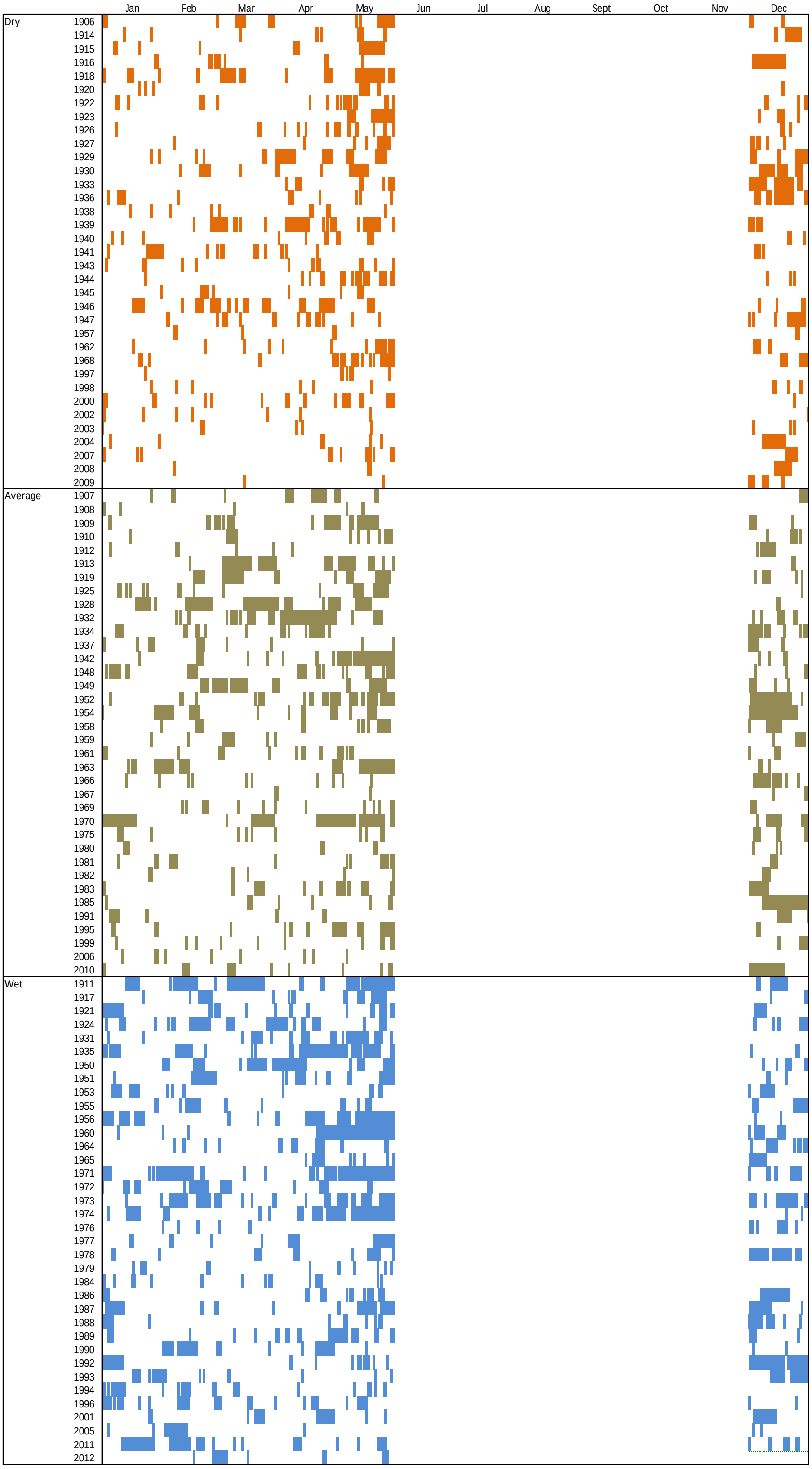


Figure 6-15: Spells of 137 ML/day or above for the unimpacted flow regime

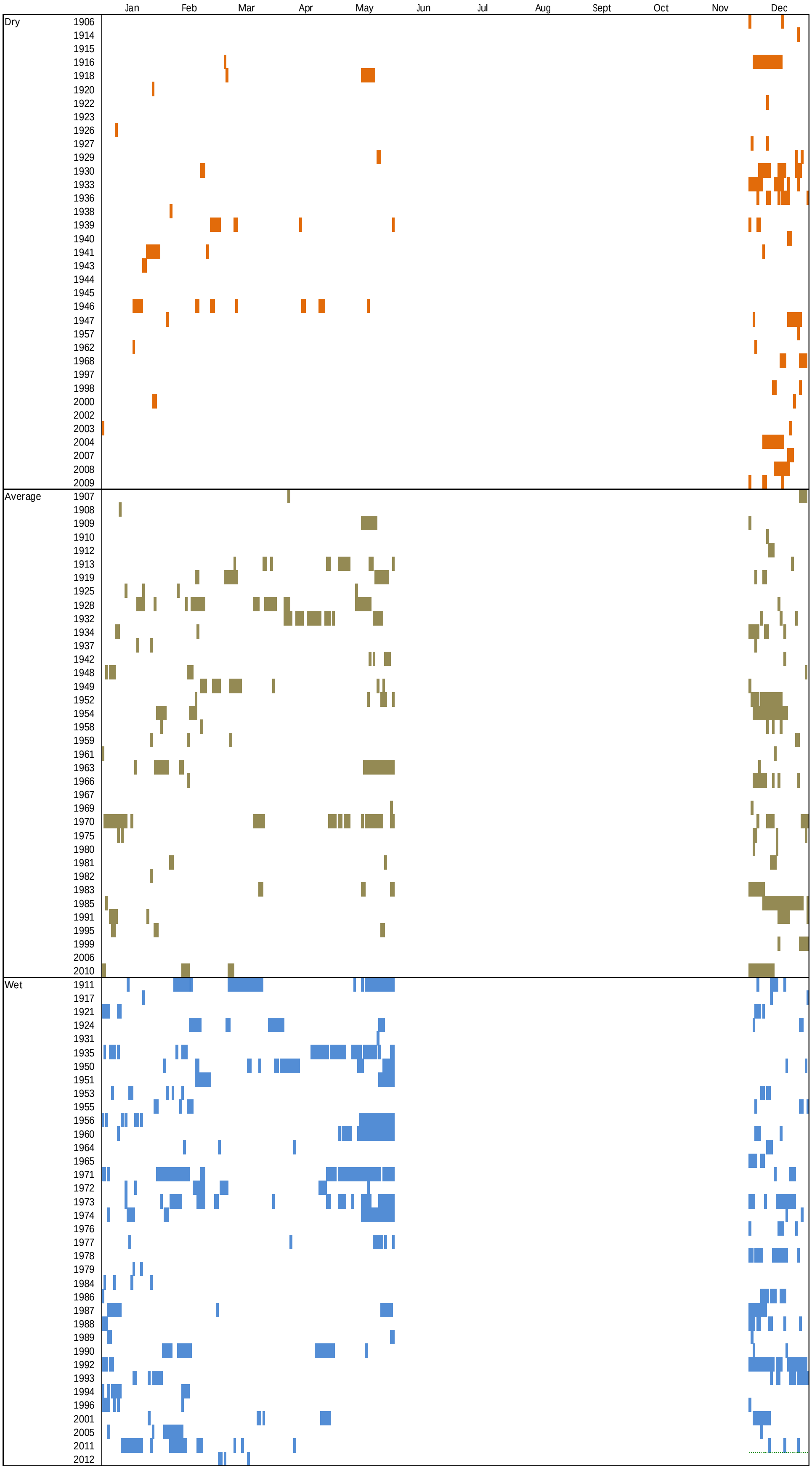


Figure 6-16: Spells of 215 ML/day or above for the unimpacted flow regime

6.7.3 Winter low flow

A higher baseflow is needed in winter to maintain a clear flow path and control the spread of terrestrial vegetation into the middle of the channel, especially in the braided section of the reach downstream of Bungey's Hole. Having a winter low flow that is noticeably higher than the summer low flow will also help to increase the diversity of littoral plants near the channel margin and may encourage woody shrubs such as Woolly Tea Tree and River Bottlebrush and a variety of sedges (e.g. from the genera *Carex, Cyperus* and *Isolepis*) and different types of *Juncus spp* to grow. Moreover, the winter low flow will create more distinct vegetation zones up the bank with species that require frequent or prolonged inundation near the channel and species that can only tolerate occasional inundation higher up the bank. Higher winter flows will also allow fish and platypus to move more easily throughout the whole reach and will provide a cue to Platypus to build their nesting burrows higher up the bank.

Finally, the winter low flow may also be important for controlling the movement of the salt wedge in the estuary. Melbourne Water plans to review the estuary flow requirements and the results of that study may cause the winter low flow recommendation for Reach 9 to be further revised.

