The Environmental Water Needs of the Werribee River:

Final Report - Flow Recommendations

Melbourne Water

100 Wellington Parade
EAST MELBOURNE VIC 3002

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ECOLOGICAL ASSOCIATES REPORT BN001-3D

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1.1 Introduction

Introduction

The objective of the Werribee River Environmental Flows Project is to recommend the flows required to achieve a 'healthy river ecosystem', as defined by the Victorian River Health Strategy (DNRE 2002b). The project applies the FLOWS methodology for determining environmental water requirements (DNRE 2002a).

This project follows the recent Victorian Government White Paper, *Our Water Our Future* (DSE 2004), that recognised that water in the Werribee River is fully allocated and that existing environmental flow provisions are inadequate. *Our Water Our Future* sets out a plan where the water saved through the use of recycled water in irrigation may be made available for environmental uses.

This report presents the final recommendations of the Environmental Flows Technical Panel (EFTP) that was established to undertake the project. The report recommendations the flows required to achieve specific ecological objectives and assesses the degree to which these flows are currently provided.

The Werribee River

The Werribee River is located approximately 40 km south-west of Melbourne and drains the southern slopes of the Great Dividing Range. It rises in the of Wombat State Forest and discharges to Port Phillip Bay at Werribee. It provides water for major irrigation districts at Bacchus Marsh and Werribee and for several urban and rural centres.

The river provides water to support a growing community of urban and industrial customers along with two major irrigation districts at Bacchus Marsh and Werribee and private diverters. To supply these significant demands, the catchment is highly regulated with a number of diversion weirs and reservoirs both on the main river channel and its tributaries.

As a result, the natural flow regime of the river has changed significantly. Flows within the regulated reaches reflect the demands of consumers. Flows in the winter-spring period are reduced while water is harvested. Flows are increased in the increased during the irrigation season, mainly between November and April. Diversion of the river flows to supply both irrigation and urban customers have resulted in a reduction of the mean annual discharge to approximately 58% of mean natural annual flow.

The threat to river health posed by changes in the flow regime provide the background to this investigation.

Adopted Methodology

This project applies the FLOWS method to determine environmental flows in rivers and streams in Victoria (DNRE 2002a). The steps involved in the application of the method are presented in Figure 1.

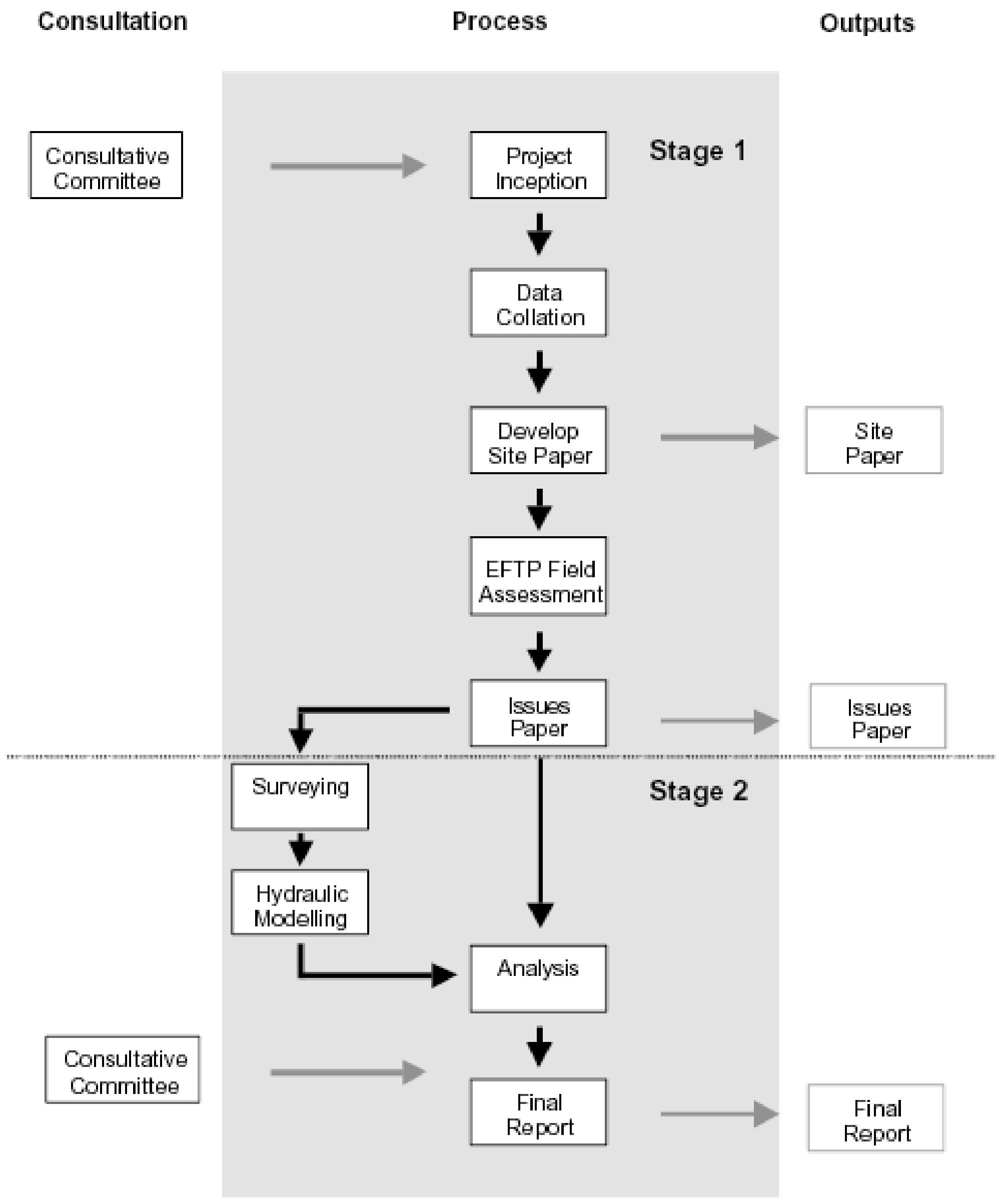

Figure 1. Flow chart illustrating the implementation of the FLOWS methodology. Note EFTP refers to the Environmental Flows Technical Panel (DNRE 2002a).

FLOWS assumes that the flow regime required to achieve the desired ecological condition in a river can be represented by a set of flow components. Flow components are defined in terms of the timing, duration and magnitude of flow events. Flow components are attributed to a representative set of ecological and physical characteristics and functions.

Stage 1 of the project was completed with the preparation of the Issues Paper (Ecological Associates 2005), which presented a conceptual model of the desired condition of the study area, and assessment of the current condition. This assessment was based on existing policy and strategy statements, a review of important physical and ecological values (or 'assets' in FLOWS) and a detailed field assessment. The conceptual model is formally articulated by relating the required status of the flow components to the intended condition of each environmental asset. Within each reach, representative sites were selected for further, detailed hydrological and ecological assessment in Stage II. The key findings of the Issues Paper are summarised in Section 2 of this report.

This report, the Flow Recommendations Report, concludes Stage II of the project. It provides specific recommendations for flows that must be provided to maintain or restore the health of the Werribee River. The recommendations are based on a detailed analysis of the behaviour of the river. A hydraulic model was used to relate river flows to the depth and width of flow at a number of representative sites. This information was used to make specific links between ecological and physical processes with particular river discharges. On this basis, quantitative flow recommendations were developed.

Stage II of the project has involved:

- physical survey of a representative site in each reach to support the development of hydraulic models;
- the development of hydraulic models for the surveyed sites to relate discharge to stream depth, width, velocity and shear stress;
- setting of quantitative objectives for river health;
- recommendations for a flow regime that will provide the defined environmental water requirements.

This report also includes a preliminary assessment of the degree to which the flow recommendations are achieved under the current management regime of the river.

Later investigations, which are beyond the scope of this project, will investigate the priority of the recommended flows and the ways and means in which they can be achieved.

It should be remembered that the environmental flow recommendations determined through the FLOWS method are produced without regard for operational considerations, or the current level of diversions from the river. There is no guarantee that the recommendations can be implemented with the current infrastructure and/or operation, or without any impact on security of supply.

The Study Area

The study area includes the Werribee River between Ballan and the estuary at Werribee. It includes two regulated tributaries, Coimadai (also known as Pyrites) Creek and Djerriwarrh Creek. It excludes the Lerderderg River which joins the Werribee at Bacchus Marsh, but has recently been assessed for environmental flow requirements in a separate study.

The study area was divided into reaches in which the physical and ecological characteristics of watercourses are relatively uniform. On the basis of biodiversity, surface hydrology, geology and geomorphology, nine reaches were adopted:

- Reach 1 - Ballan (Upstream of Upper Werribee Diversion Weir);
- Reach 2 - Pykes Creek (Pykes Creek from Pykes Creek Reservoir to the Werribee River);
- Reach 3 - Upper Werribee Diversion Weir to Pykes Creek;
- Reach 4 - Werribee Gorge (Werribee River from Pykes Creek to Bacchus Marsh Weir);
- Reach 5 - Bacchus Marsh (Bacchus Marsh Weir to the confluence with the Lerderderg River);
- Reach 6 - Coimadai Creek (Coimadai Creek below Lake Merrimu to Melton Reservoir);
- Reach 7 - Djerriwarrh Creek (Djerriwarrh Creek below Djerriwarrh Weir to Melton Reservoir);
- Reach 8 - Werribee River below Melton Reservoir (Melton Reservoir to Lower Werribee Diversion Weir); and
- Reach 9 - Lower Werribee Diversion Weir to estuary limit (downstream of the Maltby bypass).

The study reaches are presented in Figure 2.

Figure 2. Reaches Assessed in the Environmental Flow Assessment

1.2 The Environmental Flows Technical Panel

The determination of the environmental flow requirements of the Werribee River is being undertaken by the Werribee River Environmental Flows Technical Panel (EFTP) which comprises:

- Dr Marcus Cooling Plant Ecology
- Dr Chris Gippel Hydrology and Fluvial Geomorphology
- Dr Brett Anderson Hydrology
- Dr Nick O'Connor Aquatic Fauna Ecology
- Dr Melody Serena Platypus Ecology

The project is being reviewed by Dr Mike Stewardson of The University of Melbourne, who is a hydrologist and environmental flows expert.

The Panel's investigations have been assisted by the Steering Committee which comprises:

- Sarah Lamshed, Melbourne Water;
- Col Wilkie, Southern Rural Water;
- Phil Mitchell, Department of Sustainability and Environment (DSE); and
- Murray McIntyre, DSE.

Gary Howell (DSE) was a member of the Steering Committee in the early stages of the project.

2.1 Background

The following information is summarised from the Issues Paper (Ecological Associates 2005) and is presented here to provide context to the flow recommendations developed in this report.

2.2 Water Resources

The total amount of water diverted on average from the Werribee River is estimated to be 25.8 GL/yr. The Werribee and Bacchus Marsh Irrigation Districts account for 16.6 GL/yr (64% of total use), urban diversions account for 7.2 GL/yr (28% of total use), and a further 2 GL (8%) is accounted for by other uses.

In an average year, approximately 26 GL of water is diverted from the Werribee River, of which 64% is used for irrigation and 28 % is used by domestic consumers.

There are three major water storages.

Pykes Creek Reservoir is located near Ballan and lies on a tributary of the Werribee River and has a capacity of approximately 22 GL. Water is diverted from the Werribee River via a tunnel from the Upper Werribee Diversion Weir. The weir allows the first 5 ML of flow to pass downstream and diverts an estimated maximum flow of 310 ML/day. During the irrigation season, mainly from November to April, water is released from Pykes Creek Reservoir via Pykes Creek and the Werribee River to consumers at Bacchus Marsh and Werribee.

Merrimu Reservoir is located on Coimadai Creek and has a capacity of 32 GL. It provides a passing flow of 2 ML/d.

Melton Reservoir is located on the Werribee River below Bacchus Marsh and has a capacity of approximately 14 GL. Water is released to the river downstream to supply the Werribee Irrigation District during the irrigation season. A passing flow is released from May to August of 15 ML/day.

In addition to these structures weirs have been constructed at Bacchus Marsh and Werribee to facilitate the diversion of water to irrigators.

2.3 Physical and Ecological Characteristics

The upper catchment drains wet sclerophyll forest in the Great Dividing Range. Towards Ballan the river encounters the upper basalt plain and forms broader valleys with less steep grades. The river has a floodplain with deep basalt sediments which support predominantly exotic vegetation of Desert Ash, Willow, Gorse and Blackberry. The river has a 'Poor' Index of Stream Condition. There area has deep pools which provide habitat for macro-invertebrate communities and native fish including River Blackfish, Common Galaxid and Southern Pygmy Perch.

As the Werribee River approaches the steep drop in the landscape associated with the Rowsley Fault at Bacchus Marsh, the grade of the river increases dramatically, forming the steeply incised Werribee Gorge. A significant section of the gorge is protected in State Park and retains natural habitat features and has a 'Good' Index of Stream Condition. The riparian vegetation is diverse, and includes Red Gum and Blackwood, with an understorey of native shrubs and aquatic plants. The gorge has extensive riffles and deep pools which provide high quality habitat for native fish, platypus and invertebrates. Fish species recorded from this reach are River Blackfish and Shortfinned Eel, however the habitat appears suitable for Common, Mountain, and Climbing Galaxids and possible Southern Pygmy Perch.

The river reaches deep alluvial floodplain sediments in the outwash of the gorge at Bacchus Marsh. Originally a swamp, the floodplain has been drained, but retains sparse vegetation of Red Gum, Tea Tree and reeds along the stream bank. The reach has a 'Moderate' Index of Stream Condition, but provides habitat for native fish including River Blackfish, Shortfinned Eel, Mountain Galaxid, and Flathead Gudgeon.

Downstream of Melton Reservoir the Werribee River passes through a gorge which becomes progressively shallower as the river flows across the basalt plain towards the pool of the Werribee Diversion Weir at Werribee. Heavily infested by woody weeds for much of its length, this reach retains natural vegetation in areas as well as gravel riffles and pools. The river has an 'Moderate' Index of Stream Condition. Native fish species recorded from this reach include Shortfinned Eel, River Blackfish, Common Galaxid, Pouched Lamprey, Flathead Gudgeon, Tupong, and Australian Smelt. Other species that may have occurred in the past include Yarra Pygmy Perch, Dwarf Galaxid, Estuary Perch, Spotted Galaxid and Australian Grayling. The latter three species are probably prevented from inhabiting this reach by downstream barriers such as the Werribee Diversion Weir.

Downstream of the Werribee Diversion Weir, the river becomes a series of pools maintained by a small, constant release of water from the weir. It retains native woodland and shrubby vegetation, and supports a significant population of Platypus. The fish fauna recorded at this reach consists of Shortfinned Eel, Common Galaxid, Pouched Lamprey, Shortheaded Lamprey, Flatheaded Gudgeon, Tupong and Australian Smelt.

Coimadai Creek and Djerriwarrh Creek drain exposed bedrock and sandstone in subcatchments to the north, and meet the low-relief basalt plain where they join the Werribee River downstream of Bacchus Marsh. The ecology of these creeks is distinctive. In their lower reaches, these subcatchments have a relatively low rainfall and support Bull Mallee vegetation associations. The streams naturally flow intermittently and support plants and animals tolerant of dry periods and intermittent flow. The streams are infested by weeds in some areas and appear to have become more densely vegetated as a result of flow changes. Djerriwarrh Creek has a 'Poor' Index of Stream Condition.

2.4 Hydrology

Historical, natural and current flow data were prepared by Sinclair Knight Merz (SKM) for the Werribee River environmental flows assessment (SKM, 2004). The modelling was conducted for six locations:

- Werribee River at Ballan (231225)
- Werribee River at Bacchus Marsh (231200)
- Werribee River d/s Confluence with Toolern Creek
- Werribee River at Werribee (231204)
- Pyrites Creek d/s Merrimu Reservoir (231223)
- Djerriwarrh Creek d/s Djerriwarrh Reservoir

The hydrological model estimated daily flows over the period 1st May 1959 to 30th April 2000. Historical flows are flows actually occurring in the river, natural flows are flows that would have occurred in the river under conditions of no water resources development, and current flows are flows that would have occurred in the river under current levels of water resources development. The hydrology of the Werribee River has been altered by storages and diversions. For two of the sites (Bacchus Marsh and Coimadai), the natural modelled flows were compared with historical flows, because of difficulties in realistically modelling the pattern of daily flows released from storages. A modelled natural flow record was not available for Pykes Creek downstream of Pykes Creek Reservoir, so at this site only the historical flow record was analysed.

The impacts of regulation on flow indices are variable throughout the Basin (Table 1). In general, the most impacted sites are the Werribee River at Werribee, Coimadai Creek, Djerriwarrh Ck and Pykes Creek (by inference). These sites have been severely impacted across most hydrological indices (mean flow, median flow, flow duration, seasonality, cease-to-flow and flood frequency). Werribee River downstream of Toolern Creek and Pykes Creek have suffered seasonal flow reversal.