Ecological Associates (2005b) recommended a winter low flow of 81 ML/day or natural from May to December to a depth of at least 380 mm through two thirds of the riffles at the FLOWS assessment site. The migratory fish in the Werribee River are all small bodied species and can probably move through riffle habitats when flows are much less than 81 ML/day. However, it is important that the winter low flow is greater than the summer low flow to help maintain a clear flow path and to promote greater vegetation diversity. The hydraulic models developed for this study do not extend to the braided channels downstream of Bungey's Hole and therefore we cannot determine the specific flow magnitude required to clear a wider flow path through those channels. However, using the shallowest riffle at the FLOWS site as a surrogate for the narrow, shallow channels downstream of Bungey's Hole we see that a flow of 81 ML/day increases water depth by 16 cm and wetted width by 3.17 m compared to the summer low flow level (Figure 6-17). In the absence of more specific criteria, the winter low flow of 81 ML/day recommended by Ecological Associates (2005b) should be retained to increase channel wetted width and to encourage platypus to build their nests higher than the expected winter fresh level (i.e. the winter low flow should be less than 1 m below the height of the recommended winter fresh) see Figure 6-17. However, the winter low flow is probably less important than some of the other flow components recommended for this reach and therefore it may not be necessary to deliver a flow of 81 ML/day for all of winter.

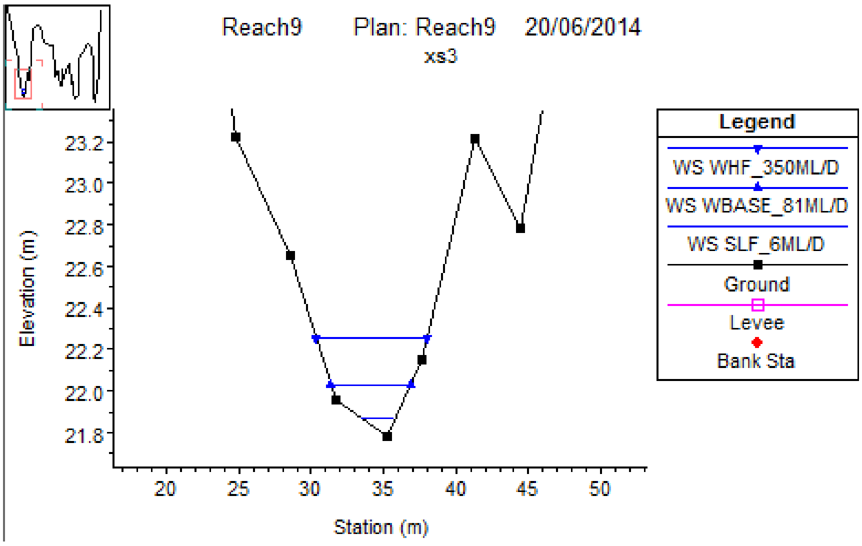


Figure 6-17: Cross section 3, a shallow riffle section showing the winter base flow of 81 ML/day, along with the summer low flow and the winter high flow.

6.7.4 Winter fresh

Winter freshes are needed to inundate vegetation on low lying benches in the main channel to promote the growth and recruitment of native woody riparian vegetation, cue and facilitate fish movement through the reach, and inundate depressions that may support frog breeding events. Ecological Associates (2005b) recommended five high flow freshes of 350 ML/day for five days between July and September and two high flow freshes of the same magnitude and duration between October and December.

We think the recommended magnitude for the winter fresh is appropriate. Our updated hydraulic models confirm that it inundates the low lying benches (see Figure 6-18 and Figure 6-19), and is also not too much higher than the winter low flow recommendation to flood Platypus burrows and nesting young. However, it may not be necessary to deliver seven events per year. In wet or average years, four events of three days each between June and November are likely to be sufficient to meet the ecological objectives for Reach 9. Two of these events should be between June and August to cue Tupong to migrate to the estuary to spawn. The other two events should preferably be between September and October to attract juvenile Common Galaxias to move into freshwater reaches and to water woody riparian vegetation such as River Bottlebrush, Woolly Tea Tree and Tree Violet during their main growing season. Fewer winter freshes would naturally occur in dry years and therefore it is only necessary to deliver 1-2 events in dry years. These should be spread out so that one is delivered between June and August and another is delivered in September or October. Having fewer freshes in dry years is likely to stress some riparian vegetation and may result in poor recruitment. Such an outcome is part of the natural cycle for aquatic ecosystems and is acceptable, provided some vegetation and fish recruitment occurs every 2-3 years and good recruitment occurs at least once every 4-5 years.

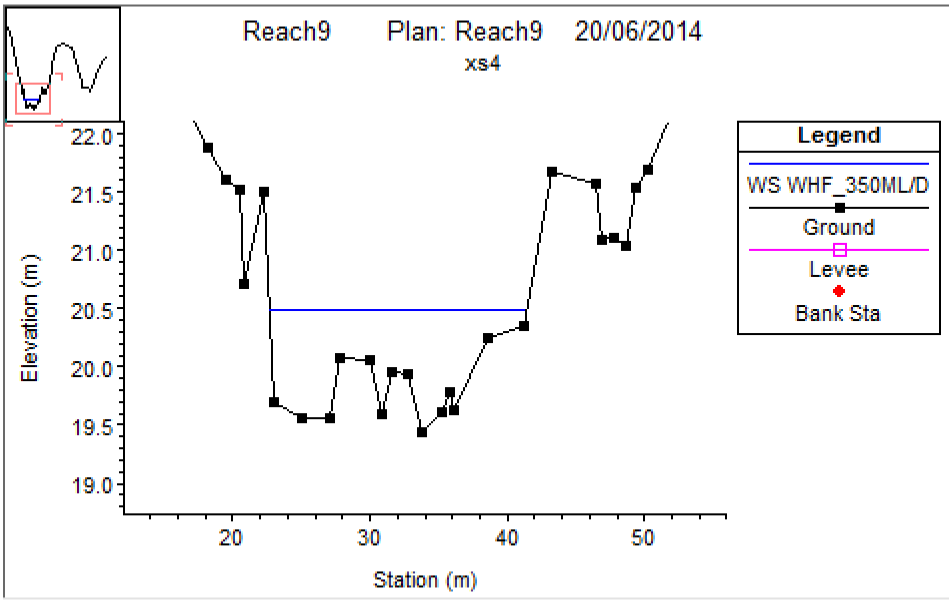


Figure 6-18: Winter fresh of 350 ML/day at cross section 4

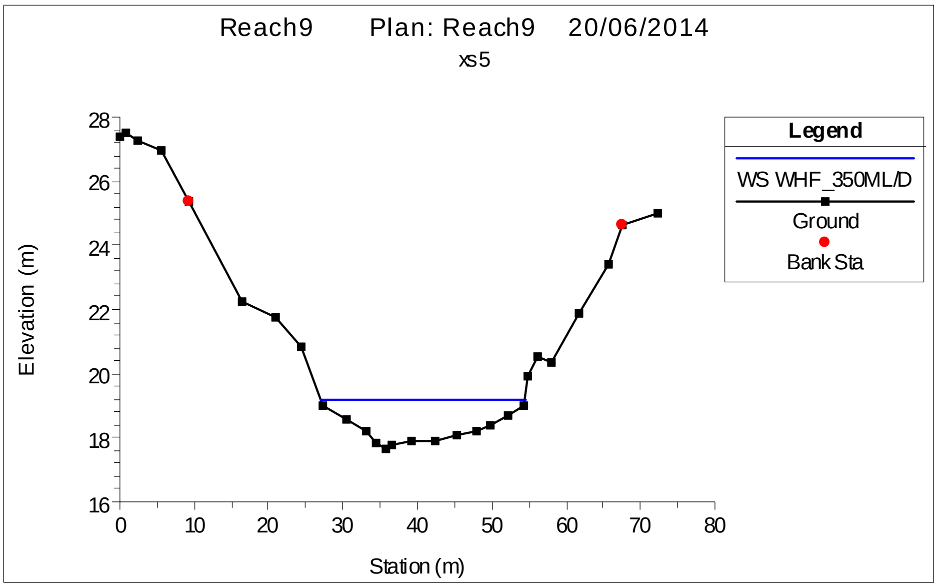


Figure 6-19 Winter fresh of 350 ML/day at cross section 5

6.7.5 High/Bankfull flows

A high or bankfull flow of at least 3,000 ML/day is recommended every two years on average to fill secondary high flow channels and billabongs within the main channel. A flow of 3,000 ML/day is considered the minimum magnitude for this event because it will exceed the invert at the upstream end of the secondary flow channel by 25 cm (see Figure 6-20). It will also create sufficient shear stress to scour pool habitats and therefore maintain channel form and dimensions. The high flows should last for two days to ensure the secondary flow channel and billabong completely fill and provide a connecting flow that will flush organic material out of these habitats. Flows greater than 3,000 ML/day will inundate more of the secondary flow channels and the island habitats in the main channel, which is likely to benefit riparian vegetation, geomorphic processes and biota that are likely to use billabong habitats.

High/Bankfull flows are not likely to be delivered with existing infrastructure and therefore their frequency and timing will be determined by natural events in the catchment. Flows of 3,000 ML/day will increase water depth in the main channel by approximately 1.09 m compared to the winter low flow. Such increases have the potential to flood Platypus burrows and could drown juvenile Platypus if they occur between late October and February. Platypus would not have good recruitment every year and therefore bankfull flows during the breeding season will not have a significant effect on the population as long as they don't occur in more than two successive years or they don't coincide with other stresses such as prolonged drought that will also affect recruitment.

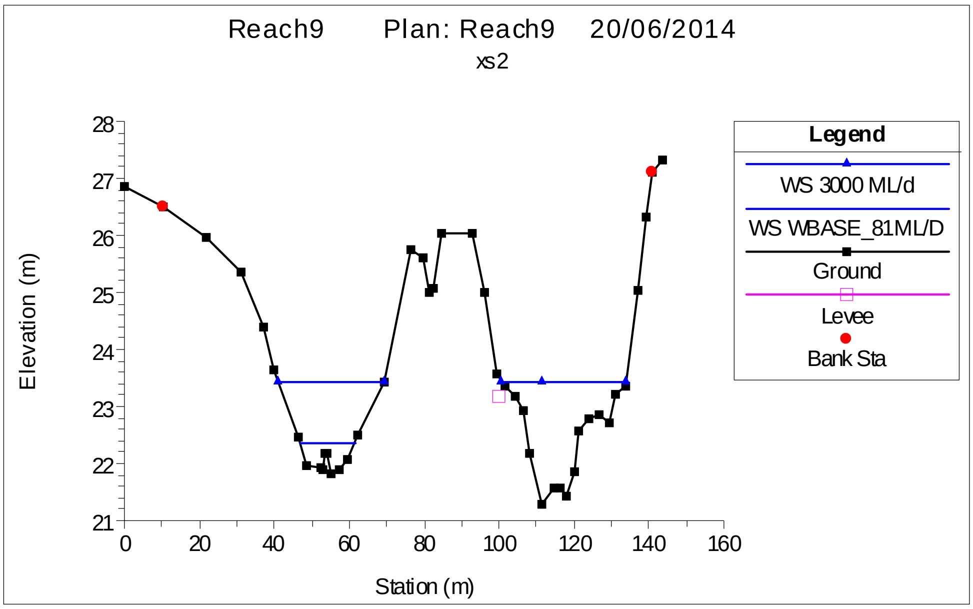


Figure 6-20: High/ Bankfull flow of 3000 ML/day at cross section 2 showing that this flow will inundate the secondary flow channel

6.8 Compliance

The recommended environmental flows are compared to the current flow regime as modelled in REALM by GHD (2014) to determine how well the flow recommendations for Reach 9 are currently met (Table 6-5). The REALM model overestimates flows in this reach (Figure 6-5), and therefore the recommended environmental flows are also compared to the gauged flow records (Table 6-6).

Both assessments include an ‘or natural’ clause, which considers the flows that would have occurred in the lower Werribee River under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation. The gauged flow record does not identify the flow that would have occurred under unimpacted conditions and therefore the GHD REALM model was used to estimate the flows that would have occurred under unimpacted conditions for both assessments.

6.8.1 Modelled current flow regime

Overall, compliance for the modelled current flow regime is relatively low for this reach. The summer and winter low flows comply 75 % and 69 % of the time respectively.

The summer fresh flow of 137 ML/day complies only 27 % of the time. The compliance assessment was based on the wet and average year recommendation for five events per year. Fewer events are needed in dry years and therefore the recommended flows may be achieved more often than 27 % of the time, but still not often enough to meet the environmental flow objectives for the reach.

The winter fresh is achieved 51% of the time. Fewer winter fresh events are required during dry years and therefore the overall level of compliance may be slightly higher than reported here. However, as with the summer fresh, more frequent winter freshes are needed to meet the environmental flow objectives for this reach

The bankfull flow is delivered as often as recommended because the infrastructure in the lower Werribee River cannot contain natural events of that magnitude.

Table 6-5 Compliance of environmental flow recommendations to the current flow regime for Reach 9

Component	Months	From	To	Flow Recommendation					Or Natural	Compliance
Summer low	Dec - May	12	5	Magnitude	6	ML/day			Yes	75%
Summer fresh	Dec - May	12	5	Magnitude	137	ML/day			Yes	27%
				Frequency	5	per year				
				Duration	1	days				
Winter low	Jun - Nov	6	11	Magnitude	81	ML/day			Yes	69%
Winter fresh	Jun - Nov	6	11	Magnitude	350	ML/day			Yes	
				Frequency	4	per year				
				Duration	3	days				
Bankfull	Jun - Nov	6	11	Magnitude	3000	ML/day			Yes	100%
				Frequency	1	in	2	years		
				Duration	2	days				

6.8.2 Gauged flow regime

The gauge period of record extends from 1997 to current. South-east Australia was in severe drought through more than half of that period and therefore we would expect compliance with the environmental flow recommendations to be lower than if the record covered a longer period and a higher proportion of years with average or above average rainfall. The compliance results based on available gauged data are presented in Table 6-6. The , but lower than those reported in Table 6-5.

Based on the available flow record, current compliance with the proposed environmental flow recommendations for Reach 9 is very low (see Table 6-6) and is much lower than the compliance based on the modelled REALM flow regime described in the previous section. The recommended summer low flow recommendation is met only 14% of the time and the recommended winter low flow is met only 5% of the time.

The recommended summer fresh of 137 ML/day is only met 18 % of the time. The compliance assessment was based on the wet and average year recommendation for five events per year. Fewer events are needed in dry years and therefore the recommended flows may be achieved more often than 18 % of the time, but still not often enough to meet the environmental flow objectives for the reach.

The recommended winter fresh is achieved 29% of the time. Fewer winter fresh events are required during dry years and therefore the overall level of compliance may be slightly higher than reported here. However, as with the summer fresh, more frequent winter freshes are needed to meet the environmental flow objectives for this reach

The recommended bankfull flow is delivered 67% of the time. This result is most likely because the available data record includes such a long period of drought. The infrastructure in the lower Werribee River cannot contain or specifically deliver bankfull flows and therefore these events probably still occur at a relatively natural frequency.

Table 6-6 Compliance of environmental flow recommendations to the gauge flows for Reach 9

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance
Summer low	Dec - May	**12**	**5**	Magnitude	**6**	ML/d	**Yes**	*14%*
Summer fresh	Dec - May	**12**	**5**	Magnitude	**137**	ML/d	**Yes**	*18%*
				Frequency	**5**	per year		
				Duration	**1**	days		
Winter low	Jun - Nov	**6**	**11**	Magnitude	**81**	ML/d	**Yes**	*5%*
Winter fresh	Jun - Nov	**6**	**11**	Magnitude	**350**	ML/d	**Yes**	*29%*
				Frequency	**4**	per year		
				Duration	**3**	days		
Bankfull	Jun - Nov	**6**	**11**	Magnitude	**3000**	ML/d	**Yes**	*67%*
				Frequency	**1**	in **2** years		
				Duration	**2**	days		

7. Review of environmental flow recommendations for Reaches 4 and 5: Werribee River from Pykes Creek to Lerderderg River

7.1 Reach description

Reach 4 extends from the Pykes Creek confluence to the Bacchus Marsh Weir and includes the Werribee Gorge. The morphology of Reach 4 varies between a narrow (2-15 m wide bed), steep sided bedrock gorge; fast flowing riffle and runs, and pools up to several hundred metres long. The pools have varying depth and are thought to be supplemented by groundwater during periods of low flow (Ecological Associates, 2005a). The steep rocky banks have helped preserve the morphology of the channel through the Werribee Gorge section, but there is limited woody debris in the channel, which may be due to a combination of high velocity flow and land clearing in parts of the catchment (Ecological Associates, 2005a).

Reach 5 extends from Bacchus Marsh Weir to the confluence with the Lerderderg River. The river channel at the 2005 FLOWS site is approximately 2 – 5 m wide and meanders through an alluvial plain that is bounded on one side by bedrock. The stream morphology in this area is course riffles and pools separated by runs (Ecological Associates, 2005a). There is limited woody debris providing habitat in this reach, although it likely would have been present naturally (Ecological Associates, 2005a). There is some evidence that the reach may have been straightened and channelised to aid drainage during the agricultural development of the region.

7.2 Environmental objectives for Reaches 4 and 5

Melbourne Water's Healthy Waterways Strategy management objectives for the Werribee River between Pykes Creek and Melton Reservoir are to stabilise platypus populations, maintain fish diversity and abundance, maintain and improve riparian vegetation condition, maintain macroinvertebrate diversity and improve amenity (Melbourne Water, 2013). The main mechanisms that Melbourne Water can use to achieve these objectives are through improving instream habitat (including removing barriers to fish movement), improving flow, catchment management actions to reduce nutrient run-off to the river, fencing to exclude livestock, weed control (especially willow removal) and active revegetation of riparian corridors (Melbourne Water, 2013).