Table 1. Summary of the impact of regulation on hydrology, Werribee River and tributaries

Hydrological Index	Werribee River				Tributaries		
	D/S Upper Werribee Diversion Weir	Bacchus Marsh	D/S Toolern Ck	Werribee	Pykes Ck	Coimadai Ck	Djerriwarrh Ck
Annual discharge	-17%	-27%	-25%	-42%	No data	-38%	-83%
Median daily discharge	-30%	-59%	+29%	-80%	No data	Zero in both cases	Zero in both cases
Flow duration curves	Reduced full-range	Reduced full-range	Increased low range	Reduced full-range	No data	Severely reduced low range	Severely reduced full-range
Seasonal distribution – median flows	Reduced all months, esp. Jun to Sep	Reduced Winter-Spring, increased Sum-Autumn	Seasonal flow reversal	Reduced Winter-Spring, increased Sum-Autumn	Seasonal flow reversal	NA	NA
Seasonal distribution – cease-to-flow duration	No impact	Less common Summer, More common late Autumn	No change – never occurred naturally	Minimal change – never occurred naturally	Not common currently	Less common Summer and Autumn	Increased all months especially Winter
Cease to flow spells	No impact	Reduced duration	No change – never occurred naturally	Minimal change – never occurred naturally	Currently low frequency and duration	Reduced frequency, Much increased duration	Much reduced frequency, Much increased duration
Flow events ≤1 ML/d spells	Reduced duration	Much reduced frequency, Much increased duration	Increased frequency, Much reduced duration	Increased frequency, Reduced duration	Currently high frequency and very low duration	Reduced frequency; Much increased duration	Much reduced frequency, Much increased duration
Flood magnitude - partial series	Up to 30% reduction (for 0.5 yr ARI) - floods <1 yr ARI affected	Up to 50% reduction (for 0.5 yr ARI) - floods <2 yr ARI affected	Up to 52% reduction (for 0.5 yr ARI) - floods <5 yr ARI affected	Up to 54% reduction (for 0.5 yr ARI) - full range affected	No data	Major reduction across range, but less so near 0.6 yr ARI	Up to 99% reduction (for 0.5 yr ARI) - full range affected
Flood recession rates	Not analysed	Not analysed	Not analysed	Not analysed	Not analysed	Recessions much shorter	No significant change

2.5 Preliminary Biodiversity and Flow Objectives

Geomorphology

The aim of fluvial geomorphology is to describe and analyse landform features created by flowing water, and to develop an understanding of the ways in which surface processes operate and control the development of these landform. The geomorphology of rivers is mainly concerned with sediment erosion, transport and deposition.

The geomorphic objectives for this environmental flows assessment are to maintain or improve channel form and processes for ecological benefit, which includes maintaining:

- substrate type and diversity;
- presence of pools and riffles;
- channel shape including the presence of backwaters and undercut banks;
- presence of woody debris and riparian vegetation; and
- connectivity - the degree to which there is access for biota, organic material and sediments to move both along the river and laterally into floodplains and wetlands.

The Victorian River Health Strategy identifies characteristics of an ecologically health river. Aspects of this strategy of particular relevance to the geomorphic objectives are:

- that major natural habitat features are represented and are maintained over time; and
- that linkages between river and floodplain and associated wetlands are able to maintain ecological processes.

Geomorphic objectives are closely linked to those for riparian and aquatic vegetation, because of the role of vegetation in stabilising sediments. The geomorphic objectives are all connected to the processes of sediment mobilisation, transport and deposition, so High- and Low Flow Freshes and Bankfull Flow components are relevant (Table 2).

Table 2. Flow requirements to meet geomorphic objectives.

Geomorphic Objective	Main Flow Components
Movement of sand bed material to maintain bed morphological and hydraulic diversity	High Flow Freshes
Scour sediments from base of pools to maintain quantity and quality of pool habitat	High Flow Freshes
Prevent excessive macrophyte colonisation of the bed leading to channel capacity reduction and potential erosion	High Flow Freshes
Disturb riparian vegetation to provide new habitats and regeneration and to control riparian vegetation encroachment into stream channel (to prevent catastrophic erosion processes)	High Flow Freshes and Bankfull Flows
Maintain channel form and key habitats, including in-channel benches	High Flow Freshes and Bankfull Flows
Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones	Bankfull Flows
Scour surficial and interstitial fine sediment from riffles and overturn bed substrate (gravels and cobbles)	Low Flow Freshes (surface) and High Flow Freshes (interstitial)

Riparian zone condition is relevant to achievement of geomorphological objectives. Bank stability is partly related to the integrity, coverage and structure of riparian vegetation. The health of the riparian zone vegetation is partly reliant on appropriate environmental flows, but it is also dependent on non-flow related factors. Riparian zone vegetation can be affected by stock access and invasion by pest plant species (especially willows). The riparian zone is also the source of large woody debris, which interacts with the hydraulics and sediment dynamics in the channel to create habitat for various organisms. Stock access to the riparian zone can also directly affect bank stability and water quality, through pugging, trampling and other physical disturbance.

Vegetation

Reaches affected by summer flows, that are used to transfer water from storages to consumers, share a poor cover of aquatic and reedy riparian vegetation. The growth of these plants is limited by sustained high flows that inundate their habitat during the spring and summer growth period. This leads to a very narrow zone of riparian macrophytes near the upper extent of summer flows, which in turn contributes to potential for bank instability, poor riparian plant diversity and poor habitat for aquatic fauna. This impact is most pronounced in Pykes Creek, Bacchus Marsh and the Werribee River downstream of Melton Reservoir (data were unavailable to assess if the channels have been widened under the regulated flow regime, but bank erosion did not appear to be a prominent problem). The impact is less pronounced in the Werribee Gorge, where the steep and wide stream channel has a greater capacity to accommodate the transfer flows.

Several reaches feature very dense and continuous shrubby vegetation on the low in-stream alluvial benches. A mosaic of vegetation structures would be expected in a healthy stream ecosystem, including reed beds and grassland assemblages. The range of vegetation structures is related to diversity in the riparian plant community and promotes fauna diversity by providing a wider range of habitats. The high density of shrubby vegetation is most pronounced in Pykes Creek, Coimadai Creek, Djerriwarrh Creek and the Werribee River downstream of Melton Reservoir. Energetic, erosive bank-full flows are likely to be important by periodically removing patches of shrubby vegetation and providing colonisation opportunities for other plant assemblages.

The natural vegetation structure of Coimadai Creek and Djerriwarrh Creek is thought to be relatively open, with extensive sections of open rocky stream bed, and patches of reeds and shrubs around pools and seeps. In addition to the dense shrubs described above, reed beds occur extensively in Coimadai Creek. Dense reed growth (particularly Cumbungi and Common Reed) is generally associated with a stable shallow water level and is likely to reflect the artificial water regime created by seepage from the dam wall and small flow releases during summer and autumn. A more natural, diverse and open stream vegetation structure would require natural no-flow periods and occasional energetic erosive flows.

Biodiversity objectives and flow objectives for vegetation are presented in Table 3.

Table 3. Vegetation Biodiversity and Flow Objectives

Vegetation Biodiversity Objective	Main Flow Components
Maintain pools to support aquatic vegetation	All flows
Maintain in-stream bench soil moisture to support emergent vegetation	Low Flows
Create disturbance and patches in emergent vegetation to promote vegetation diversity	High Flow Freshes
Replenish floodplain soil moisture and trigger recruitment of floodplain vegetation	Bank-full Flows, Overbank Flows
Create broad riparian zone of aquatic macrophytes by gradually exposing bank over spring and summer	Gradually decreasing High Flow through to Low Flow
Inundate in-stream bench to promote riparian plant growth and submerged plants in pools and backwaters	Low Flow Freshes, High Flow Freshes
Promote open, diverse vegetation structure in stream bed	No flow period in Summer and Autumn

Platypus

Platypus are known to inhabit the Werribee River from the Estuary Limit to the Werribee River Gorge, and are also reliably predicted to live farther upstream where conditions are appropriate. The lack of surface flow for extended periods along Coimadai and Djerriwarrh Creeks means that these streams are unsuited to permanent occupation by the species.

Platypus mainly feed on benthic (or bottom-dwelling) macro-invertebrates. Although platypus can obtain food from the entire range of in-stream habitats, foraging is often concentrated in pools, along stably undercut banks, or around large woody debris. Backwaters are also highly favoured when available.

Platypus feed only in the water and become highly vulnerable to predators (including foxes, feral and domestic dogs, and the larger birds of prey) if they are forced to move across dry land. Their survival during periods of cease to flow relies entirely on the availability of large, permanent pools. Habitat features which contribute to the safety of platypus when travelling across riffles include dense vegetation overhanging the banks, and occurrence of enough water in the channel that the animals can remain submerged.

Platypus burrows are mainly found in more or less steeply vertical banks, particularly at sites where cover is provided by adundant overhanging vegetation. Young are confined to the nursery burrow for a period of 3-4 months after eggs hatch (in October or November). For platypus reproduction to succeed, it is essential that a nursing female be able to access aquatic feeding habitats around the nursery burrow entrance at least until the young can first be moved, in late January or early February.

The flow requirements of Platypus are presented in Table 4.

Table 4. Platypus biodiversity and flow objectives.

Platypus Biodiversity Objective	Main Flow Components
Scour sediments from base of pools and silt from riffles to maintain quantity and quality of feeding habitat	Low Flow and High Flow Freshes
Maintain water quality in permanent pools	Low Flow and Low Flow Freshes
Provide feeding habitat in backwaters and in-channel benches	High Flow Freshes
Disturb stream environment to create a diversity of habitats including deep pools, riffles, emergent vegetation and snags	High flow freshes and Bankfull Flows
Maintain quality of riparian habitat in in-channel benches	Low Flow and High Flow Freshes
Maintain and regenerate stable undercut banks for burrows and feeding habitat	Low Flow and High Flow Freshes

Fish

The Werribee River provides an extensive system of diverse fish habitats which have been somewhat compartmentalised by flow control structures. While some of the migratory habitat components of the system have been lost, the river maintains the potential to support a large and diverse community of native fish.

In most reaches, the provision of drought refuges are important to fish, which depend on scouring flows to maintain the depth of pools and low flows and freshes to maintain pool water levels. However, drought refuges may not occur in the Djerriwarrh Creek, which may be re-colonised after prolonged dry periods.

The flows that link the refuges provide the main aquatic habitat on which fish depend. A diversity of habitat components, such as deep water, fast flowing rocky reaches, submerged vegetation and reed beds are important to providing shelter from predators, a productive environment that provides prey and breeding opportunities. In general, the size of fish populations will increase with the extent of habitat. Occasional bank-full flows and overbank flows provide additional habitat in the riparian zone and off-stream pools.

Barriers to migration are an important feature of the Werribee River. Some moderate barriers (Werribee Weir, Bacchus Marsh Weir) and the large barrier at Melton Reservoir prevent the migration of fish between the sea and the upper tributaries and are likely to prevent re-establishment of species such as Spotted Galaxid and Australian Grayling. However, smaller barriers within the reaches are impediments to the movement of other fish. These barriers fragment populations and make local populations more vulnerable to disturbance.

There is little evidence that changes to river flow regimes can control exotic fish. However, research suggests that Mountain Galaxids may be more tolerant of low flow than Brown Trout, so cease to flow events in the upper reaches may be important in promoting native species

The flow requirements of fish are presented in Table 5.

Table 5. Fish Biodiversity and Flow Objectives

Fish Biodiversity Objective	Main Flow Components
Overcome low barriers to fish passage, including barriers within reaches and barriers to the estuary	High Flow Freshes
Overcome high barriers to fish passage	Overbank Flows
Promote native species that tolerate intermittent flows over exotic species that depend on sustained flow	Cease to Flow in upper reaches (upstream of gorge) and in Djerriwarrh and Coimadai Creeks
Sustain local fish populations by maintaining water level in permanent pools	Low Flow Freshes
Scour pools to provide refuges during cease to flow events	High Flow Freshes
Disturb stream environment to create a diversity of habitats including deep pools, riffles, emergent vegetation and snags	High Flow Freshes and Bankfull Flows
Scour pools to remove excessive macro-algal growth	High Flow Freshes
Provide flooded aquatic vegetation habitat	High Flow (in channel)
Provide breeding and sheltering habitat in backwaters and off-stream pools	Bankfull Flows and Overbank Flows

Macro-invertebrates

A variety of habitat components were identified as important to the structure and diversity of macro-invertebrate communities. The main stem of the river provides a diversity of pool, riffle and emergent vegetation habitats. Permanent pools support mature macro-invertebrate communities, particularly of larger predatory species such as Odonata (Dragonfly), which are prey for vertebrate fauna and also limit the abundance of smaller macro-invertebrates. Temporary pools are re-colonised when flow recommences and provide habitat for contrasting macro-invertebrate assemblages. Linkages between permanent and temporary pools are provided by freshes and are important to the overall distribution and population size of macro-invertebrate communities. The size of macro-invertebrate populations increases with the extent of available habitat, and bankfull flows and overbank flows, which inundate riparian vegetation, backwaters and off-stream pools, provide important opportunities for macro-invertebrate production and increase overall diversity.

The flow requirements of macro-invertebrates are presented in Table 6.

Table 6. Aquatic Macroinvertebrate Biodiversity and Flow Objectives.

Macroinvertebrate Biodiversity Objective	Main Flow Components
Maintain permanent pool levels to provide refuges for large predatory macro-invertebrates	Low Flows
Provide riffle habitat for benthic macro-invertebrate species	Low Flows and High Flow Freshes
Provide recolonisation opportunities following low flow periods	Low Flow Freshes and High Flow Freshes
Provide flooded aquatic vegetation habitat	High Flows (in channel)
Provide colonisation opportunities in backwaters and off-stream pools	Bankfull Flows and Overbank Flows
Disturb stream environment to create a diversity of habitats including deep pools, riffles, emergent vegetation and snags	High Flow Freshes and Bankfull Flows

Other Fauna

Brush-tailed Phascogale are small arboreal mammals that have a vulnerable conservation status in Victoria. They depend indirectly on the stream flow regime which sustains the hollow-bearing trees in which they live. They particularly depend on rough-barked trees such as Blue Box but also on hollow-bearing Red Gum.

Growling Grass Frog is considered vulnerable in Australia and endangered in Victoria. This species is associated with a mosaic of permanent and ephemeral ponds which are connected by drainage lines or swampy vegetation. Low Flows and High flows freshes which maintain swampy conditions in the riparian zone are likely to be important to this species.

Bibron's Toadlet is found near watercourses in forested areas. It depends on surface water to lay eggs and for tadpoles to develop.

Ecological objectives related to these species are presented in Table 7.

Table 7. Biodiversity and Flow Objectives for Other Fauna.

Ecological Objective	Main Flow Components
Maintain health of riparian habitat trees for Brush-tailed Phascogale	Low Flows
Restore diversity and density of riparian habitat trees for Brush-tailed Phascogale	High Flow Freshes
Scour stream bed to maintain pool habitat for frogs	Low Flow Freshes, High Flow Freshes
Maintain aquatic macrophyte growth for frog habitat	Low Flows, High Flow Freshes

3.1 Physical Survey

Cross-sectional surveys were undertaken of the seven selected reaches of the Werribee River and tributaries in March and April of 2005. At each reach between 6 and 8 cross-sections were surveyed at locations identified by pegs placed during field reconnaissance in Stage 1. Transects were selected so as to capture the principal features of each reach, particularly geomorphic features such as pools, riffles and runs, and hydraulic features including channel constrictions, expansions and hydraulic controls. These surveys, plus independent determination of hydraulic roughness, provided the data required to define the hydraulics of each reach using a one-dimensional flow model, that is: Northing; Easting; and elevation (measured relative to the Australian Height Datum (AHD)).

The surveys were delivered by Connell Wagner in both hardcopy and digital form. The digital data is included on the enclosed CD-ROM:

directory \ WerribeeHydraulics \ SurveyData

3.2 Hydraulic Analysis

The Hydraulic Analysis Report is provided in the accompanying CD ROM:

directory \ WerribeeHydraulics \ Hydraulic Analysis Report

The following provides a synopsis of the report.

Numerical hydraulic models were developed for each of seven focus reaches on the Werribee River. Two additional reaches (Upstream of Ballan and Pykes Creek) were qualitatively assessed in the Issues Paper, but hydraulic analysis of these reaches was not included this project. Hydraulic analysis provides an efficient means to estimate the relationship between flow depth, width, velocity, shear stress and discharge for each reach. For this project models were constructed using the HEC-RAS software (U.S. Army Corps of Engineers, 2004), which is designed to perform one-dimensional steady state calculations for natural and artificial or modified river reaches. Three components are required to define a river reach within HEC-RAS: reach geometry; a downstream boundary condition; and a specification of hydraulic roughness.

Downstream boundary condition

The flow scenarios examined during this analysis were restricted to sub-critical flows, hence only a downstream boundary condition was required (Chow, 1959). Given the information available, normal depth was specified as the downstream boundary condition, applying the so-called ‘Slope-Area Method’ (Sturm, 2001). Under this condition the flow depth at the outlet is determined by the geometry of the outlet cross-section, the roughness coefficient, and the local water surface slope. Water surface slope was generally unavailable so the bed slope was used as an estimate.

The uncertainty associated with the specification of the downstream boundary condition revolves principally around errors in the value of roughness and the water surface slope. A sensitivity analysis was conducted where both of these parameters were perturbed around the best-estimate value. The results of this investigation are described in detail in the Hydraulic Analysis Report, however two principal conclusions were drawn:

- reaches of low slope are more sensitive to errors in the downstream boundary condition than reaches of higher slope; and
- uncertainty in the value of the friction factor is the key determining factor in the accuracy of predicted water surface profiles.