Melbourne Water currently has limited ability to control flow in Reaches 4 and 5 of the Werribee River, but has implemented several other catchment management works to help meet the main environmental objectives. Specific programs include re-introducing large pieces of wood to the Werribee River in the Werribee Gorge to improve habitat for River Blackfish and riparian revegetation, weed control and stock exclusion. The riparian management works are likely to be particularly effective if they can create near continuous vegetation corridors that allow frogs, birds and Platypus to move between suitable habitats. Improving the riparian vegetation will also help to filter nutrients and sediment from surface water run-off during high rainfall events and therefore maintain or improve water quality in the Werribee River.

7.3 Summary and review of existing flow objectives and flow recommendations

Ecological Associates (2005b) recommended an environmental flow regime for Reaches 4 and 5 to specifically maintain and/or improve habitat and connectivity for River Blackfish, food and nesting habitat for Platypus and to promote the growth of diverse riparian vegetation (see Table 7-1 and Table 7-2). Given Melbourne Water has little ability to control flow through these two reaches, we have not reviewed the hydraulic models for Reaches 4 and 5 as part of this project. However, we do review the environmental flow objectives and recommended flows for these reaches in light of new ecological information since 2005.

Table 7-1: Current environmental flow recommendations and objectives for Reach 4 – Werribee River from confluence of Pykes Creek to Bacchus Marsh Weir including Werribee Gorge (modified from Ecological Associates, 2005b).

Flow recommendations					Rationale / objective
Season	Component	Magnitude	Frequency	Duration	
Feb-April	Cease-to-flow	0 ML/day	2 per year with a minimum separation of 7 days	15 days each (30 days total per year)*	Curtail growing season of in-channel emergent macrophytes
Dec-May	Low flow	10 ML/day*	All years except extended drought	Residual time after other flows	Wet the perimeter of riffles to provide habitat for macroinvertebrates Maintain pool habitats for fish, macroinvertebrates and platypus Maintain water quality in pools Maintain natural hydrologic variability to maintain stable undercut banks and benches for fish and platypus.
Dec-Feb	Small freshes	13 ML/day*	2 per year with a minimum separation of 7 days	5 days	Provide longitudinal connection between pools to allow River Blackfish fry to disperse throughout whole reach
Dec-May	Large freshes	90 ML/day*	2 per year with a minimum separation of 14 days	1 day	Disturb in-stream emergent macrophytes to limit vegetation encroachment Mobilise gravels on the streambed in riffles
Jun-Nov	Low flow	29 ML/day*	All years	Residual time after other flows	Provide spawning habitat in pools for River Blackfish and adequate depth through riffles to allow adult River Blackfish to disperse between pools Inundate full wetted perimeter of channel to sustain macrophytes in the channel and at the channel margins and to provide foraging habitat for Platypus.
Jul-Nov	Freshes	245 ML/day*	4 in Aug-Sep 2 in Oct-Dec with a minimum separation of 5 days	2 days	Disturb in-stream emergent macrophytes to limit vegetation encroachment Inundate benches frequently in winter and spring and less frequently towards summer to promote the growth of riparian shrubs and macrophytes Mobilise gravels on the streambed in riffles and pools
Anytime	Bankfull flow	3,160 ML/day	Natural (1 in 2 years)	1 day	Rework sediment including gravels to maintain channel dimensions Disturb shrub vegetation on channel benches and emergent macrophytes in the channel

* Or natural if the natural magnitude or duration is less than what is specified.

Table 7-2: Current environmental flow recommendations and objectives for Reach 5 – Werribee River from Bacchus Marsh Weir to the confluence with the Lerderderg River (modified from Ecological Associates, 2005b).

Flow recommendations					Rationale / objective
Season	Component	Magnitude	Frequency	Duration	
Feb-April	Cease-to-flow	0 ML/day	2 per year with a minimum separation of 7 days	15 days each (30 days total per year)*	Curtail growing season of in-channel emergent macrophytes
Dec-May	Low flow	4 ML/day*	All years except extended drought	Residual time after other flows	Wet the perimeter of riffles to provide habitat for macroinvertebrates Maintain pool habitats for fish, macroinvertebrates and platypus Provide longitudinal connection between pools to allow River Blackfish fry to disperse throughout whole reach Maintain natural hydrologic variability to maintain stable undercut banks and benches for fish and platypus.
Dec-May	Freshes	12 ML/day*	4 per year with a minimum separation of 14 days	≥1 day	Maintain water quality in pools during low flow period Duration of event should be less than 5 days to avoid flushing fish from the reach
Jun-Nov	Low flow	18 ML/day*	All years	Residual time after other flows	Provide spawning habitat in pools for River Blackfish and adequate depth through riffles to allow adult River Blackfish to disperse between pools Inundate full wetted perimeter of channel to sustain macrophytes in the channel and at the channel margins and to provide foraging habitat for Platypus. Flush fine sediment and sand from streambed to maintain habitat quality for macroinvertebrates and Platypus
Jun-Nov	Freshes	141 ML/day*	1 per month	2 days	Disturb in-stream emergent macrophytes to limit vegetation encroachment Inundate shrub assemblages on benches to support growth in winter and spring. Mobilise sand throughout entire reach and gravels in riffles
Anytime	Bankfull flow	1,400 ML/day	Natural (1 in per year)	1 day	Rework sediment including gravels to maintain channel dimensions

Flow recommendations					Rationale / objective
Season	Component	Magnitude	Frequency	Duration	
Anytime	Overbank flow	3580 ML/day	1 in 10 years	1 day	Disturb shrub vegetation on channel benches and emergent macrophytes in the channel Rework sediment including gravels to maintain channel dimensions

* Or natural if the natural magnitude or duration is less than what is specified.

7.3.1 Water quality

Water pollution such as increased nutrient loads and toxicants to due agricultural or urban activities should be managed through activities that treat the cause of that pollution. The only water quality parameters that are typically influenced by changes in flow are dissolved oxygen, salinity and water temperature. Dissolved oxygen concentrations in the Werribee River at Bacchus Marsh have consistently remained above 5 mg/L at all flows since 2005 (see Figure 7-1) and is therefore not likely to represent a threat to aquatic biota (Koehn and O'Connor, 1990). Electrical conductivity in the Werribee River at Bacchus Marsh is usually less than the SEPP WoV trigger level in years with frequent high flow events, but rises to more than 6,000 µS/cm in dry years when flows fall below 1 ML/day for extended periods (see Figure 7-2). Adult River Blackfish can tolerate electrical conductivity levels up to 16,000 EC (Koehn and O'Connor, 1990), but larvae and juveniles are more sensitive and are likely to die if electrical conductivity is close to or greater than 10,000 EC (Bacher and Garnham, 1992). Southern Pymgy Perch cannot tolerate electrical conductivity greater than 6,000 EC (Chessman and Williams, 1974) and Mountain Galaxias cannot tolerate electrical conductivity greater than 2,500 EC (Koehn and O'Connor, 1990). In order to prevent electrical conductivity increasing to a level that is likely to threaten the native fish that live in the middle and upper reaches of the Werribee River we recommend that flow in Reaches 4 and 5 does not drop below about 4 ML/day for extended periods.

The current environmental flow recommendations for Reaches 4 and 5 of the Werribee River include short cease-to-flow periods, summer low flows of at least 4 ML/day and regular summer freshes to maintain water quality. These recommended flows are likely to prevent electrical conductivity rising above a level that will threaten native fish or aquatic macroinvertebrates and should therefore meet the flow related water quality objectives for these reaches.

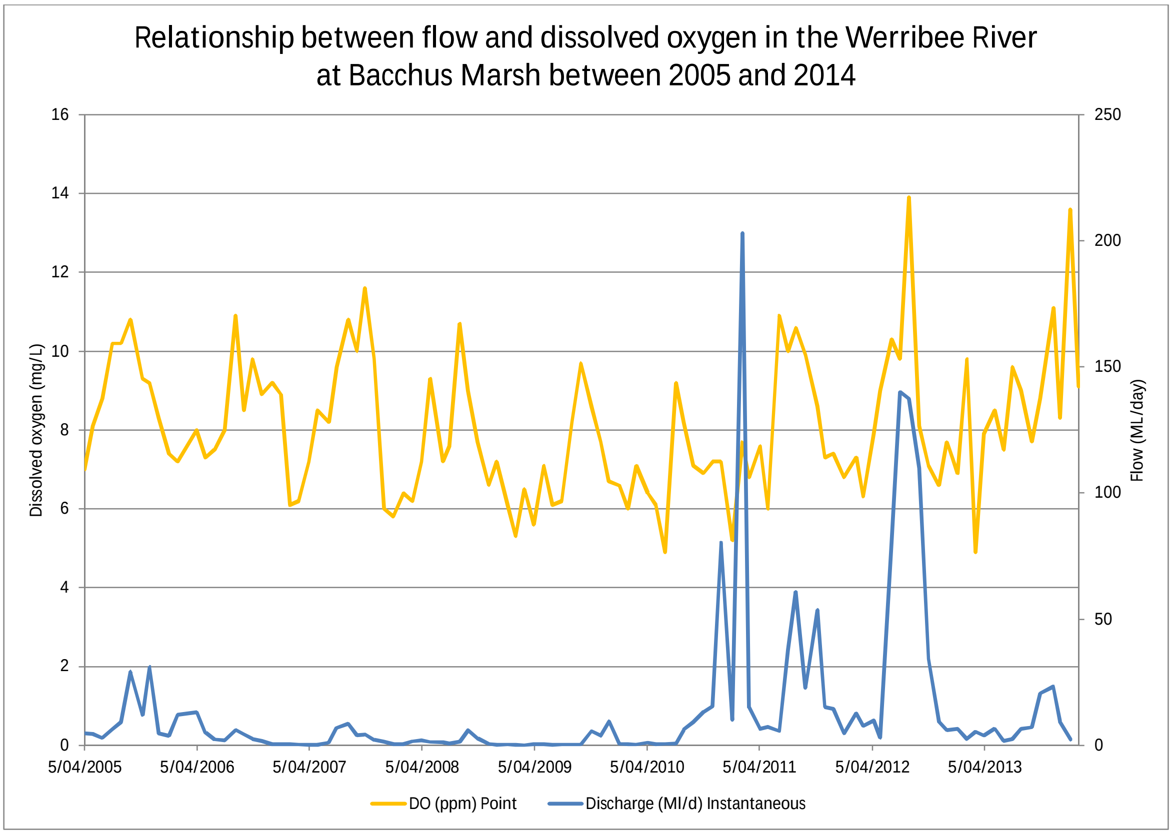


Figure 7-1: Time series showing the relationship between flow and dissolved oxygen in the Werribee River at Bacchus Marsh between 2005 and 2014.

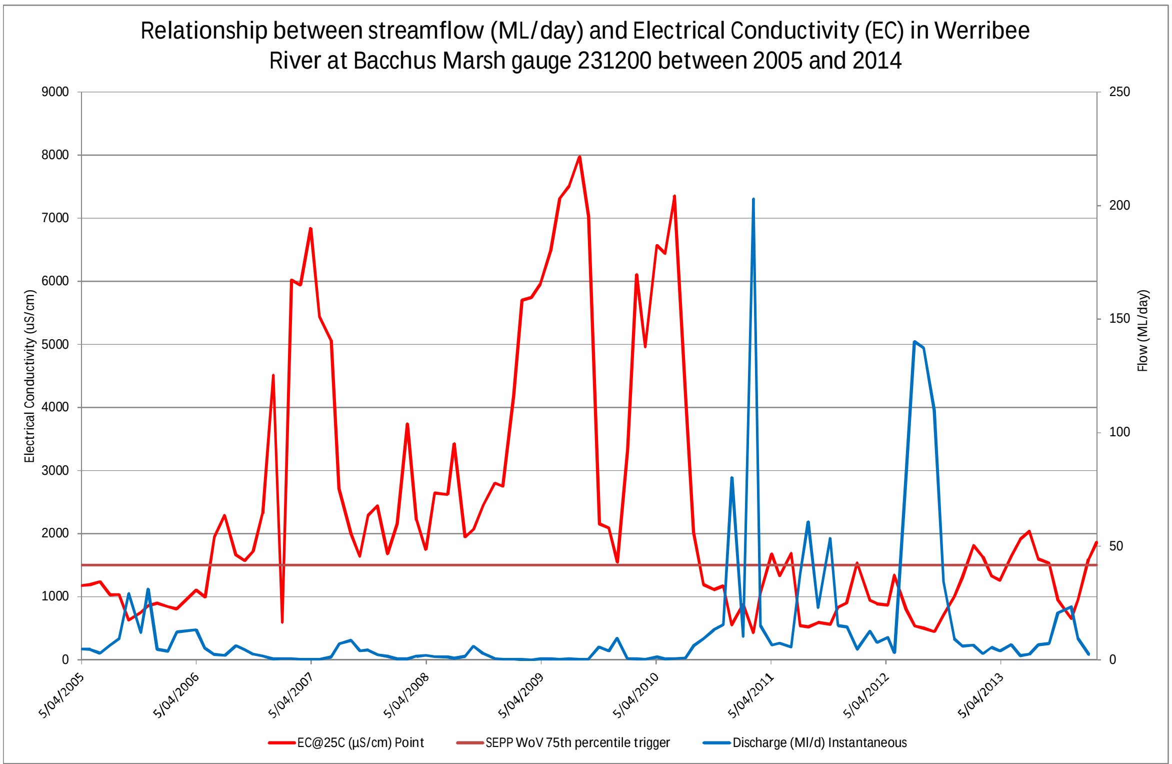


Figure 7-2: Time series showing the relationship between flow and electrical conductivity in the Werribee River at Bacchus Marsh between 2005 and 2014.

7.3.2 Geomorphology

Ecological Associates (2005b) recommended a series of low flows and freshes to mobilise gravel and sand on the streambed and bankfull and overbank flows to scour pools and re-work the streambed to maintain channel form. Without any updated hydraulic models, we cannot confirm or reject any of these recommended flows. In general, the overbank flows, bankfull flows and winter freshes will mobilise streambed elements and should help to maintain channel form, especially in the Werribee Gorge which is highly influenced by bedrock features. The recommended summer low flows are probably not sufficient to mobilise sand and gravel as suggested by Ecological Associates (2005b), but there are likely to be enough summer freshes and other high flow events to meet the geomorphological objectives for these reaches.

7.3.3 Fish

Reaches 4 and 5 of the Werribee River support a range of native fish species including River Blackfish, Mountain Galaxias, Spotted Galaxias, Flathead Gudgeon, Australian Smelt, Southern Pygmy Perch, Short-finned Eel, and provides suitable habitat for other species such as Common Galaxias and Climbing Galaxias (Ecological Associates, 2005a). Of these, Short-finned Eel is the only species that needs to migrate to the sea to complete its life cycle (Crook *et al.*, 2014). Common Galaxias, Australian Smelt and Climbing Galaxias will migrate to the sea if they have reasonable passage, but there are many examples of sustainable land locked populations where the larvae and juveniles develop in large lakes or reservoirs before moving further upstream (McDowall, 1996). Because most of the native fish species in the middle and upper reaches of the Werribee River can complete their life cycle in the same river reach, flow regime and the quality and quantity of available habitat will determine the abundance and condition of populations in each reach.

The Millennium Drought significantly reduced flow and habitat quality in Reaches 4 and 5 of the Werribee River. John McGuckin conducted extensive fish surveys in the Werribee River in 2006 and 2012 and concluded that although the same species were present in 2005 and 2012, the drought affected the relative abundance of each species (McGuckin, 2006, 2012). Mountain Galaxias, Flathead Gudgeon and Australian Smelt were more abundant and widespread in 2012 compared to 2006, while River Blackfish and Southern Pygmy Perch were much less abundant (McGuckin, 2006, 2012). These differences can be explained by the habitat requirements and mobility of each species. Mountain Galaxias cannot tolerate salinity levels greater than 2,500 EC (Koehn and O'Connor, 1990), and although salinity levels in some parts of the middle and upper Werribee River clearly exceeded that tolerance, Mountain Galaxias are able to disperse long distances and therefore individual fish would be able to move to refuge habitats as conditions declined and then disperse from refuge habitats to colonise other sections of the Werribee River when the drought ended (Dexter *et al.*, 2013). River Blackfish and Southern Pygmy Perch can tolerate higher salinity than Mountain Galaxias (Chessman and Williams, 1974, Koehn and O'Connor, 1990, Bacher and Garnham, 1992, Hart *et al.*, 1991, Tunbridge, 1988), but cannot disperse as far or as quickly and cannot readily move to escape very poor conditions (Dexter *et al.*, 2013). High salinity and a decline in the abundance and quality of submerged vegetation and submerged wood and increased siltation are likely to have caused some mortality and almost certainly reduced recruitment of River Blackfish and Southern Pygmy Perch in the Werribee River during the drought, and without a large source of potential colonists, these populations have been slow to recover. Environmental flows for Reaches 4 and 5 should aim to maintain suitable habitat and water quality for populations of native species that cannot readily disperse to refuge habitats, and provide good breeding conditions to optimise recruitment in years when sufficient water is available.