Therefore, the impact of uncertainty in the specification of hydraulic roughness is reported explicitly for the one-dimensional simulations presented herein.

Estimation of hydraulic resistance: Manning's n

Hydraulic resistance (also called 'stream roughness') is a measure of the friction generated between flowing water and the channel boundary. The magnitude of resistance determines the discharge at which different channel features are inundated, dictating how much flow is required to wet a vegetated bench or for flooding to commence.

It is generally accepted that the greatest uncertainty in one-dimensional hydraulic modelling is associated with estimating the value for the roughness coefficient (Aronica et al., 1998; Burnham and Davis, 1986; Coon, 1998; Western, 1994). There is no single 'best' tool, technique or equation, as numerous studies have demonstrated (Coon, 1998; Lang et al., 2004; Phillips and Ingersoll, 1998). A procedural method that builds on the recommendations of Coon (1998) was developed for assessing the roughness of each of the seven reaches assessed for in the Werribee River FLOWS study.

The accuracy to which roughness may be estimated depends primarily on the experience of the practitioner and is aided by use of various roughness estimation tools. There are four standard types of tools used to estimate the resistance of natural rivers and streams; they are: (i) procedural approaches; (ii) roughness tables; (iii) using roughness handbooks; and (iv) empirical or theoretical equations. For this project six different tools were employed, giving six Manning's n values (n_1, n_2 … n_6). The average of these estimates was selected as the 'best' estimate of reach roughness, and the spread of the values was used to estimate the likely error associated with the 'best' estimate. Details of the tools used and commentary describing their application to Reach 3 (Upper Werribee Diversion Weir to Pykes Creek) can be found in the Hydraulic Analysis Report.

3.3 Results of Hydraulic Analysis

A series of standard outputs were compiled for each reach. A sample of the output is presented here for Reach 3, Werribee River upstream of Bacchus Marsh.

Table 8. List of hydraulic analysis outputs produced for each of the surveyed reaches.

Hydraulic Analysis Output
Plan view of the site with each of the surveyed cross-section labelled.
List of geometric properties associated with bankfull channel stage at each cross-section, including: flow area, A; top width, B; and hydraulic radius, R.
Longitudinal profile of the reach showing the elevation of the ground at the thalweg (deepest point across the channel) and a simulated water surface elevation at a very low discharge (WS).
Summary of the development of the estimate of in-channel Manning's n for the reach (a short description of the selection of a separate floodplain roughness value is also given, if applicable).
Summary of hydraulic characteristics computed for Site 3 [at cross-section 6 (146.7m)]. There are four charts: a cross-section plot; a stage:discharge chart; a magnified cross-section plot; and a stage:shear stress chart. Various thresholds and flow depths associated with the hydrologic regime are also shown.
List of thresholds associated with sediment entrainment and vegetation removal, with the discharge estimated to breach each threshold listed in the final column.

These products were used by the EFTP to quantify each component of the environmental flow regime (low flows to overbank floods) developed at the two-day workshop.

Sample hydraulic results: Site 3 – Werribee River upstream of Bacchus Marsh

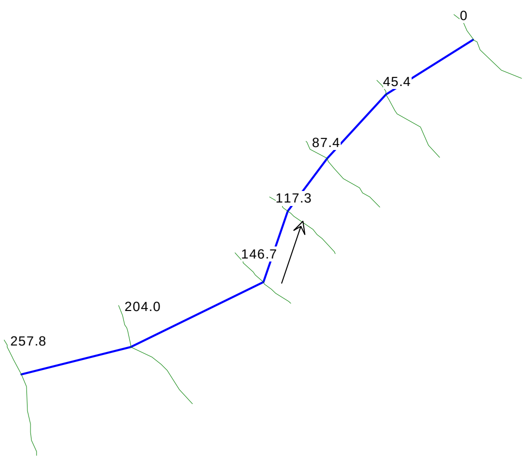

Figure 3. Plan view of Site 3 with cross-section labels giving distance(m) upstream of the reach outlet.

Table 9. Summary of bankfull parameter values (estimated from survey data).

XS	Distance (m)	Estimated Bankfull Parameters A (m^2)	B (m)	R (m)
3-7	257.8	16	14	1.1
3-6	204.0	22	26	0.8
3-5	146.7	19	15	1.2
3-4	117.3	3	6	0.6
3-3	87.4	9	17	0.5
3-2	45.4	11	13	0.8
3-1	0.0	11	11	0.9
Reach average:		13	15	0.9
Std. deviation:		6	6	0.3

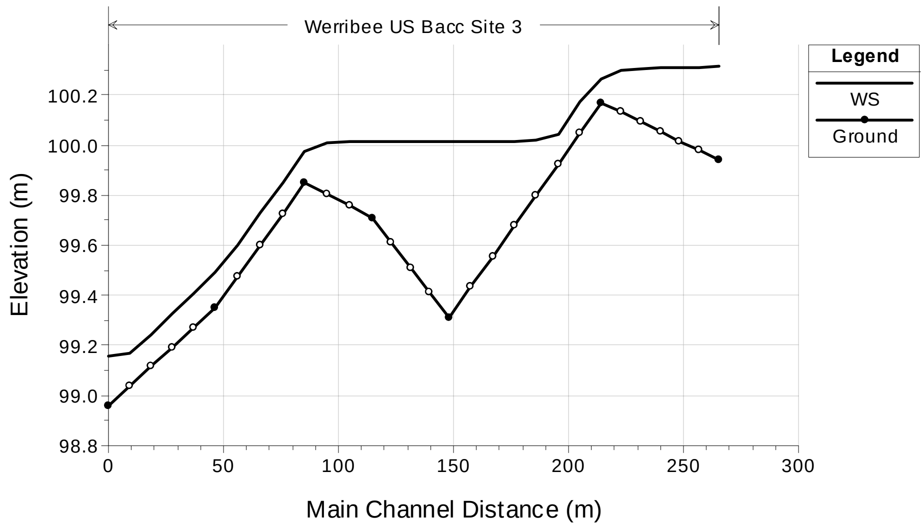

Figure 4. Longitudinal profile of Site 3 for very low flow (2.5 ML/d) with normal roughness specified (i.e. best estimate Manning's n).

Water surface elevation (m) is the unbroken line (WS), and the ground represents the thalweg profile (deepest point at each section). Main channel distance is measured from the most downstream transect in an upstream direction.

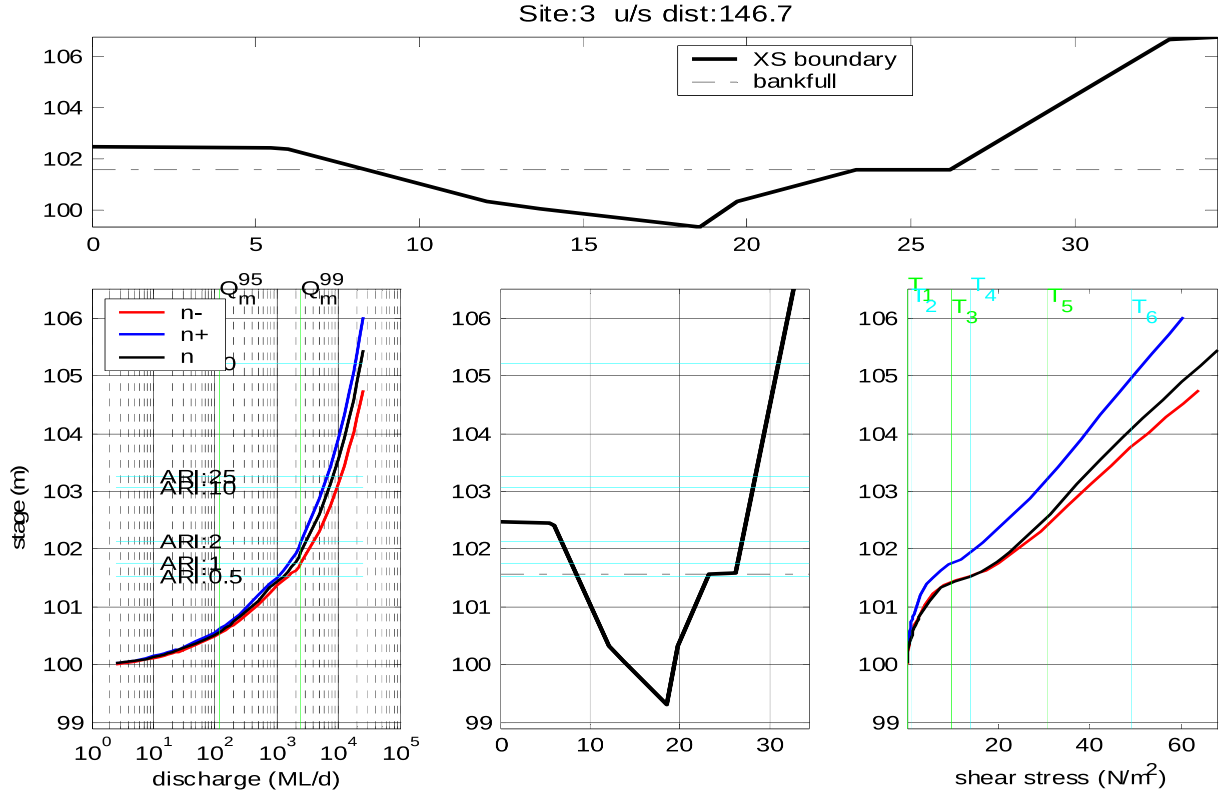

Figure 5. Summary of hydraulic characteristics computed for Site 3, cross-section 6 (@146.7m).

Upper Chart: cross-section boundary with bankfull stage highlighted for reference. Bottom Left: stage discharge curves for three roughness values: **n** = best estimate; **n+** = upper estimate; **n-** = lower estimate. Also plotted are two discharge thresholds (Q^{95} and $Q^{99.9}$) that are associated with the removal of immature and mature emergent macrophytes respectively. Bottom centre: enlarged cross-section plot with the scale of the vertical axis (stage) matching the scale on the bottom left and right plots. Also highlighted in these two plots are the stage associated with natural flows having return intervals of 0.5, 1, 2, 10, 25 and 70 years. Bottom right: shear stress versus stage plot with various shear stress thresholds highlighted.

Table 10. Site 3 thresholds for sediment entrainment and vegetation removal expressed in terms of either a critical shear stress (N/m2) or a threshold discharge (ML/d). The application of these criteria is described in Section 4.2 below

Substrate	Conditions	Equation	Threshold	Discharge
SEDIMENTS			**(N/m²)**	(ML/d)
fines (d = 0.01 mm)	flushing from surface of gravel	$\tau_c = 0.34\ d$	*T1*# 0.0034?	0.4
sand (d = 1.0 mm)	spherical shape normal, settled bed	$\tau_c = 0.97\ d$	*T2*# 0.97	12
gravel (d = 10 mm)	spherical shape normal, settled bed	$\tau_c = 0.97\ d$	*T3*# 9.7	896
Riffle d_{16} 28.2mm d_{50} 62.5mm d_{84} 100mm	flat shape normal, settled bed	$\tau_c = 0.49\ d$	*T4*# 13.8 *T5*# 30.6 *T6*# 49.0	1673 >25000 >25000
VEGETATION				(ML/d)
bunch grass	removal of bunch grass (minimum)	erosion study	*T7*# 80 N/m²	> 25000
macrophytes	removal or disturbance of macrophytes and shrubs d_m = 0.0119 m u = velocity (m/s) D = flow depth (m)	$uD/d_m = 12.8$ $uD/d_m = 128$	(flow dependent)	Q^{95}: 125 $Q^{99.9}$: 3510

* Median discharge (of all cross-sections excluding the outlet cross-section)

T1, …T7 values are plotted in the shear stress versus stage charts

d= particle diameter

d_{16} = sixteenth percentile particle diameter

d_{50}- = fiftieth percentile particle diameter

d_{84} = eightieth percentile particle diameter

d_m = median particle diameter

3.4 Flood Recession Rates

Flood recessions are relevant to the implementation of flow recommendations where regulating structures will be used to make the release or control the end of a flow event. There is little scope for the current structures in the Werribee River to control the recession of freshes and floods, which will mostly reflect the discharge generated by individual rainfall events. These structures (particularly Melton Reservoir) may be modified in the future to allow floods and freshes to be controlled, at which time appropriate recession rates recommendations should be determined.

In the Djerriwarrh and Coimadai creeks, floods and freshes are likely to result directly from the management of storages, and flood recession rates have been calculated for these reaches (Ecological Associates 2005).

3.5 Analysis

Environmental flow recommendations were developed at a workshop held at Melbourne Water on May 17 and 18, 2005. The EFTP developed flow recommendations on a reach by reach basis.

The analysis involved the following tasks:

- review of the environmental assets in each reach and their condition, as presented in the Issues Paper (Ecological Associates 2005);
- review of the relevant hydrological objectives, as presented in the Issues Paper;
- use of the hydraulic model and hydrological analysis to characterise the flows that relate to the ecological objectives; and
- discussion and agreement on the required status and flow requirement of environmental assets.

4.1 Development of Specific Flow Objectives

The EFTP reviewed the flow objectives that were identified in the Issues Paper and rationalised them on the basis of common or similar flow requirements (Table 11). The rationalised objectives were numbered for reference in the reach analysis presented in Section 4.

Table 11. Specific Flow Objectives.

Category	Sub-category	Specific Objective
1. Fish	Habitat for River Blackfish	1a) passage (dispersal) of River Blackfish fry between pools
		1b) maintain pool refuge habitat (persistence)
		1c) passage (dispersal) of River Blackfish adults
		1d) to avoid flushing fish from reach keep duration lesser of 5 days or natural
		1e) provide deep spawning habitat in pools or submerged rocks and snags
		1f) maintain pool water quality during low flows
	Trout	1g) control trout
	Habitat for Pygmy Perch	1h) maintain pools in autumn
		1i) access to emergent vegetation in stream bed
		1j) fish passage throughout reach during spawning period
	Habitat for Tupong	1k) habitat connectivity from Lower Werribee Diversion Weir to the estuary
2. Vegetation	Maintain / restore semi-emergent, emergent and shrub assemblages	2a) in-channel flow to sustain in-channel macrophyte growth (including marginal vegetation) in winter and spring
		2b) high flow to inundate shrub assemblages on benches and support growth in winter and spring
		2c) support the growth of emergent macrophytes in the riparian zone by providing falling water levels during the transition from spring to summer
	Maintain a mosaic of plant assemblages	2d) curtail growing season of in-channel emergent macrophytes
		2e) disturb in-stream emergent macrophytes to limit vegetation encroachment
		2f) disturb shrubby vegetation on benches
3. Macro-invertebrates	Restore / maintain macroinvertebrate community	3a) inundate in-stream macroinvertebrate riffle habitat – flow depth to cover top of cobbles in riffle during baseflow AND maintain full wetted perimeter of stream bed for macroinvertebrate habitat
		3b) flushing of fines or sands for macroinvertebrate habitat
		3c) maintain pools for drought intolerant macro-invertebrate fauna
		3d) flowing water to encourage riverine fauna
		3e) intermittent turning over of substrate via bed mobilisation (minimum requirement) OR Removal of fines from under cobbles and remove filamentous algae

Category	Sub-category	Specific Objective
4. Geomorphology	Maintain capacity to mobilise sediment and shape channel and habitat features	4a) no longitudinal barriers to sediment supply
		4bi) mobilise gravels on bed
		4bii) scour pools / mobilise riffles, achieve "effective discharge" for sediment transport (equivalent to morphologically defined bankfull discharge)
		4biii) grass removal from benches to allow reworking of sediments in gross channel forms
		4c) maintain / mimic natural hydrologic variability of baseflows and floods to maintain bank stability (avoid long periods of constant regulated flow in summer; avoid rapid rise and fall of floods), and; maintain sediment transport by maintaining adequate frequency/duration of high flows
5. Platypus	Habitat for Platypus	5a) scour fine grain sediments from the base of pools and silt from riffles
		5b) maintain pool water quality during low flows
		5c) maintain refuge pools in summer and autumn
		5d) maintain stable undercut benches for burrows and feeding habitat
		5e) flow extends laterally to bench habitat during reproductive period from late winter into summer (typically August – February)

4.2 Criteria to Evaluate Flow Objectives

To assess the flows required to achieve ecological objectives, quantitative physical indices of specific physical processes were sought. The indices identify the physical events in the stream, such as substrate mobilisation or velocity, which support ecological objectives and allow the required discharge to be objectively calculated. This process provided consistent and objective guidance for the assessment of flow requirements by the EFTP. Table 12 summarises the flow indices that were related to the flow objectives. The method used to develop and apply the indices is provided below.

Cease to Flow

Periods of cease to flow in summer and autumn are a natural characteristic of the reaches above Melton Reservoir. They contribute to the open structure of the stream bed habitat by curtailing the growing season of emergent macrophytes. If these reaches do not cease to flow, sustained flows may promote the growth of perennial emergent species such as *Typha* and *Phragmites*, which will replace other vegetation assemblages and may degrade habitat for Platypus, larger fish species, such as River Blackfish, and macroinvertebrates.

A requirement for cease to flow in summer and autumn was specified in most reaches to limit the growing season of aquatic vegetation and to restrict the density and extent of invasive emergent plant species on the stream bed (Objective 2d).

It should be noted that cease to flow events represent a threat to Platypus. Platypus young hatch in October or November and are confined to the nursery burrow until the end of January or February. Female platypus with young are obliged to remain in close proximity to their burrows over this period. If the area of aquatic habitat near the burrow declines significantly during cease to flow events, both females and their recently emerged young will be exposed to greater predation from foxes, Australian Ravens or Kookaburras. Burrows located near large permanent pools will therefore have a lower risk than burrows in reaches with shallow riffles. This threat is relevant to the Gorge and Bacchus Marsh reaches where Platypus are present and cease to flow events are recommended.

Lateral Flow Extent

In-stream emergent and submerged plants require waterlogged soils or inundation during the main growing season, which extends approximately from August to December. Inundating riffle cross sections is also an important indicator of the availability of habitat for benthic macroinvertebrates. Benches in the channel or at the edge of the channel are important feeding and burrow habitats for Platypus and the spread of water to these benches is a component of their habitat requirements. The flows required to fully wet the perimeter of riffles were interpreted from the surveyed cross sections and referral to field notes and photographs. These were related to discharge using the hydraulic model.

Velocity

The quality of water in pools is important to their value as a refuge habitat for macroinvertebrate production and larval, juvenile and adult fish survival. Water quality relates to improving water quality in pools. In this respect the most important water quality parameters are dissolved oxygen and temperature. Provided inflows to pools are adequate to exchange the water over a reasonable time frame, that the inflows to the pools are turbulent, and that average velocities in pool transects remain positive, mixing of the water column should maintain water quality.

Table 12. Flow Indices and Objectives

Index Type	Index	Objectives
Cease to Flow	Cease to Flow	2d) curtail growing season of in-channel emergent macrophytes 1g) control trout
Lateral Flow Extent	Full wetting of riffle perimeter	2a) in-channel flow to sustain in-channel macrophyte growth (including marginal vegetation) in winter and spring 3a) maintain full wetted perimeter of stream bed for macroinvertebrate habitat 5e) flow extends laterall to bench habitat during winter, spring and early summer
Velocity	Velocity (0.1 m/s)	1f) maintain pool water quality during low flows 5b) maintain pool water quality during low flows
Flow Depth	Hydraulic depth at riffles (flow required to cover d50 particles + defined depth)	3a) inundate in-stream macroinvertebrate riffle habitat, where defined depth was 10 mm
	Depth across riffle at thalweg (flow required to cover d50 particles + defined depth)	1a) passage (dispersal) of River Blackfish fry between pools, where defined depth was 50 mm
	Depth across riffle at thalweg (flow required to cover d50 particles + defined depth)	1c) passage (dispersal) of River Blackfish adults, where defined depth was 100 mm in Reaches 3, 4 and 5 and 200 mm in Readches 9 and 9
	Inundation of benches	2b) inundate shrub assemblages on benches and support growth in winter and spring
Sediment Mobilisation	Flush fines (0.0034 N/m2)	3b) flush fines or sands for benthic macroinvertebrate habitat 3e) Removal of fines from under cobbles and remove filamentous algae
	Entrain sands (0.97 N/m2)	3b) flush fines for benthic macroinvertebrate habitat
	Mobilise fine gravel (97 9.7 N/m2)	4bi) maintain channel shape and habitat features
	Mobilise fine gravel (97 N/m2)	4bi) maintain channel shape and habitat features
	Mobilise riffle material – d16	4bii) scour pools and mobilise riffles
	Mobilise riffle material – d50	4bii) scour pools and mobilise riffles
	Mobilise riffle material – d84	4bii) scour pools and mobilise riffles
Vegetation Removal	Q95	2e) disturb in-stream emergent macrophytes to limit vegetation encroachment
	Q99.9	2f) disturb shrubby vegetation on benches
Channel Dimensions and Form	Q99.9	4biii) maintain channel dimensions and form
	Mobilise riffle material – d50	4bii) maintain channel dimensions and form
	Mobilise riffle material – d84	4bii) maintain channel dimensions and form
	Bankfull flows	4c) maintain channel dimensions and form
	Grass removal (80 N/m2 shear stress)	4biii) maintain channel dimensions and form

For most pools in the Werribee River, low mean velocities are adequate to maintain mixing. The FLOWS study of the Little Yarra River and Don River, LYDEFTP (2004) chose an average water velocity of 0.1 m/s as the criterion for positive pool velocity, but this is an arbitrary value, not justified by LYDEFTP (2004) using any theory of physical mixing, nor supported by empirical observations. In this study of the Werribee River we adopted the criterion of 0.1 m/s, but it was exercised with great caution because of its lack of theoretical or empirical basis. In reality, a mean velocity of 0.1 m/s through a pool is in all likelihood in excess of that required to maintain mixing. For example, a pool 1.5 m deep and 10 m wide flowing at 0.1 m/s has a discharge of 130 ML/d, which is far in excess of a natural summer low flow in the Werribee river, or any other medium sized Victorian river. The threshold required for mixing is probably better expressed as a discharge related to pool depth and pool volume. This kind of information is not collected in a routine FLOWS field assessment or transect survey, so, proper consideration of flows required to maintain pool mixing requires an improvement in the methodology. These limitations were particularly apparent in the lowland reaches (8 and 9). Velocity was not applied as an indicator of pool water quality in these reaches even though it was still considered to be an important factor in river health.

Flow Depth

The depth of water in riffles connecting pools during baseflow can limit the movement of adult River Blackfish between pools. For movement of adult fish between pool habitats, there needs to be a minimum depth of around 150 to 300 mm at the thalweg (deepest point) of the shallowest riffle. The optimum value for this depth is uncertain, but it is reasonable to assume that fish will make effective use of such avenues for movement as long as they remain wholly submerged and there is sufficient cover available. When food is scarce or the water level in pools is low, fish may attempt to move or disperse across riffles so shallow that their backs are exposed, however, they are particularly vulnerable to predation by birds at this time. For this reason the EFTP have recommend thalweg depths sufficient to keep the whole fish submerged (taking into account the likely size of adult blackfish in the Werribee System, estimated to be a length of 300 mm and dorsal-ventral height of 100 mm). For most reaches on the Werribee we have specified a depth at the thalweg of the shallowest riffle of d50 + 100 mm for adult dispersal where d50 is the diameter of the fiftieth percentile of susbtrate particles. This means that median size cobbles should be covered by at least 100 mm of water and that based on the likely distance between the fish's dorsal and ventral surface (i.e. its height) there should be sufficient depth for fish to navigate through the spaces between the cobbles. Maintaining a minimum depth of 100 mm of water over median size cobbles will enable Platypus to remain submerged when moving between pools, reducing their vulnerability to predators.

River Blackfish spawn from November to January and the fry are ready to disperse and feed after a few weeks. The EFTP considered that the provision of freshes during the low flow period is required for the fry to disperse between pools. As the fry are only around 10 mm in height at this age, the EFTP have recommended a minimum depth at the thalweg of the shallowest riffle of d50 + 50 mm.

For maintenance of aquatic habitat for macroinvertebrates (see lateral flow extent above) over the baseflow period, riffle areas should have at least a thin covering (e.g. 10 to 20 mm) of flowing water. This depth should be maintained over the natural width of the stream bed. To meet this objective we recommend a flow depth sufficient to cover the top of cobbles in riffles (riffle d50 +10 mm) *or* to fully inundate the perimeter of the stream depth (see lateral flow extent above) whichever is the greater.

The inundation of benches in winter and spring supports the seasonal growth of aquatic macrophytes and other riparian plant species. The flows required to inundate benches (where present) were interpreted from cross sections that showed benches, using the hydraulic model.

Sediment Mobilisation

For sediment mobilisation, shear stress thresholds were computed by applying Shields Critical Shear Stress Method (Gordon et al., 2004, p.194). Three generic sediment thresholds were computed, specifically the shear stress required to: a) flush fines (d = 0.01m) from a gravel surface ($\tau_c = 0.34\ d$); b) entrain (mobilise) a normal, settled bed of sand; and c) to mobilise fine gravel. Three thresholds were also computed relating to the riffle sediments measured at each site. The shear stress required to mobilise the 16%, 50% and 84% of the riffle sediments were computed (i.e. sediment calibre equal to the median and two standard deviations either side of the median particle size - see accompanying CD: Hydrology Report).

Vegetation Removal

For vegetation, thresholds for the removal of grasses and rupture ('lodging') of macrophytes. The minimum shear stress required to impact the least hardy of grasses (i.e. poorly established bunch grass) is 80 N/m2. The discharge required to rupture macrophytes was computed by application of Groeneveld and French's (1995) relationship. The diameter of the macrophyte stems tested was set, as recommended by Groenveld and French (1995), to 0.0119m (11.9mm). Two thresholds were then evaluated to represent a 95% and 99.9% chance of stem rupture respectively (Table 5). The thresholds are reported as a discharge required for the product of flow depth and velocity to exceed either 0.152 (Qm95% - referred to as Q95) or 1.52 (Qm99.9% - referred to as Q99.9). Shrubs are present in many of the channels, and it is ecologically desirable to occasionally check their growth. There are no published data available on which to base an index for removing shrubs, so here we assumed that the shear stress to remove grass and macrophytes would disturb shrubs, as shrubs are less flexible and present a greater drag on the flow (due to larger projected area) - countering this is the possibility of greater rooting strength. It is emphasised that the removal of vegetation can only be predicted as a probability, and that for any given event only a proportion of vegetation will be disturbed. Vegetation may remain undisturbed due to variations in flow velocities within a stream, the stability provided by the substrate in which plants grow or the path taken by debris entrained by the flow. For this reason, this criterion is expressed in terms of 'checking the growth of' or 'disturbing' shrubby vegetation. It is not intended to represent the removal of all shrubby vegetation.

Channel Dimensions and Form

Channel maintenance means maintaining the overall structure of the stream bed, banks and morphological features within the channel, such as benches, bars, riffles, pools and undercuts. Bankfull flow, which is the flow that corresponds to the top of the bank (in an un-incised stream) is widely regarded as a reasonable index for the flows that maintain the overall channel form, although it is also recognised that channel form is the product of a wide range of flow frequencies and durations. The flow required to maintain channel dimensions and form was assessed with regard to the Q99.9 threshold.

Note that one day is specified as the duration for flows that maintain the physical habitat of the stream, although flows less than this duration will achieve the objective. One day is the minimum time step in the flow model.

4.3 Flow Threshold Interpretation

All of the measured and modelled discharge time series data analysed for this project are were in units of "mean daily discharge". This means that on that day if there was a flood, then the instantaneous flow peak would have been higher.

The hydraulic analysis reports discharge for a given height (or shear stress or velocity) in the channel. When this is converted to a flow recommendation, it is implicit that this discharge is over a certain time period. The recommendations made for the Werribee River stated the frequency and duration for a given discharge magnitude. In doing this, reference was made back to the hydrological analysis, which was based on mean daily discharge. So, for example, if a magnitude of 30 ML/d was required to inundate a bench, then the hydrological analysis of mean daily discharge was referred to in order to determine how frequently (and for what duration) this discharge was achieved as a mean daily discharge.

Some processes may not require the threshold discharge to be achieved as a daily average. For example, if stones just need to be turned over (i.e. not rolled for a whole day), then a day long duration is not required and the specification can be as an **instantaneous discharge**. If the stone turning recommendation is made as a mean daily discharge, then unless the operator holds the flow very steady, the discharge on that day will be sometimes above 30 ML/d (stones turning) and sometimes below 30 ML/d (stones not turning).

Flows are often **managed** (for water supply) over a daily time step (although conventionally **measured** over a 6 minute time-step), so we specified the environmental flows as mean daily flows. So, a recommendation of 30 ML/d for one day means a mean daily flow of 30 ML/d. On that day, the operator can vary the flow around 30 ML/d, but the mean should be 30 ML/d. In some smaller streams where the dam control is just upstream the discharge can be controlled over short time steps (such as hourly). In these situations it might be appropriate to specify some environmental flows as instantaneous flows – provided the threshold only needed to be crossed for a short period in order to achieve the objective.

The above discussion applies to all environmental flow processes. For removing vegetation for example, plants can withstand a certain shear stress for a period of time before failure (the literature does not indicate how long is this period). Bed mobilisation, formation of undercut banks, re-working sand bars, scouring pools etc. – in practice these processes are not achieved instantaneously, even though the process may be defined theoretically as being achieved once a critical shear stress is reached. This is an area of process understanding that is weak. The exact durations required to complete these physical processes are unknown, but intuitively, maintaining a discharge for say 3 hours will probably allow most of them to be achieved. An exception might be processes that require mass transport of sediment in a river, such as reshaping benches and bars and scouring undercuts. These processes might require durations in the order of one whole day. In most cases expert judgement cannot reliably determine the required duration, and the exact specification of the duration will require adaptive management.

When it comes to future assessment of the flow regime to check for compliance with the agreed environmental flow regime, the analysis must be done on an appropriate time step. If flows are recommended as mean daily discharge values, then this is straightforward. For those objectives that have flow durations specified over minutes or hours, then the analysis will have to be done on a sub-daily time step – a data intensive exercise.

5.1 Reach 3 - Upper Werribee Diversion Weir to Pykes Creek

Environmental Flow Objectives

Flow recommendations are provided in Table 13.

The open vegetation of the stream bed in this reach reflects the rocky substrate, frequent energetic flows and regular cease to flow events. Dry periods between January and April will curtail the growing season of aquatic macrophytes and maintain an open vegetation structure. A cease-to-flow period of 40 days, comprised of blocks of 20 days, was considered by the EFTP as the minimum required to restrict the extent of emergent macrophyte growth.

Vegetation growth is physically disrupted by energetic flows. Emergent vegetation encroachment to the stream bed is restricted by flows represented by the Q95 threshold that is achieved at all cross sections by flows in excess of 165 ML/d. Flows of this magnitude exceed the threshold of 87 ML/d requirement to mobilise gravels at nearly all cross sections. They have been associated with High Flow Freshes, but there is no strict seasonal requirement for these flows. They must occur intermittently over the course of the year to effectively restrict aquatic macrophyte growth.

Similarly, there is no strict duration or seasonal requirement for the bankfull flows required to maintain the dimensions and form of the channel. The bankfull flow threshold varies over the site. They are achieved by 700 ML/d in the upper part of the site, but by 1,500 ML/d in the lower part of the site. The mobilisation of d16, which is required to maintain a coarse stream bed with interstitial spaces for macroinvertebrate fauna, is achieved at 6 out of 8 cross sections (4 of 5 riffle cross-sections) by flows of 700 ML/d and this was adopted by the EFTP as an appropriate threshold to achieve this objective over the majority of the reach.

The threshold of Q99.9, which is required to disturb shrubby riparian vegetation and to rework bench alluvium is achieved at 6 out of 8 cross sections by flows of 3400 ML/d. The EFTP considered that to provide a mosaic of plant assemblages on the benches, disturbance events were required within approximately half the maturation time of shrubby riparian species such as Woolly Tea Tree (*Leptospermum lanigerum)*, which was estimated at 20 years.

Trout populations in this reach are potentially controlled by cease to flow events. Trout will be restricted to pools at these times and may be subject to more intensive predation by fishing birds (e.g Herons, Cormorants, etc.) and by warm summer temperatures.

The movement of adult River Blackfish through this reach in winter and spring (between July and November) will be limited by the depth of flow in the riffles. An adequate flow to provide passage was estimated as d50 at the thalweg + 100 mm, which equates to a water depth of 230 mm at the thalweg. The flows required to achieve this threshold vary between cross sections, but a flow of 37 ML/d was adopted as having a high likelihood of providing for this objective, and was adopted as the baseflow. The provision of aquatic habitat for macroinvertebrates and aquatic macrophytes is indicated by the extent to which the perimeter of riffles is fully wetted. The perimeter of 4 of the 5 riffles was fully wetted at 15 ML/d and this flow is achieved by the baseflow threshold.

The baseflow threshold is to be provided in all years over the period from July to November, unless natural flows are lower.

Low flow freshes are required after the spawning period in early summer to facilitate the dispersal of River Blackfish fry throughout the reach. Passage for fry is estimated to occur above a discharge of 14 ML/d which provides a depth of 180 mm at the thalweg (d50 + 50 mm). Low flow freshes should last at least one day, but a duration of more than 5 days is expected to result in the flushing of fish and other aquatic fauna downstream, unless natural flows are lower.

The extent and quality of pool habitat is important to maintain local populations of River Blackfish, Platypus and drought-intolerant macroinvertebrate fauna in summer and autumn. The maintenance of pool water quality is indicated by a flow velocity 0.1 m/s. This is achieved in all the pools of the reach by a flow of 3 M/d, which is also considered sufficient to maintain pool extent.

The provision of flows to inundate the coarse bed material in autumn was considered important for this community. The perimeter of the stream is fully wetted at 3 out of 5 sites at 5 ML/d and this was considered to be the minimum necessary to maintain the macroinvertebrate population. These flows would provide temporary habitat between cease to flow events. These flows would also serve to maintain the extent and water quality of pools, thereby maintaining refuges for River Blackfish and macro-invertebrates.

Table 13. Flow objectives for Reach 3 – Upper Werribee Diversion Weir to Pykes Creek.