Ecological Associates (2005b) recommended minimum summer low flows and four summer freshes to maintain water quality and in-stream habitat for native fish in Reaches 4 and 5 and recommended higher winter low flows to allow native fish to move throughout the reaches as needed. We are satisfied that these flow recommendations will meet the water quality and habitat needs of resident native fish species and do not require any further modification. However, environmental flows alone will not significantly improve native fish populations in these reaches and efforts to reduce predation pressure from exotic species such as Trout and Redfin and to improve riparian vegetation and the diversity of logs in the stream are also needed. Werribee Gorge has a good, intact, riparian zone that provides shade and cover for native fish and occasionally contributes large wood to the stream. Recent works by Melbourne Water to re-introduce hollow logs to the Werribee River in Werribee Gorge should help to improve breeding habitats for River Blackfish. Recent willow removal works have temporarily increased disturbance and light levels in some sections of the Werribee River, but will ultimately improve habitat and cover as native riparian trees and shrubs grow.

7.3.4 Aquatic macroinvertebrates

The middle reaches of the Werribee River support a macroinvertebrate community that is near reference condition for this type of catchment, but shows signs of mild pollution. Such communities are relatively insensitive to changes in flow as long as riffle and pool habitats are maintained throughout the year (Dewson *et al.*, 2007, Miller *et al.*, 2007). The current environmental flow objectives for Reaches 4 and 5 of the Werribee River aim to limit the cease-to-flow period to no more than two events of up to two weeks each year and provide summer low flows and freshes that will maintain the quality and spatial extent of riffle habitats for the rest of the time (Ecological Associates, 2005b). Recent monitoring in Coimadai Creek has shown that prolonged low flows during summer can allow biofilms and filamentous algae to grow rapidly (SKM, 2012, 2014). The relatively high nutrient levels that occur in virtually all reaches of the Werribee River catchment mean that excessive biofilm and algal growth could reduce the quality of macroinvertebrate habitats throughout most of the Werribee River. The current environmental flow recommendations do not specifically address this issue, but the recommended summer freshes are probably frequent enough to clear filamentous algae from the substrate and prevent it from having a significant effect on the macroinvertebrate fauna. Overall, we conclude that the recommended flow regimes for Reaches 4 and 5 are likely to maintain the current condition of the macroinvertebrate community and therefore do not need to be modified.

7.3.5 Vegetation and aquatic plant communities

The section of the Werribee River that flows through Werribee Gorge has good native riparian vegetation and pools within the river support submerged and emergent vegetation. In contrast, Reach 5 supports limited in-stream vegetation and the riparian zone is very weedy.

Ecological Associates (2005b) recommended minimum low flows throughout summer to maintain submerged and emergent aquatic vegetation in Reaches 4 and 5; a series of freshes to water riparian vegetation on the lower sections of the river bank and in-stream benches and bankfull flows to disturb encroaching vegetation in the channel and shrubs on the banks. Based on our review of hydraulic models in Coimadai Creek, we suspect that the recommended freshes and high flows may not scour as much vegetation from in-stream habitats or the river bank as Ecological Associates (2005b) predict. However, bankfull flows should help to maintain a clear flow path through the whole reach and recommended freshes and high flows will help to encourage and maintain the growth of native riparian vegetation across a range of elevation zones in the channel.

Ecological Associates (2005b) recommended several short cease-to-flow periods each summer to limit encroachment of unwanted emergent macrophytes in the channel (Ecological Associates, 2005b). Soil around the roots of *Phragmites* and *Typha* will retain water for several weeks or months after flow ceases (Rogers and Ralph, 2011), and therefore the recommended cease-to-flow events are likely to be too short to limit the encroachment of these species. The cease-to-flow events that Ecological Associates (2005b) recommended are not needed for any other environmental flow objectives and while they are not likely to have an adverse effect on any environmental values, and may occur naturally in some years, we do not think they need to be specifically provided as part of a managed flow regime.

7.3.6 Platypus

The Werribee River between Pykes Creek and Melton Reservoir historically supported resident Platypus populations (Serena and Williams, 2008). Platypus numbers significantly declined throughout all of the Werribee River catchment during the Millennium drought (CESAR, 2012, 2013), and stabilising then growing the Platypus population throughout the Werribee River is a high priority (Melbourne Water, 2013).

Platypus require long pools with a minimum depth of 0.5 m for foraging and continuous flow through riffles and runs to allow them to move throughout their range without leaving the stream and therefore exposing themselves to predators such as foxes, dogs and cats (Serena and Williams, 2008). Juvenile Platypus cannot swim for their first 3-4 months, and therefore very high flows between September and February may drown the young in their burrows.

Ecological Associates (2005b) recommended minimum summer flows and winter flows to maintain foraging habitat for Platypus. Those recommended flows are expected to meet most of the flow requirements for Platypus, but they do not specifically consider the risk of high flows that could flood nesting burrows. We recommend that several freshes should be delivered in winter to encourage Platypus to build nesting burrows higher up the bank and to limit the magnitude of high flows between September and February to ensure they are no more than 1 m higher than the winter freshes.

7.4 Suggested changes to the existing environmental flow recommendations for Reaches 4 and 5 of the Werribee River.

We conclude that the existing environmental objectives for Reaches 4 and 5 of the Werribee River are sound and that most of the recommended environmental flows are adequate to meet those objectives. We recommend only two changes.

First, we do not think there is any need to provide a cease-to-flow period. Cease-to-flow events would probably not have occurred in most years under a natural flow regime and the recommended cease-to-flow period is too short to meet its stated objective of drying out *Typha* and *Phragmites* that are already growing in the channel and preventing further expansion of those plants. The recommended cease-to-flow is unlikely to harm any of the values identified in the middle reaches of the Werribee, but given it will not deliver any specific benefits, we suggest that it be removed.

Second, the current environmental flow recommendations do not specifically consider the risk that high flows or floods may have on juvenile Platypus. Stabilising and increasing the Platypus population in the Werribee River is a very high management priority, but high flows during the breeding season can flood burrows and drown juveniles. We think the environmental flow recommendations for Reaches 4 and 5 should include several high freshes in July or August to encourage female Platypus to build their nests higher up the bank to reduce the risk of being flooded if higher flows are delivered in spring or summer.

8. Review of environmental flow recommendations for the Lerderderg River

8.1 Reach description

The Lerderderg River rises on the slopes of the Great Diving Range, within the Wombat State Forest, and flows south, joining the Werribee River at Bacchus Marsh. The reaches upstream of Blackwood are densely forested. Downstream of Blackwood, the river flows through the deeply incised Lerderderg Gorge and consists primarily of pool-riffle sequences (LREFTP, 2002). The Lerderderg Gorge ends near Darley where the river flows through a short alluvial fan. Low discharges in this section of the river usually flow through the channel bed. The river re-forms into a defined channel downstream of the alluvial fan, with surface flow once again predominant (LREFTP, 2002). Sections of the Lerderderg River between the alluvial fan and the Werribee River have been straightened, de-snagged and isolated from the surrounding floodplain by artificial levee banks (LREFTP, 2002).

The main flow regulation on Lerderderg River occurs at Lerderderg Weir, which is used to divert a proportion of high flows to Merrimu Reservoir via Goodman Creek and Pyrites Creek. The Lerderderg Tunnel runs from Lerderderg Weir to Goodman Creek and has a capacity of 1,000 ML/day, which sets the upper limit for the volume that can be diverted from the Lerderderg River at any given time.

The Lerderderg River Environmental Flows Technical Panel (LREFTP) determined environmental flow requirements for the Lerderderg River and Goodman Creek in 2003. Their recommendations focussed on the Lerderderg River between the Lerderderg Weir and the downstream end of the Lerderderg Gorge (Reach 3) and the Lerderderg River between Darley and Bacchus Marsh (Reach 7). Summer low flows and winter low flows (up to 50 ML/day) in Reach 3 and Reach 7 are relatively unaffected by regulation, but the magnitude and frequency of higher flows has significantly decreased (LREFTP, 2003). In particular there has been a significant reduction in the magnitude of the 80th percentile flows in Reach 7 between June and September.

8.2 Environmental objectives for the Lerderderg River

The LREFTP (2003) identified the following environmental flow objectives for Reach 3 and Reach 7:

- To provide conditions suitable for native fish species including Mountain and Common Galaxias, River Blackfish, and Australian Grayling;
- to promote natural macroinvertebrate communities;
- To maintain and restore in-stream, bench and bank vegetation; and
- To maintain the geomorphic form of the channel (LREFTP, 2003).

The objectives for Mountain Galaxias, River Blackfish, Common Galaxias, macroinvertebrates, in-stream and riparian vegetation and geomorphology are compatible with the current objectives outlined in Melbourne Water's Healthy Waterways Strategy (Melbourne Water, 2013). However, Australian Grayling will not be able to move upstream past Melton Reservoir and therefore the objective for that species is redundant.