Flow				Rationale
Season	**Magnitude**	**Frequency**	**Duration**	
January to April	Cease to flow	2 x 20 days per year minimum event separation 7 days	40 days total or natural if natural is less	2 d) curtail growing season of in-channel emergent macrophytes 1 g) control trout
December – June	Low flows 5 ML/d or natural if natural is less	all years except extended drought	residual time after other flows	3 a) fully wetted perimeter achieved at 3 of 5 riffle sites at 5 ML/d and 4 of 5 riffle sites at 15 ML/d; 140mm hydraulic depth over riffles (d_{50} hydraulic depth + 10mm) achieved at 4 of 5 riffle sites at 24 ML/d) 1 f) suitable pool water quality (<3 ML/d for entire reach) 1 b, 3 c) maintain pool extent 3 b) Sand and silt mobilised (<3 ML/d for entire reach)
December – March	Low flow freshes 14 ML/d or natural if natural is less	minimum 2 per year minimum event separation 14 days	5 days	1 a) 180mm depth over thalweg–(d_{50} at thalweg + 50mm) longitudinal flow connectivity for fry dispersal achieved at 3 of 5 riffles at 16 ML/d and 4 of 5 riffles at 19 ML/d (median 14 ML/d) 1 d) duration lesser of 5 days or natural
July – November	Baseflows 37 ML/d or natural if natural is less	all years	residual time after other flows	1 c) 230mm depth at thalweg (d_{50} at thalweg +100mm) of shallowest riffle – to ensure longitudinal flow connectivity of sufficient depth for adult blackfish to disperse dispersal achieved at 37 ML/d 2 a, 5e) Platypus habitat and stream edge macrophyte growth supported by fully wetted perimeter at 4 of 5 sites at 15 ML/d 1 e) Blackfish spawning habitat 2 b) bench vegetation part inundated (low benches not distinctive on cross-sections)
Anytime	High flow freshes 165 ML/day or natural if natural is less	min 6 per year minimum event separation 14 days	at least 1 day	2 e) macrophyte advance does not occur at Q95 for entire reach (achieved at 165 ML/d) 4 b i) mobilisation of gravels (7 of 8 cross-sections achieved by 87 ML/d)
Anytime	Bankfull Flows 700 ML/d	Natural (2 in 1 year)	at least 1 day (in excess of 700 ML/d)	4 bii, 3 e) Maintain channel dimensions and form through sediment reworking (bankfull for lower part of reach is 1500 ML/d and upper reach is 700 ML/d; Q99.9 occurs at half of sites at 2800 ML/d so is largely an overbank phenomenon; at 700 ML/d d_{16} mobilised at 6 of 8 sites (4 of 5 riffle sites) and d_{50} mobilised at 2 of 8 sites (1 riffle site); at 1500 ML/d d_{16} mobilised at 7 of 8 sites (4 of 5 riffle sites) and d_{50} mobilised at 6 of 8 sites (3 of 4 riffle sites))
Anytime	Overbank flows 3,400 ML/d	Natural (1 in 10 years)	minimum 1 day	4 biii, 2 f) woody vegetation disturbance and bench reworking approximately every 10 years. Natural flood occurring 1 in 10 years is 3400 ML/d. Macrophyte removal Q99.9 occurs at 6 of 8 of sites at 3400 ML/d; grass removed from benches at 7 of 8 sites at 3400 ML/d.

Achievement of Recommendations

Due to the largely natural water regime of this reach, nearly all flow objectives are currently met (Table 14). The only deficiency relates to baseflows, which modelling data suggests is deficient in July and October.

Table 14. Analysis of the current frequency and duration of the recommended flows for Reach 3.

Season	Recommendation	Current	Achievement
January to April	Cease to flow comprising 2 periods of 20 days annually	Number of spells of 0 ML/d is 72 per 100 years, with a mean duration of 44 days	Achieved
December to June	Low flows of 5 ML/d or natural	Monthly median flows range between 0 and 9 ML/d	Achieved
December to March	Low flow freshes comprising 2 events per year of 14 ML/d or natural, for 5 days	Data on low flows is unavailable, but is likely to be achieved	Achieved
July to November	Baseflows of 37 ML/d or natural	Monthly median flows range between 23 and 60 ML/d compared to a range of 38 to 75 ML/d for natural. Current median flows in July and October are 23 and 32 ML/d respectively.	Similar to recommendation, but deficient in July and October.
Anytime	High Flow Freshes comprising 6 events per year of 165 ML/d or natural, for 1 day	Flows of more than 100 ML/d currently occur more than 5 times per year.	Achieved
Anytime	Bankfull flows of more than 700 ML/d for 1 day every 2 years	Currently occurs 2 in 1 year	Achieved
Anytime	Overbank flows of more than 3400 ML/d for 1 day every 10 years	Currently occurs approximately 1 in 10 years	Achieved

5.2 Reach 4 - Werribee Gorge

Environmental Flow Objectives

Flow objectives are presented in Table 15.

The Werribee Gorge has a complex structure that provides habitat for a diverse range of biota. Structural complexity reflects the diverse range of stream bed particle sizes, the variety of pools, riffles and benches, and the potential for energetic flows to periodically disrupt vegetation and the stream bed.

A cease to flow period is a natural characteristic of this reach and, together with scouring flows and large particle sizes, is likely to contribute to the absence of emergent macrophytes from the stream bed. A minimum duration of cease-to-flow of 30 days occurring in minimum blocks of 15 days (or less if natural is less) is recommended in the period from February to April to reduce the incursion of emergent plants to the stream bed. It should be noted that Platypus with burrows near riffles will be exposed to a higher predation threat during these periods.

Given the depth and size of pools, cease to flow periods were not believed to expose trout to increased predation in this reach and it was not set as an objective.

The provision of low flows from December to Mayis important in maintaining riffle habitats and to maintaining the size and water quality of pools. This reach is a significant habitat for Platypus and the presence of a macro-invertebrate food source and a perennial aquatic habitat is important for this species. Given that riffle habitat is naturally reduced during the drier months of the year, the EFTP recommends that inundation of riffle habitats in 3 out of 5 cross sections is a suitable objective. This is achieved by a flow of 10 ML/d. This flow is sufficient to maintain pool habitats and exceeds the threshold expected to maintain pool water quality. This flow will also maintain the quality of riffle habitat for macroinvertebrates by mobilising sand and silt from pools and riffles. A slightly higher low flow fresh of 13 ML/d is required to provide passage for River Blackfish fry.

Freshes that disturb emergent vegetation are important to maintain and open habitat in pools and riffles in this reach, which has persistent low flows. The growth of macrophytes is limited by flows in excess of the Q95 threshold which is achieved at 4 of the 6 cross sections at a flow of 90 ML/d, and this was selected by the EFTP as the requirement for low flow freshes. This objective is achieved at all cross sections by a flow of 151 ML/d, which is incorporated in the high flow freshes category. Low flow freshes also maintain interstitial spaces in the stream bed by mobilising gravels and sand at most cross sections. They can be provided at any time in the period from December to May. There is a specific seasonal requirement to provide low flow freshes for Blackfish fry dispersal between December and February to follow spawning events.

The movement of adult Blackfish in winter and spring requires a depth of 180 mm at the thalweg. A discharge of 29 ML/d gives a high confidence of fish passage by meeting this criteria at the shallowest surveyed cross section. This baseflow in the period from June to November also meets the requirements of inundating riparian vegetation to support their seasonal growth and maintaining pool habitats.

This reach features a complex variety of emergent macrophyte assemblages along main and secondary flow paths, billabongs and benches. Consequently, the survey does not clearly define low benches. A general requirement is specified to inundate the riparian zone to the greatest extent in August, followed by the gradual exposure and drying of the bank over the following months. This is described in terms of the frequency of high flow freshes that achieve a flow over 2 days of 245 ML/d. This flow is intended to achieve a full wetted perimeter over the reach and to inundate the lower extent of riparian emergent macrophytes over most of the reach.

Bankfull flows are important to the channel shape and structural habitat components of the gorge such as undercut banks for Platypus burrows, pools for aquatic fauna refuges, riffles for macrophyte habitat and a variety of bench levels to support macrophyte assemblages. A discharge of 3160 ML/d is recommended to maintain channel dimension and form. This will mobilise d50 bed particles at all cross sections and achieve the Q99.9 threshold at 4 out of 6 cross sections. This flow will also maintain patchiness and age variation in bench vegetation by knocking down or removing shrubby vegetation. These flows are required to occur with the natural frequency of 1 in 5 years.

Due to the absence of a floodplain in the constricted gorge, overbank flows do not apply in this reach.

Table 15. Flow objectives for Reach 4 - Werribee Gorge

Flow				Rationale
Season	**Magnitude**	**Frequency**	**Duration**	
February to April	Cease to flow	2 x 15 days per year minimum event separation of 7 days	30 days total or natural if natural is less	2 d) curtail growing season of in-channel emergent macrophytes
December – May	Low flows 10 ML/d or natural if natural is less	all years except extended drought	residual time after other flows or natural if natural is less	3 a) 90mm hydraulic depth over riffle (d_{50} hydraulic depth +10mm) at 3 of 5 riffle cross sections at 10 ML/d; a flow of 5 ML/d will satisfy this criterion at 2 of 5 riffle sites; at 13 ML/d wetted perimeter inundated at 2 of 5 riffle sites 1 b, 3 c, 5 c) maintain pool habitat 1 f, 5 b) suitable pool water quality achieved by 0.1 m/s flow at 2 ML/d 3 b, 3e, 5 a) Sand and silt mobilised from all pools and riffles by 2 ML/d 4 c, 5 d) Avoid long periods of high regulated flows in summer
December – February	Small Low flow freshes 13 ML/d or natural if natural is less	2 per year minimum event separation 7 days	5 days	1 a) 130mm depth (d_{50} at thalweg + 50mm) across riffle - longitudinal flow connectivity for fry dispersal achieved over entire reach at 13 ML/d
December – May	Large Low flow freshes 90 ML/d or natural if natural is less	minimum 2 per year minimum event separation 14 days	1 day	2 e) macrophyte advance does not occur at Q95 for entire reach at 150 ML/d, and for 4 of 6 cross sections (90 ML/d) 4 b i) Mobilisation of gravels (and sand) occurs for entire reach at 186 ML/d, and at 5 of 6 cross-section at 72 ML/d 1 d) duration lesser of 5 days or natural
June – November	Baseflows 29 ML/d or less if natural is less	all years	residual time after other flows	1 c) 180mm depth at thalweg (d_{50} at thalweg +100mm) of shallowest riffle to provide longitudinal flow connectivity, for adult dispersal occurs at 29 ML/d 2 a, 5e) Platypus feeding habitat and stream edge macrophytes part inundated - wetted perimeter fully inundated at 2 of 6 sites at 13 ML/d, and d_{50} + 10mm over all riffles for entire reach achieved at 20 ML/d 1 e) spawning habitat provided in pools
June – November	High flow freshes 245 ML/d or natural if natural is less	4 in Aug to Sep 2 in Oct to Dec minimum event separation 5 days	2 days	2 b) Low benches are not well defined in this reach. Bed fully wetted over entire reach at 245 ML/d, which will partly inundate the lower extent of stream edge macrophytes over much of the reach 2 c) Inundate aquatic macrophytes in riparian zone with decreasing frequency towards summer followed by transition to low flows 2 e) Q95 to disturb macrophytes achieved over entire reach at 151 ML/d 4 bi) Gravels mobilised in all riffles and pools at 186 ML/d, and mobilised at all riffles at 72 ML/d

Flow				Rationale
Season	Magnitude	Frequency	Duration	
Anytime	Bankfull flows 3160 ML/d	Natural (1 in 2 years)	1 day	4 bii) Maintain channel dimensions and form through sediment reworking (median value of morphological bankfull is 3160 ML/d; Q99.9 occurs at 4 of 6 cross sections at 2230 ML/d; at 3340 ML/d d_{50} mobilised over entire reach); maintain natural frequency and rate of rise and fall 2 f) disturbance to shrubby vegetation required at least approx 1 in 5 years. Q99.9 achieved at 4 of 6 cross sections at 2230 ML/d; grass removed from channel at 4 of 6 sites at 2160 ML/d. 3 e) d_{16} and d_{50} mobilised at all riffle cross sections by 1413 ML/d

Achievement of Recommendations

Cease to flow events over summer are deficient (Table 16), probably due to the transfer of water from Pykes Creek to consumers downstream. A significant deficiency occurs in the seasonality of baseflows, which fail to meet the recommendation in June, July and November. This deficiency will curtail the main growth and reproduction period for aquatic biota.

Table 16. Analysis of the current frequency and duration of the recommended flows – Reach 4.

Timing	Recommendation	Current	Achievement
February to April	Cease to flow comprising 2 periods of 15 days annually	71 cease to flow events per 100 years with a mean length of 13 days. Monthly median flows at Bacchus Marsh range from 5 to 16 ML/d currently compared to 0 to 2 ML/d naturally	Not achieved
December to May	Low flows of 10 ML/d or natural	Monthly median flow at Bacchus Marsh range from 3 to 16 ML/d compared with 0 to 13 naturally.	Likely to be achieved
December to February	Low flow freshes comprising 2 events per year of 13 ML/d or natural, lasting 5 days	Events in excess of 554 ML/d currently occur 3 times per year on average	Achieved
December to May	Low flow freshes comprising 2 events per year of 90 ML/d or natural, lasting 1 day	Events in excess of 554 ML/d currently occur 3 times per year on average	Achieved
June to November	Baseflows of 29 ML/d or natural	Monthly median flow at Bacchus Marsh range from 7 to 59 ML/d	Does not appear to be achieved in June, July and November
June to November	High flow freshes comprising 6 events annually of 245 ML/d or natural, lasting 2 days	Currently occurs approximately 5 times per year. Seasonality not assessed.	Likely to be achieved
Anytime	Bankfull flows of 3160 ML/d occurring 1 in 2 years	Currently occurs approximately 1 in 3 years	Largely achieved

5.3 Reach 5 - Bacchus Marsh

Environmental Flow Objectives

Flow objectives for the Bacchus Marsh reach (from the Bacchus Marsh Weir to the confluence with the Lerderderg River) are presented in Table 17.

The floodplain of this reach has been extensively drained and developed. It was not considered by the EFTP to be a functioning component of the stream ecosystem and was not addressed by the flow recommendations.

The channel has also been modified, particularly through the removal of native riparian vegetation. The site that was assessed retains representative features of the natural watercourse environment and was used to guide the flow recommendations for the reach.

A cease-to-flow during the February to April period is recommended to curtail the growth season of emergent macrophytes, particularly *Typha* sp. and *Phragmites australis*, and to limit their extent on stream bed. Their extent is further controlled by flows in excess of 141 ML/day, which is defined as the threshold for high flow freshes and is required on a monthly basis (or less if natural is less) from June to November. Platypus with burrows in shallow sections of this reach will be exposed to a greater risk of predation during cease to flow events.

Low flows between December and May are required to maintain aquatic habitat, pool extent and pool water quality. The hydraulic depth of riffle cross sections exceeded d50 + 10 mm at 3 out of 4 riffle sites at a flow rate of 4 ML/d. Given that a reduction in riffle habitat is likely to be a natural phenomenon in summer and autumn, this threshold was recommended by the EFTP for low flows. While this flow will maintain pools, low flow freshes are required to sustain pool water quality. While there is uncertainty in the calculation of flow required to achieve this objective, a flow rate of 12 ML/d was recommended by the EFTP on the basis of achieving a 0.1 m/s velocity in 3 out of four pools. These are required to occur 4 times per year with a minimum event separation of 14 days.

In this reach, Blackfish fry dispersal can occur at the low flow threshold, in the absence of high flow freshes.

The growth of emergent macrophytes in the riparian zone will be supported by inundation between June and November. The EFTP recommended a baseflow of 18 ML/day in order to achieve a fully inundated channel perimeter at all sites. This flow will also support the movement of adult Blackfish, which is achieved at the shallowest riffle at a flow of 9 ML/d. The excessive growth of filamentous algae was considered a threat to fish and macroinvertebrate habitat quality in this reach. Fines will be mobilised, and it is expected that algae will be disturbed at flows of more than 8 ML/d.

The threshold for high flow freshes of 141 ML/d between is guided by the requirement to disturb stream bed emergent macrophytes over the entire reach. High flow freshes provide other aquatic habitat and physical habitat objectives of the reach. The inundation of low benches between June and November supports aquatic macrophytes that grow as an understorey to River Red Gum, Silky Tea Tree, River Bottlebrush and other riparian trees and shrubs. Low benches are generally not well defined in this reach, but inundation at one well-defined bench will occur at a flow rate of 133 ML/d. High flow freshes also maintain interstitial spaces for benthic macroinvertebrates by mobilising bed material in pools and riffles.

An annual flow event in excess of 1400 ML/d was recommended by the EFTP to maintain the dimensions and form of the stream channel. This represents the flow required to mobilise gravel at most sites and will maintain benches, pools and other physical features.

The removal of macrophytes and disturbance of shrubby vegetation occurs at flows over 3580 ML/d, as indicated by the Q99.9 threshold. These events are important in maintaining a mosaic of vegetation assemblages, but need only occur with a frequency of 1 in 5 years to represent approximately half the time required for stands of riparian vegetation to establish and mature. It should be noted that grass removal from benches requires flows in excess of 25,000 ML/d and is not a common phenomenon in this reach.

Table 17. Flow objectives for Reach 5 - Bacchus Marsh

Flow				Rationale
Season	**Magnitude**	**Frequency**	**Duration**	
February – April	Cease to flow	2 x 15 days per year minimum event separation of 7 days	30 days total or natural if natural is less	2 d) curtail growing season of in-channel emergent macrophytes
December – May	Low flows 4 ML/d or natural if natural is less	all years except extended drought	residual time after other flows	3 a) 72.5 mm hydraulic depth over riffle (d_{50}+10mm across riffle) achieved at 3 of 4 riffle sites at 4 ML/d and all riffle sites at 7 ML/d; full wetted perimeter at 1 riffle and all pools at 5 ML/d, 2 of 4 riffles sites at 15 ML/d and all riffle sites at 18 ML/d 1 b, 3 c, 5 c) maintain pool habitat 1 a) 112mm depth (d_{50} at thalweg+50) –for longitudinal flow connectivity for fry dispersal achieved over entire reach at 4 ML/d) 3 c) survival of drought intolerant fauna 4 c, 5 d) Avoid long periods of high regulated flows in summer
December – May	Low flow freshes 12 ML/day or natural if natural is less	minimum 4 per year minimum event separation of 14 days	minimum 1 day	1 f, 5 b) suitable pool water quality achieved at 1 of 3 pools at 6 ML/d and 2 of 3 pools at 12 ML/d 1 d) duration lesser of 5 days or natural
June – November	Baseflow 18 ML/d or natural if natural is less	all years	residual time after other flows	2 a, 5e) perimeter fully inundated at all sites at 18 ML/d and 3 of 6 sites at 10 ML/d; d_{50} + 10mm over all riffles for entire reach achieved at 7 ML/d 1 c) 162.5mm depth (d_{50} at thalweg + 100mm) of shallowest riffle to ensure longitudinal flow connectivity, for adult dispersal occurs at 9 ML/d 1 e) provide deep spawning habitat in pools or submerged rocks and snags 3b, 3e, 5a) Silt mobilised over entire reach at 8 ML/d;
June – November	High flow freshes 141 ML/d or natural if natural is less	1 per month	2 days	2 e) Q95 to disturb macrophytes achieved over entire reach at 141 ML/d and 4 of 7 sites at 120 ML/d 2 b) Low benches are generally not well defined in this reach. One well-defined bench is inundated at 133 ML/d. 3 b, 3e,5a i) Mobilisation of sand occurs for entire reach, and mobilisation of gravels at 2 of 4 riffles, occurs at 116 ML/d 4 bi) Gravels mobilised in 2 of 4 riffles at 9 ML/d
Anytime	Bankfull Flows 1400 ML/d	Natural (1 per year)	1 day	4 bii) Maintain channel dimensions and form through sediment reworking (median value of morphological bankfull in upper part of reach where it is well-defined is 1350 ML/d; at 1400 ML/d gravel mobilised over 4 of 7 sites; maintain natural frequency and rate of rise and fall
Anytime	Overbank 3580 ML/d	1 in 10 years	1 day	2 f) Q99.9 for shrubby vegetation disturbance occurs at 4 of 7 sites at 3580 ML/d; Natural flood occurring 1 in 10 years was 6,680 ML/d 3 e) d16 achieved at 2 of 4 riffle sites at 1810 ML/d.

Achievement of Recommendations

The recommended cease to flow events are unlikely to be currently provided due to the transfer of water from Pykes Creek reservoir to consumers downstream over the irrigation season (Table 18). The baseflow requirement appears to be deficient at the beginning of the winter / spring period. This will limit growth and reproduction opportunities for aquatic biota.

Table 18. Analysis of the current frequency and duration of the recommended flows at Reach 5.

Season	Recommendation	Current	Achievement
February to April	Cease to flow comprising 2 periods of 15 days annually	Currently there are 73 cease to flow events per 100 years with a mean length of 13 days. Monthly median flows at Bacchus Marsh between January and April range from 9 to 24 ML/d currently compared to 0 to 2 ML/d naturally. The natural mean duration is 41 days.	Not achieved
December to May	Low flows of 4 ML/d or natural	Monthly median flow ranges from 6 to 29 ML/d	Achieved
December to May	Low flow freshes comprising 4 events per year of 12 ML/d or natural, lasting 1 day	Flow of over 563 ML/d currently occurs 3 times per year.	Likely to be achieved
June to November	Baseflow of 18 ML/d or natural	Monthly median flow ranges from 8 to 58 ML/d	Does not appear to be achieved in June
June to November	High flow freshes comprising 6 events per year of 141 ML/d or natural lasting 2 days	Currently occurs approximately 5 times per year. Seasonality not assessed.	Current is similar to recommendation
Anytime	Bankfull flows of 1400 ML/d annually lasting 1 day	One in 1 year event is 1720 ML/d	Achieved
Anytime	Overbank flow of 3580 ML/d for one day once every 10 years	One in 2 year event is 3266 ML/d	Achieved

5.4 Reach 6 - Coimadai Creek

Environmental Flow Objectives

Flow objectives are presented in Table 19.

The main consequence of hydrological change in Coimadai Creek is the development of dense and extensive beds of emergent macrophytes in the stream channel. Leakage from the Merrimu Reservoir dam wall contributes to perennially waterlogged conditions which promotes macrophyte growth and provides a competitive advantage to species such as *Typha* sp. and *Phragmites australis* that continue to grow in summer and autumn if water is available.

Under natural conditions the reach is considered more likely to provide an open, rocky stream habitat comprising a mosaic of pools, rocky riffles and stands of emergent macrophytes and riparian shrubs. The reach would have flowed intermittently and briefly, with the stream bed drying completely over significant periods of the year, particularly in summer and autumn.

The development of a dry stream bed during cease-to-flow events is therefore particularly important to the ecological character of this reach. A period of at least 2 months without flow should be provided, or for the natural duration during this period, if the natural duration is longer. Particular regard should be given to applying the natural cease-to-flow conditions from December to February, as this will curtail the growing season of emergent macrophytes and will reduce the competitive advantage of the summer-growing species *Phragmites australis* and *Typha* sp.

Modelled and actual flow data suggests that flow persists between freshes and floods in winter and spring, but only in wet years. A baseflow of 0.5 ML/d is recommended between July and December but this should not be implemented in low rainfall years. Naturally occurring permanent pools are maintained by baseflows, intermittent flows and probably by groundwater discharge, although the contribution of groundwater has not been assessed in this project. Between freshes, the pool fauna is likely to be limited to species that tolerate increasingly saline conditions and the development of an anoxic lower layer. The maintenance of pool water quality is therefore not an objective relevant to this reach, but the role of freshes in maintaining pool extent is. The EFTP considered that four low flow freshes were required over the period between December and June to maintain pool extent. The flow must be sufficient to extend along the entire reach and was estimated to be achieved by a discharge of 5 ML/d over 3 days, although the extent of flow will depend on the moisture present in the stream. There are no flow records to support estimates of the flows required, and this matter should be evaluated by trial releases.

Between July and November, the stream habitat is maintained by intermittent high flow freshes. Two types of freshes in this period were recognised by the EFTP. Small seasonal freshes support the growth of stream bed vegetation,. A discharge of 10 ML/day is indicated by achievement of a hydraulic depth (d50 + 10 mm) at 3 of the 4 riffle sites. This also inundates the stream bed perimeter at three of the four riffle cross sections. These freshes also provide temporary access to the stream bed habitat for Pygmy Perch outside their pool refuges. They mobilise silts and sands from riffles and pools, which maintains the quality of the benthic habitat for macroinvertebrate fauna.

Larger freshes in winter and spring are required to disturb stream bed vegetation and to contribute to an open channel environment. The Q95 threshold is achieved by a discharge of 93 ML/d, which under natural conditions occurred approximately twice every year.

Bankfull flows of 1900 ML/d occur every five years. The EFTP recognised the importance of these flows to maintain channel dimensions and form. These flows will also significantly disrupt stream bed vegetation by meeting the Q95 criterion at all cross sections.

The removal of stream bed vegetation (indicated by Q99.9) at half the cross sections occurs at flows above the bankfull level, which is defined as the over bankfull flows category. These flows, of 3000 ML/d occur naturally 1 in 10 years and should be maintained. The removal of grass from benches requires flows in excess of 10,000 ML/d, so is not a common phenomenon in this reach.

Table 19. Flow Objectives for Reach 6 - Coimadai Creek

Flow				Rationale
Season	**Magnitude**	**Frequency**	**Duration**	
December – February	Cease to flow	annual	1 month or natural if natural is longer	2 d) curtail growing season of in-channel emergent macrophytes
March – June	Cease to flow	annual	1 month or natural if natural is longer	2 d) curtail growing season of in-channel emergent macrophytes
December – June	Low flow freshes 5 ML/d or natural if natural is less	4 per year or more frequent if natural is more frequent minimum event separation of 20 days	3 days	1 h, 3 c) maintain pool habitat
July to December	Baseflow 0.5 ML/d or natural if natural is less	not in low rainfall years	Commence after first winter runoff event	1 h, 3 c) maintain pool habitat
July – November	Small high flow freshes 10 ML/d or natural if natural is less	10 per year or natural if natural is less frequent minimum event separation of 7 days	5 days	2 a) In-stream vegetation growth. 107.5mm hydraulic depth (d_{50} + 10 mm) achieved at 3 of 4 riffle sites at 10 ML/d; wetted perimeter fully inundated at 3 of 4 riffle sites at 9 ML/d 1 i) Pygmy perch access stream bed vegetation, 147.5mm over thalweg (d_{50} at thalweg + 50mm) achieved at all sites at 3 ML/d 3 b, 4 bii) Silts mobilised from all riffle sites at <1 ML/d and pools at 6.5 ML/d; sands mobilised at 3 of 4 rifle sites at 1 ML/d
July – November	Large high flow freshes 93 ML/d or natural if natural is less	2 per year minimum event separation 14 days	2 days	2 e) Q95 to disturb macrophytes at 2 out of 6 cross sections achieved at 93 ML/d
Anytime	Bankfull flows 1900 ML/d	Natural (1 in 5 years)	1 day	4 bii) Maintain channel dimensions and form through sediment reworking (bankfull for lower part of reach is 800 ML/d and upper reach is 1900 ML/d; at 890 ML/d d_{16} mobilised at 2 of 6 sites; d_{50} is mobilised at >10,000 ML/d so is an overbank phenomenon; gravels mobilised at 4 of 6 sites at 960 ML/d; maintain natural frequency and rate of rise and fall) 2 e) Q95 to disturb macrophytes at all cross sections achieved by 217 ML/d
Anytime	Over bankfull flows 3000 ML/d	Natural (1 in 10 years)	1 day	2 f) Q99.9 to disturb shrubby vegetation occurs at 3 of 6 sites at 3000 ML/d and 5 of 6 sites at 3700 ML/d; Natural flood occurring 1 in 10 years was 2800 ML/d

Achievement of Recommendations

Leakage from Merrimu Reservoir is believed to be the cause of a persistent trickle flow in this reach throughout the year which has eliminated cease to flow events (Table 20). Freshes have significantly reduced by the capture of flow in Merrimu Reservoir and these affect objectives relating to macroinvertebrate, fish and vegetation habitat. Bankfull and overbankfull flows are not achieved.

Table 20. Analysis of the current frequency and duration of the recommended flows at Reach 6.

Season	Recommendation	Current	Achievement
December to June	Cease to flow for two periods of 4 weeks, one in summer, one in autumn	Persistent trickle flow throughout the year	Not achieved
December to June	Low flow freshes comprising 4 events per year of 5 ML/d or natural, lasting 3 day	Negligible freshes	Not achieved
July to December	Baseflow of 0.5 ML/d, but not in low rainfall years or natural	Mean monthly duration of zero flows is currently between 20.5 and 27.8 for the period between July and December	Not achieved
July to November	Small high flow freshes comprising 10 events per year of 10 ML/d or natural, lasting 5 days	Events of 13 ML/d currently 3 times per year	Not achieved
July to November	Large high flow freshescomprising 2 events per year of 93 ML/d or natural, lasting 2 days	Two in 1 year event is 50 ML/d	Not achieved
Anytime	Bankfull flow of 1900 ML/d (peak) provided once every 5 years	One in 5 year event is 450 ML/d	Not achieved
Anytime	Overbankfull flows of 3000 ML/d provided once every 10 years	One in 10 year event is 550 ML/d	Not Achieved

5.5 Reach 7 - Djerriwarrh Creek

Environmental Flow Objectives

Flow objectives for Reach 7 are presented in Table 21.

Djerriwarrh Creek naturally flows intermittently, experiencing brief flow events that follow rainfall events in the catchment. The EFTP considered that the natural character of the stream was a rocky channel bed that supported sparse vegetation tolerant of drought and provided extensive temporary habitat to aquatic fauna, and limited permanent habitat aquatic to fauna tolerant of conditions in small, shallow saline pools.

This character has changed dramatically through regulation. Djerriwarrh weir intercepts virtually all frequent flows, so that the reach only experiences relatively infrequent high flows. The original stream bed vegetation is believed to have had an open structure comprising drought-tolerant aquatic plants. These plants would have grown in conditions of temporary inundation and flow, with prolonged dry conditions. In the absence of flow, the stream bed is simply a slightly more damp environment than the surrounding landscape due to the collection of moisture from local rainfall and groundwater discharge. This has resulted in the loss of aquatic plants and their replacement by a dense cover of waterlogging-tolerant terrestrial plants.

A cease-to-flow period is an important component of the water requirements of the stream. Cease-to-flow allows the channel to dry out, curtailing the spring growth of emergent macrophytes, shrubs and invasive terrestrial plants in the stream bed. The most important timing of a prolonged cease-to-flow is therefore in summer.

Intermittent cease-to-flow is also an important component of winter and spring flows. The fauna dependent on this reach are likely to be strongly influenced by the retreat of water to small, shallow saline pools between flow events. The preservation of these conditions between flow events is important to the ecological character of the reach. These conditions are specified by requiring that flows between November and June do not exceed the natural duration.

Low flow freshes between November and June are required to maintain the extent of pool habitats, but are not required to achieve a particular water quality objective. There will be a gradual depletion of flow along this reach, so the compliance point for this flow is the surveyed site where a flow of 2 ML/d matches the interpreted requirements of the stream. This flow provides a level of 145 mm (d50 at the thalweg + 50 mm) which is more than enough for maintaining water in pools and is achieved at 2 of 4 riffles. Groundwater discharge is also likely to make an important contribution to the salinity and level of pools, but was not investigated as part of this assessment.

A baseflow of 0.3 ML/d occurs in wet years, such as 1978 and is recommended as a flow requirement between July and December. This flow would contribute to riffle habitat for macroinvertebrates between freshes and floods, would contribute to the growth of macrophytes at the fringes of the pools and would contribute to the water quality and water level of pools. The times at which baseflows should be provided could be indicated by flows in a tributary within the catchment, at Notuk (gauge 231212).

Small high flow freshes between July and October support the main growing season of aquatic fauna by wetting the stream bed and temporarily extending the aquatic habitat from the pools. A flow duration of 5 days was considered by the EFTP as sufficient to sustain the growth of stream bed macrophytes between flow events. A flow of 9 ML/d was recommended to provide access for Pygmy Perch to the stream bed at most riffles, as indicated by a thalweg depth of 145 mm, and to support vegetation growth by wetting the stream bed, as indicated by a hydraulic depth of 105 mm.

A larger high flow fresh of 100 ML/d is recommended to maintain the structural habitat of the stream. This flow is required approximately on an annual basis and will remove silts from pools and will disturb stream bed vegetation, as indicated by the achievement of the Q95 threshold in 2 of 6 cross sections.

The channel dimensions and form will be maintained by bankfull flows, which are interpreted to occur at 310 ML/d.

Due to the interpreted invasion of the stream bed by terrestrial shrubs, a recommendation is made to provide high bankfull flows of 2400 ML/d every 25 years.

The discharge required to remove grasses is greater than 4000 ML/d, so is not a common phenomenon at this reach. A flow recommendation for grass removal is not made.

Overbank flows are not recommended this reach. The stream at the surveyed site is deeply inset into the landscape and is not hydrologically linked to a floodplain.