8.3 Summary and review of existing flow objectives and flow recommendations

The LREFTP (2003) recommended environmental flows for two reaches of the Lerderderg River downstream of the Lerderderg Weir to maintain habitat for fish, provide movement opportunities for fish, maintain instream and riparian vegetation and maintain geomorphic processes (see Table 8-1 and Table 8-2). Given Melbourne Water has little ability to control flow through the Lerderderg River, we have not reviewed the hydraulic models for Lerderderg River Reaches 3 and 7 as part of this project. However, we do review the environmental flow objectives and recommended flows for these reaches in light of new ecological information since 2003.

Table 8-1: Current environmental flow recommendations and objectives for Lerderderg River between Lerderderg Weir and the base of the Lerderderg Gorge (modified from LREFTP, 2003).

Flow recommendations					Rationale / objective
Season	Component	Magnitude	Frequency	Duration	
All year	Cease-to-divert flow	30 ML/day			Maintain depth of 0.4 m through pool/run habitats for fish and in-stream vegetation Maintain depth of 0.1 m through riffles for macroinvertebrates and Galaxiid movement Ensure natural cease-to-flow period is not extended.
June-Dec	High flow fresh	>150 ML/day*	5 per year including one in June and one in July for Australian Grayling	5 days	Inundate low benches at the margin of the channel to promote native riparian vegetation Flows in June and July aim to facilitate Australian Grayling migration and spawning.
June-Dec	Overbank flows	>1,500 ML/day*	3 in 4 years	At peak for 1 day	Inundate high benches and fill the width of the channel to the edge of the gorge walls to maintain stream dimensions and geomorphic processes.

Table 8-2: Current environmental flow recommendations and objectives for Lerderderg River between Darley and Bacchus Marsh (modified from LREFTP, 2003).

Flow recommendations					Rationale / objective
Season	Component	Magnitude	Frequency	Duration	
All year	Cease-to-divert flow	40 ML/day			Maintain depth of 0.4 m through pool/run habitats for fish and in-stream vegetation Maintain depth of 0.1 m through riffles for macroinvertebrates and Galaxiid movement Ensure natural cease-to-flow period is not extended.
June-Dec	High flow fresh 1	>580 ML/day*	4 per year including one in June and one in July for Australian Grayling if they occur naturally	2 days	Inundate low benches at the margin of the channel to promote native riparian vegetation Flows in June and July aim to facilitate Australian Grayling migration and spawning.
June-Dec	High flow fresh 2	>1,500 ML/day*	3 in 4 years	At peak for 1 day	Inundate high benches and fill the width of the channel to the edge of the gorge walls to maintain stream dimensions and geomorphic processes.
Any time	Overbank flow	>4000 ML/day	1 year in 2	At peak for 1 day	Fill the channel to maintain channel dimensions and scour riparian vegetation. Note levees isolate the floodplain from the Lerderderg River and this flow does not aim to water the floodplain.

8.4 Evaluation of existing flow objectives and flow recommendations

8.4.1 Water quality

Water quality in the Lerderderg River is likely to vary as a function of flow. When the river is flowing (i.e. in winter, spring and early summer) water quality is likely to be very good. As flow drops and the river contracts to a series of isolated pools, water quality is likely to deteriorate. In particular dissolved oxygen levels will probably fall and salinity and water temperature are likely to rise. These seasonal patterns are a natural aspect of ephemeral streams and do not need to be mitigated unless water harvesting prolongs the duration of cease-to-flow periods or reduced the magnitude of very low flows.

The existing recommendation to pass all flows up to 30 ML/day at Lerderderg Weir will preserve the natural cease-to-flow period and the natural summer low flow magnitude and therefore maintain water quality in Reach 3. Water quality in Reach 7 is likely to be slightly worse than Reach 3 because the floodplain is used for agriculture and urban development, which are likely to contribute higher nutrient and suspended sediment loads to the river. Those issues should be addressed through better land management practices rather than environmental flows and therefore the environmental flows for Reach 7 are also considered adequate for water quality objectives.

8.4.2 Geomorphology

The LREFTP (2003) recommended overbank flows in Reach 3 and a combination of high flows and overbank flows in Reach 7 to turn over the streambed and maintain channel form. Those flow components are typical of what is needed to disturb the streambed, scour pools and refresh low channel benches and while we have not specifically reviewed the accuracy of the hydraulic models the LREFTP used, the recommendations seem reasonable. Moreover, most of the Lerderderg River is controlled by bedrock and the morphology is unlikely to change over any foreseeable management period. Therefore as long as flows are sufficient to periodically turn over the cobble streambed, the geomorphological objectives for the river should be met.

8.4.3 Fish

The Lerderderg River currently supports populations of Common Galaxias, Mountain Galaxias, Short-finned Eel, Australian Smelt and Flathead Gudgeon (McGuckin, 2006, 2012). As with the upper Werribee River, Common Galaxiids in the Lerderderg River are likely to move downstream and spawn in Melton Reservoir if they cannot migrate all the way to the estuary (McDowall and Fulton, 1996). Most of the other native fish species are able to persist in permanent pools and/or migrate long distances under relatively low flow conditions to find suitable refuges as streams begin to dry up. The current environmental flow recommendations that cease diversions from Lerderderg Weir when flows drop below 30 ML/day aim to maintain a minimum depth of 0.4 m in pool and run habitats when the river would naturally have at least moderate flow and therefore maintain native fish habitat and access to that habitat at the same rate as under the unimpacted flow regime.

The main change that is recommended to the environmental flow objectives for fish relates to high flows to trigger Australian Grayling migration and spawning. The LREFTP (2003) acknowledged that Australian Grayling have not been recorded in the Lerderderg River for a long time, but suggested that they could use the lower reaches of the river if fish passage was provided through to the Werribee estuary. On that basis they recommended that if fish barriers were removed then two high flow freshes should be delivered in the Lerderderg River in June and July each year to trigger Australian Grayling to migrate downstream and spawn (LREFTP, 2003). Australian Grayling have not been caught in any reach of the Werribee River for a very long time (McGuckin, 2006, 2012) and even if they enter the estuary they are unlikely to move upstream of Melton Reservoir. Moreover, because much of the Lerderderg River is ephemeral, it is unlikely to provide viable habitat for Australian Grayling even if they could access it. The 4-5 high flows that the (LREFTP, 2003) recommend for the Lerderderg River will meet a range of vegetation and geomorphological objectives and should therefore be delivered. However, they are not likely to serve any purpose for Australian Grayling and therefore there is no need to deliver two of them in June and July.

8.4.4 Aquatic macroinvertebrates

The macroinvertebrate community in the Lerderderg River has been extensively studied under a range of flow conditions (Boulton and Lake, 1990, 1992a, b). Changes in flow have very little effect on the composition or condition of the macroinvertebrate unless there is a significant change in available habitat. For example, reducing a moderate flow to a low flow will have no effect, but a change from a low flow to no flow will result in the loss of taxa that rely on riffle habitats (Boulton, 2003, Stubbington *et al.*, 2009). Macroinvertebrates that typically live in pool habitats will be relatively unaffected unless water quality in remnant pools deteriorates markedly or the water level drops so far that the pool is no longer connected to fringing vegetation (Boulton, 2003, Stubbington *et al.*, 2009). The next step change occurs when remnant pools completely dry and the last step change occurs when the hyporheic zone dries (Boulton, 2003, Stubbington *et al.*, 2009). The macroinvertebrate community in the Lerderderg River has adapted to these changes. Some species seek refuge in permanent pools or the hyporheic zone as habitats dry. Some species have resting life stages (usually eggs) that can resist desiccation and other species have terrestrial life stages that allow them to fly to other waterbodies as the river dries. Each of these strategies enables macroinvertebrates to tolerate dry conditions and quickly recolonise the whole stream channel when flows resume.

The Lerderderg River would naturally cease-to-flow for a period in all but the wettest years. The recommendation to pass all flows up to 30 ML/day downstream of the Lerderderg Weir ensures that water extraction will not increase the frequency or prolong the duration of natural cease-to-flow events in Reaches 3 and 7 and therefore should be adequate to maintain the current macroinvertebrate community in both reaches.

8.4.5 Vegetation and aquatic plant communities

Reach 3 of the Lerderderg River supports predominantly native instream and riparian vegetation, although the flow diversions from the Lerderderg Weir have reduced the frequency of medium and large freshes through the reach, which have allowed bank vegetation to become quite dense in some places (LREFTP, 2002). Reach 7 is more heavily influenced by adjacent agricultural and urban land development and as a result has a much higher proportion of weeds and willows in the channel and on the river bank (LREFTP, 2002).

The Lerderderg Weir still spills during very high flow events and delivers scouring bankfull flows through all reaches of the lower Lerderderg River. These very large flows help to maintain a clear flow path in the Lerderderg River and prevent the channel from being choked by *Phragmites, Typha* and woody shrubs such as tea tree as has occurred in Coimadai Creek. However, fewer freshes and high flows have probably reduced the diversity of riparian vegetation and allowed terrestrial species to colonise lower sections of the channel. The cease-to-divert flows that are recommended for Reach 3 and Reach 7 should be adequate to maintain native aquatic plants in permanent pools and allow semi-aquatic plants to grow in run habitats when flow is present. The combination of high flow freshes, bankfull and overbank flows that the LREFTP (2003) recommended should also improve the diversity of riparian vegetation and reduce the density of terrestrial plants on the river banks in Reach 3. Active weed management and willow removal are probably needed to significantly improve the composition and condition of riparian and aquatic vegetation in Reach 7.