Table 21. Flow objectives for Reach 7 - Djerriwarrh Creek

Flow				Rationale
Season	**Magnitude**	**Frequency**	**Duration**	
December – February	Cease to flow	annual	1 month or natural if natural is longer	2 d) curtail growing season of in-channel emergent macrophytes
March – June	Cease to flow	annual	1 month or natural if natural is longer	2 d) curtail growing season of in-channel emergent macrophytes
November – June	Low flow freshes 2 ML/d or natural if natural is less	6 per year or natural if natural is less minimum event separation 14 days	3 days or less natural if natural is less	1 h, 3 c) maintain pool habitat. A level of 145mm (d_{50} at the thalweg+ 50 mm) is more than enough for maintaining water in pools and this is achieved at 2 of 4 riffles at 3 ML/d and 3 of 4 riffles at 4 ML/d;. It was estimated that a flow of 2 ML/d will maintain pools throughout the reach
July – December	Baseflow 0.3 ML/d or natural if natural is less	only in wet years (could be based on Notuk gauge 231212)	6 months	1 i) The full wetted perimeter of the two pool sites was maintained at <1 ML/d
July – October	Small high flow freshes 9 ML/d or natural if natural is less	6 per year or natural if natural is less minimum event separation is 7 days	5 days or less if natural is less	2 a) 105mm hydraulic depth (d_{50} over riffle + 10mm) to provide for in-stream vegetation growth achieved at 4 of 6 sites at 9 ML/d and 5 of 6 sites at 10 ML/d 1 i) 145mm thalweg depth (d50 at thalweg + 50mm) for Pygmy perch access stream bed vegetation achieved at 3 of 4 riffle sites at 4 ML/d and all riffle sites at 22 ML/d 3 b, 3e, 4 bi) Silts mobilised from all riffle sites at <1 ML/d; sand mobilised at all rifle sites at 9 ML/d
Anytime	Large high flow freshes 100 ML/d or natural if natural is less	1 per year or natural if natural is less	1 day (peak flow)	5 a) Silts mobilised from pools at 41 ML/d 1 i) 145mm thalweg depth (d50 at thalweg + 50mm) for Pygmy perch access stream bed vegetation achieved at all riffle sites at 22 ML/d 2 e) Q95 achieved at 2 out of 6 cross sections at 104 ML/d
Anytime	Bankfull 310 ML/d	Natural (1 in 3 years)	1 day	4 bii) Maintain channel dimensions and form through sediment reworking (morphological bankfull is 310 ML/d; Q99.9 occurs at half of sites at 2400 ML/d so is largely an overbank phenomenon; at the high central riffle d_{16} –d_{84} is mobilised at 44 ML/d, but d_{16} is not mobilised at other sites until >1500 ML/d; gravels mobilised at 2 of 4 riffle sites at 145 ML/d and all riffle sites at 903 ML/d; maintain natural frequency and rate of rise and fall) 2 e) Q95 to disturb macrophytes achieved at all sites at 204 ML/d
Anytime	High bankfull flows 2400 ML/d (within ~1:100 year terrace)	Natural (1 in 25 years)	1 day	2 f) Q99.9 to disturb shrubby vegetation achieved at 3 of 6 sites at 2400 ML/d and all sites at 2680 ML/d

Achievement of Recommendations

As outlined in the Issues Paper, the flow regime of this reach has been significantly impacted by the operation of the Djerriwarrh Weir. Baseflows are deficient and freshes have been eliminated so that the stream only rarely flows (Table 22). The restoration of freshes is important to objectives for fish, macroinvertebrate and vegetation and for the maintenance of the channel form..

Table 22. Analysis of the current frequency and duration of the recommended flows for Reach 7.

Season	Recommendation	Current	Achievement
December to June	Cease to flow for two periods of 4 weeks, one in summer, one in autumn	No data on seasonality, but likely to meet recommendation	Achieved
November to June	Low flow freshes comprising 6 events per year, or natural of 2 ML/d or natural, lasting 3 days or natural	Limited data available on very low flows, but unlikely to be achieved	Not achieved
July to December	Baseflow of 0.3 ML/d, but only in high rainfall years or natural	Mean monthly duration of zero flows is currently between 28.4 and 29.7 for the period between July and December	Not achieved
July to October	Small high flow freshes comprising 6 events per year, or natural of 9 ML/d or natural, lasting 5 days or natural	1 in 1 year event is 12 ML/d. No data on seasonality	Not achieved
Anytime	Large high flow freshes comprising 1 event per year, or natural of 100 ML/d or natural for 1 day	1 in 1 year event is 12 ML/d	Not achieved
Anytime	Bankfull flows comprising 1 event every 3 years of 310 ML/d	1 in 3 year is approximately 100 ML/d	Not achieved
Anytime	High bankfull flows of 24000 ML/d once every 25 years	1 in 25 year event is approximately 20000 ML/d	Achieved

5.6 Reach 8 - Werribee River below Melton Reservoir

Environmental Flow Objectives

Flow objectives for Reach 8 (the Werribee River from Melton Reservoir to the Lower Werribee Diversion Weir) are presented in Table 23.

Flow in this reach is strongly influenced by the operation of Melton Reservoir to deliver water to consumers in the Werribee Irrigation District. Storages upstream of this reach, including Melton Reservoir are used to capture and store water during winter and spring when river flows are high and irrigation demands are low, depleting river flows over this period. During the irrigation season, which occurs mainly between November and April, naturally low flows are augmented by the delivery of water from storage, via the river, to the Werribee Irrigation District.

Cease to flow is not a natural phenomenon at this reach and is not included as a flow recommendation.

Low flows from January to May are required to maintain pool extent, which sustains permanent populations of fish, macroinvertebrates and Platypus. Macroinvertebrate productivity is related to the availability of riffle habitat and a flow threshold of 10 ML/d was recognised by the EFTP as sufficient to maintain pools and provide riffle habitat for macroinvertebrates, as indicated by the achievement of a 32 mm hydraulic depth at 4 of the 5 riffle cross sections.

Intermittent low flow freshes over this period provide opportunities for River Blackfish fry to disperse. This lowland reach is vulnerable to silt accumulation, and the removal of silt during autumn and summer was considered important. The discharge of 167 ML/d for low flow freshes was set to maintain water quality in most pool and run habitats for fish and platypus and to remove silt from deepest pool.

The current flow regime represents a significant seasonal shift from natural conditions which has significant implications for the riparian vegetation community, and consequently for other stream fauna. A gradual recession in water levels from winter to summer is required to gradually expose the stream bank and to provide conditions suitable for the growth of emergent macrophytes over several months and over a broad section of the stream bank. Under the current flow regime, the peak in flow has moved from August to September / October and flows do not recede significantly until the end of the irrigation season in March.

This regime is described by the provision of high flow freshes over baseflows from June to December. A baseflow of 36 ML/d (or less if natural is less) will sustain winter and spring habitat requirements for aquatic biota such as providing passage for adult River Blackfish, providing deep pool habitats for fish and Platypus, sustaining instream plant growth and inundating emergent vegetation at the fringes of the channel bed. A flow rate of 350 ML/d for high flow freshes is recommended, which is required to inundate aquatic macrophytes on the low bench within the stream. The requirement for a seasonal recession is specified by a higher frequency of these freshes from July to September and a lower frequency in the period from October to December. Freshes of this magnitude will also serve to limit the growth of emergent macrophytes in the channel (as indicated by the Q95 threshold).

It should be noted that a higher threshold of d50 + 200 mm at the thalweg (rather than + 100 mm) is used in this reach to represent the habitat requirements of larger River Blackfish individuals that are expected in this reach.

Channel dimensions and form is maintained by bankfull and overbank flows. Reworking of sediment and removal of shrubby vegetation is indicated by the achievement of the Q99.9 threshold by 4000 ML/d at 4 of the 7 cross sections. These flows should be provided with sufficient frequency to check the growth of shrubby riparian vegetation, which the EFTP recommended as 1 in 5 years. Overbank flows of 28000 ML/d contribute to channel structure by mobilising sediment (as indicated by achieving the d16 threshold at all cross sections and d50 at 3 of the seven cross sections).

Table 23. Flow recommendations for Reach 8 - Werribee River below Melton Reservoir

Flow				Rationale
Season	**Magnitude**	**Frequency**	**Duration**	
January – May	Low flows 10 ML/d or natural if natural is less	all years except extended drought	residual time after other flows	3 a) 32mm hydraulic depth over riffles (d_{50} hydraulic depth +10mm) achieved at all riffle sites at 3 ML/d; fully wetted perimeter at 2 of 5 riffles at 5 ML/d and 4 of 5 riffle sites at 10 ML/d 1 b, 3c, 5c) maintain pool habitat 4 c, 5 d) Avoid long periods of high regulated flows in summer
January – May	Low flow freshes 167 ML/d or natural if natural is less	3 per year minimum event separation 14 days	1 day	3 b, 5 a) Mobilise silts from riffles at 4 of 5 riffles at 6 ML/d and achieved at all riffles at 10 ML/d; silt removed from second deepest pool at 90 ML/d and deepest pool at 167 ML/d 1 f, 5 b) maintain pool water quality achieved at deepest pool at 400 ML/d, and shallower runs at 12 – 77 ML/d 1 a) 62 mm depth at thalweg (d50 + 50 mm) for fish fry dispersal provided at all riffle sites at 4 ML/d
June – December	Baseflows 36 ML/d or less if natural is less	annual	residual time after other flows	2 a, 5e) Wetted perimeter achieved over entire reach, such that lower extent of stream edge macrophytes and Platypus bench habitat part inundated at 36 ML/d 1 c) 222mm flow depth at thalweg (d50 at thalweg + 200mm) for large adult fish dispersal achieved for 4 of 5 riffle sites at 4 ML/d; achieved at all riffles at 16 ML/d – estimated by extrapolation) 1 e) spawning habitat provided in pools
June – December	High flow freshes 350 ML/d or natural if natural is less	5 in Jul to Sep 2 in Oct to Dec minimum event separation 5 days	5 days	2 b) Inundate aquatic macrophytes on low bench – low bench apparent at 2 sites – inundated at 172 ML/d and 353 ML/d 2 c) Inundate low bench with decreasing frequency towards summer 2 e) Q95 to disturb macrophytes achieved at 6 of 7 sites at 265 ML/d and all sites at 410 ML/d 4 bi) Mobilise gravels not achievable with freshes in this reach
Anytime	Bankfull flows 4000 ML/d	Natural (1 per year)	1 day	4 bii) Maintain channel dimensions and form through sediment reworking (bankfull for lower part of reach is 2000 - 4000 ML/d and upper reach is 5000 - 6000 ML/d; Q99.9 occurs at 4 of 7 sites at 4080 ML/d; d_{16} mobilised at 4 of 7 sites at 9800 ML/d so is largely an overbank phenomenon; maintain natural frequency and rate of rise and fall) 2 f) Disturbance to shrubby vegetation required at least every 1 in 5 years. Q99.9 to remove shrubby vegetation achieved at 4 of 7 sites at 4080 ML/d and all sites at 6000 ML/d

Flow				Rationale
Season	Magnitude	Frequency	Duration	
Anytime	Overbank flow 28,000 ML/d	Natural (1 in 10 years)	1 day	3 e) Mobilise d_{16} achieved at 4 of 7 sites at 9800 ML/d, at 6 of 7 sites at 13,000 ML/d and all sites at 27,000 ML/d; natural 1 in 10 flood was 28,000 ML/d 4 biii) Grass removal from benches and banks requires >60,000 ML/d so is not a common phenomenon here; mobilise d_{50} achieved at 3 of 7 sites at 28,000 ML/d

Achievement of Recommendations

Baseflows are curtailed in this reach at the beginning and end of the winter / spring period, which will reduce opportunities for growth and reproduction by fish, macroinvertebrates and vegetation (Table 24). The seasonality of flows is further affected by shift of peak winter / spring flows from August / September naturally to September / October currently. The restoration of the natural pattern of seasonal flows involves extending the baseflow period and introducing high flow freshes earlier in the year.

It should be noted that within the range of flows provided for water supply purposes, the absolute discharge is not as important as the seasonal peak and recession of flow. Even if summer flows cannot be reduced due to irrigation demands, it may be possible to impose a seasonal pattern above these flow levels.

Table 24. Analysis of the current frequency and duration of the recommended flows for Reach 8.

Season	Recommendation	Current	Achievement
January to May	Low flows of 10 ML/d or natural	Exceeded in January, February and March. Similar to recommendation at other times	Achieved
January to May	Low flow freshes comprising 3 events per year of 167 ML/d or natural, lasting 1 day	Events of this magnitude are common, but seasonality has not been assessed.	Likely to be achieved
June to December	Baseflows of 36 ML/d or natural	Current median daily discharge is deficient in June and July, but sufficient in other months	Not achieved
July to September	High flow freshes comprising 5 events per year of 350 ML/d or natural, lasting 5 days	Three in 1 year event is 1094 ML/d. Seasonality has not been assessed.	Likely to be achieved
October to December	High flow freshes comprising 2 events per year of 350 ML/d or natural, lasting 5 days	Two in 1 year event is 1702 ML/d. Seasonality has not been assessed.	Likely to be achieved
Anytime	Bankfull flow of 4000 ML/d required once every year	Occurs approximately once every year	Achieved

Anytime	Overbank flow of 28000 ML/d once every 10 years	Occurs approximately every 10 years	Achieved

5.7 Reach 9 – Lower Werribee Diversion Weir to the Estuary Limit

Environmental Flow Objectives

Flow objectives for Reach 9 (from the Lower Werribee Diversion Weir to the estuary limit at the ford downstream of the Maltby bypass) are presented in Table 25.

Flow in this reach is strongly affected by the capture of water in storages upstream and its delivery to urban, industrial and agricultural consumers. There are no consumers below the Lower Werribee Diversion Weir, so water that passes this point is limited to the environmental flows required under the Bulk Entitlement or water that cannot be harvested upstream.

The seasonal cycle of flows in this reach has been largely eliminated by the capture of freshes by storages upstream and the release of an almost constant discharge of 1 ML/d.

A low flow of 6 ML/d (or less if natural is less) is recommended for the period from January to April to maintain pool habitat and to fully wet the perimeter of the riffle habitat (in two of the three riffle cross sections) to support macroinvertebrate production.

While there is uncertainty regarding the presence of River Blackfish in this reach, its presence upstream of the Lower Werribee Diversion Weir strongly suggests that it occurred naturally in this reach and that it is a suitable species to set environmental flow targets. Low flow freshes during this same period are required to provide opportunities for River Blackfish fry to disperse and will provide temporary passage for Tupong from the estuary. Low flow freshes of 137 ML/d will maintain pool water quality and will also remove silt from 2 of the 3 pool cross sections, which will maintain the quality of habitat for macroinvertebrates, fish and Platypus.

Baseflows are required to provide safe passage for adult River Blackfish and Platypus between pools. This was interpreted to occur at 2 of the three riffles at flows in excess of 81 ML/d. This flow will also inundate the stream bed and support the main growing season of riparian macrophytes. This is indicated by the achievement of a fully wetted perimeter at a discharge of 48 ML/d. This discharge will also provide deep pool habitats for fish and Platypus and will provide habitat for benthic macroinvertebrates that depend on riffle habitat.

High flow freshes between July and December are required to support the growth of riparian vegetation on benches and the riparian zone. Low benches are apparent at 3 cross sections and all are inundated at 350 ML/d. A seasonality to these flows is specified by a higher frequency of events between July and September and a lower frequency from October to December. These flows are likely to support the movement of fish upstream from the estuary. They will limit the instream growth of emergent macrophytes, as indicated by the Q95 threshold.

A discharge of 6000 ML/d is interpreted as the bankfull threshold. This flow is sufficient to disturb shrubby vegetation and will maintain channel dimensions and form. This discharge was determined by the morphological bankfull for the lower part of the reach and the threshold to disturb vegetation as indicated by Q99.9 across the entire site.

A requirement for overbank flows of 13,600 ML/d to occur every 5 years is specified to rework the stream bed by mobilising gravels over the stream bed. This flow will also exceed the threshold of 10,000 ML/d to fully inundate the high side-channel that was observed at this site.

Table 25. Flow objectives for Reach 9 - Werribee River from the Lower Werribee Diversion Weir to the Estuary Limit

Flow				Rationale
Season	Magnitude	Frequency	Duration	
January – April	Low flows 6 ML/day or less if natural is less	annually	residual time after other flows	3 a) 190mm hydraulic depth across riffle (d50 +10mm achieved for 1 of 3 riffles at 60 ML/d and all riffles at 300 ML/d; wetted perimeter fully inundated at 2 of 3 riffles at 6 ML/d and all riffles at 42 ML/d 1 b, 3 c, 5 c) maintain pool habitat
January – April	Low flow freshes 137 ML/d or natural if natural is less	3 per year minimum event separation 14 days	1 day	3 b, 5 a) Mobilise silts from all riffles at <1 ML/d; silt removed from deepest pool at 196 ML/d; silt removed from run site and 2 of 3 pools at 137 ML/d 1 c) 230mm (d_{50} at thalweg + 50mm) for fry dispersal achieved for 1 of 3 riffle sites at 9 ML/d; achieved at all riffles at 42 ML/d) 1 f, 5 b) Maintenance of pool water quality requires 80 to 320 ML/d, and 87 ML/d for run site – run site and 2 of 3 pools maintained at 256 ML/d
May – December	Baseflows 81 ML/d or less if natural is less	annual or natural	residual time after other flows	1 c) 380mm (d_{50} at thalweg + 200 mm - interpolated) for adult fish dispersal achieved for 2 of 3 riffle sites at 81 ML/d; achieved at all riffles at 141 ML/d) 2 a) Wetted perimeter achieved over entire reach, such that lower extent of stream edge macrophytes part inundated at 48 ML/d 1 e) spawning habitat provided in pools
July – December	High flow freshes 350 ML/d or natural if natural is less	5 in Jul to Sep 2 in Oct to Dec minimum event separation of 5 days	5 days	2 e) Q95 to disturb macrophytes achieved over entire reach at 350 ML/d 2 b) Inundate aquatic macrophytes on low bench. Low bench apparent at 3 sites with all inundated at 300 ML/d and extent of inundation increasing with higher flows 2 c) Inundate low bench with decreasing frequency towards summer 4 bi) Mobilise gravels achievable at 2 of 3 riffles at 38 ML/d; sand mobilised at all riffles at 54 ML/d 1 k) Tupong access from estuary to Lower Werribee Diversion Weir – all barriers exceeded

Flow				Rationale
Season	Magnitude	Frequency	Duration	
Any time	Bankfull flows 6000 ML/d	natural (1 in 2 years)	1 day	4 bii) Maintain channel dimensions and form through sediment reworking (bankfull for lower part of reach is 4000 - 5000 ML/d and upper reach is 7000 - 8000 ML/d; Q99.9 occurs over entire reach at 5800 ML/d; d_{16} mobilised at 1 of 7 sites at 1200 ML/d, but all other riffle material mobilised at >60,000 ML/d so is largely an overbank phenomenon; maintain natural frequency and rate of rise and fall) 2 f) disturbance to shrubby vegetation required at least approx 1 in 5 years. Q99.9 to strip macrophytes achieved over entire reach at 5,800 ML/d
Anytime	Overbank flow 13,600 ML/d	natural (1 in 5 years)	1 day	4 biii) 10,000 ML/d will fully inundate high level side channel (inundates high level channel through island portion of reach from 362.8m to 377.3m); gravels mobilised over entire reach at 13,600 ML/d

Achievement of Recommendations

The current constant release of 1 ML/d is insufficient to meet either low flow requirements in summer / autumn or baseflow requirements in winter / spring (Table 26). While low flow freshes are likely to be sufficient, high flow freshes occur too infrequently. These flows are important to the growth of riparian vegetation, to the provision of a flow linkage to the estuary and the maintenance of the channel structural habitat. Bankfull flows and overbank flows are sufficient.