The existing environmental flow recommendations for Lerderderg River are considered appropriate for riparian and instream vegetation.

8.4.6 Platypus

The LREFTP (2003) did not specify any flow objectives or set flow recommendations for Platypus. Platypus are not expected in Reach 7 of the Lerderderg River, because it is ephemeral. However, numerous Platypus were recorded in the Lerderderg River near Bacchus Marsh prior to 2000 (Serena and Williams, 2008), and CESAR (2013) suggested that the lower reaches of the Lerderderg River have suitable Platypus habitat.

Platypus require a minimum depth of 0.5 m through pool and run habitats to allow them to forage for food and move throughout their territory without exposing themselves to predators. The recommended cease-to-divert flow in Reach 7 aims to maintain a depth of 0.4 m in pool and run habitats. That depth is probably too shallow for Platypus. However, the cease-to-divert recommendation acknowledges that flows will naturally drop below 40 ML/day and will probably cease-to-flow in many years. We expect that Reach 7 will have too little flow for Platypus in summer and autumn in most years, but will provide good foraging habitat when it does flow. Platypus that have permanent burrows in the Werribee River near Bacchus Marsh may therefore move into the lower reaches of the Lerderderg River during foraging expeditions in winter and spring. Reach 7 has many pools that will be more than 1 m deep when there is flow and therefore the recommended flows are likely to be adequate for Platypus foraging expeditions provided there are relatively few sections of stream between the deeper pools that have water depth less than 0.4 m. Willows in the lower sections of the Lerderderg River are likely to reduce the suitability of Platypus habitat and foxes, cats and dogs are a major threat.

8.5 Suggested changes to the existing environmental flow recommendations for the Lerderderg River.

The existing environmental flow recommendations for the Lerderderg River are generally sound and if implemented should maintain and in some cases improve the condition of flow dependent values in the Lerderderg River. We suggest two revisions.

First, the environmental flow objective for Australian Grayling and the associated high flow recommendations in June and July to trigger their spawning and migration should be abandoned because Australian Grayling are not likely to use the Lerderderg River. The total number of recommended high flows should be retained to meet objectives for vegetation and geomorphology, but there is no need to deliver those flows in June and July. The timing of those high flows should therefore be determined by flow events in the upper Lerderderg River each year.

Second, the existing environmental flow recommendations do not specifically consider Platypus. The Healthy Waterways Strategy includes specific objectives to stabilise and then grow the Platypus population in the Werribee River (Melbourne Water, 2013). Flow throughout most of the Lerderderg River is too ephemeral to support resident Platypus populations, but animals that live in the Werribee River near Bacchus Marsh may move into the lower sections of the Lerderderg River to forage when there is sufficient flow. The existing recommendation to cease diverting water when flow in Reach 7 drops below 40 ML/day should allow Platypus to access parts of the Lerderderg River as often as they would under an unimpacted flow regime.

9. Complementary management actions

Environmental flows are an important way of improving the function of regulated rivers and the condition of the ecological values those rivers support. However, water harvesting, and associated changes to the flow regime, is one of many anthropogenic factors that affect Victoria's rivers. The recommended environmental flows described in this report will have limited effect unless other management actions are implemented to mitigate or minimise other non-flow related impacts. In the Werribee River, the main complementary works should address fish passage past artificial in-stream barriers, weed control and actions to reduce hydrological and water quality issues associated with historical and expanding agricultural and urban development. Specific actions to address these issues are briefly described below and are also highlighted in the Healthy Waterways Strategy (Melbourne Water, 2013).

9.1 Improving fish passage

There are many artificial barriers to fish movement throughout the whole Werribee River catchment. They include small concrete bars that drown out at relatively small flows, large diversion weirs such as the Lower Diversion Weir and Upper Diversion Weir that will only drown out during bankfull flows, and major dams such as Melton Reservoir and Merrimu Reservoir that will almost never drown out (see examples in Figure 9-1). The 9 km reach between the lower Diversion Weir and the Werribee Estuary has at least 10 potential migration barriers (McGuckin and Borg, 2013). All barriers represent a potential threat to native fish. Species that spend part of their life in freshwater and other stages of their life in the estuary or the sea will not be able to colonise the Werribee River or will have very low populations and only occur in the most downstream reaches. Migration barriers in upstream reaches may prevent fish from accessing refuge habitats during cease-to-flow events and also prevent recolonisation from refuges when flows resume, thereby reducing the overall ability of the fish community to cope with drought and other major environmental stresses.

Some of the large barriers in the Werribee Catchment, for example Lerderderg Weir have constructed fishways to improve fish passage under a range of flows (see Figure 9-2). Melbourne Water is also investigating a range of low cost options to improve fish passage on some small barriers in the lower Werribee River (Stefanie Wabnik, Melbourne Water, Pers. Comm.). If implemented those works should improve the abundance of existing fish populations in the Werribee River and potentially increase the diversity of native fish species, especially in the most downstream reaches.

Figure 9-1: Examples of fish barriers in the Werribee River catchment. Top left – Lower Diversion Weir (Werribee); Top right – small concrete barrier downstream of Bungeys Hole; Bottom left – Upper Diversion Weir (Bacchus Marsh); Bottom right – Lerderderg Weir (this structure has a vertical slot fishway to assist fish passage).

Figure 9-2: Lerderderg Weir (left) and vertical slot fishway (right)

9.2 Improving instream habitat for native fish

Most native fish require instream habitat such as submerged wood, rocks, undercut banks or overhanging vegetation to provide protection from predators, nesting sites and feeding habitat. Historical actions to straighten river channels and remove woody debris to improve hydraulic efficiency have reduced much of this habitat. Land clearing has also removed many of the trees along the riparian zone that would ensure an ongoing supply of new wood to the stream when they die. In some cases, willows have been planted in place of native riparian trees and while they frequently shed limbs, that wood does not provide good fish habitat and their roots take over and degrade other habitats. More information on willows is provided in the next section.

Melbourne Water is currently implementing a program throughout many of its waterways to re-instate submerged wood in rivers that have been cleared to provide habitat for native fish. They have already installed hollow logs in the Werribee River at the downstream end of the Werribee Gorge to provide nesting habitat specifically for River Blackfish (see Figure 9-3). That program should be extended in that reach and other reaches to increase the quality and quantity of habitat for native fish.

Figure 9-3: Photos showing information sign and an example of submerged wood that has been placed in the Werribee River to provide habitat for River Blackfish.

9.3 Weed control including willow removal

Lerderderg Gorge, Werribee Gorge and much of Coimadai Creek have a high diversity of native plants in their riparian zones. However, many other reaches of the Werribee River, particularly the sections that flow through Bacchus Marsh and Werribee have a high proportion of weeds. Environmental flows that frequently inundate the low banks of the channel will help to eliminate some weeds that cannot tolerate prolonged inundation, but weed control programs such as selective spraying and replanting with native species will be needed to significantly improve the proportion of native species in the riparian zone. Melbourne Water has already implemented some weed control programs throughout the catchment. For example they have sprayed Spiny Rush near Happy Valley on Coimadai Creek and have removed Peppercorn Trees and revegetated the banks of the river through Riverbend Park, near the lower Diversion Weir.

Willows are a major concern in some reaches. Their dense root masses change channel morphology and flow paths, reduce the quality and quantity of macroinvertebrate habitat and reduce burrowing sites for platypus. Moreover, they drop their leaves in winter, which delivers a large carbon load to the river at a time when there are few macroinvertebrates and other biota to process them. Most Australian native plants shed more leaves in summer and therefore the native macroinvertebrate fauna are more adapted to higher carbon loads in summer. Willows have been removed from some sections of the Werribee River near Bacchus Marsh and although their removal causes significant short term disturbance to the streambed, river banks and biota (McGuckin, 2012), the long-term benefits will outweigh the negative effects.

Future weed control and revegetation programs should specifically target the Werribee River downstream of Bungeys Hole, and sections of the Werribee River and lower Lerderderg River near Bacchus Marsh.

9.4 Reducing water quality impacts from agricultural and urban land

The main water quality risks in the Werribee River are high nutrient loads due to run-off from market gardens and other agricultural activities in the catchment and urban run-off from the ever increasing urban developments. Common effects of high nutrient loads include algal blooms in weir pools and excessive growth of filamentous algae, which can smother the streambed and reduce habitat and foraging opportunities for macroinvertebrates, fish and Platypus. These effects are often exacerbated during very low flow or cease-to-flow conditions, but water quality problems should be addressed at the source to prevent pollutants from entering the waterway rather than using environmental flows to dilute pollutants once they are in the river.

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