Table 26. Analysis of the current frequency and duration of the recommended flows for Reach 9.

Season	Recommendation	Current	Achievement
January to April	Low flow of 6 ML/d or natural	Constant flow of 1 ML/d	Not achieved
January to April	Low flow freshes comprising 3 events per year of 137 ML/d or natural, lasting 1 day	Currently occurs approximately 8 times per year. Seasonality has not been assessed.	Likely to be achieved
May to December	Baseflow of 81 ML/d or natural	Generally a constant flow of 1 ML/d	Not achieved
July to December	High flow freshes comprising 7 events per year spaced to match seasonal requirements of 350 ML/d or natural, lasting 5 days	Currently occur approximately 5 times per year. Seasonality has not been assessed.	Not achieved
Anytime	Bankfull flows of 6000 ML/d one year in two	1 in 2 year event is 6783 ML/d	Achieved
Anytime	Overbank flows of 13,600	1 in 5 year event is 14683 ML/d	Achieved

	ML/d one year in five		

5.8 Rates of Rise and Fall

Upper Diversion Weir

The offtake will impact freshes of a magnitude less than the rate at which water is diverted, which is a maximum of 250 ML/d and often less than this. However, it is likely that flows of the magnitude of the recommended freshes (165 ML/d winter) are impacted. The impact is to eliminate some of the freshes, so the flow recommendation is to reinstate them. The reinstatement would involve shutting off the diversion and allowing the fresh to pass unimpeded. Thus, the rate of rise and fall is determined solely by the conditions upstream. Analysis of rates of rise and fall suggested that the upper ranges of the current rates are slightly higher than natural. The rate of rise and fall could be manipulated to modify the rate of rise by operation of the offtake, but there is no strong reason for doing this.

Thus, the recommendation is to allow current rates of rise and fall, with opening of the offtake allowed when the flow has fallen to an agreed level when the fresh is declared “over”. This could be set equivalent to the recommended baseflow levels (5 ML/d in summer and 37 ML/d in winter). However, these limits may be unrealistically low in some cases. A suggested rule to declare the end of the fresh is to use as an end point when the flow reaches *whichever is higher* of the following thresholds:

- the discharge just prior to the start of the event, or
- the discharge that is equal to 10% of the fresh peak magnitude (at this location for an “ideal” fresh these limits are 1.4 ML/d summer and 16.5 ML/d winter), or
- the recommended baseflow levels (at this location 5 ML/d in summer and 37 ML/d in winter)

Pykes Creek

Natural rates of rise and fall cannot be calculated for Pykes Creek downstream of the reservoir because there are no unimpacted data at this site, or upstream of the reservoir.

At Pykes Creek the current flood time series suggests that the reservoir spills quite frequently, and the flood frequency appears to be similar to the unimpacted flood series for Coimadai Creek. This observation suggests that in winter the reservoir is often operated to be full, or near to full. Thus, it would be expected that most floods on Pykes Creek would have a hydrograph similar to natural. The exception would be small freshes that are damped as they pass through the reservoir, theoretically decreasing their peak magnitude and extending their duration. The degree of this modification cannot be readily calculated.

Freshes for Werribee Gorge could be controlled from Pykes Creek Reservoir. The freshes recommended for the gorge are of the order of 100 – 250 ML/d. The Pykes Ck summer releases are currently at a maximum rate of 150 ML/d. In terms of satisfying the magnitude recommendations, the summer freshes currently occur as irrigation releases, but of course, these flows have completely different hydrographs compared to a natural summer fresh, which would be a brief event. The winter freshes still occur in the gorge, but at a reduced frequency. Assuming that the summer fresh requirement is satisfied by the summer flow releases, the following discussion refers to winter freshes.

Rate of rise and fall of a winter fresh in Pykes Creek could potentially be controlled entirely by a reservoir release, but it would make more sense to allow natural spills to provide the environmental requirements. If the reservoir is not full at the time, the dam will absorb the first part of the fresh, and the main part of the fresh event will probably have a shorter duration and lower magnitude [Note: the reservoir may actually extend the total duration of the fresh, by extending the tail of the recession]. It may be necessary to make a release during the mid-part of the recession limb to artificially extend the duration of the main part of the recession to mimic the natural duration of the fresh. There are currently no data available on which to base a recommendation regarding how long to extend this recession.

In very dry years, in winter, it is conceivable that natural freshes may occur in the inflows to Pykes Ck reservoir, but be absorbed by the reservoir. In this case it may be appropriate to release the entire fresh from the reservoir. The hydrograph should mimic a natural hydrograph, but currently there are no data on natural hydrographs in Pykes Creek.

Bacchus Marsh Weir

At Bacchus Marsh Weir, Pykes Reservoir, the Upper Diversion Weir, diversions from the Bacchus Marsh Weir, plus farm dam development in the catchments, act to decrease the magnitude of freshes less than about 1,000 ML/d magnitude (expressed as mean daily flow). Thus, the freshes are impacted here. The maximum rates of storm event rise are higher under current conditions, and the rates fall tend to be generally higher than natural.

Rate of rise is determined by the rainfall intensity and antecedent catchment conditions. For rainfall events intense enough, and of large enough magnitude to cause a fresh, the response in the stream would be rapid. For the majority of events the peak would occur on the day of the peak of the rainfall event, or the next day. So, duration of the rising limb of the storm event hydrographs would usually be one or two days.

At Bacchus Marsh Weir, rate of recession also varies according to the characteristics of the rainfall event, and the characteristics of the catchment, more than through any impact of the regulating structures. However, the regulating structures have generally increased the rates of recession.

Bacchus Marsh Weir is too small to allow control over rates of recession. The best way to manage freshes in this part of the river is to coordinate them with freshes in the upper part of the catchment. Thus, a fresh managed in a coordinated way at the Upper Diversion Weir and at Pykes Creek will travel through the system and result in a fresh at Bacchus Marsh Weir. If properly managed at these upper sites, the fresh will have a close to natural rate of rise and recession at Bacchus Marsh Weir, provided diversions cease. The rules for when to declare the event over, and diversions can resume can be the same as described for the Upper Diversion Weir.

Downstream of Melton Reservoir

Melton Reservoir has the effect of damping storm event rates of rise, but surprisingly, increasing rates of fall. The maximum irrigation flow is up to 240 ML/d, so the summer freshes requirement is satisfied (in terms of magnitude) by this flow. Natural rates of rise can be quite rapid, with recommended maximum daily flow increases being 689% (or approximately 8 times higher than the previous day). The long-term median rate of rise calculated over all rates of rise for all events should be lower than this at 70% (or approximately 1.7 times higher than the previous day). This requirement still allows for a day of high rate of rise at the start of the event. The rate of rise should be varied from the maximum rate to lower rates, provided the median rate is achieved in the long term.

Recession rates should not generally exceed 53% (or flow approximately half the value of the previous day), and should never exceed 75% (or flow approximately one quarter of the value of the previous day). The long-term median rate of fall calculated over all rates of fall for all events should be 22% (or flow approximately 80% of the previous day). A hypothetical example of a winter fresh that accords with the guidelines for rate of rise and fall is illustrated in Figure 6. Freshes managed in this way at Melton Reservoir outlet will satisfy the requirements for sites downstream of Toolern Creek and at Werribee.

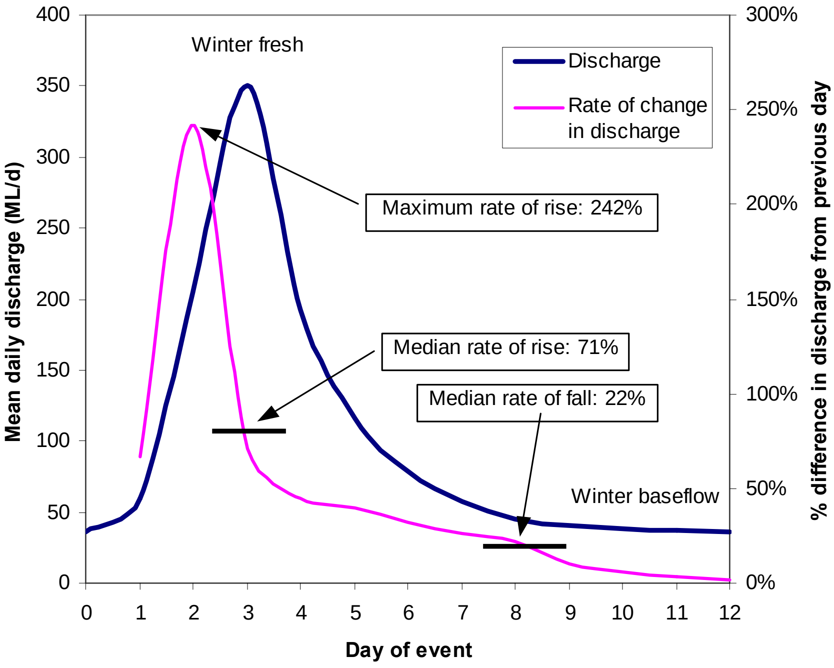

Figure 6. Hypothetical winter fresh event on Werribee River downstream of Melton Reservoir that accords with the specifications for rate of rise and fall.

Note: this example is not to be used to model every fresh event at this site, as variability is required between events. The requirement for median rates of rise and fall are calculated over the long-term and do not need to be met in each event (as illustrated in this example).

Coimadai Creek

For rainfall events intense enough, and of large enough magnitude to cause a fresh, the natural response for this headwater streams would be to peak on the day of the peak of the rainfall event. So, duration of the rising limb of storm event hydrographs would usually be one day or less. Apart from the passing flow requirements, releases are made from Merrimu storage to Coimadai Creek generally for one of two reasons: either flood releases or bulk transfer of water to Melton Reservoir. In either situation, flows are stepped up over time, continued for the required time, then stepped down. It would appear that most of the time the stepping rates (for both rises and recessions) are lower than the natural rates. Instances of higher than natural rates of rise appear to be related more to the very low antecedent flow conditions rather than the volume by which flow is increased.

It is recommended that releases be stepped up to the peak rate over one day, for flows up to about 250 ML/d, as appears to be the current practice. Flows should be stepped down at a maximum rate that is lower than appears to be the current practice. The recommendation is to draw down the flows to 20% of the peak over three days, 10% of the peak over the next two days, and to 5% of the peak over the next two days (total recession being 7 days). This is a recommended target for the median rate of recession. The rate of recession can be varied about this median, so that total event recession durations can be between 2 and 10 days, provided the median of 7 days is achieved in the long-term.

Djerriwarrh Creek

Djerriwarrh Creek is a very flashy stream, and all freshes and flood event rises can be achieved in one day or less. The creek also has naturally rapid event recessions, with the median recession duration being one day. It is recommended that any releases be stepped up over one day. The median flow event recession should be one day, but the rate of recession can be varied about this median, so that duration can be between half a day and 2 days, provided the median of 1 day is achieved in the long-term.

6.1 Conclusions

Recommended and Current flows

Reaches of the Werribee upstream of Melton Reservoir show relatively minor departures from the flows recommended to achieve river health. The main conflicts occur where the duration of baseflow is curtailed by the capture of water in storages upstream and where summer flows are augmented for delivery to consumers downstream.

The two tributaries assessed in this study, Coimadai Creek and Djerriwarrh Creek, show significant departures from the recommended flows. They exhibit marked changes in geomorphology, vegetation structure and fauna habitat that can be attributed to changes in the flow regime.

In Coimadai Creek a low trickle flow is believed to create permanent waterlogging in the stream bed that has eliminated the natural cease-to-flow condition of the stream. Freshes and flood flows have been greatly reduced.

Djerriwarrh Creek currently flows only rarely. Baseflow, freshes and flood flows have been significantly reduced.

The Long Forest Conservation Reserve, through which both of these tributaries flow, contributes to their high conservation significance. The restoration of the recommended flow components to these stream should be considered as a matter of priority.

The capture of water in storages upstream of Reach 8 (below Melton Reservoir) has reduced winter and spring baseflows and is interpreted to have affected the growing season of riparian vegetation. In other respects, the flow in this reach aligns with the environmental flow recommendations. The recommendations attempt to define a seasonal trend in winter and spring flows in terms of the frequency of high flow freshes. Investigations into the feasibility of environmental flow provisions, that will follow this project, will be required to examine the degree to which freshes meet this seasonal requirement.

Flows in the Werribee River below the Lower Werribee Diversion Weir depart significantly from the flows recommended to achieve river health. The current low, release is less than the recommended baseflow in winter and spring and the recommended low flow in summer and autumn. A significantly higher baseflow is required to address the habitat requirements of fish, macroinvertebrates and vegetation, and high flow freshes are required to restore a seasonal trend in flows that matches the habitat requirements of dependent biota. The current flow regime might be considered to be 'maintaining' a degraded habitat, but is insufficient to achieve river health.

Interpretation of Flow Recommendations

Where spell frequencies are recommended, they are the minimum required to achieve stream health. Therefore it is appropriate to deliver more spells than recommended, provided they do not exceed the natural maximum. Similarly longer durations can be delivered, as long as they do not exceed the natural maximum.

Most spells are recommended for a particular season. However the seasonal cutoff is arbitrary and designed to reflect general seasonal patterns in hydrology and ecological requirements. Spells that overlap the start or end of a specified season should be treated as belonging to the season.

The recommendations provided in this report are based on long-term statistics that describe an 'average year'. Over the long term, a range of spell frequencies and durations would be occur. When developing rules to implement the recommendations, consideration should be given to the scope (and operational necessity) to vary spells implementation in 'wet' and 'dry' years so that the long term average is achieved.

A long term compliance period is required to evaluate:

- the incorporation of variability in flow delivery; and
- adherance to the recommended average flow.

A period of 10 to 20 years might be most appropriate from an ecological point of view in order to describe long term (5 to 10 year) cycles in hydrology and ecological responses. However a shorter compliance period, say 5 to 10 years, might be more appropriate from an operational point of view to allow management to be adapted within the current management and policy framework.

Comparing Recommendations between Reaches

Flow recommendations are not necessarily consistent between reaches. The recommended baseflows, low flows, freshes and flood flows vary in consecutive reaches. When viewed as a whole, the recommendations may appear inconsistent and impossible to apply, particularly where higher flows are recommended in upstream reaches than in downstream reaches, at the same time. This is not a condition that could occur in a natural system.

The reason for these inconsistencies is that the adopted FLOWS methodology considers the water requirements of reaches in isolation from each other. Flows are recommended on the basis of hydraulic modelling at a single representative site and field observations and existing data elsewhere in the reach. The behaviour of the river system outside the reach is not considered.

In general this approach is appropriate, because in regulated systems there is normally scope to manage the flow regime of reaches individually. However, the inconsistencies do highlight a real limitation of the method. The degree to which a single site can represent an entire reach depends on the variability within the reach. If additional sites were modelled, different, and perhaps more representative, flow recommendations would be made. It is likely that some of the inconsistencies between reaches would also be reduced.

6.2 Recommendations

It is recommended that the feasibility of implementing the flows recommended in this study is investigated.

The recommendations of this study will be used in a review of river management that seeks to balance environmental, social and economic requirements for water. In making allocations to the environment, it should be recognised that this study recommends the minimum flows required to achieve river health. Partial implementation of the recommended flows may not achieve river health.

There are constraints on the delivery of the flow recommendations presented in this report. In some cases the water management structures (weirs and reservoirs) have physical constraints that, without modification, do not enable flows of the recommended magnitude to be provided. The delivery of water for enviornmental purposes may represent safety risks or risks to property. Environmental requirements for water may conflict with the requirements of other consumers. The process to implement environmental flow recommendations must account for these factors.

While this study is based on the best available information and the opinions of experts, more detailed and site specific information would increase the confidence with which the recommendations are made. The recommended flows should be considered as hypotheses that will be tested in an adaptive management framework through implementation, monitoring and periodic review.

In particular attention should be given to the potential conflict of the objectives of controlling aquatic macrophytes by drying the stream bed out in summer and maintaining Platypus populations. While summer cease to flow events are intended to limit the growth of reeds on the stream bed, they may also expose breeding Platypus to increased predation. Further investigations are required to confirm the timing of these events under natural conditions and to assess predation during trial summer cease to flow events.

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